Fracture, Fatigue and Failure of Materials
Professor Indrani Sen
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Kharagpur
Lecture 57
Failure Analysis- Case Study- Rail Crash

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Hello everyone, welcome back to the 57th lecture of the course Fracture Fatigue and Failure of Materials. And in this module on failure, we are going to discuss about the case studies on rail crash.

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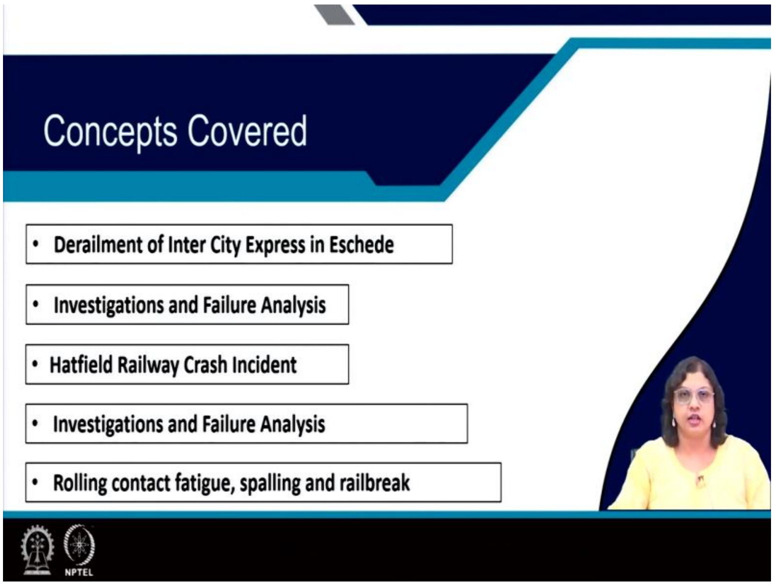

So, let us see what we have in store for this lecture. First of all, we will be discussing about very famous derailment incident for the Intercity Express in Eschede that was in Germany. And of course, we are going to do the failure analysis to find out the actual reason for the failure. This will be followed by another rail crash incident that happened in Hatfield in England. And subsequently the failure analysis will be discussed and the actual root cause for the failure will be more elaborated. And several reasons that can lead to failure for the case of railways will be also discussed such as the rolling contact fatigue spalling and the rail brake will be analyzed.

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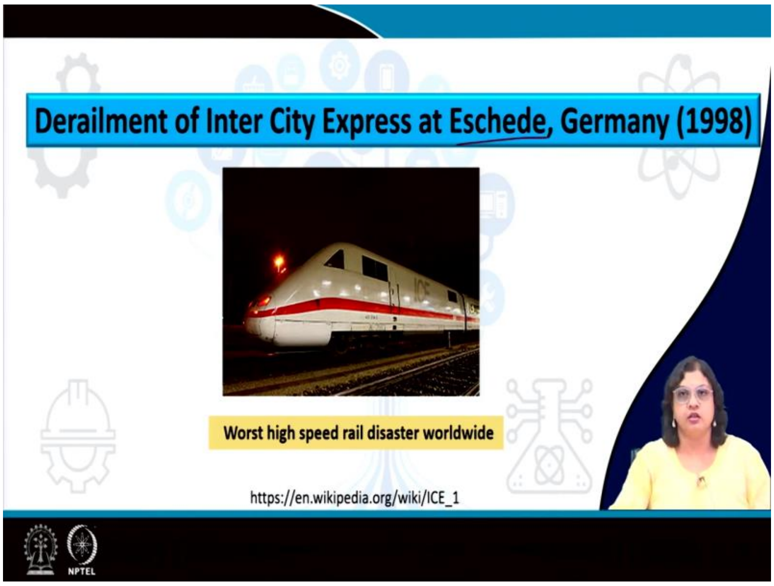

So, the first incident happened in 1998. And this is actually considered as the worst high speed rail disaster worldwide. And this happened in Germany at a place called Eschede in Germany.

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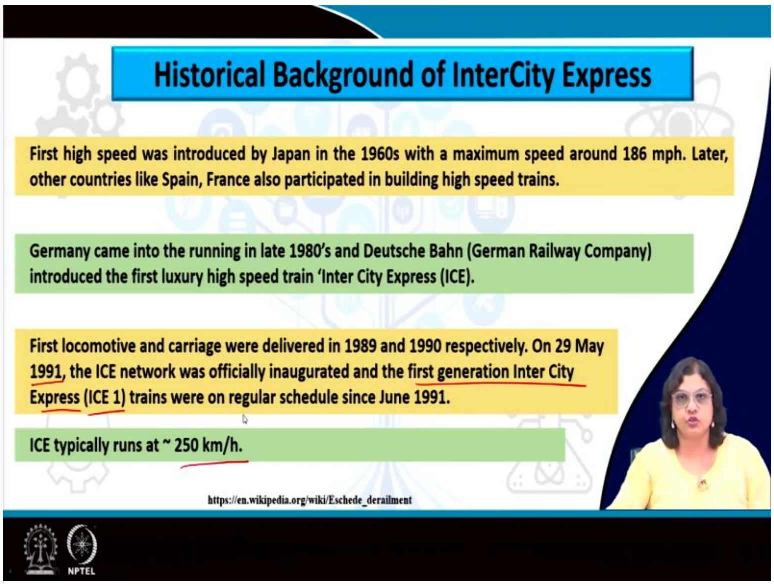

So, before we go through the details of the failure incident, let me give you a brief about the Intercity Express and how did we actually land on this. Actually, the first high speed trains were introduced by Japan in the 1960s as known to us, the high-speed trains are considered as the ones which travels at a speed around 186 miles per hour. So that is quite a high value. And later, other European countries are also using such kind of high-speed trains.

And Germany actually came into the picture at around 1980s and Deutsche Bahn, which is the German Railway Company is the one that introduced this kind of high-speed train which is very much a luxurious one as and named that as Intercity Express. So, the first one started on around 1991 it is known as the first generation Intercity Express or ICE 1 and typically this ICE travels at a speed of around 250 kilometer per hour. So, that is quite some high speed.

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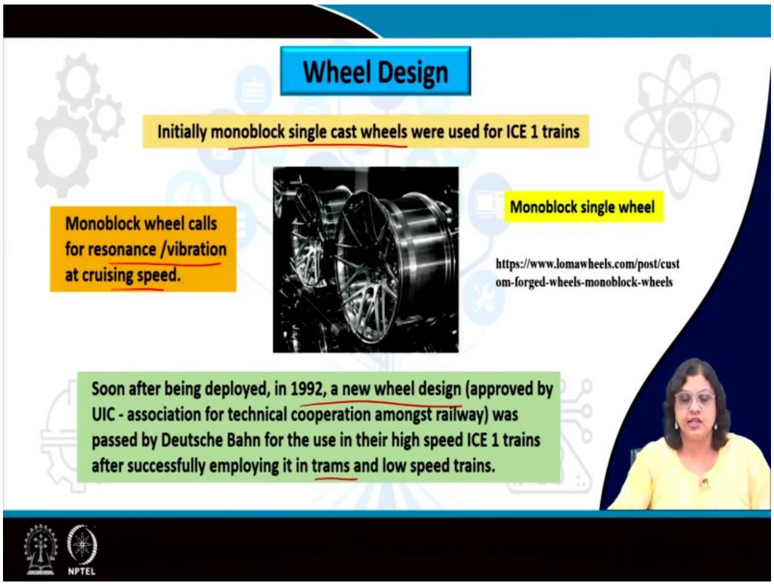

And typically, such kind of high-speed trains were initially using monoblock single cast wheels. Here is a picture of the monoblock wheel how it looks like. However, such kind of wheels often leads to the resonance or formation of some vibration at the cruising speed, and that often leads to some kind of turbulence and are not very much favored.

So, later on around 1992 a new wheel design has been employed and such kind of wheel design has been successfully used in trams, and later on has also been employed under high-speed ICE trains.

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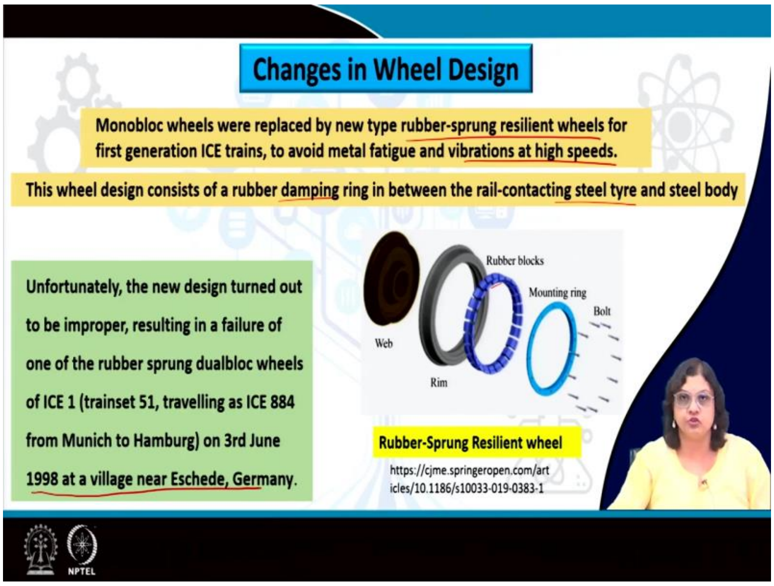

Now, what exactly is this new wheel design? To understand that, let us look into the picture how it looks different from the monoblock wheels. So typically, this new rubber sprung resilient wheels were used to avoid this vibrations at the high speeds. And this kind of wheel consists of a rubber damping ring in between the rail contacting steel tire and the steel body. You can see the rubber blocks here, which is actually helpful for avoiding the vibration.

However, this kind of new design actually led to the failure of one of the very famous incidents that I am going to discuss, which happened in 1998, at a village near Eschede in Germany. So later on, it has been realized that the design of the wheels are at fault that lead to this catastrophic event.

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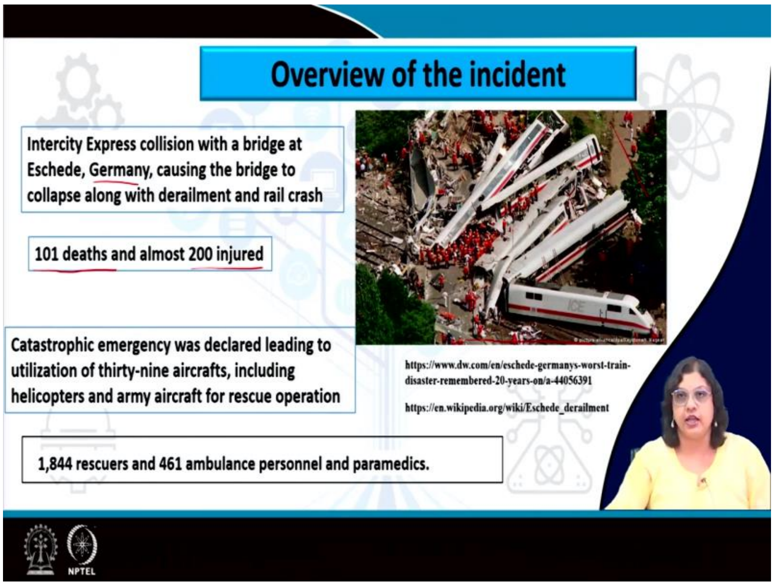

So, this Intercity Express, actually collided with a bridge in this place in Germany, when it was leading to a failure of the bridge as well. And along with that around 101 people died as well as almost 200 people were injured in the overall incident. It is considered as a catastrophic emergency and several rescue workers and helicopters and all those rescue operations are being used to save whoever are still alive. So, you can see from this picture here the incident which was quite some catastrophic one and the entire train has been just piled up like a stack of cards.

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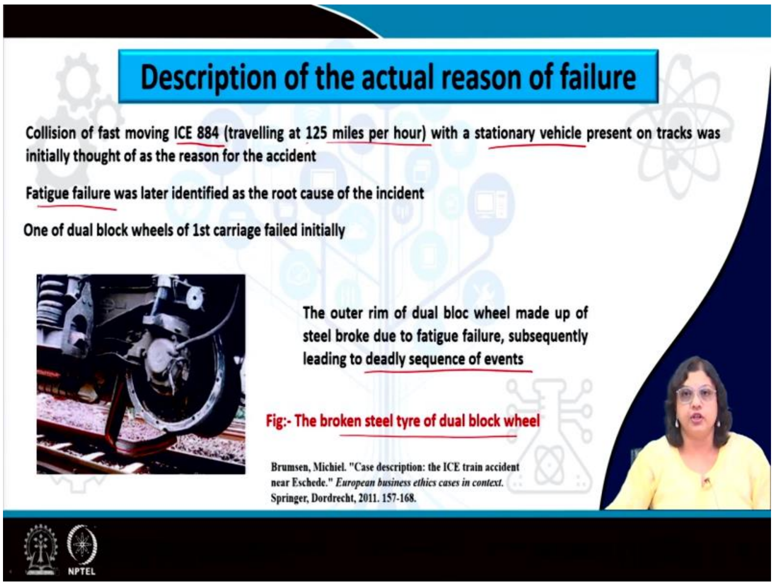

So, what actually happened on that day is this fast-moving ICE which was named numbered as ICE 884. This is traveling at around 125 miles per hour and it initially got hit by a stationary vehicle and that was considered as a reason for the accident at the very first instance. But later on, after some detailed survey, it was realized that fatigue failure is actually the main reason for this incident. One of the dual block wheels for the first carriage that is the first compartment failed initially and that lead to a series of deadly events one by one.

So, here is the picture of the broken steel tire of the dual block wheel where you can see that how this has been broken from the wheel.

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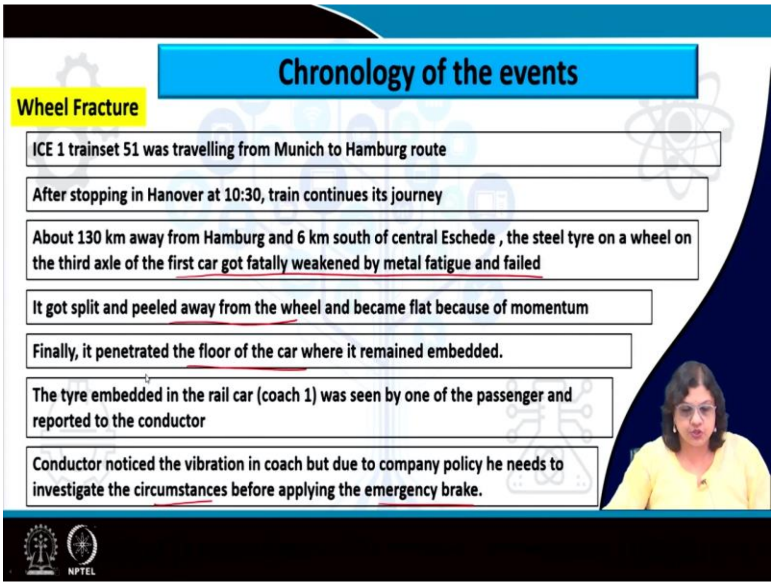

So, wheel fracture is one of the main incidents here. So initially, the trainset 51 was traveling from Munich to Hamburg route. And it after stopping at Hannover at around 10:30 in the morning. It continues its journey while at around 130 kilometers away from Hamburg, and 6 kilometers south of Central Eschede the steel tire on the wheel on the third axle of the first car got fatally weakened by the metal fatigue and failed.

It actually got split and peeled away from the wheel and became flat. So, completely flat because of the momentum. And not only that it penetrated the floor. So, it becomes visible to the passengers actually one of the passengers also noted that it has something has come out from the floor, and he reported that to the conductor of the train. But there were some specific rules for the Deutsche one of the German Railway Company based on which the conductor could not use the emergency brake right away. He needed to understand the situation and investigate the circumstances.

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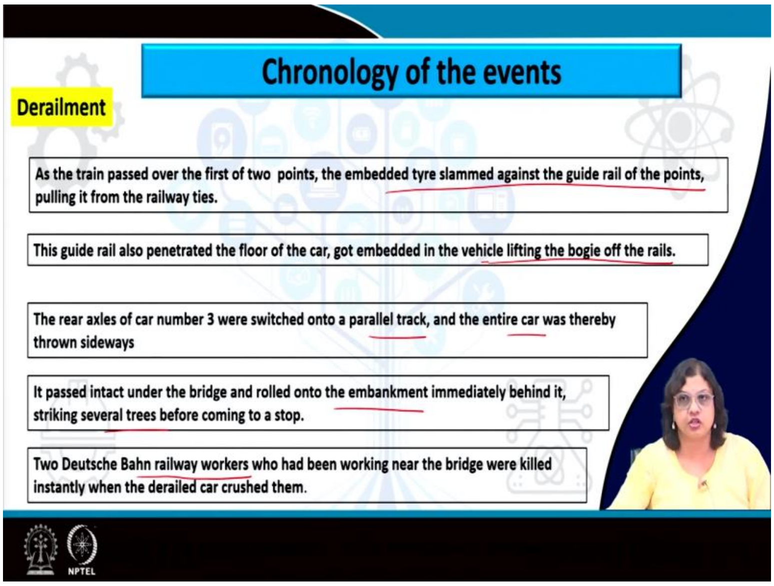

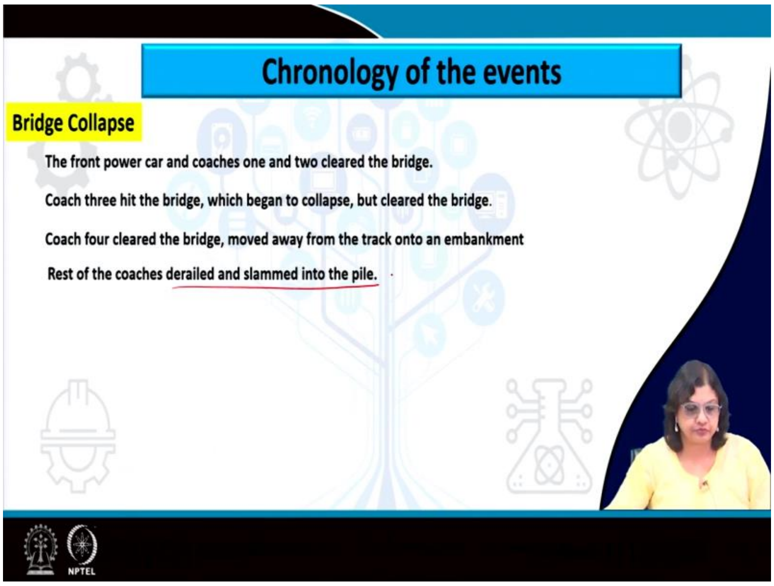

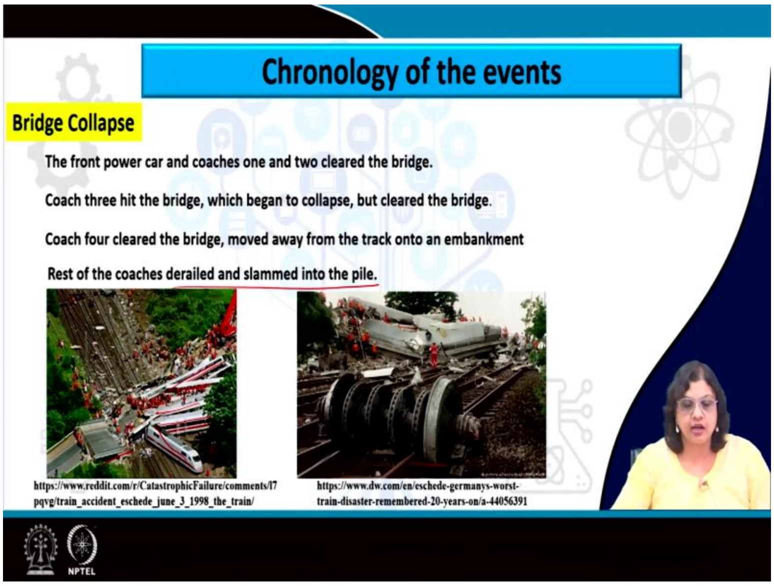

So, by the time he was doing that, the derailment already happened. So as the train passed over the first of the 2 points, the embedded tire slammed against the guide rail, pulling it from the railway ties. And this guide rail also penetrated the floor of the car. And this led the vehicle lift from the bogie of the rails. The rear axle of the wagon number 3 is actually switched on to a parallel track and the entire car was there by thrown sideways. As it moved sideways from the track, it actually rolled onto the embankment immediately behind it and striking several trees at the first instance.

And there were 2 Deutsche Bahn railway workers who are working on the nearby locality, they were also crushed by this incident. So, this is not the end of it, the most catastrophic event happened when there was a bridge, and the train has to pass beneath the bridge. And although the first few coaches cleared the bridge. The fourth coach onward it actually hit the bridge and the rest of the coaches derailed and slammed into the pile.

So, here are the pictures as you can see that this is the broken wheel and these are all the train compartments which are kind of stacked one over the other and the entire bridge also got collapsed. And this is such a huge incident. Almost all the passengers particularly those who are on the backside of the train got severely affected and killed.

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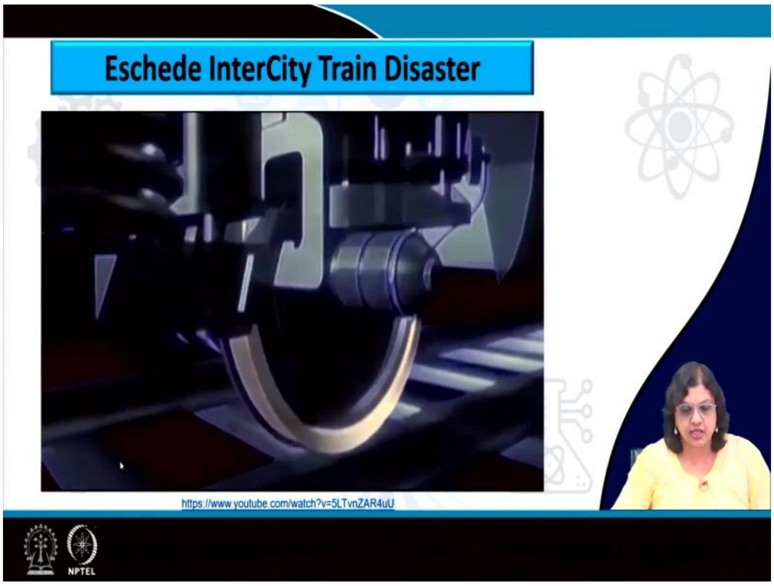

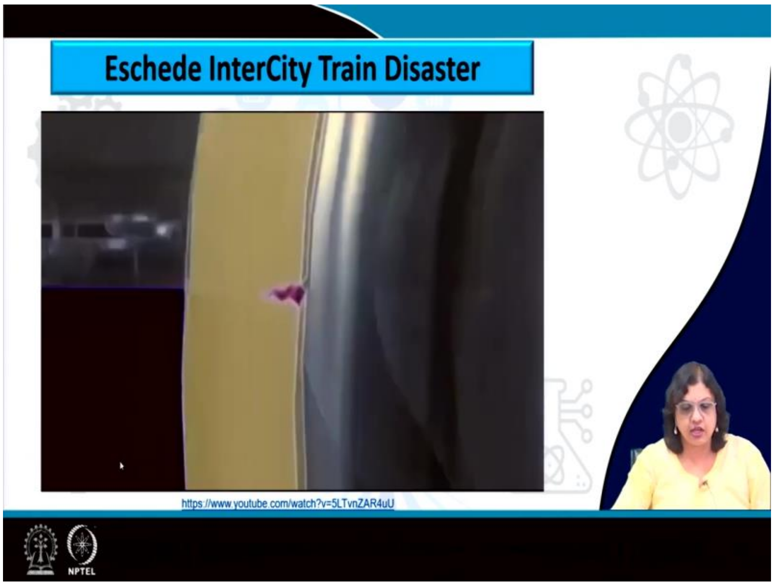

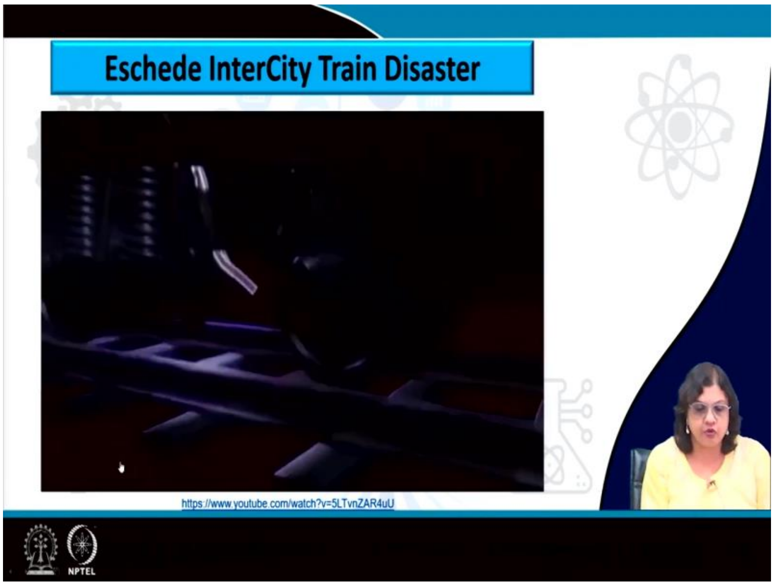
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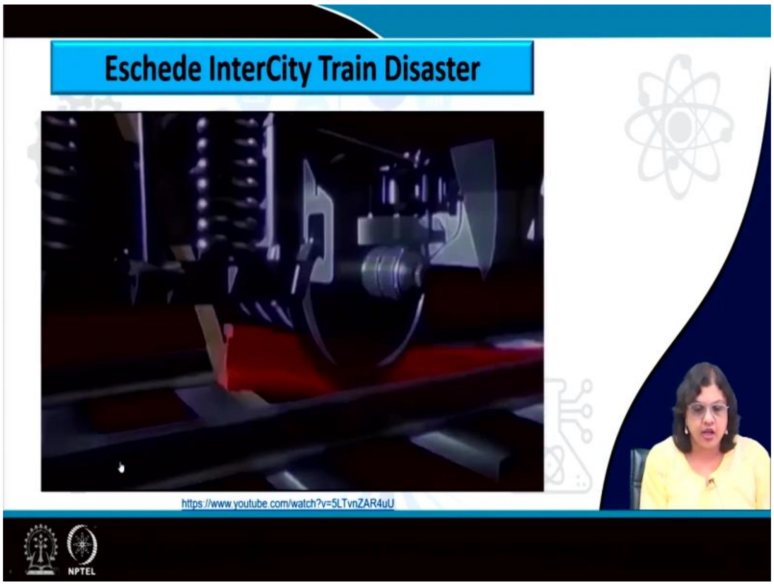
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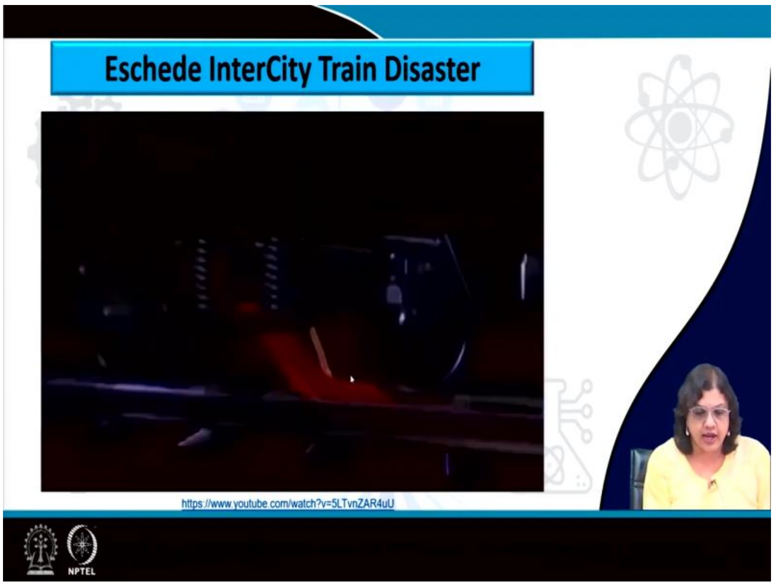
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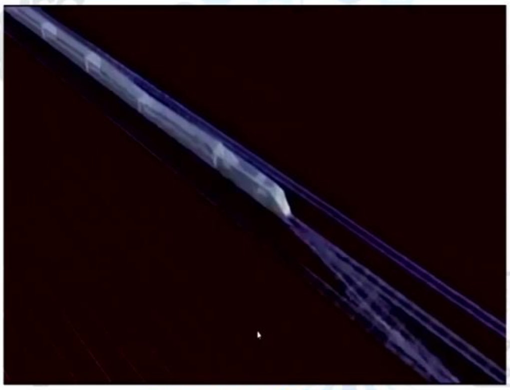

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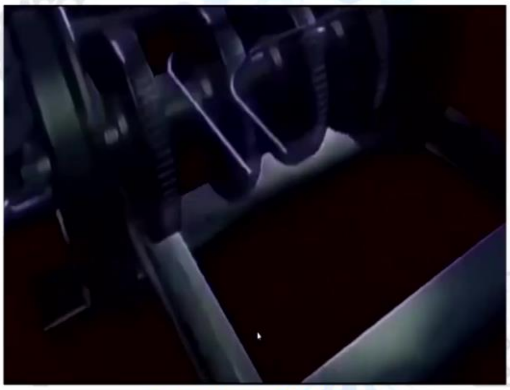

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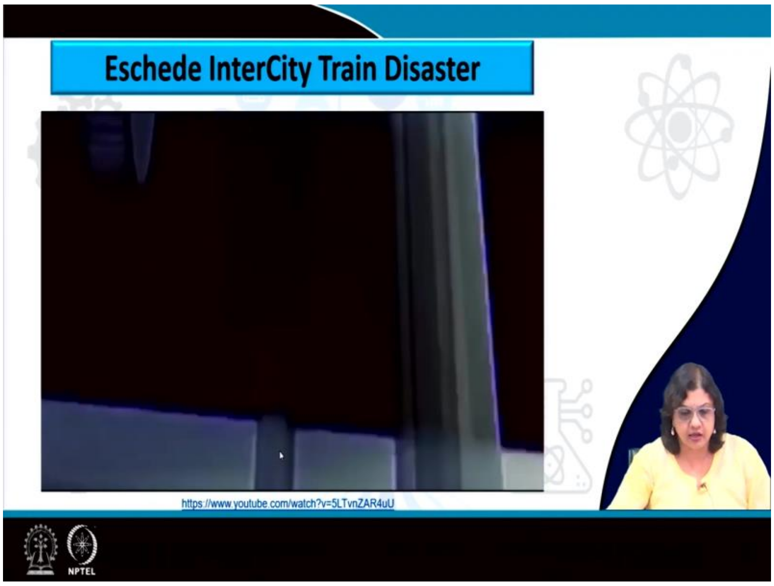
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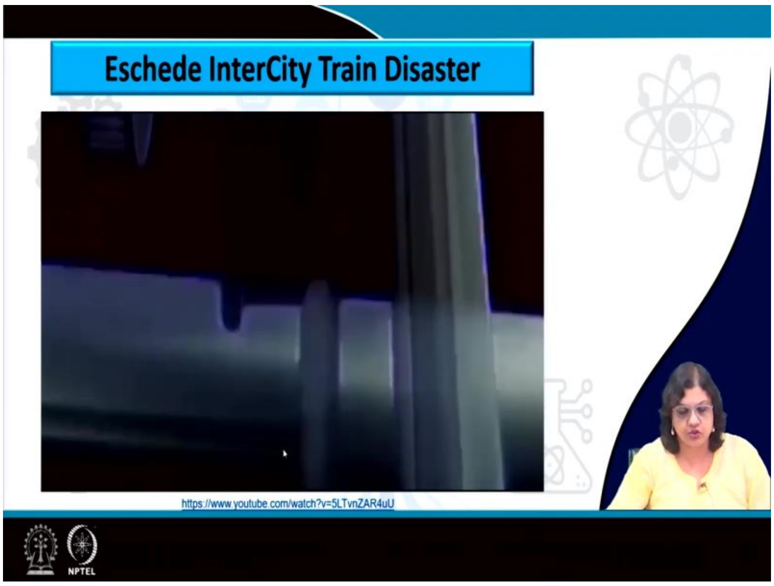
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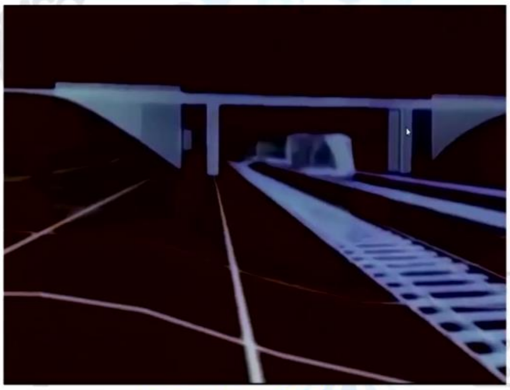

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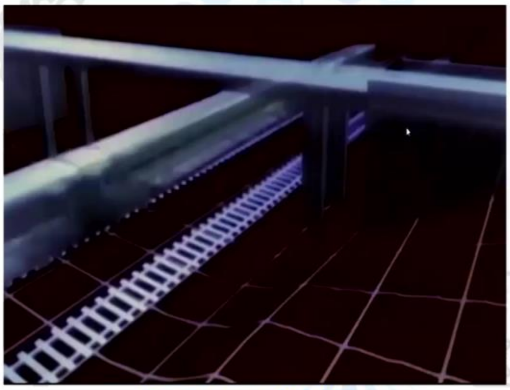

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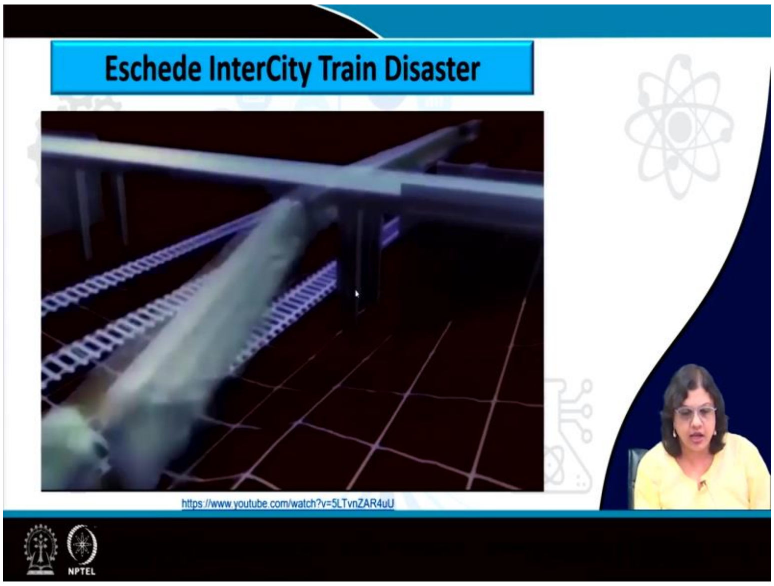
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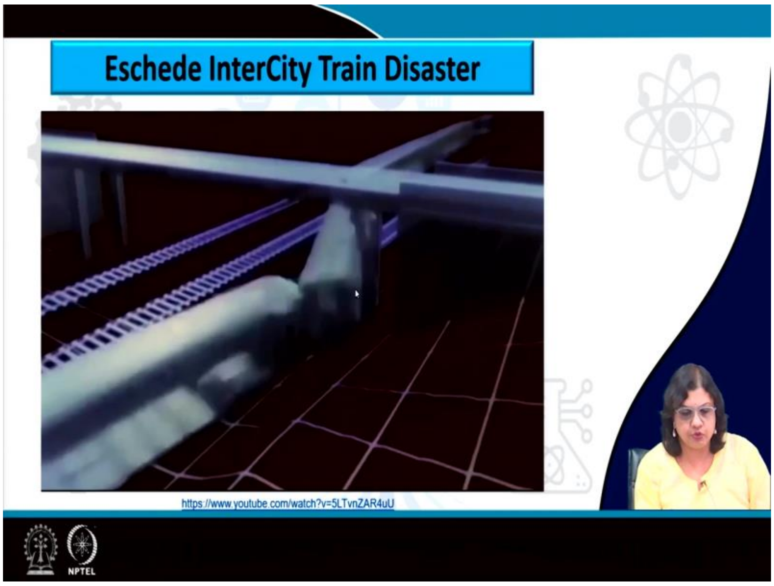
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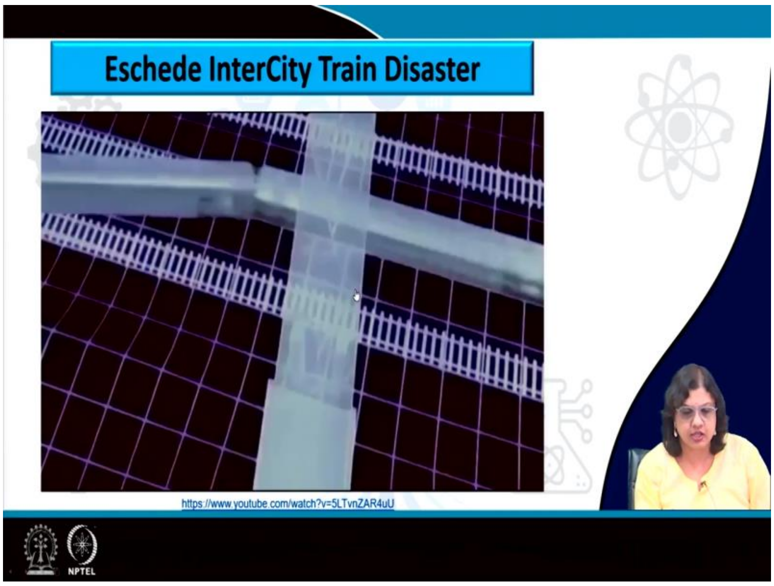
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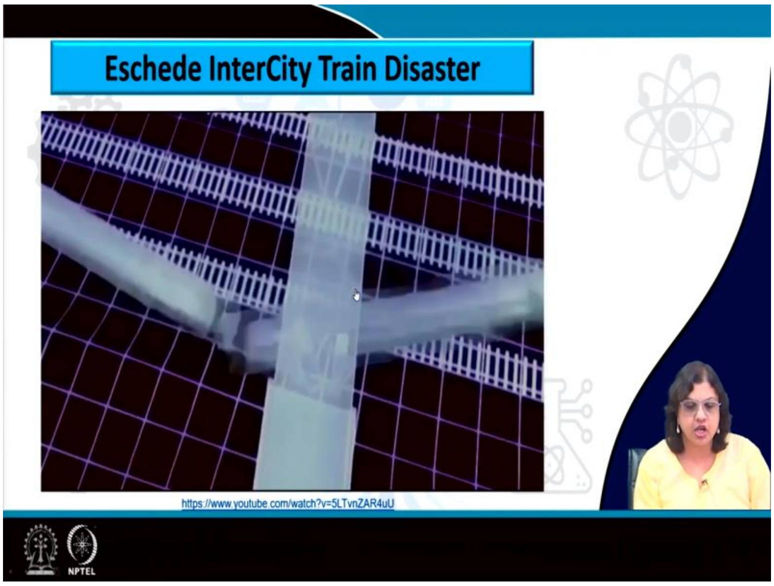
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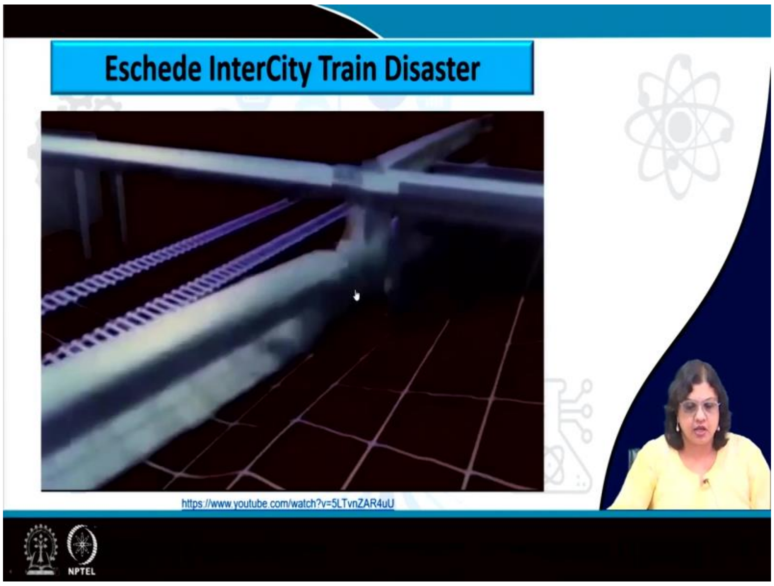
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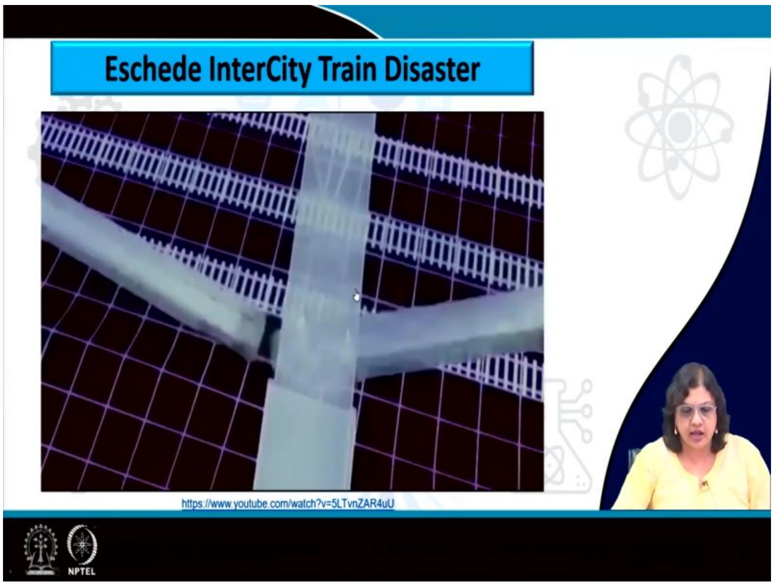
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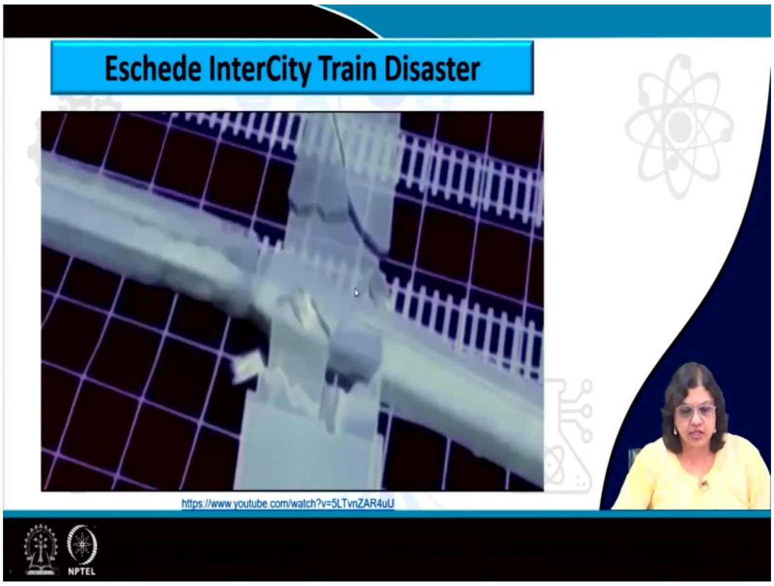
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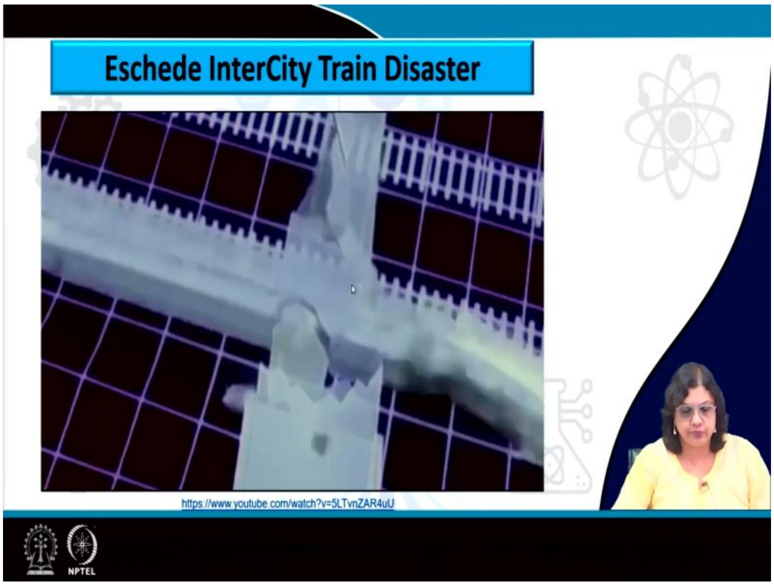
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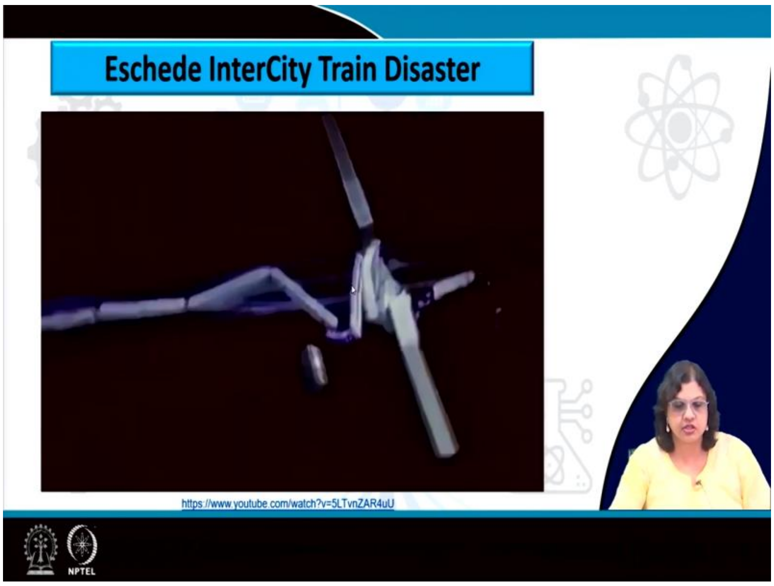
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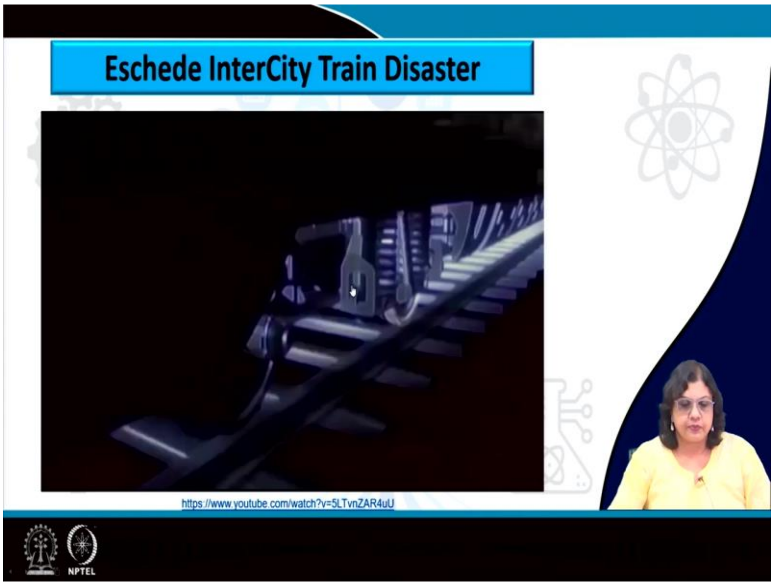

And here is video to understand what actually has happened. As you can see that while it was traveling at certain speed, this crack moved forward, it broke and then it just penetrated through the floor. And while it was moving at some particular track as it was thrown on the sideways that made it actually hit the bridge. As you can see that it is moving sideways and here comes the bridge which just got hit by the 4th wagon onward as it moves sideways. And you can see how the entire bridge collapsed based on that and suddenly the wagons are also being affected and as we have seen in the pictures they have been just stacked like a pile of cards.

So, this is a simulated one based on the actual reason for failure and you can see that this is such a catastrophic event.

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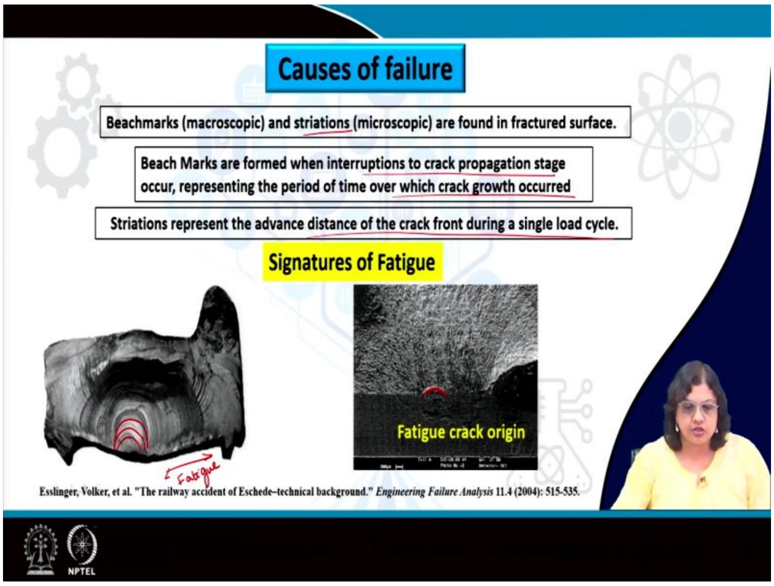

So, when the detailed investigation has been made to find out the actual reason for the failure, it has been noted from the failed surfaces that there are some formation of beach marks that has been noted at quite low magnification as well as the high magnification investigation of the fractograph shows the presence of striation we have already discussed in details in module 2 about the fatigue behavior and there we have seen that such kind of Beach Marks are formed when the interruptions to the crack propagation stage occur.

And this represent the period of time over which the crack has grown and this is also reflected in the presence of striations, which actually signify the advancement of the crack front during a single load cycle. So, each of distraction with signify that and here are the pictures where you can see this kind of rings very clearly from the microstructures and this suddenly signifies the reason as fatigue.

So, fatigue failure must have occurred, if we look into this very carefully, you will be able to note this semicircular point here, which signifies actually the crack initiation point. So, that those are the indications that fatigue must have been the actual reason that the tire broke at the very first place.

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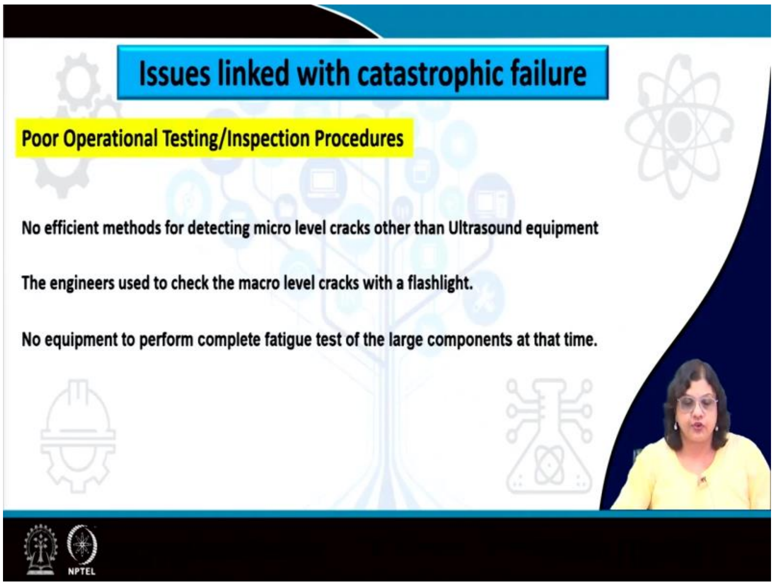

So, the signatures of fatigue were something very important to notice. And typically, this rubber sprung wheels are used in place of the monoblock cast wheels as discussed right to overcome the problem of noise and vibration at high speed. However, the cyclic loading caused the inner wheel to wear out which subsequently weakened the already the thin out of tire. The low thermal expansion coefficient of the rubbers now that is a difference between a rubber as well as a metal. The tire typically is made of metal, but this rubber one is having quite low thermal expansion coefficient. And that lead to less expansion on heating, whereas more stress is there on the wheel tire.

And suddenly this kind of new design, although were fine for trams for which it has been tested and has been quite in practice. But when it came to the high-speed rail, this actually led to the fatigue failure to occur and that led to the whole catastrophic incident. So, this design of the double block rubber sprung wheels are not suitable for such kind of high-speed trains.

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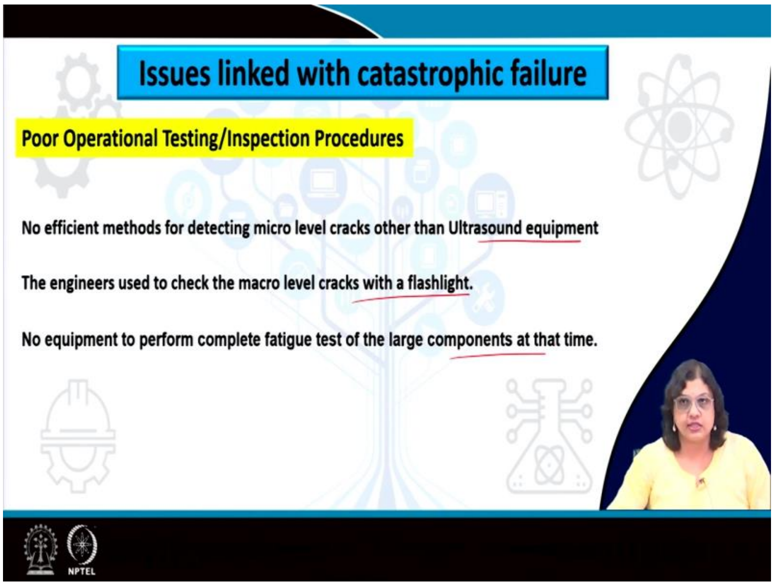

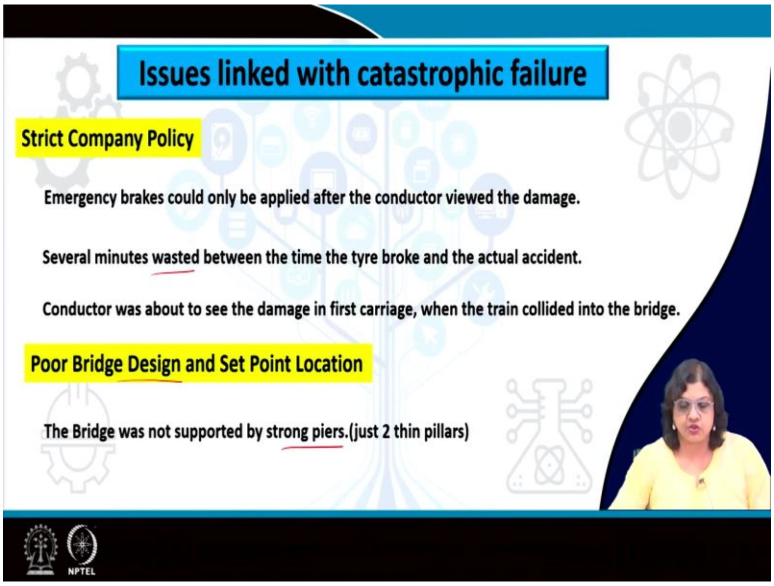

Not only that, there is some poor operational or inspection procedures at that time as well. So, there were actually no efficient methods for detecting micro level cracks as we have discussed that often, such kind of structures need to be continuously monitored or monitored after a certain period of time to see whether there has been any crack that has been formed during the process. And this has typically been done by the ultrasound equipment, but that was not sufficient to detect the presence of any such crack.

The engineers used to check the macro level cracks with the flashlight. Again, that is not very much appropriate but no equipment to perform complete fatigue tests of the large components were not seriously considered at that time.

Not only that, there were some strict company policies that also plays hand in hand to have this catastrophic incident for instance, emergency brakes could not be applied. So, there was a company policy or rule that emergency brakes cannot be used unless there is a serious incident and for to understand that whether the matter is serious or not, that needs to be investigated first.

So, of course, there was not enough time for that and several minutes were actually wasted to understand the severity of the process. And by that time, it got hit by the bridge and everything collapsed. Not only that, the bridge design was also poor, it was not supported by strong piers rather, there was just 2 thin pillars over which the entire bridge was structured.

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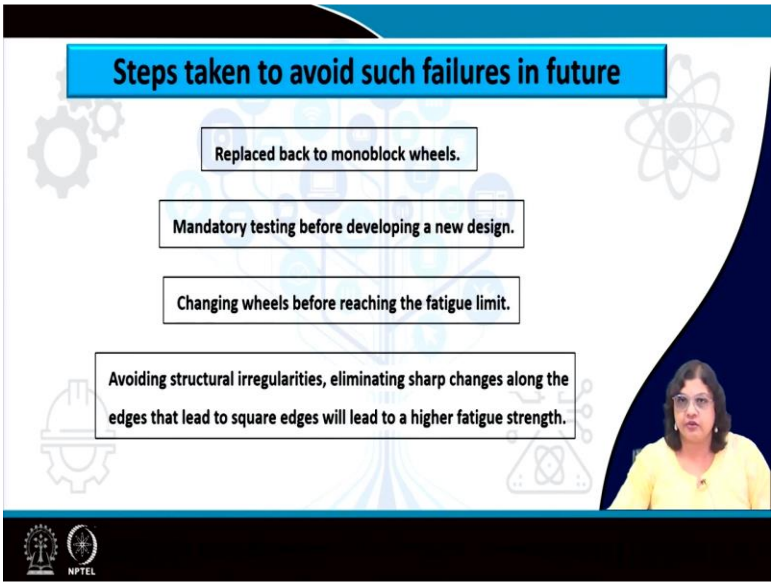

Now after this incident has happened, as I mentioned, this is still considered as the worst rail crash worldwide. So, of course there were several steps that were taken to avoid such failures in future and first of all, the monoblock wheels are being used once again. And then there was mandatory testing before developing any new design and changing wheels before the fatigue limit has been reached.

So, there comes the importance of safe life design where the life period of the wheels and the axels as well as the tracks, railway tracks are all estimated and then there has been thorough investigation to understand whether there has been any cracks generated in the process and then that needs to be replaced even if there no cracks has been found but still if it has exceeded the safe life period.

And avoiding structural irregularities, eliminating sharp changes along the edges that lead to square edges, that may lead to higher fatigue strength are been typically used.

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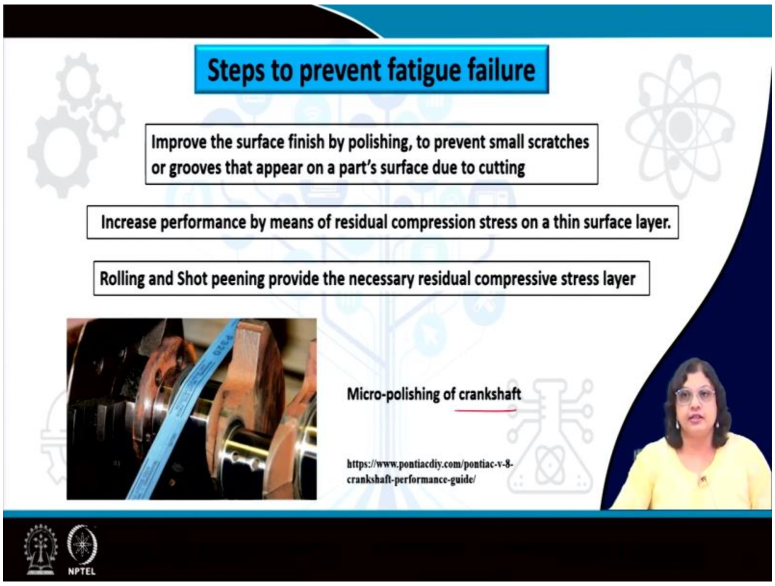

Now, what could have been done to prevent the fatigue failure is the surface finish could have been improved and this is what is being practiced these days. So, the surface finish is improved by polishing to prevent small scratches or groups that appear on the surface or there would have been residual compressive layer that is formed typically by rolling or short painting that enhances the fatigue strength of the material as discussed in the module for fatigue. So, this is one example of micro polishing of crankshaft to enhance the life of that structure.

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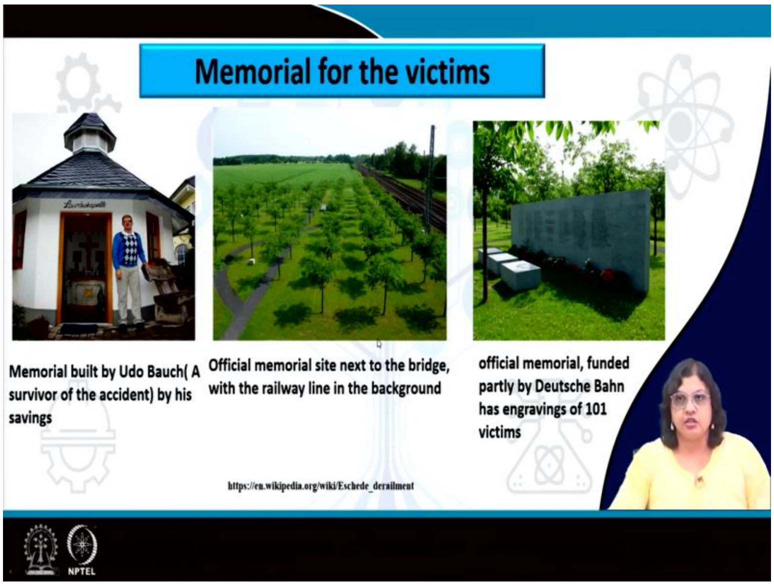

So, here is the memorial for the victims that has been built in honor of the Eschede rail crash.

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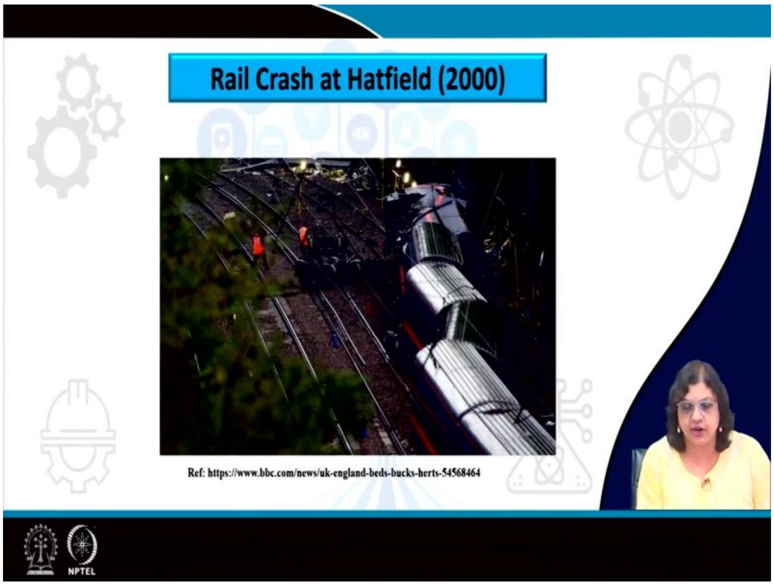

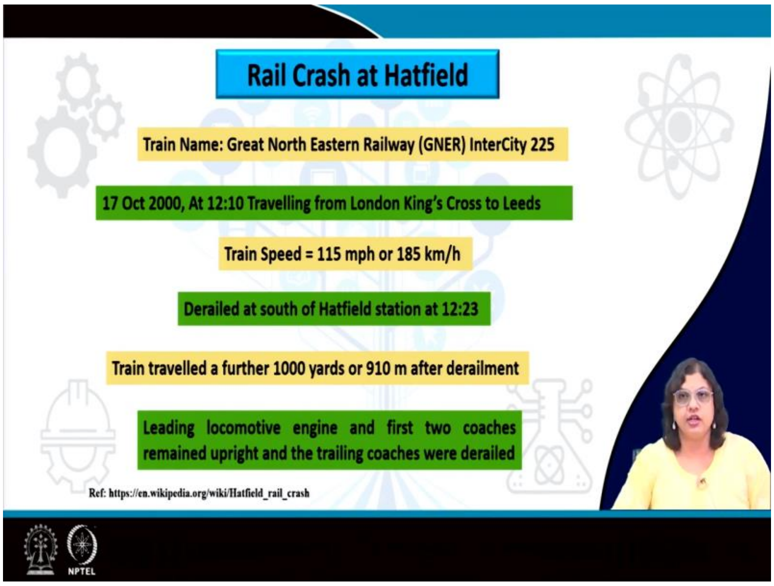

So let us move on to another incident that happened just after 2 years at Hatfield that is in England. So here also you can see that the rail has been derailed from its actual track. And basically, this is once again an Intercity Express, Intercity 225 are a great North Eastern Railway. And this incident happened and on 17th of October 2000, while the train was traveling from London's King's Cross to Leeds. It was traveling at a speed of 185 kilometer per hour and it actually derailed at the south of Hatfield Station at around 12:23. After derailment happened, it also traveled farther for around 900 meter and leading to locomotive engine and the first 2 coaches that remain upright and the trailing coaches were actually derailed.

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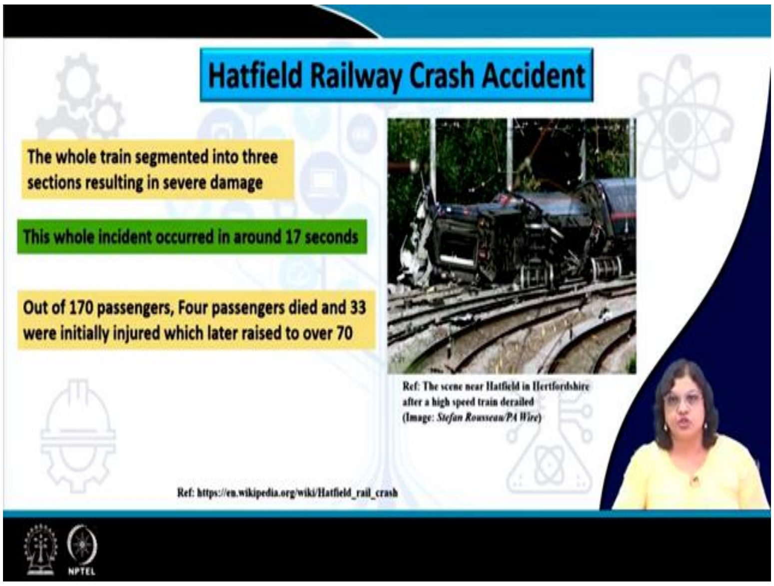

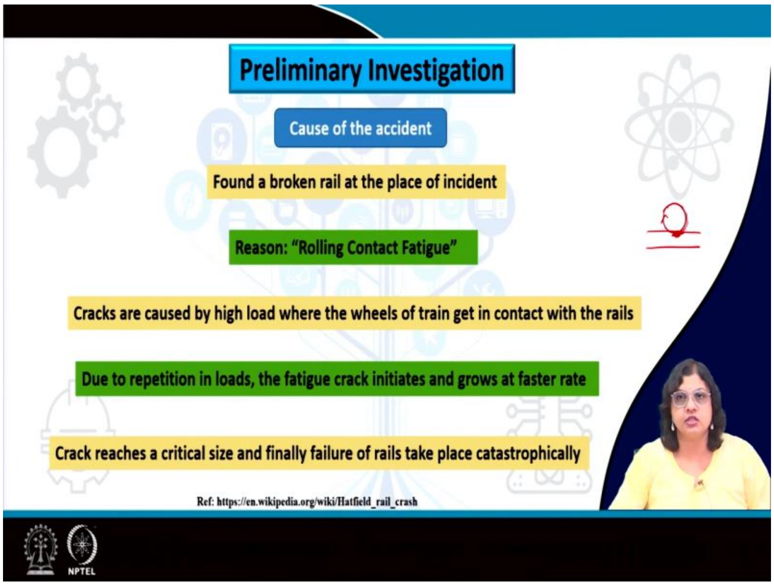

So, the entire structure of the entire whole train actually segmented into three sections resulting in severe damage, this whole incident happened just within 17 seconds. Now, here the casualties are much less compared to the previous incident. So, out of 170 passengers, only 4 passengers died reportedly and 33 were initially injured, which later the number came to around 70, but still the numbers were quite less than the Eschede train rail crash. However, when we come to the cause for the accident, a broken rail was found at the place of the incident which has been severely examined and the reason for the failure has been considered as a rolling contact fatigue.

Now, this is a very common phenomenon that happens that is a very much significance particularly for railway tracks. So, what happens is that the cracks are caused by the high load where the wheels of the train get in contact with the rails. So, there are the rail tracks and there comes the wheel. So, at this point of contact at this point here, which happens repeatedly. So, once the wheel turn and then again comes back here. So, this point of contact, which actually is all throughout the wheel structure, this leads to generation of fatigue crack initiation.

And due to the repetition in loads the fatigue crack initiates and grows at a very faster rate. Once it reaches a critical size, final failure often occurs in a catastrophic manner.

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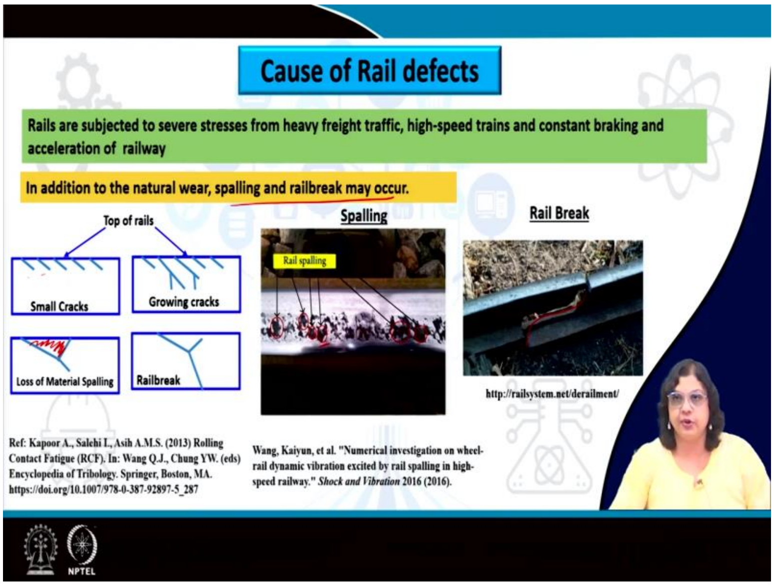

So, the same thing happened here also, along with that, there are some other reasons, which are typically found as the rail defects such as the rails are subjected to severe stresses from heavy freight traffic, high speed trains and constant braking and acceleration of railway. So, because of these fluctuations in the load levels also, along with the natural wear, spalling and rail break may occur.

So, let us see what do we mean by this incident. So, the top of the rails often leads to formation of some small cracks, which then keeps on growing and that may lead to some loss of the materials. So, this entire part gets eroded up and that is known as a spalling or it may lead to the rail break. So, you can see the pictures here for spalling where the parts come out and the rail break where the entire rail track actually breaks because of this kind of damage.

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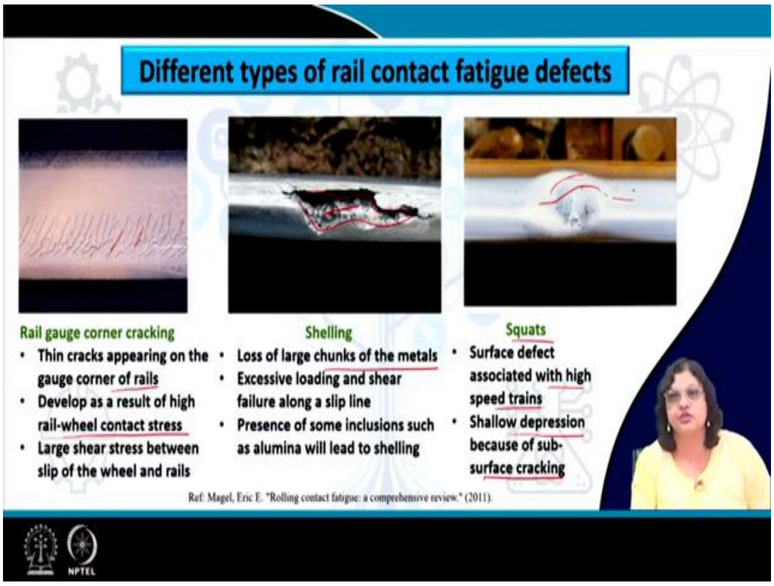

So, here are again the different types of rail contact fatigue defects that may occur. Rail gauge corner cracking, you can see the cracks that are developing here the thin cracks appearing on the gauge corner of rails and this typically develop as a result of high rail to real contact stress. Large shear stress between the slip of the wheels and rails. They can be shelling also as you can see, the material can get chipped off from the structure and this kind of large chunks of metals are coming out and certainly if such kind of irregularity are formed on the tracks.

These are not a good news these are the sources for a lot of damage to occur. For example, let us say fatigue damage and that lead to the overall failure of the rail track. This is the example of squats were the surface defects associated with high-speed trains. This is nothing but shallow depression, as you can see here. So, not like the entire part is being chipped off as we are seeing for the case of shelling. But in this case, there is actually a subsurface cracking and that leads to once again irregularity in the surface structure leading to the early sensation of fatigue cracks.

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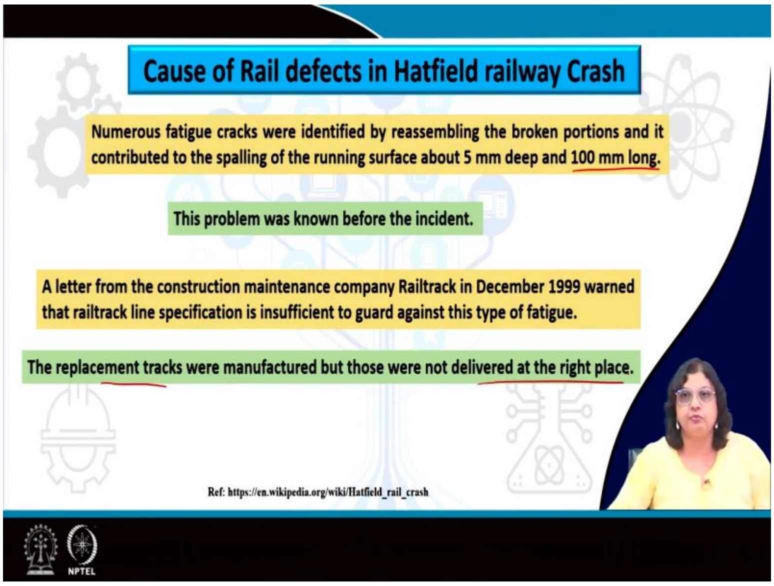

So, in case of the Hatfield railway crash numerous fatigue cracks were identified by when investigated the broken portions and it contributed to the spalling of the running surface about 5 millimeter deep and 100 millimeter long. So, that is quite some length, which actually has led to the fracture. This problem has been known before the incident actually happened and there was a provision to change the rail track however, the replacement tracks was not delivered at the right place at the right time and that leads to this severe incident.

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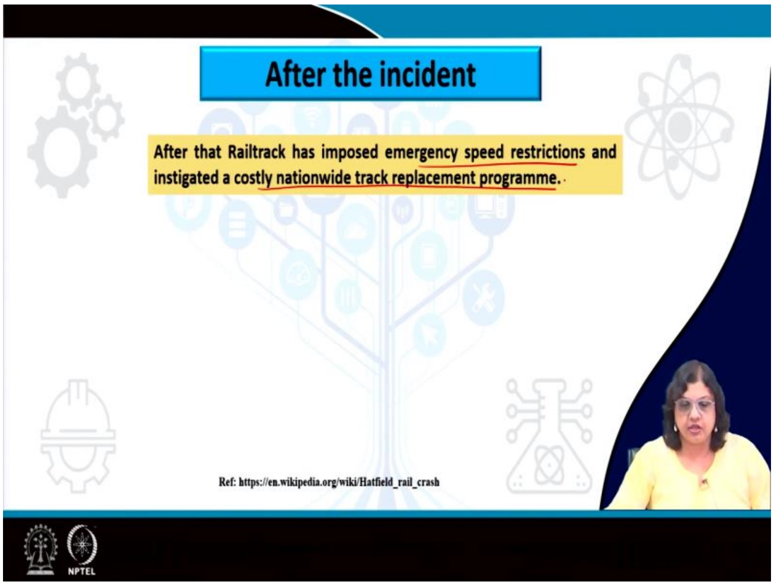

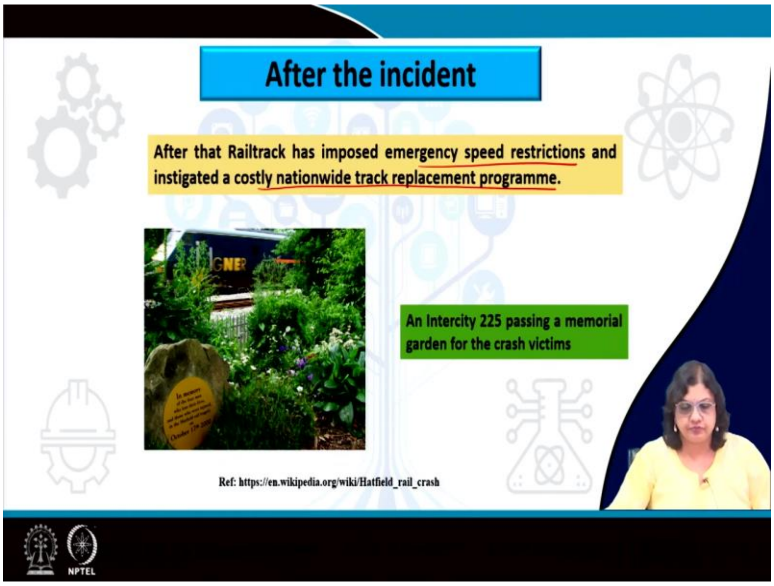

So, after the rail track has imposed several procedures to avoid such kind of incidents in future. For example, emergency speed restrictions were imposed, and a costly nationwide track replacement program has been instigated all throughout. Here is the memorial for the Intercity 225.

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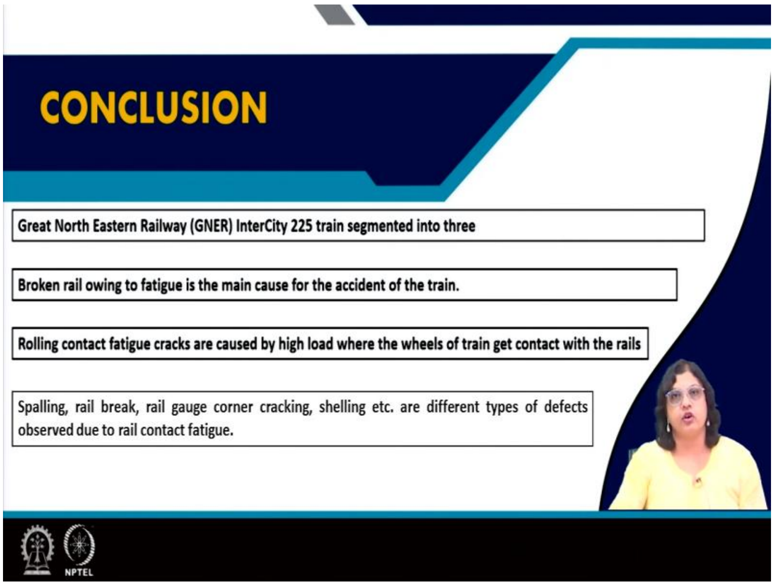

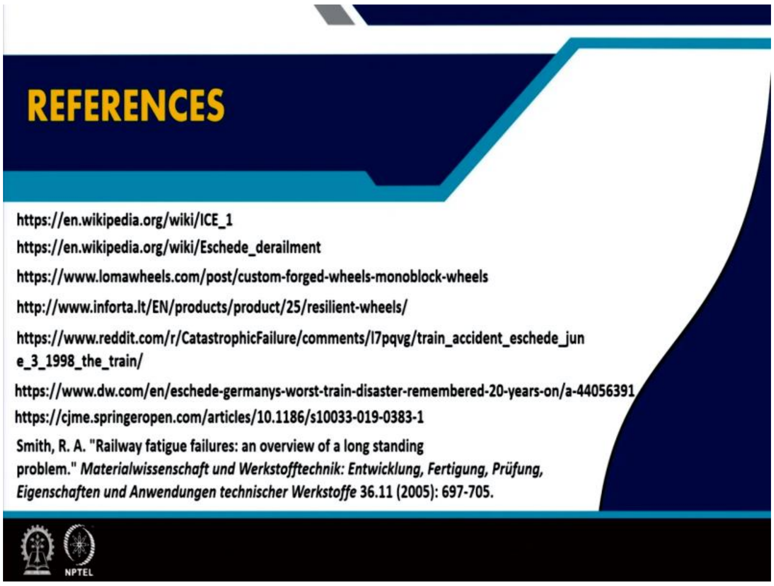

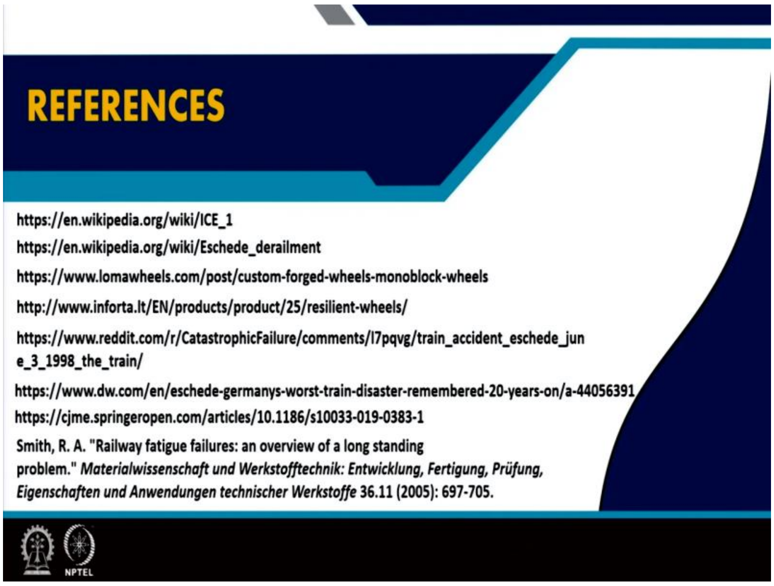

So, what we understand from these two rail crash is that the derailment of high speed Intercity Express and collapse of the bridge near Eschede, Germany was the worst real failure worldwide. The fracture of the wheel tire that brought the accident of ICE 884 this actually happened because of the formation of a fatigue crack and which finally propagated at a relatively low mean stress due to the reduced cross section of the tyre.

The collision of the bridge and its collapse actually made it a catastrophic incident with the total death toll of around 101. Now some ways to improve the fatigue performance and the fatigue strength of such kind of structure would be rolling and short painting to generate the residual compressive stress layer that may improve the performance of the structure.

In case of the Hatfield incident, which happened for the Great Northeastern Railway, Intercity 225 actually the train has been segmented into 3 broken rails owing to the fatigue is once again found as the main reason for the failure. So, for both the cases we are seeing that fatigue failure is very much relevant and is of high concern for the case of the railway. Rolling contact fatigue cracks are caused at high load where the wheels of the train get in contact with the rails and that is one of the very important causes that may lead to such kind of catastrophic failure.

The other reasons that could lead to rail defects are spalling or rail brake or rail gauge corner cracking, shelling etc, are different types of defects observed due to the rail contact fatigue. So, following the references for both two case studies and thank you very much.