Fracture, Fatigue and Failure of Materials
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Lecture 55
Failure Analysis-Case Study-ALK

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Hello everyone, we are at the 55th lecture of this course fracture fatigue and failure of materials. And today also we will be discussing about a very real-life incident a case study on capsizing of Alexander L. Kielland. So, let us see what we have in store for this lecture.

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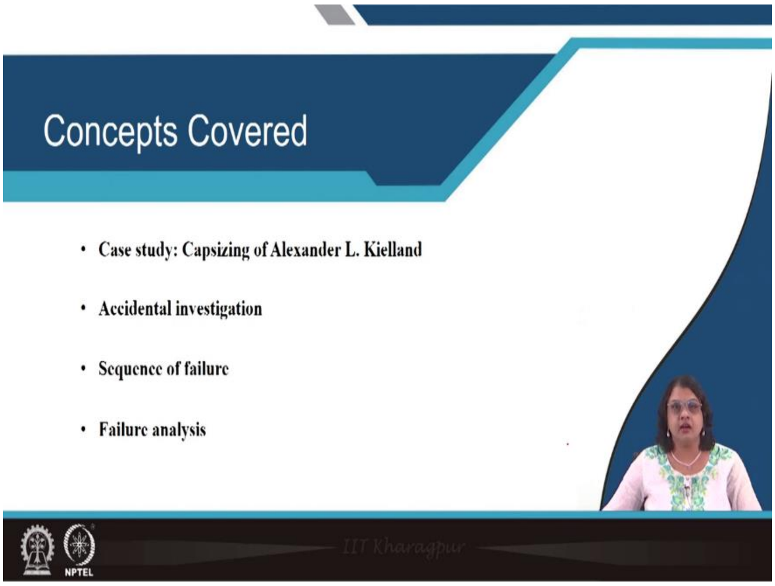

We will be basically talking about the capsizing of Alexander L. Kielland. And the accidental investigation will include a thorough investigation of what actually has happened and the sequence of failure, how exactly the incident has happened? And of course, we will look into the failure analysis and what we can understand from there.

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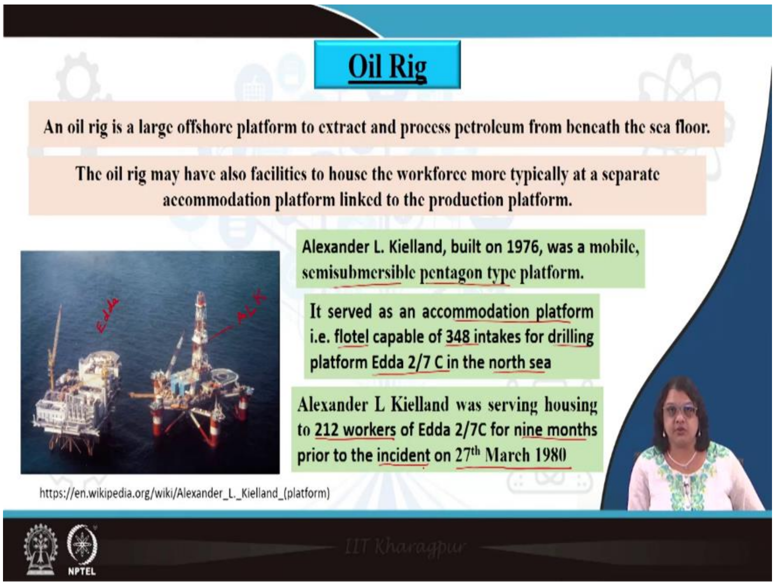

So, let us see, what is there. So, first of all, many of you might be surprised by this name itself, maybe you are not familiar with the title of this lecture that is Alexander L. Kielland. What is that? So, that is basically an oil rig? Now, what is an oil rig? Again, many of you may not have an exact idea of what an oil rig is and how does it perform, what it does? Exactly, so, let us see, an oil rig is basically a large offshore platform. Typically, it is in most of the cases it is an offshore platform that is in the sea and the main purpose of the oil rig is to extract and process petroleum from beneath the seafloor.

Now, in most cases, also the oil rig has the facilities to house the workforce that means the workers who are working on the oil rig has to stay there in the middle of the sea. So, that needs a platform in most of the cases, it is a separate platform from the oil rig and it is linked to the main production platform. So, Alexandre L. Kielland was built in 1976 and it was actually a mobile submersible pentagon type platform.

So, mobile you can understand that it can move from one place to another and we can place it at different locations based on the requirement it is semi-submersible, again it is partly under the sea and partly on top of the sea such that workers can live there and it served as an accommodation platform. So, basically, this one is not used directly for drilling rather this serves as an accommodation platform, which is also known as flotel, floating hotel and which has the capability of having around 348 workers can stay there and it was connected to the drilling platform.

The name was Edda 2/7 C and the entire thing was positioned in North Sea. You can see the image here. This is what the Alexandre L. Kielland. Alexandre L. Kielland short form is ALK and this is what is the Edda? So, workers typically used to stay there. And Alexander L Kielland was serving housing for around 212 workers for Edda for nine months prior to the incident. Now by the incident, I mean, the capsizing of Alexander L. Kielland and that happened on the fateful day of 27th, March 1980. So, again, we have to understand what is capsizing what is the structure of an oil rig or the platform and what exactly has happened? So, let us dig into the more details of that.

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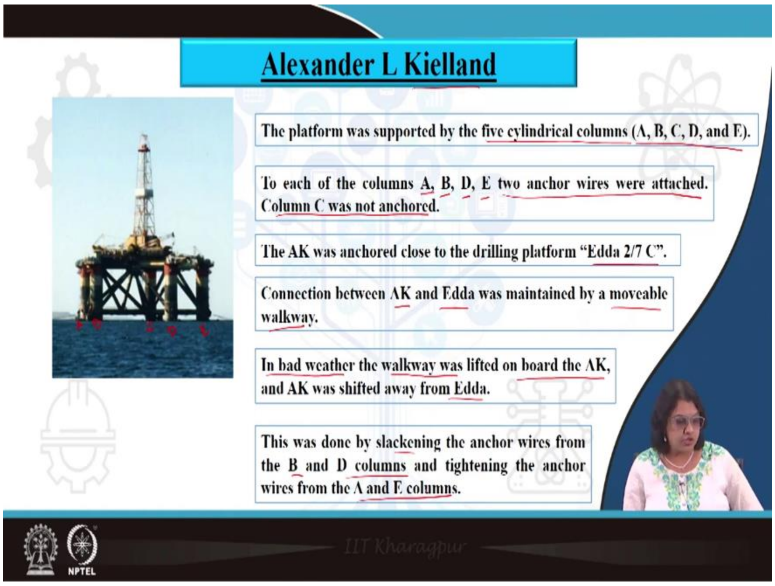

So, this Alexandria Kielland as I mentioned, this is a pentagon type platform. So, pentagonal means it has 5 legs, or actually 5 cylindrical columns. As you can see, these are marked as A, B, C, D, and E. So, this is a picture of a similar kind of pentagonal platform where you can see that there are the 5 legs, legs name this as A, B, C, on the other side, D and E.

Now, the each of the columns for the case of Alexandre L. Kielland for the columns A and B and D and E that means excluding C, two anchor wires were attached to each other. And column C however, was not anchored. The key was anchored close to the drilling platform Edda 2/7 C as I mentioned that it is in association with Edda that it worked and the connection between AK and Edda was maintained by a movable walkway typically the workers use this walkway for going from AK to Edda and vice versa.

However, in bad weather, especially since these are all positioned at the middle of the sea, they have to be extra careful about the violent weather that may have happened in the sea. And during that time, the walkway was lifted on board of the AK and AK was shifted away from the Edda. So, that they should not be influenced further by the influence of the storm or any such bad weather because of the presence of Edda.

Now, at the middle of the sea, when there was no obstructions and there is a storm and suddenly, there is a long tall structure that may actually hinder the movement of the wind and that may also influence the weather farther. So, that is the reason that typically AK shifted away from Edda such that at least the worst condition can be avoided. And this was done by slackening of the anchor wires from B and D columns and tightening the anchor wires of the A and E columns. So, let us visualize the design to make these things more clear.

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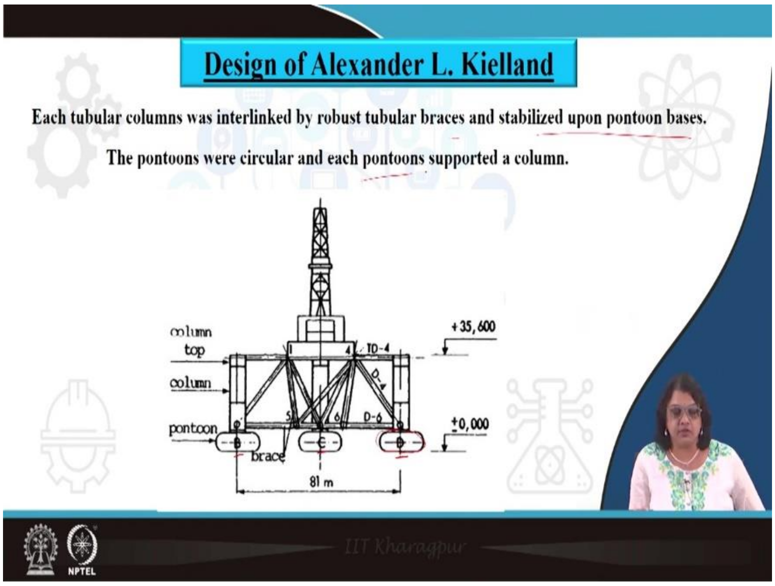

So, you can see here the drawing for the Alexander L Kielland and we can see the B, C and D columns, but A and E are on the other side. So, not visible here in this drawing, but we can understand that each tubular columns are interlinked by robust tubular braces and stabilized upon pontoon bases. So, these are the pontoons so, these are the circular bases over which the columns are standing and each pontoon actually supported the individual columns.

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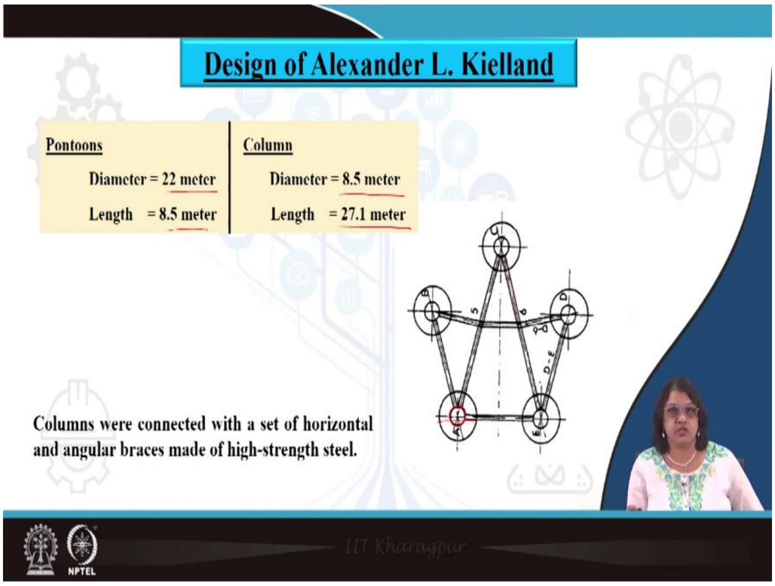

So, this is the structure of the pontoons you can see this is the top view and we can also have the detailed design of this the pontoons were having a diameter of 22 meter and length of 8.5 meters. So, this diameter is around 22 meter on the other hand, the column has much less a diameter of 8.5 meter and the length is again very, very high tall so, it is around 27 meter. Each of these columns are positioned on the pontoons.

Now, columns were connected with a set of horizontal and angular braces, we can see that how B is connected to A and B is connected to D and likewise E is connected to A and E is connected to D. But C on the other hand is connected to A and E and these braces are made of very high strength steel. So, that they can survive whatever is the weight. Typically, the weight of this entire structure entire platform Alexander L. Kieland is more than 10,000 tons. So, that is quite a huge structure at the middle of the sea.

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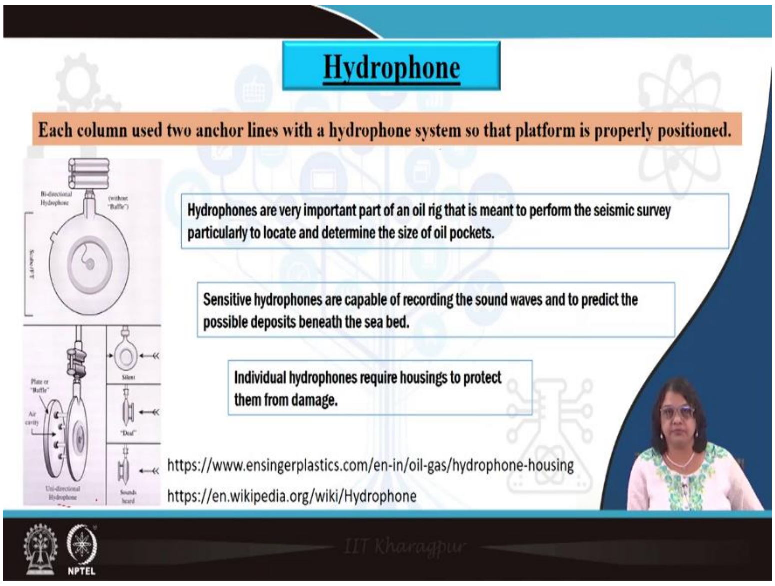

Now in the structure, there is also present a hydrophone. Each column used to anchor lines with a hydrophone system such that the platform is properly positioned. Again, the question comes maybe to some of you that what is a hydrophone, how does it work? So, hydrophones are very important part of an oil rig. So, this is meant to perform the seismic survey and that is necessary to locate and determine the size of the pockets are the places from which the oil can be extracted.

So, that needs to be determined. So, hydrophones does the purpose for that. So, these are some typical hydrophones it could be bi directional or unidirectional and based on the sound waves, it is capable of locating the positions as well as any other necessary information that are required. So, sensitive hydrophones are capable of recording the sound waves and from there from the sound waves itself it can predict the possible deposits beneath the seabed.

And individual hydrophone however required and housing so, that it can be placed within that hydrophone housing and that can prevent it from damage the entire structure this hydrophone is typically it stays below the water level so it stays inside the sea.

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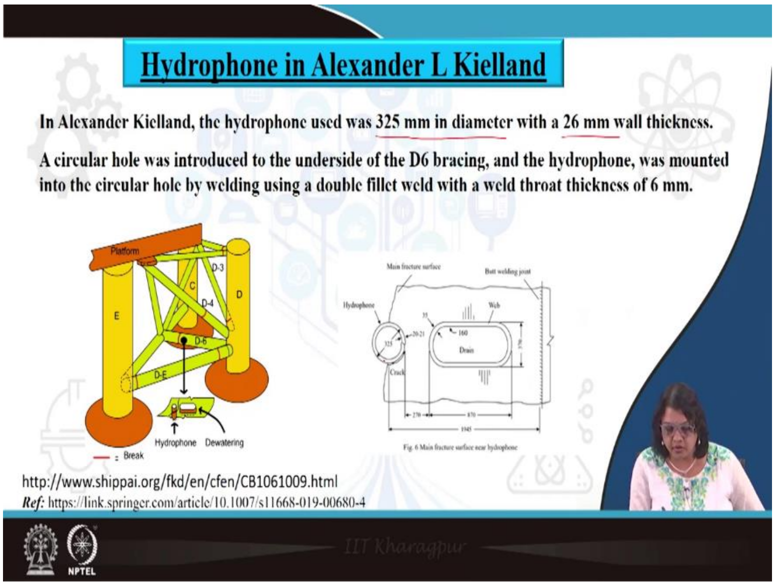

In case of this Alexander L. Kielland that we were discussing, this hydrophone is of the dimension of 325 millimeter in diameter and wall thickness of 26 millimeter. A circular hole was introduced to the underside of D6 bracing. So, this is the D and this particular bracing is numbered as D6 you can see there are other numbers like D4, D3 et cetera. It is connected with the D column and the hydrophone was mounted into the circular hole by welding. So, in this D6 it is placed by welding and that typically uses a double fillet with a weld throat thickness of 6 millimeter.

Now, this is the entire structure and we will see that how the presence of such a small instrument or such a small location in comparison to the entire structure can be dominant factor for the entire event. So, this is once again the design of how the hydrophone looks like and what the structure of the rest of the accessories.

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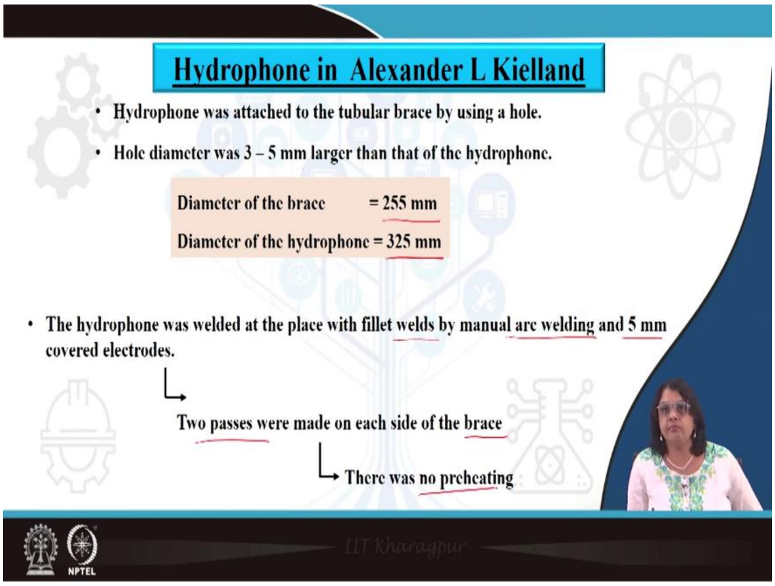

So, this hydrophone was attached to the tubular brace using a hole which has a diameter which is more than 3 to 5 millimeters than that for the hydrophone of course the hole has to have a higher diameter. So, that it can accommodate the hydrophone. The diameter of the hydrophone is as I mentioned earlier 325 millimeter but diameter of the brace is 255 millimeter.

So, hydrophone has to be just placed there does not need to be of exact diameter as the brace. So, the hydrophone was welded at this place with fillet welds by manual arc welding and 5 millimeter covered electrodes. So, 2 passes were made on each side of the brace and there was no preheating that was done.

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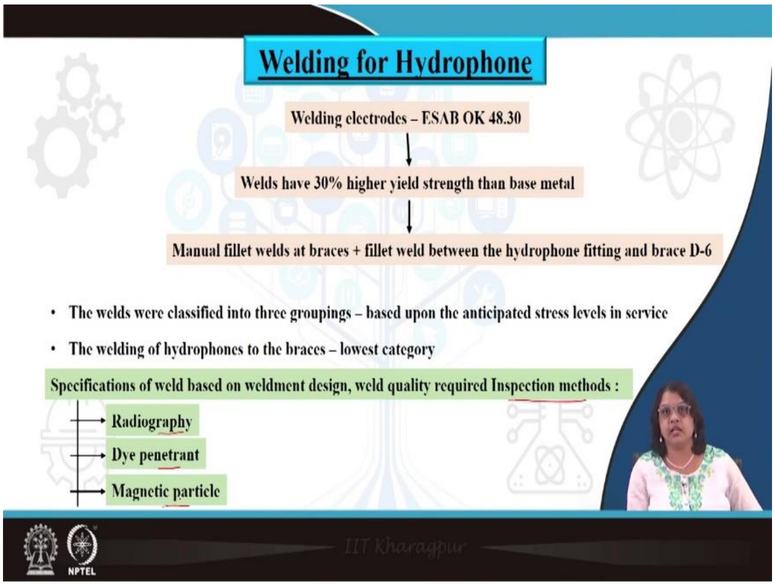

Now, typically the welding electrodes that was used is ESAB OK 48.30. And welds have 30 percent higher yield strength than the base metal that is necessary to maintain the proper strength of the structure such that the weld should not act as a weak location in terms of strength. Now, this manual fillet welds addresses plus fillet weld between the hydrophone fitting and brace D6 these are the entire structure.

The welds typically are classified into 3 groupings based upon the anticipated stress levels in service and the welding of the hydrophone however, accounts for the lowest category and being on that category it actually requires inspection. So, regular inspection should be done based on radiography, dye penetrant method or magnetic particle. So, that we can find out that if there has been any defect that has formed.

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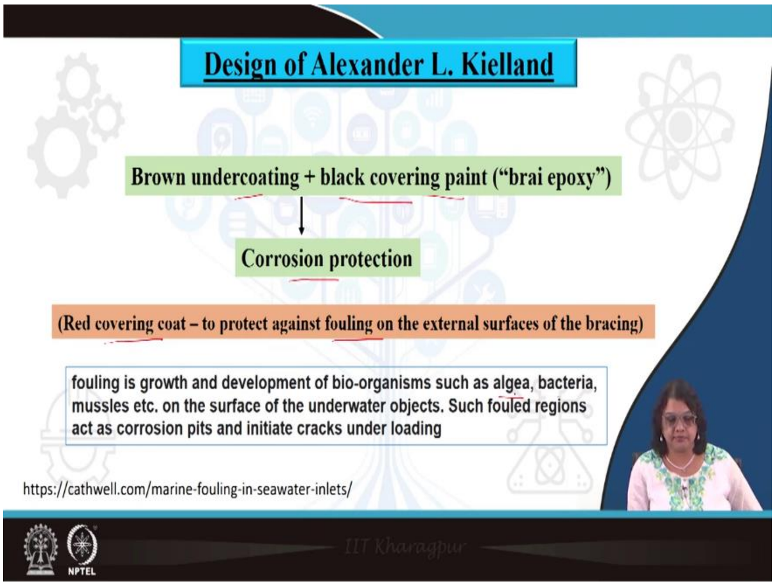

So, the entire structure however, is covered with a brown under coating and on top of that black covering paint. So, like you can understand that for any kind of structures, we typically give a coating and one of the main very important purpose of that coating is to protect it from corrosion. So, similarly, we do brown under coating and over that there is a corrosion resistant coating and on top of that actually there is a red covering coat and the purpose of that is to protect the structure from fouling on the external surface of the bracing.

Now, again the question may come to some of you that what is fouling? This is very interesting fouling is the growth and development of bio-organisms. Remember we are talking about a structure which is placed inside the sea and see houses several such millions of organisms, living organisms, and this living organisms such as the algae, bacteria, mussels, et cetera.

Actually, sticks on the surface of the underwater objects. And if it does so, there are some chemical bleaching out from them as well, which may have some reaction with the metals and such fouled regions act as the corrosion pits and so far we have understood that whenever there is a pit that may act as the crack initiation site under the circumstance of loading.

So, falling is not a much-wanted situation and we often need to protect the surface by using coating, which is has also been used for the case of Alexander L. Kielland. So, that way a proper steel has been used, all kinds of design was maintained and corrosion resistant as well as fouling resistant coatings were applied. So, that way it appeared to be quite safe.

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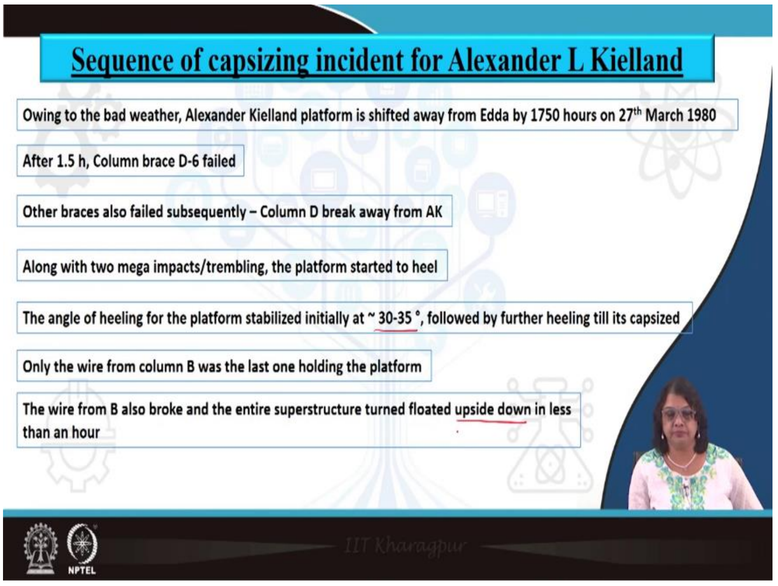

Now, let us see what actually happened on that day. Now, on the day of the 27th March 1980, there was a bad weather. So, there was an indication for storm and Alexander L. Kielland platform is shifted away from the Edda in the evening at around 5:50 pm. So, as I mentioned, this predicting that there could be some bad weather they have already removed it and most of the workers are actually resting on the Alexander l Kielland they were having their relaxation time watching TV's and doing other amusement whatever they can do when the close circle.

Now, after 1.5 hours, one of the column braces failed and other braces also failed subsequently. So, Column D break away from the Alexander L. Kielland. But this was not known however, to the workers who were staying there, this was just a sequence of events that has happened and later on found out based on the failure analysis.

So, along with the 2 mega impacts and there was a sudden trembling on which the workers became aware that something serious might have happened this time it is not just the storm and the storm was also quite heavy, it was having almost like 70 to 100 miles per hour, the speed of the wind and the waves were also quite high. And with all this the platform started to heel, it means that it is getting inclined towards the sea.

Now, this healing continued after around 30 to 35 degree and then for a certain period it kind of stabilized at there. So, you can understand that kind of feeling by 35 degree is quite extensive, which means that it has been completely inclined.

And after that, after a certain period it continued healing until it is completely capsized. Only the wire from column B was the last one holding the platform. So, all the other has already been broken and the wire from B also broke after some point and the entire superstructure turned floated upside down in less than an hour. So, that is what is known as capsizing it has completely turned down.

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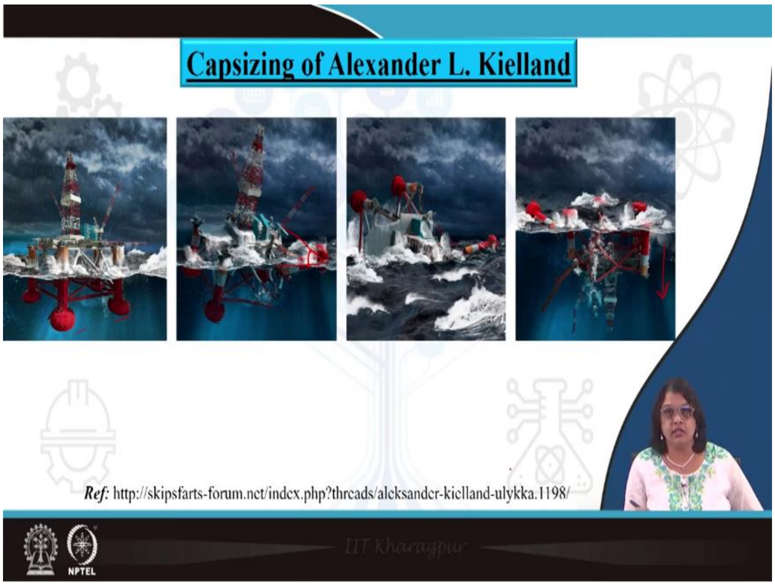

So, you can see through the schematics and you can understand how it looked like. So, this is the original way by which Alexander L. Kielland was standing you can see the columns also underwater. And then there was some heeling as you can see the water level as well as the angular degree by which it has been inclined and the ceiling continued and this is initially partly submerged and finally, it has been completely capsized.

So, you can see that it has turned upside down completely. So, that was and please do note that this has a weight of more than 10,000 tones. So, capsizing such a huge structure was quite unseen of at least up to that period.

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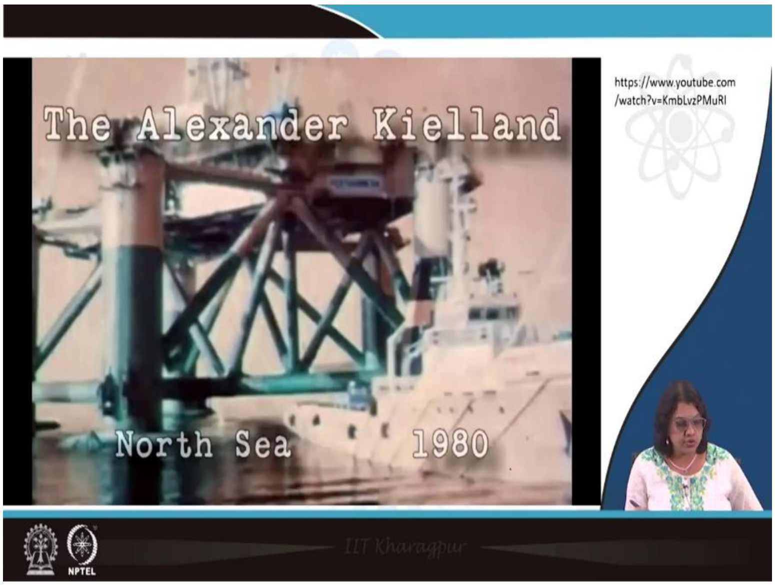

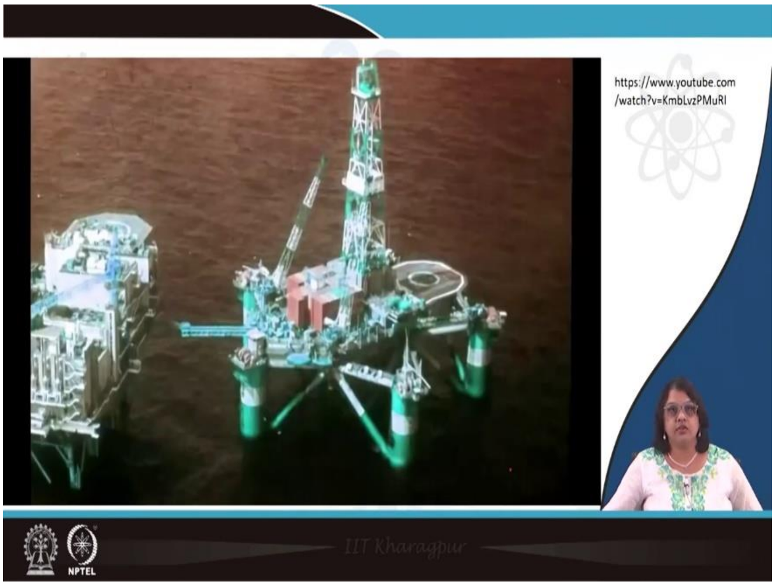

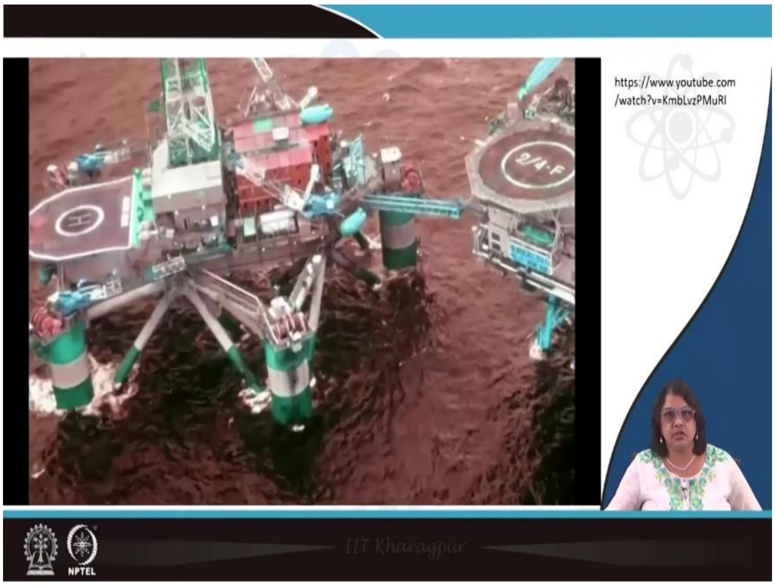

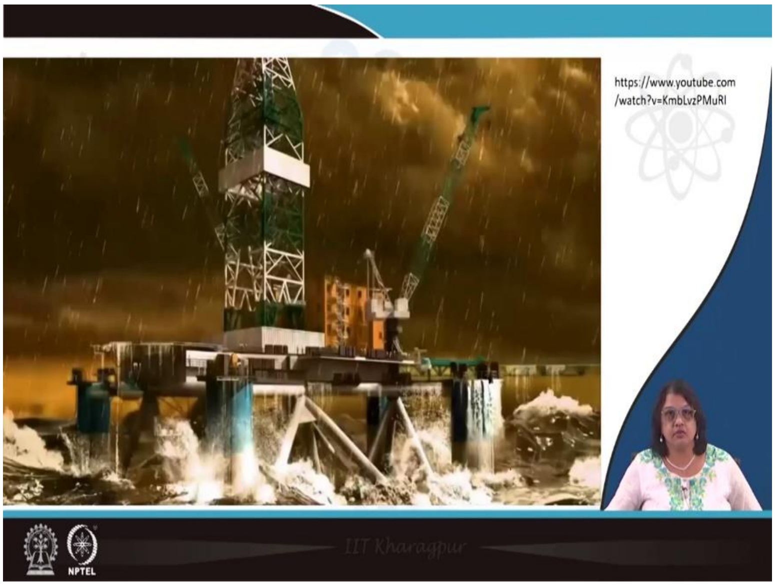
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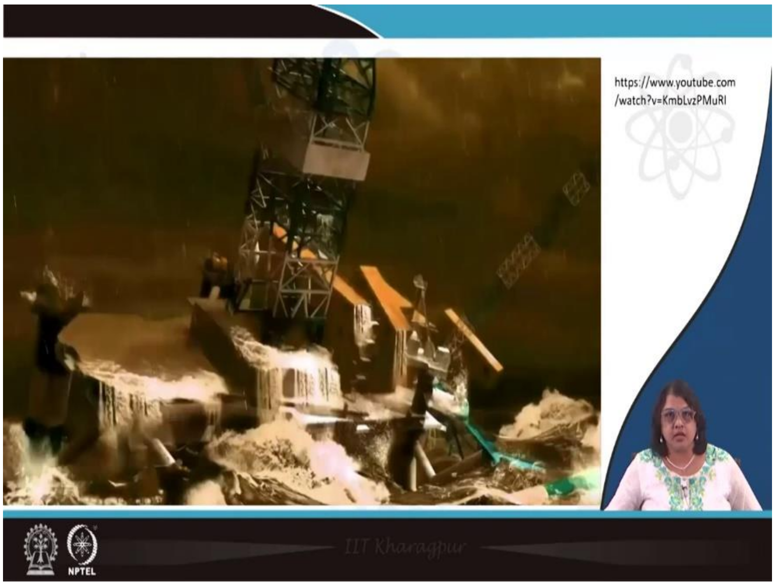
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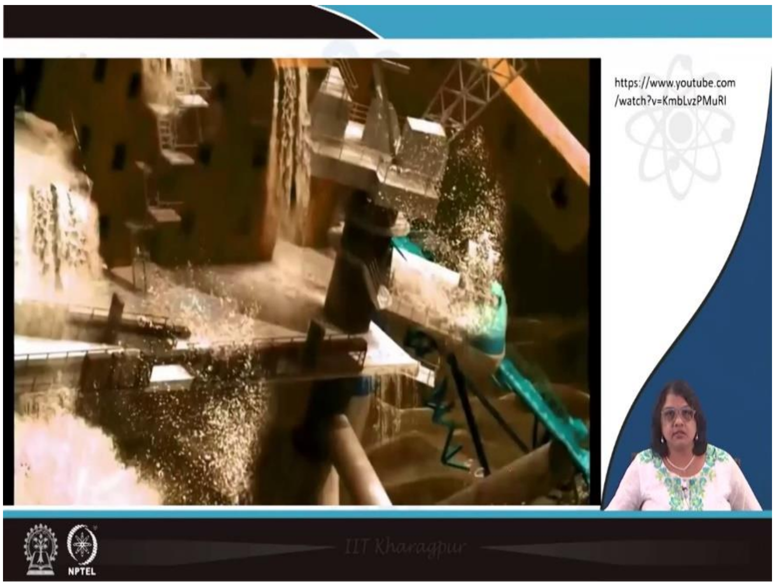
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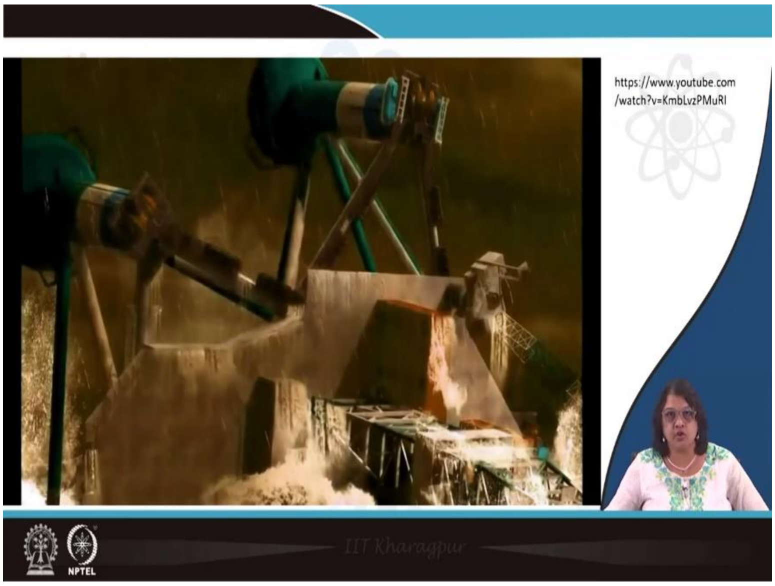
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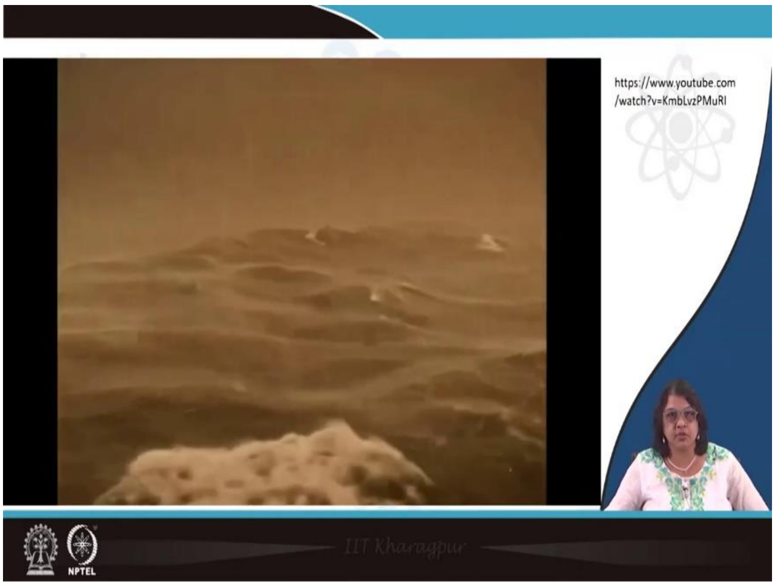
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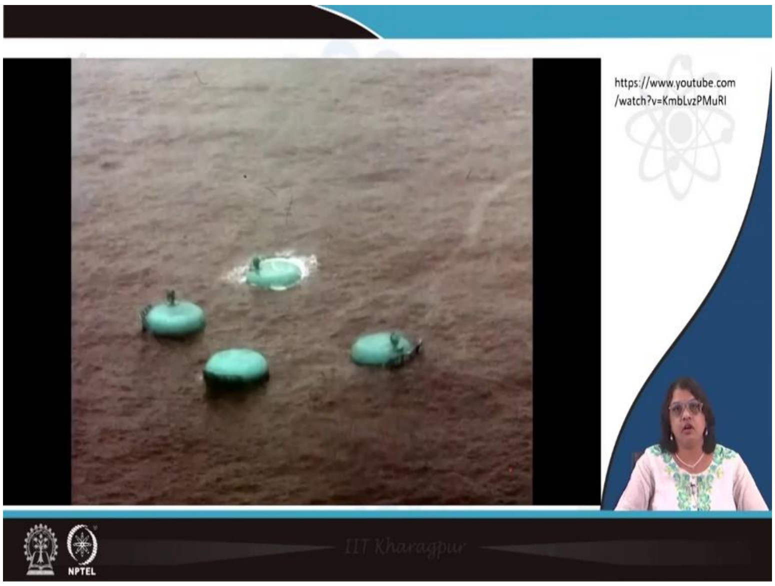
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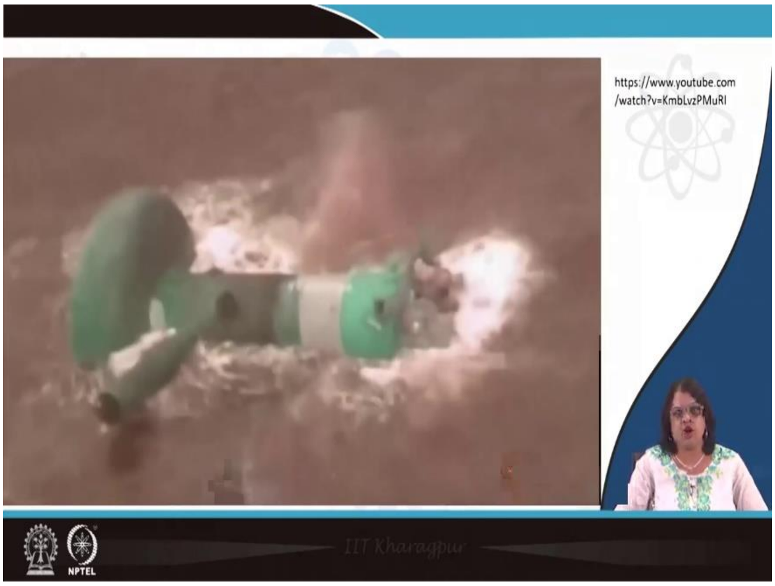

So, here is a small video to demonstrate what has happened? So, you can see the structure, these are the photos, but in most of the cases, these are the schematics or the simulation of the actual events. Of course, no photography has been taken during that period. And later on, this were all clubbed together to understand now this could be the real images, but you can see the 5 legs all upward. But most of the cases these are all simulated thing.

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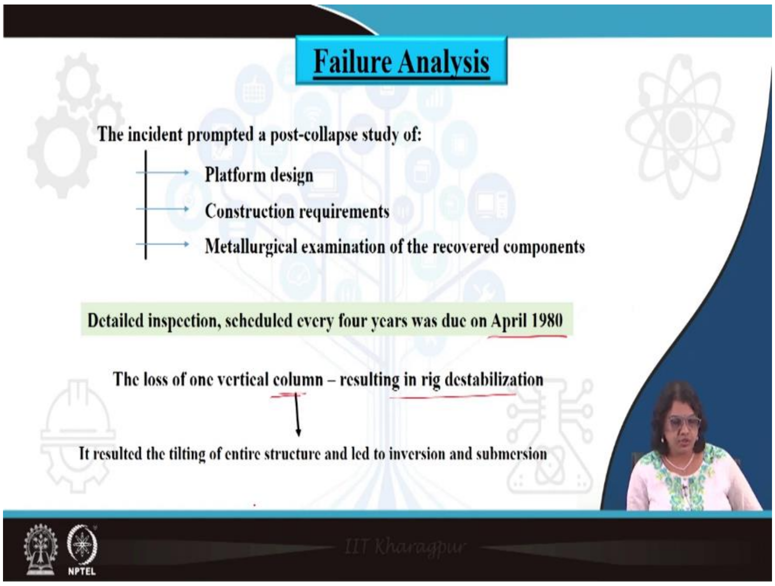

Now, after this incident, of course, this was a very much shocking incident and there was a lot of casualties actually more than 50 persons died in that incident. So, out of the 212, 123 workers died, and the dead bodies has been recovered up to 3 years actually the entire structure has been recovered and 6 dead bodies were recovered from that structure itself stuck in on that. So, that was quite a shocking incident and those who have survived, if you are interested, you can go through some YouTube videos and you can read the reviews and you will see that some of the survivors actually wrote the incident and you can have a better understanding of that, of course, that has nothing to do with the engineering failure analysis that is the main purpose of the course. But we still need to understand how much impact can a failure have?

So, of course, such an incident called for the post collapse study, which is the failure analysis based on the platform design, construction requirement and metallurgical examination of the recovered components. So, there could be different possibilities, first of all, it people might have thought that the design is faulty, of course, it is out for several months and years, but that does not guarantee that there is no mistake in the design itself.

So, that could be one of the reasons. The second thing that should come to you is there they might have used some bad quality material that may lead to corrosion or that may lead to the overall failure. So, let us see what actually it is. Basically, there is supposed to be an inspection every year and there is a detailed inspection every 4 years and one was due on April of that year 1980 and the incident happened on March 27.

So, you can understand that is quite unfortunate. The loss of one vertical column resulted in rig destabilization. So, after all the studies has been performed and based on whatever the survivors has noted, on which side it has heeled and what how exactly it has been seen. The scientists have realized that one particular vertical column has started in capsizing.

So, that was the first one which got ripped apart and that resulted the tilting of the entire structure. And of course, if one of the leg is missing, then the load will be provided to the other legs. If they are not capable of maintaining that load, then certainly there will be failure of those 2.

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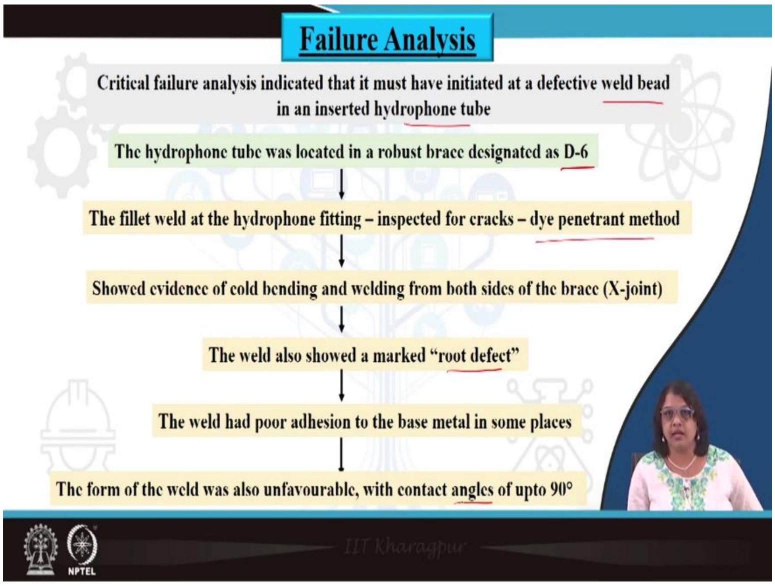

So, the critical failure analysis indicated that it must have initiated at a defective well bead in an inserted hydrophone tube. So, the entire structure has been very thoroughly scrutinized after the incident to find out that what exactly could be the reason and they have located a defective weld bead in the hydrophone tube. So, remember, we were talking about the hydrophones and the how the hydrophone is being placed by welding.

So, that has a huge impact here. The hydrophone tube first located in a robust brace designated as D 6, we have already seen that and the fillet weld at the hydrophone fitting was inspected for cracks after the incident using the dye penetrant method and when it has been done to this nondestructive method.

So, dye penetrant method is a nondestructive method, we cannot typically if such a structure is already broken, we cannot make specimens out of it rather the entire giant structure has to be tested to see that whether there are any kind of non-uniformities in the structure and that dye penetration showed evidence of cold bending and welding from both sides of the brace and also showed the marked root defect.

Thorough investigation has been done. The weld had poor adhesion to the base metal in some places the form of the weld was also unfavorable with contact angles of up to 90 degrees. So, the welding had some problem it has not been properly done, the contact angles were not up to the requirement, no preheating was done and that led to initiation of some defect.

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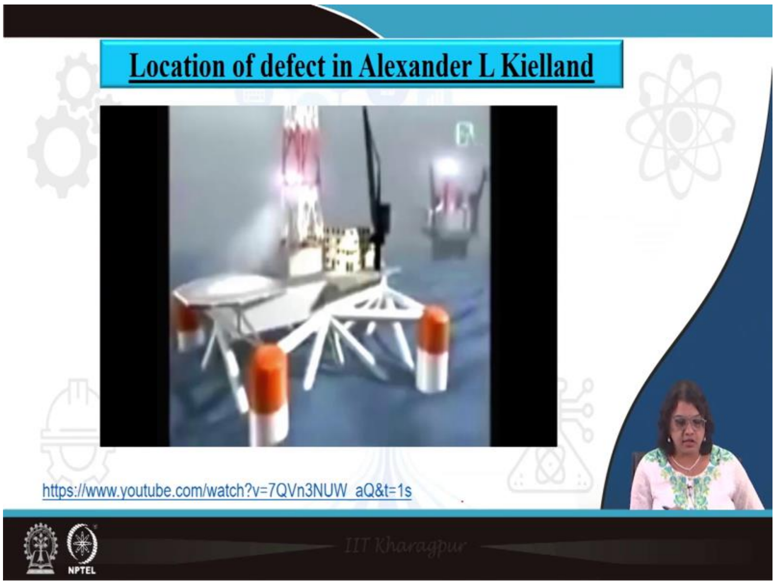

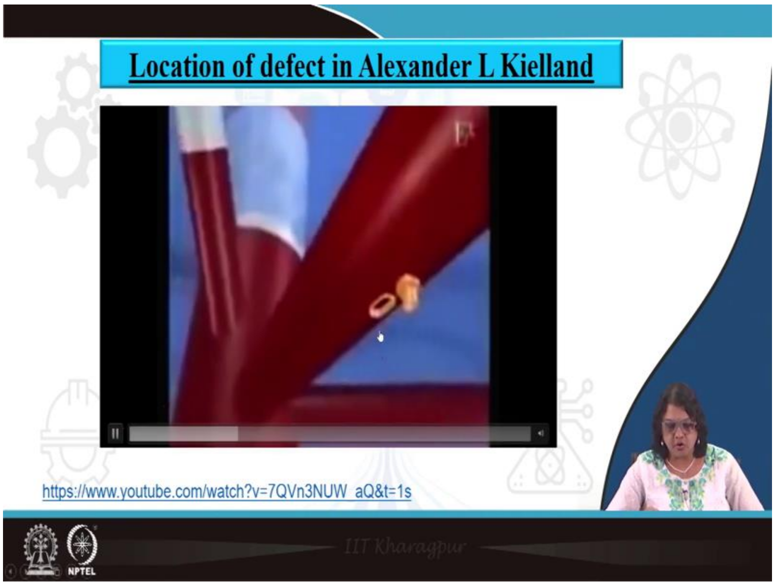
Location of defect in Alexander L Kielland
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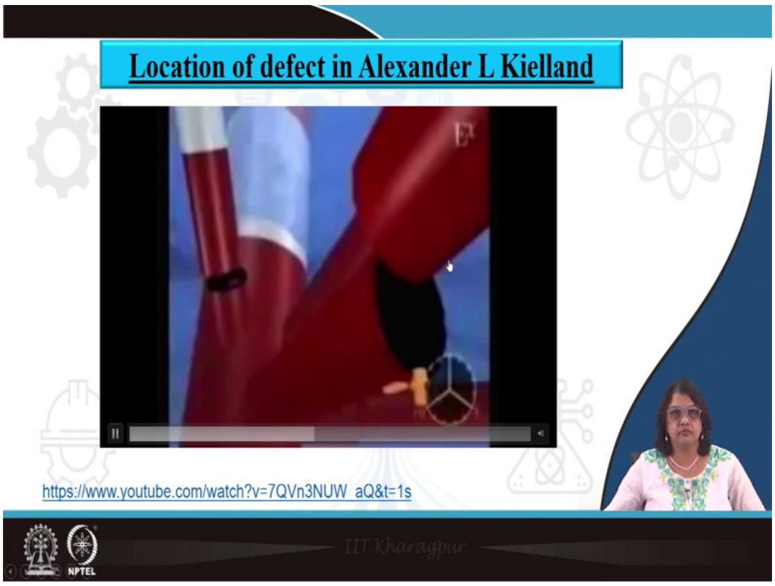
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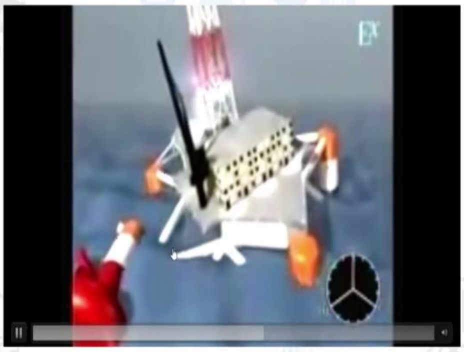

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So, here is one another video for you to understand where exactly the defect has started. So, you can see how the entire structure has been capsized based on a defect at some interior location. So, these are the 5 legs of the Pentagon structure. Of course, these are all simulated structure and if we are looking into the underwater part of this, you see at this D 6 bracing, we can see the small hydrophone locations.

And actually, this part is what has broken apart and you can see this has been recovered later on you can see the position on the hydrophone and this holes here. And how that has ripped apart the entire leg, you can see that it is floating here this one is healing down and finally it laid on the other legs or other columns also broke apart and that led to the entire capsizing of the structure upside down.

And the waves, of course, that acted as an unfavorable situation further because waves sea waves are nothing but a source of fatigue loading, it is a repeated alternate cycle that are being provided continuously. So, whenever we think of any structures, which has to be inside the seawater level, we also have to worry about the fatigue loading and such condition.

But in this case, at least, they could figure out that what is the starting point from which it has the crack has initiated and led to the final fracture of course, that is very, very small this location the size in comparison to the entire superstructure, but still, it is sufficient to lead to the capsizing of this entire giant structure.

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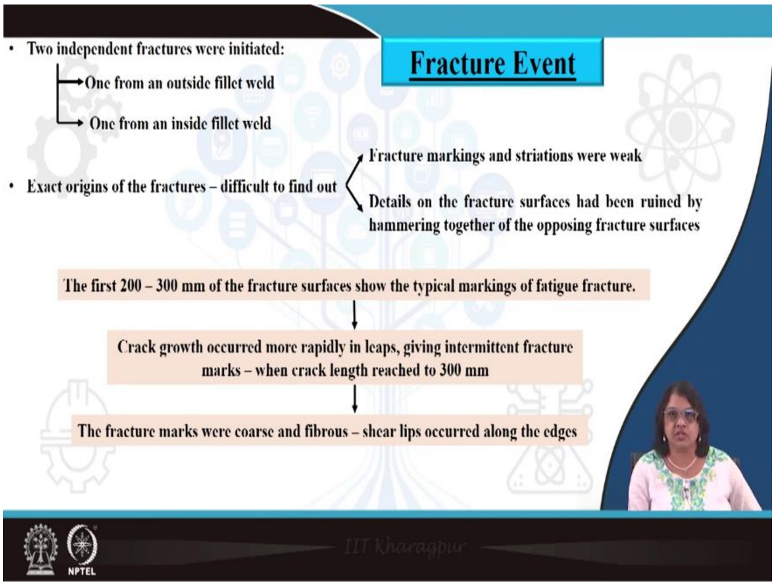

So, in the fracture even what actually has happened sequentially, we can understand is based on the 2 independent fractures that were initiated one from the outside fillet weld and one from the inside fillet weld and this has been understood based on the failure analysis of that broken piece that has been recovered later on.

Exact origin of the fracture is very difficult to find out because the fracture markings and striations were very weak and this has been recovered after a time gap and within that time period, it has been removed, it has been completely or partially ruined at some places, because these were hammering together with the opposing fracture surface.

We have discussed this earlier also the fracture surface needs to be always protected or preserved such that the signatures of fractures should not be lost and but this was not possible there this is a natural incident that happened and the broken parts were recovered quite some time later.

By that time the freshly formed fracture surfaces might have been corroded or oxidized or they at least have rubbed along with the other fracture surface and that may have removed some of the very signature fracture surface, but still from the shape of the surface and the location of the crack we can still figure out that the first 200 to 300 millimeter of the fracture surface showed typical markings of fatigue fracture.

And crack growth occurred more rapidly in leaps giving intermittent fracture marks, we have also seen that in case there is a sudden loading condition, how we can determine this from the fracture surface itself. So, when the crack length reached to 300 millimeters such kind of intermittent fracture marks were seen. The fracture marks were coarse and fibrous and there were some amount of shear lips also around the edges.

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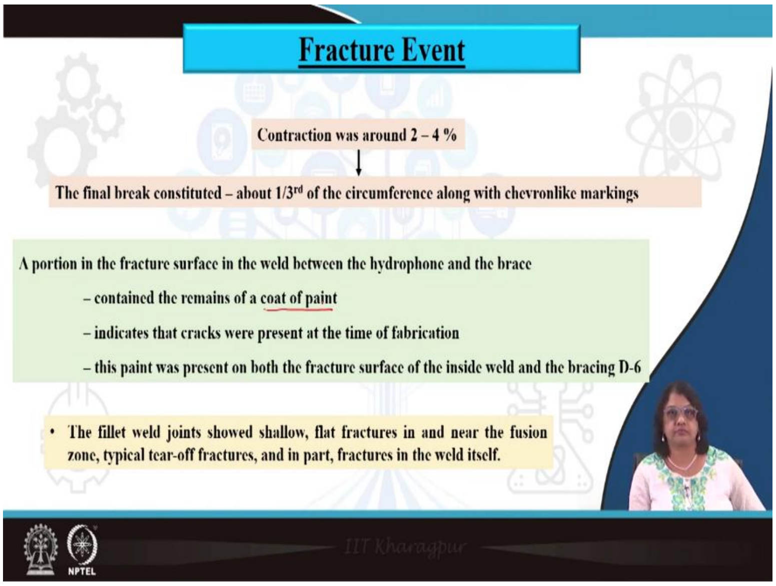

So, there was contraction of around 2 to 4 percent and the final break constituted about one third of the circumference or the entire circular structure that has been recovered. One third consists of the final fracture regime with chevron like markings. A portion in the fracture surface in the weld between the hydrophone and the brace that contains the remains of a coat of paint. Remember, we were talking about the different kinds of coatings that were put there were some corrosion resistant coating some fouling coating.

And we have seen in the previous video, which although is a simulation, but it still showed a red colored structure. So, that means that there was some paint on there. So, remains of coat of paint is recovered from the fracture surface itself. So, the fracture surface showed presence of paint there. Now, this is very surprising, if you think no fracture has happened internally, coating has been done on the surface on the top surface.

So, if a coat is a paint is already present on the fracture surface itself this indicates that cracks were present at the time of fabrication. So, when the coating has been done on the surface cracks were already existing and that is when the coating might have the paint might have leached through the crack and entered into that surface. Later on, it has a catastrophe fracture and we can see the entire fracture surface with a paint on it. So, this paint is supposed to be present on the fracture surface of the inside weld and the bracing D 6.

Of course, so, that signifies that that defect might be of very small length, but that was present at the time of fabrication itself even before it was placed on the sea for the functioning as a housing. So, that means that such kind of defects which can typically be overlooked, that can also lead to a catastrophic failure. The fillet weld joints, however, showed shallow flat fractures in a near diffusion zone and typical tear of fractures and in part fractures in the weld itself.

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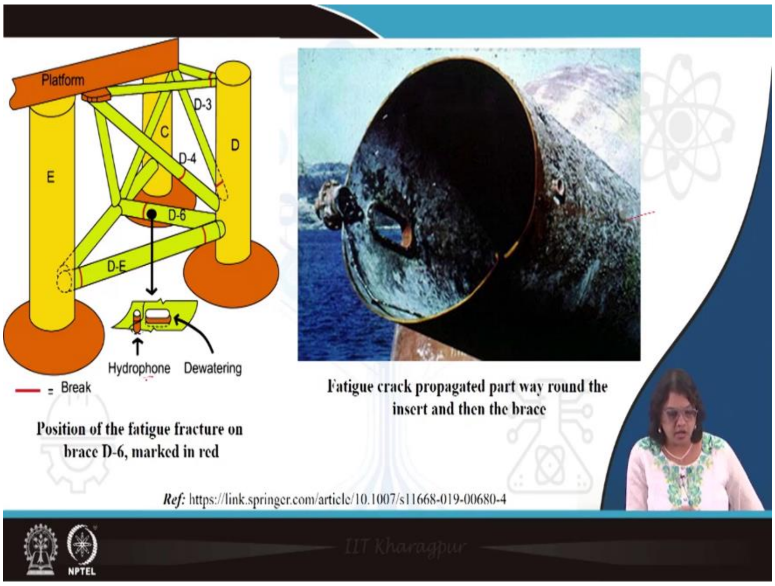

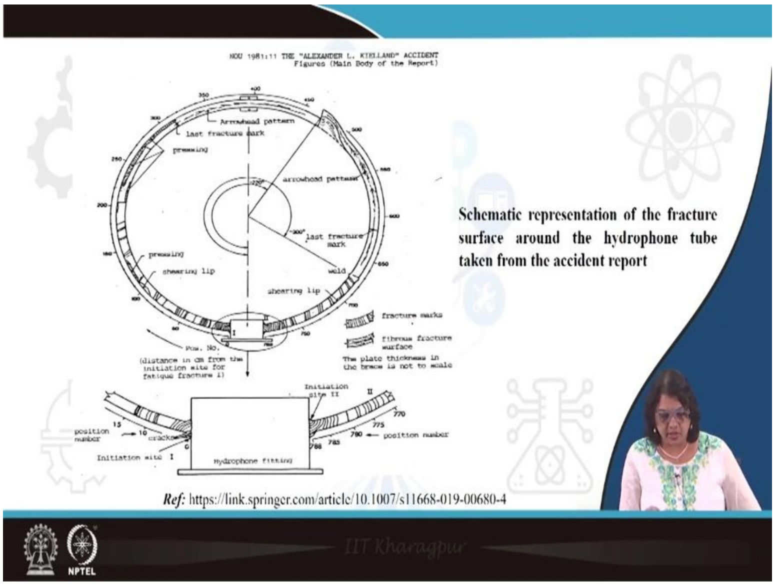

So, you can see here, this were the piece that was recovered and this was actually somewhere here, where we can see the position of the hydrophone and this hole here. And based on the studies itself, we can found out that how the fracture surfaces looked like how the markings were there, and all this has been very, very carefully and critically analyzed to determine the actual reason for the failure.

So, failure if we completely let go is of no use of course, there was a lot of deaths that happened and this is a shocking event, but if proper failure analysis has been done, then that can be used to have the information such that we understand that what is important and what needs to be avoided, how the inspection should be done, which are the key locations that need to be monitored very, very carefully. So, all those can be understood at least from search failure analysis.

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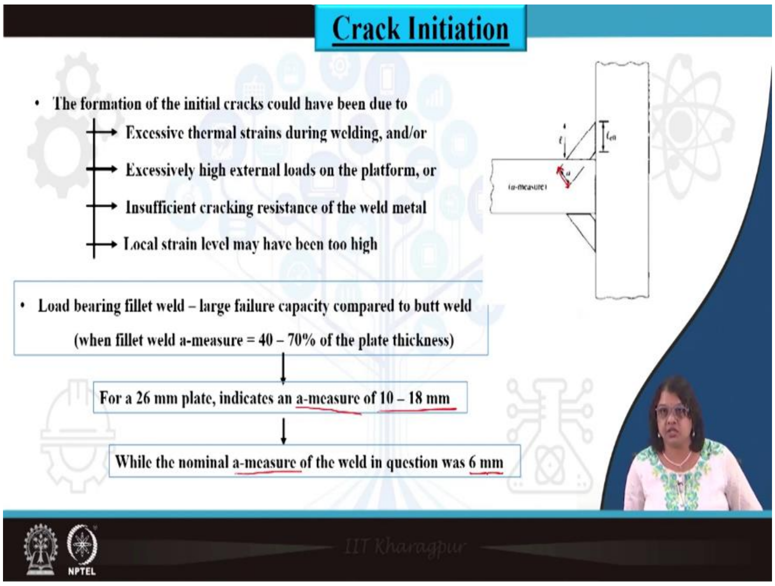

So, now, the question is that how the crack has initiated, what led the cracking session even at the time of fabrication itself? Now, this could be because of the excessive thermal strains during the welding. So, there could be a strain mismatch and that can lead to a formation of a crack. Excessive high external load on the platform can also be one of the reason or insufficient cracking resistance of the weld metal.

Now, whenever there is a weld metal versus regular metal that is used for the structure, there could be some amount of compatibility also that needs to be checked beforehand. And local strain level at any point may be too high and that can also trigger the formation of the crack. Load bearing fillet weld has large failure capacity compared to the butt weld, when the fillet weld, a measure is 40 to 70 percent of the plate thickness.

Now, this is what is the a-measure and that needs to be maintained also. So, all the welds structure weld material, everything has to be very, very carefully maintained. So, for a 26-millimeter plate, so, that was what is the weld condition, it indicates a-measure of 10 to 18 millimeter.

However, a measure that was there in this structure is 6 millimeters only. So, almost like one third one half to one third of whatever is necessary. So, that could be one of the reasons that can lead to the cracking session at quite some low levels of load.

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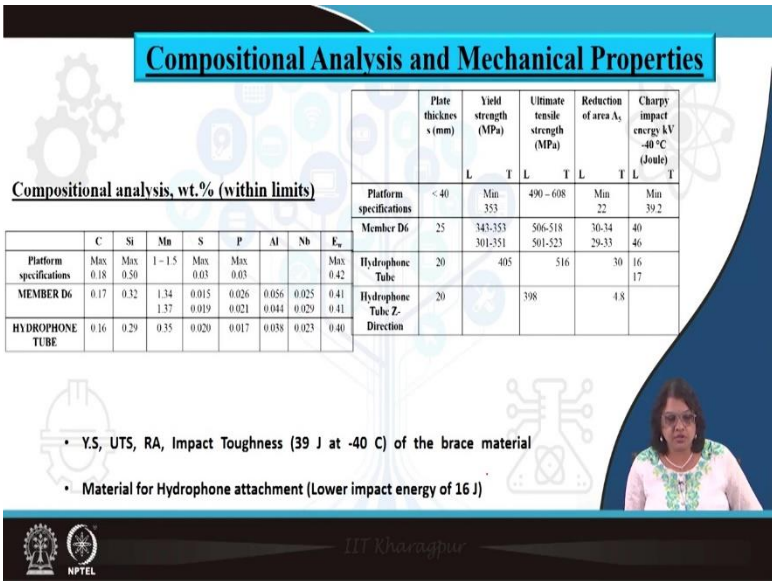

So, these are the compositional analysis, once again we can see that the carbon content was quite within the limit and most of the cases the composition was not so different than that it is then the expected values, the mechanical properties of the material used were also studied and this were also quite in the limit or what was the expected values.

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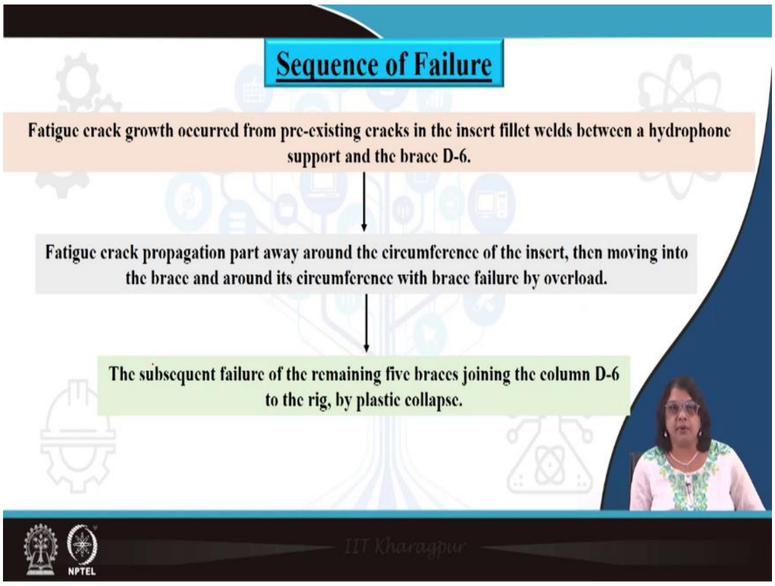

So, from this finally, we realized that the one crack that was there in the D 6 that has initiated and that led to the final fracture. So initially fatigue crack growth occurred from the pre-existing crack. So, the presence of a small defect, again, that would not be of any danger had it been not placed inside the sea where there is a corrosion atmosphere as well as there is a repeated loading based on the waves and that leads to the fatigue loading.

So, that fatigue crack propagation part way around the circumference of the insert, and then moving into the brace and around its circumference with the brace failure by overload the subsequent failure of the remaining 4 braces, joining the column D 6 to the rig also happened by plastic collapse.

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CONCLUSION

The Alexander L. Kielland rig/platform was fabricated and completed in March 1976.

It collapsed on 27th march, 1980, due to a fatigue crack propagating from a welded joint, with the loss of 123 lives.

The platform was supported vertically by five tubular columns at the apices of a pentagonal design, each interlinked by robust tubular braces and stabilized upon pontoon bases.

The failure sequence was identified as the loss of one vertical column, resulting in rig destabilization, with tilting of the entire structure leading to inversion and submersion.

All the evidence confirmed the mechanism of the initial failure as a fatigue process, initiated at a defective weld bead in an inserted hydrophone tube located in a robust brace designated D-6.

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So here is the memorial that has been formed to remember the incident of Alexander L Kielland. And I hope that we did learn something from this incident, although this is a very unfortunate one, but still we have learned what it can teach us. So, the Alexander L Kielland. Platform was fabricated and completed on March 1976. And it collapsed however, on 4 years after that on 27 March 1980, and the exact reason for this as has been found is the fatigue crack propagation from a welded joint, but that accounted for the loss of 123 lives.

The platform were supported vertically by 5 tubular columns at the emphasis of a pentagonal design and each of these columns are interlinked by robust tubular braces and stabilized upon pontoon bases. The failure sequence was identified as the loss of one vertical column that was D resulting in the rig destabilization and heeling which means the tilting of the entire structure leading to finally inversion and submersion.

So, all the evidence confirmed the mechanism of the initial failure as a fatigue process initiated at the defective weld bead in an inserted hydrophone tube located on a robust brace designated as D 6. So, following other references that has been used for this lecture. Thank you very much.