Industrial Safety Engineering
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Lecture – 21
Bow – Tie: Identification of Safety Barriers

Hello, welcome to this lecture, we will we will discuss Bow Tie with reference to Identification of Safety Barriers.

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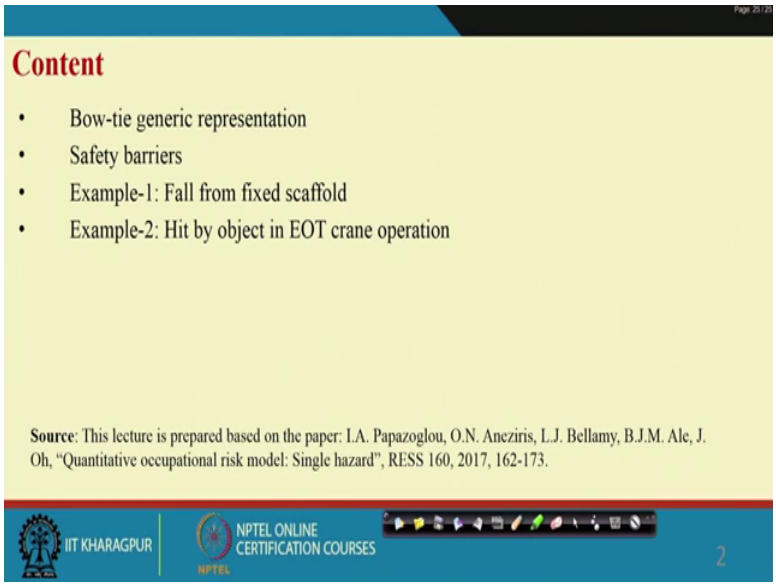

Let us see the content, first I will discuss the general representation of bow tie, then safety barriers after the two different examples; one is fall from fixed scaffold another one is hit by object in EOT crane operation. Particularly the safety barrier and the fall from fixed scaffold these two things I have taken from this paper written by Papzoglou and Aneziris Bellamy Ale and Oh. The title of the paper is quantitative occupational risk model single hazard published in reliability engineering and system safety and then the example two, where I have created for you.

So, I hope that by 30 35 minutes of time we will be able to finish it. And it is very interesting one and it will give you the preventive barriers particularly in today's lecture we will be talking about that barrier for prevention. So, now, this is an this slide particularly; we are we will discuss bow tie the generic concept, bow tie generic concept concept.

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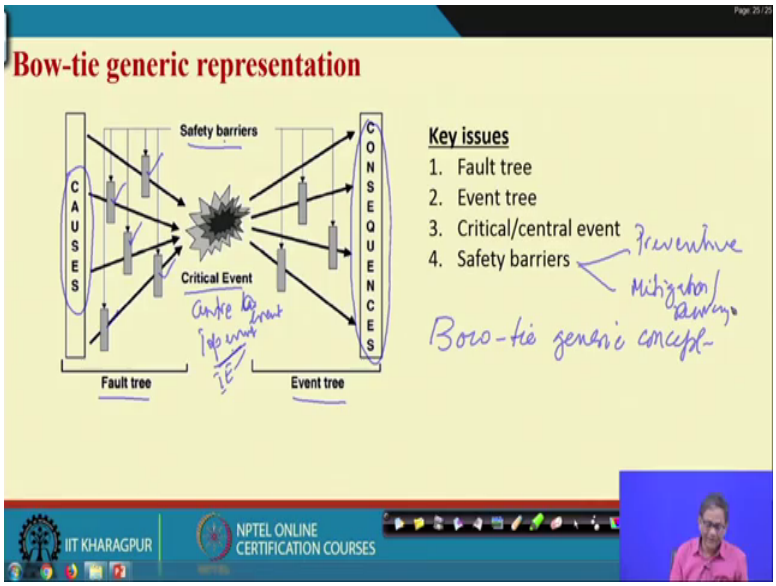

So, what is this bow tie generic concept? There will be a centre event or critical event centre event or critical event. This centre event with reference to fault tree is top event with reference to event tree it is basically initiating event. Now I told you earlier that, bow tie is combination of fault tree and event tree and here the generic representation not in terms of gates or in terms of branching, we have shown that actually the left hand side is fault tree and right hand side is event tree. So, that mean for the centre event or top event if you have the fault tree then, then from there also you can find out; ultimately the root causes. And if you develop event tree for that centre event or critical event or top event ultimately you will find out the consequences. So, now this, what is the safety barriers? Safety barriers are suppose actually the top event occurs because of many of the basic causes occur simultaneously. And in terms of fault tree from the basic event points of view we said that there a combination of basic events which leads to top event that is the cut sets.

So, you can think in this line; that means, every cut sets is the path to the top event or centre event. So, that mean if what is then barrier? All those paths can be broken; there will be some barriers which will break the path. So, that the cuts the basic events or the basic causes cannot occur simultaneously.

So, that is why these are barriers safety barriers, this is barrier this is another barrier, another barrier, another barrier, these are the safety barriers. And what happened even if

whatever may be the level of preventive barriers you put, there will be a chance of happening of the top event centre event or critical event. And ultimately your system must also be protected from the impact of such events that is what event tree we have discussed earlier.

So, now; that means, that event tree depending on the system configuration ultimately event trees will be created based on system configuration means how the system behave against the top event or critical event occurring? So, there also you can minimize the consequence by putting several barriers. So, in safety engineering terminology we can say these barriers are that mitigating barriers and these barriers are preventive barriers or these barriers basically recovery barriers. So, that is why this is what is our barrier.

So, barrier maybe preventive and may be mitigative or this is basically used for mitigation purpose or recovery barrier. So, if you know the paths; that means, you have an you have the opportunity to create barriers to generate barriers those are safety barriers which will ultimately help you in improving the safety performance of your system.

Now, with reference to two examples and then I we will we will discuss those barriers ok. So, what is this? Barriers will be of two types, one will be primary safety barrier, another will be support safety barrier.

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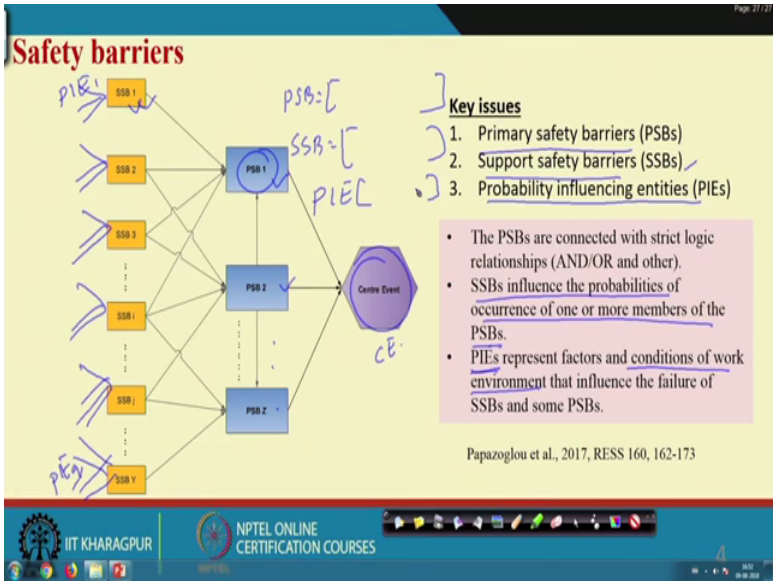

Now, what is primary safety barrier? Primary safety barrier are so, suppose this is your centre event, now why the centre event taken place? You can dig down with appropriate and OR gate or logic gate you will find out some of the reasons or the events that ultimately causing the centre events.

So, similarly so in so, that those events should not occur so you will find out that those events are nothing, but failure of some barriers. So, these are primary safety barriers, which can be related to the top event with sound relationships. Now, primary safety barrier again it is failure will be influenced by several other barriers which are known as support safety barriers. So, PSB is Primary Safety Barrier SSB is Support Safety Barrier.

So, that is what SSB influence the probability of occurrence of one more member of the PSB's. So, that mean, for a centre event there will be several PSB's. PSB 1 PSB 2 to PSB z. So, a set of PSB's primary safety barrier you will find out which ultimately prohibit the centre event to occur.

Then for every PSB primary safety barrier, you may find out a series of support safety barriers. The support safety barriers ultimately what happened it basically, affects the probability of failing the primary safety barriers. In other word you can say probability of becoming the safety barrier successful. So, when we use fault tree, we basically talk about the failures, but in the safety barriers as safety is the positive quantity so you can talk about the success.

So, for example, if this all the PSB's primary safety barriers are successful then stop event will not occur or centre event will not occur. Similarly in order to make the primary safety barriers successful, there will be many support safety barriers; we will discuss, but for the time being you understand. Now again the support safety barriers these are also barriers. So, they will also be fail or they are successful depending on some conditions and actions.

Those conditions and actions of the work environment that influence the failure of those support safety barriers or the PSB's also or some of the PSB's may not be may be some of the PSB's will be related to this events they are known as probability influencing events; probability influencing events.

So, PIE's are Probability Influencing Entities so; that means, that success of support safety barriers, some of the primary safety barriers this depends on what conditions of work environment. So, there will be many critical hidden factors and conditions that ultimately lead to this failure of the support safety barriers or some of the primary safety barriers.

So, they are known as PIE, probability influencing entities suppose this is PIE 1 so this last one will be maybe PIE q so there will be a set. So, for every centre event there will be will be a set of for PS set of events for PSB primary safety barriers.

Similarly, there will be set of SSB's support safety barriers, there will be a set of probability influencing entities so, that is, what is the concept of safety barriers. So, in nutshell what is safety barrier? Safety barrier can may be primary, safety barrier which is directly related to the top event or the centre event whose functionality, whose success ultimately helps the centre event will not occur. Then support safety barrier which are basically the another kind of barrier which whose success depends basically makes the primary safety barrier success. And there are probability influencing entities which are basically again responsible for the success of the support safety barriers or some of the primary safe safety barriers.

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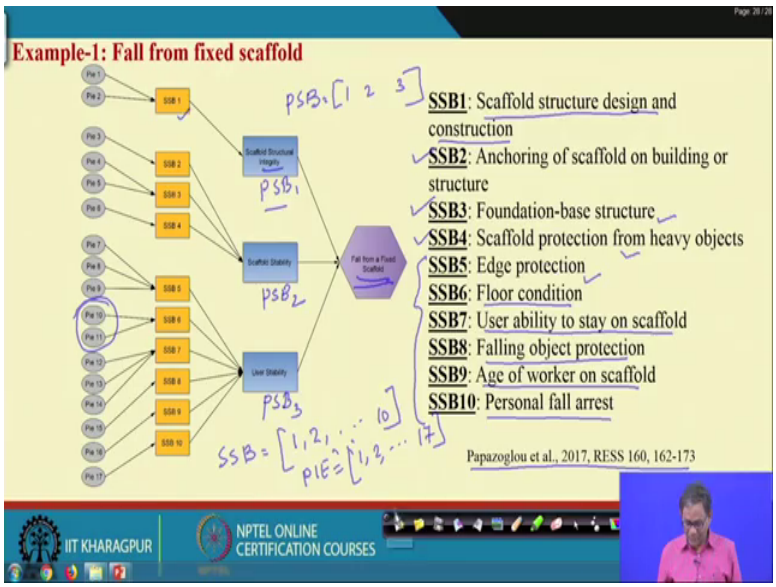

Now, let us see first example that scaffold example; what is this example? That our if you all of you know the scaffold, when you if you go to any construction site you will find

out that workers doing construction activities. For example, making a 3 storey building 5 storey building or ultimately you will be finding out that the bridge and many there are huge number of; such cases where you find out that scaffold is used basically for working at height.

Now, there is a chance of falling from scaffold. So, here we are considering that fall from fixed scaffold, this one this example I have taken from this paper. So, if you go by fault tree method what you will find out? You will find out that that fall from this may occur if the structural failure is there or the scaffold is unstable or the user is unstable because he has not used proper safety belt or he has given the he has not given proper guarding while working on the scaffold.

So, then any of the three will lead to the top event to that is means fall from scaffold. Here these are the immediate; your causes for top event or centre event to occur. Here we are basically looking into the same thing in the different way what we are saying that falls from fixed scaffold maybe because of the structural integrity. So, primary safety barrier 1 PSB 1 is scaffold structural integrity. Scaffold structure should be properly made properly erected so; that means, this is the success of the scaffold from structural integrity point of view.

So, we will see later on what is that what do you mean by the structural integrity further. Then scaffold stability that is our PSB 2 primary safety barrier 2. And then scaffold that user stability primary safety barrier 3 so; that means, the immediately you find out that, if these safety barrier fails fall from height will take place like fall from scaffold. If this safety barrier fails lead to fall from fixed scaffold, if this safety barrier fails fall from this scaffold. So, ultimately, but if the success of all this 3 will ultimately lead to that the centre event will not occur.

Now, if we want to know that what is that support safety barrier related to PSB 1 that is scaffold structural integrity. Then you see it is SSB 1; that means scaffold structure design and construction scaffold structure design. And now similarly if you see the support safety barrier for PSB 2, which is scaffold stability, then there are three support safety barriers one is anchoring of scaffold on building or structure. If that is successful then foundation base structure is good scaffold protection from heavy object is properly made then scaffold will be stable.

So, these are the three support safety barriers for scaffold stability. Now the third one is user stability, so you see that what is what are the things for user stability so, there are six support safety barrier that, ultimately lead to user stability, what is this? One is edge protection, because you are working on the scaffold which is at height. Second one is the floor condition, third one is the user ability to stay on the scaffold, forth one is falling object protection, fifth one is age of worker on scaffold and personal fall arrest. So, all those things all those things should be successful otherwise what will happen user will be unstable.

So, see we are not finding the fault rather we are finding the actions what is to be done? Because the actions these are all actionable barriers, the support safety barriers should be there ok. Now then fall from fixed scaffold immediately you find out the three primary safety barriers, you find out ten support safety barriers. So, that is why I say that PSB set is here PSB 1 PSB 2 and PSB 3 whereas, SSB state set it is 1 2 like 10 SSB's are there.

So, if you do this kind of analysis what happened? You know what is to be done. It is basically not only the not only the finding out the cause, but also finding out the action for eliminating the causes to occur. Now if I say for example, scaffold structure design or construction or if we say basically that foundation base structure or floor condition or user stability on scaffold in terms of SSB, they may not be; they may require. It require some more things to know; that means, why a floor condition a floor condition is good or bad that SSB 6. So, you find out that there are two probability influencing entities that ultimately governs the success and failure of SSB 6.

So, that mean you should not leave here, you should dig down further and get some more factors which are basically maybe at the at the from the bottom level, may be what the software level actual work is going on at that level minute level it will pin point.

So, how many such probability initiating entities found? We found out 17 so, there are there is a set of 17 PIEs. This is what is reported in this paper this paper if you have subscribing this journal then you will be able to download this paper. So, essentially then what happened you see, fall from fixed scaffold ultimately it basically is a result of this three PSB's. Then these three PSB's results of 10 SSB's, 10 SSB's are influenced by 17 probability in influencing entities.

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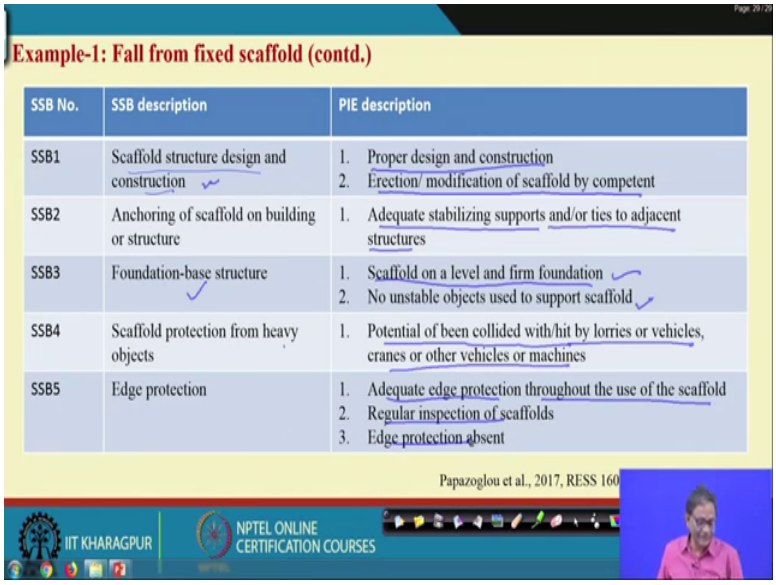

So, let us see that what are those PIE's? The PIE's first one is we say that scaffold structure design and construction scaffold structure design and construction. So, proper design, proper design erection, modification of scaffold by competent person; if these two are done by proper design and construction mean you should choose the right kind of material. So, that that design, specification must be properly laid down load calculation and all those things and then that must be correctly properly erected.

So, that mean if these two are not done properly, ultimately success of this will be limited. So, that is why they are probability influencing entities now anchoring of scaffold on building structure adequate stabilizing support and or ties to adjacent structure. So, in these manner, in this manner you can understand that what are the probability influencing entities. Foundation of base foundation based structure you see scaffold on the level or firm foundation no unstable objects used to support scaffold, this is required.

So; that means, when actually the erection will take place before that you must see this. So, that is why these are the actions or actionable, actionable barriers, actionable entities you are finding out. You are not only finding out the causes not faults that through fault tree you can find out. Fault tree give you enough idea of what is to be done, but that is what is to be done you are you are doing through safety barriers. Scaffold protection from heavy objects, potential of been collided with or hit by lorries, vehicles cranes and other vehicles that you have to understand and accordingly protection, edge production

adequate, edge protection throughout the use of the scaffold regular inspection, edge protection absent.

So, these are the basically probability initiating entities which ultimately governs the what it mean it govern the success of the support safety barriers. So, if you do more bends terming you may find out that some of this may be also directly related to the PSB's, but at present what you found that this is a reasonable one; to believe that yes, these are the these the PIE's for the support safety barriers.

And these are the support safety barriers, which ultimately improves the PSB's and if you take care of the PSB's and SSB's with the help of this PIE's also. Then obviously, the prevention part prevention through design that maybe achieved.

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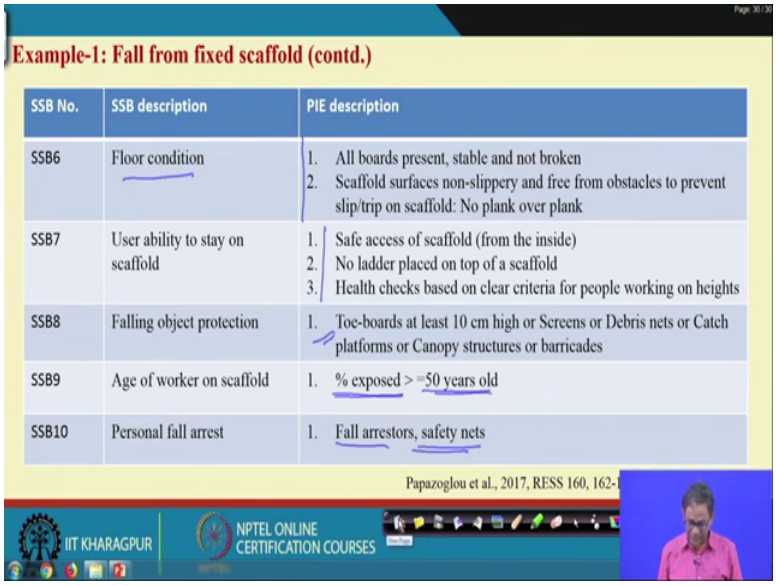

Then you see that there are few more like your floor condition, there are 2 PIE's user stability ability to stay on scaffold 3 PIE's. Then falling object 1age of worker that how many workers are more than 50 percent 50 years old. So, fall arrester, whether fall arrester safety nets these things are used or not. So, these this things ultimately helps you and you will understand that yes, my design is good or bad. So, essentially the centre event is very important, primary safety barriers very important, support safety barriers identification is extremely important. And after that PIE is required because otherwise you will not be able to quantify the success or failure probabilities of SSB's and PSB's and essentially the centre event.

So, these are the this is the concept, then this example through this example, now you understand that what is safety barrier in terms of bow tie. How bow tie will help you in identifying the safety barriers primary support safety barrier, primary support safety barriers, support safety barrier, probability influencing entities. Just to reinforce the idea further, we will see another example which we have taken from a manufacturing industry.

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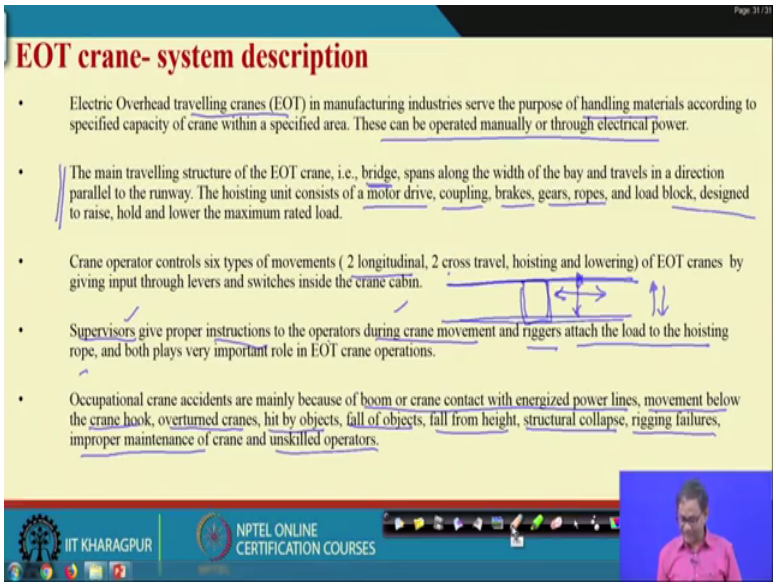

So, what is this? We are considering about electric overhead travelling cranes and you know this is a crane which basically used heavily in manufacturing industries quite large in numbers; the purpose is that handling material of specific capacity within a specified area. So, the crane actually operated through electrical power that is why electric overhead cranes. Now, you all know if you have seen by chance or based on your work experience you have seen the traveling that that EOT crane, then you will find out the main travelling structure will be will be the bridge and that spans along the width of the bay and travels in a direction parallel to the runway.

And the hoisting units having motor drive, brakes, gears and so many things. Now, something like this, so that this is basically suppose the railings on which the crane will move and suppose this is the bridge so, there will be hook then sealings down to the load. And ultimately movement will be how to longitudinal this direction and this direction

this side, that side, then two longitudinal movement to cross travel movement and lower hoisting and lowering movement.

So, six types of movement are involved in the in EOT crane and crane operator controls all movement. So, there will be supervisors who will basically provide the instruction, during crane operation movement. There will be riggers who actually attach the load to the hoisting rope and both the supervisor and the riggers, they play important role along with the operator. Particularly, both from the production or that material transfer point of view as well as from safety point of view.

So, as the we are interested here in the safety engineering. So, if you study the crane accident, you will find out that the there are various causes which are basically causing the crane accident to happen. For example, crane boom or crane contact with energized power lines, movement below the crane hook, overturned crane, hit by objects, fall of objects fall from height, structural collapse, rigging failures, improper maintenance of crane unskilled operator. So, many causes are there ok.

So, next I will show you based on around approx 3 years data from a plant, we found out that what are the crane accidents what type of crane accidents are taking place.

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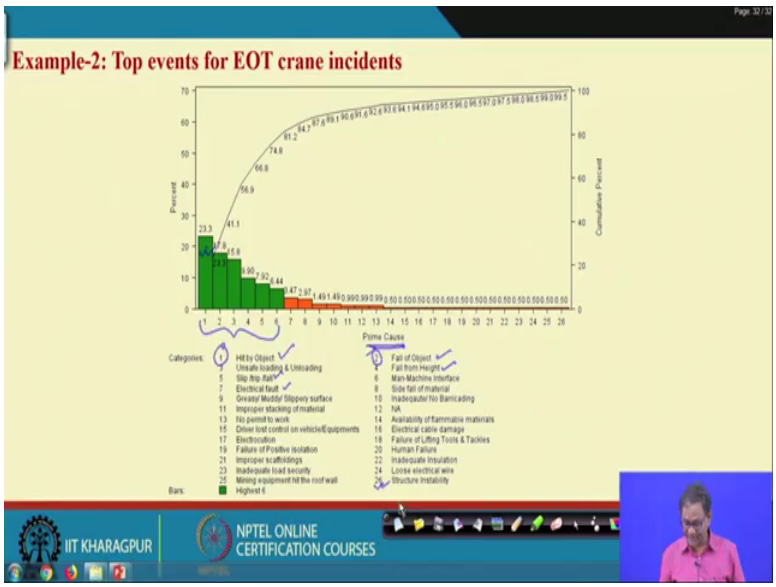

So, then you see that this is basically almost around three years data of crane accident from a manufacturing plant. And we found out that there are 26 different categories of

crane incidents which we are prime causes which we defined as prime causes, but actually what are those? They are basically the most of them are basically the centre events.

For example, hit by object slip trip and fall electrical, fault follow of object, fall from height. So, this data set if you see that it is basically little bit of mixing some are centre event, some are basically related to the PBS's failure, but essentially what happened they are they these particular company they are thinking that they all are basically the primary causes and that is relating to the EOT crane accidents and next.

So, if we go by this by this data and assume that data is collected properly and the or different causes are given and given in with proper meaning. So, then definitely hit by object is having the maximum share. So, that mean this is a centre event which is basically having the, which is accounted for the maximum number of crane accident for the plant study followed by fall of object.

So, we will not develop the safety barriers for all those important centre events. So, that is why what is required we required to have a Pareto chart kind of plot, where the 80 percent of the maybe the accidents will be related to a for few number of that centre events. So, here we found out that this first 6 they are causing 80 percent of the accidents crane related accidents and the first one hit by object that share is 23.3 percent. So, we will discuss that hit by object PSB and SSB and PIE's; that means, safety barriers for hit by object.

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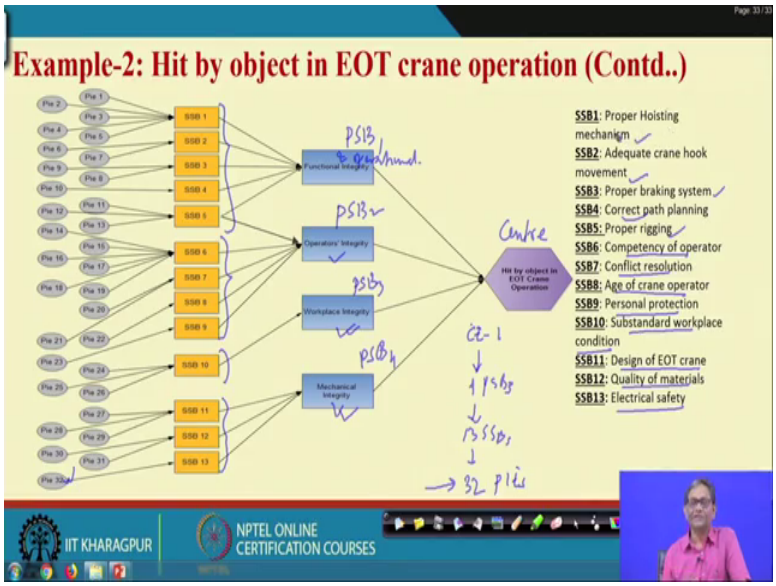

Let us see what is this? So, our centre event is hit by object in EOT crane operation. So, what are the PSB? PSB 1 is that is functional and operational I think I will use this functional and operational integrity. And then what is the PSB 2? PSB 2 is operators integrity, here by operators integrity we will basically talking about the operator supervisor and the riggers also. Then workplace integrity, the facility given for crane operation that integrity, then mechanical integrity with reference to the load, hook and all those things.

So, all those integrities are very important PSB 3 and PSB 4. So, these 4 if it is successful then this will not occur. Now again first PSB 1 that is the functional and operational integrity it has we have identified 5 support safety barriers. For the second one operators integrity there are 4 support safety barriers work place integrity we have found out 1 and mechanical integrity another 3. And ultimately when we have gone for the PIE's; that means probability influencing entities we found out 32 probability influencing entities. So, that mean for a particular centre event, centre event is 1 it has 4 PSB's, then 4 PSB's 13 SSB's then from there 32 PIE's you see. So, you have now, actionable I think information 32 PIE's take action.

So, if you see what are SSB's proper hoisting mechanism, adequate crane hook movement, proper braking system, correct path planning, proper rigging, competency of operator, conflict resolution, age of crane operator, personal protection, substandard

workplace condition, design of EOT crane, quality of materials, electrical safety so, these are all case specific.

So, may be if you see EOT crane in some other operation, then or in some other plant you may find out something more, but more or less this things you will get. Because our data set is it is a good amount of data we have considered. So, then what you will be interested to know now, that what are the PIE's related to proper hoisting mechanism so, let us see what are those.

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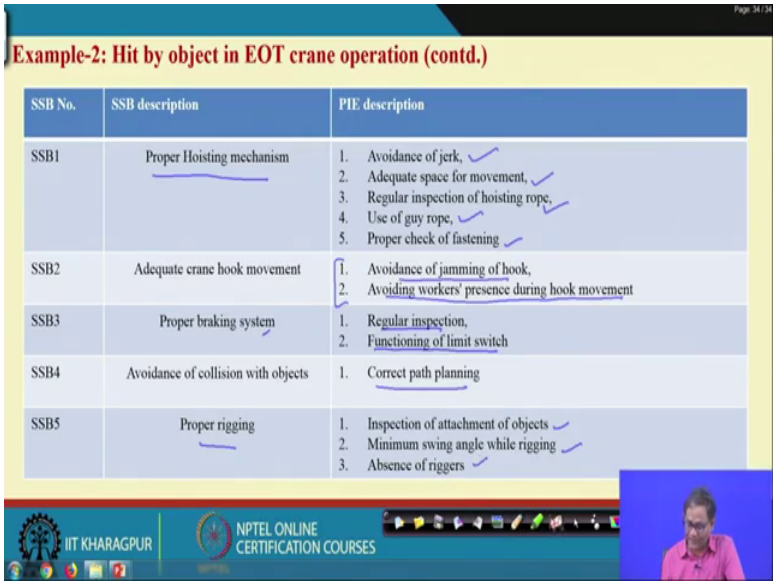

You see proper hoisting mechanism, the pies as pies are avoidance of jerk you have to understand why jerk is there and it should not happen whether that that facility is there or not adequate space for movement, regular inspection of hoisting rope, use of guy rope, proper check of fastener or fastening.

So, in this manner for adequate crane hook movement; avoidance of jamming, avoiding workers presence during hook movement, for braking system; regular inspection then function of limit switch, for avoidance of collision; correct path planning. So, I will correct it actually, we have written under SSB this correct path planning, later I have changed it to avoidance of collision with objects that is our SSB. And correct path planning is the PIE, then proper rigging proper rigging; inspection of attachment of objects, minimum swing angle while rigging, absence of riggers so, many PIE are there.

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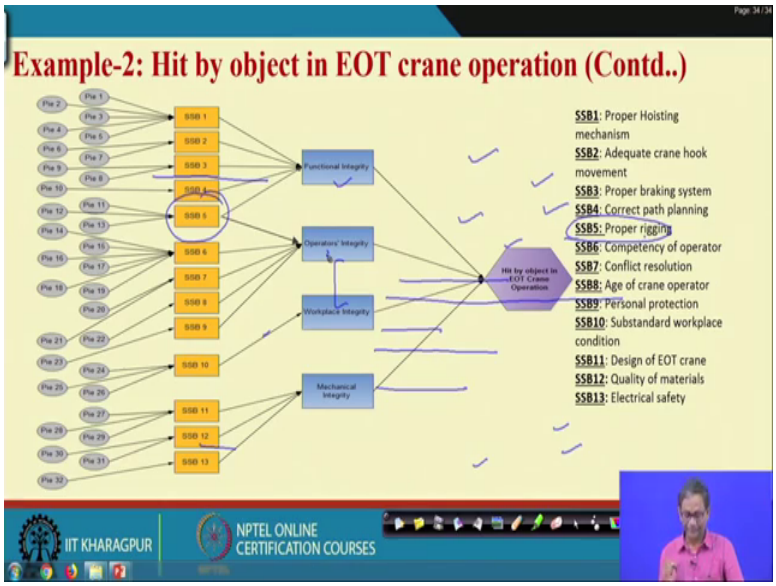

And if you see that see that ultimately SSB, what is the SSB 5? SSB 5 is proper rigging. So, it basically influencing the functional and operational integrity as well as the operator integrity because the riggers competency is important, rigger the whatever we you will ultimately that the rigging is also depends on the skill and competency of the operator. So, fine so, you got these proper rigging and these are the PIE's.

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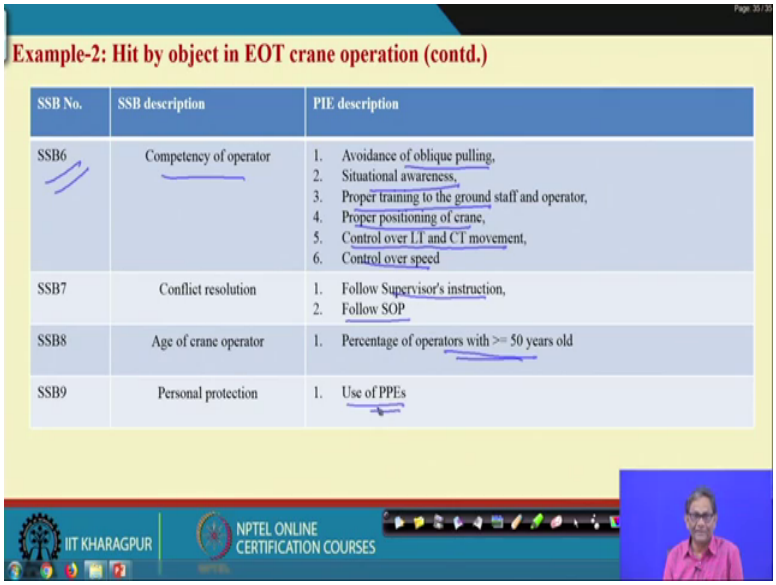

Now, similarly if you see SI 6, SSB 6 not SI SSB 6 competency of operator what are those PIE's quality influencing entities. Avoidance of oblique pulling, situational

awareness, proper training, proper positioning, control over LT, control over speed so, all those competencies that must be with the operator, with the help of worker that supervisor and riggers he will ultimately make the transfer possible. So, that is very important.

Now, conflict resolution follow supervisor instruction, follow sop, age of age of crane operator so, how many old people are there because old people the flexibility will be less. So, it will it may leads to the problem in terms of safety, but at the same time old people will be experienced one also. So, that may help. So, that may ultimately it is a different ball game because, sometimes it is useful some cases it will help some cases it may not help, where the experience counts this is better where the flexibility counts this is bad. Then personal protection use of PPE's, personal protective equipment so, this is another example with reference to PSB's.

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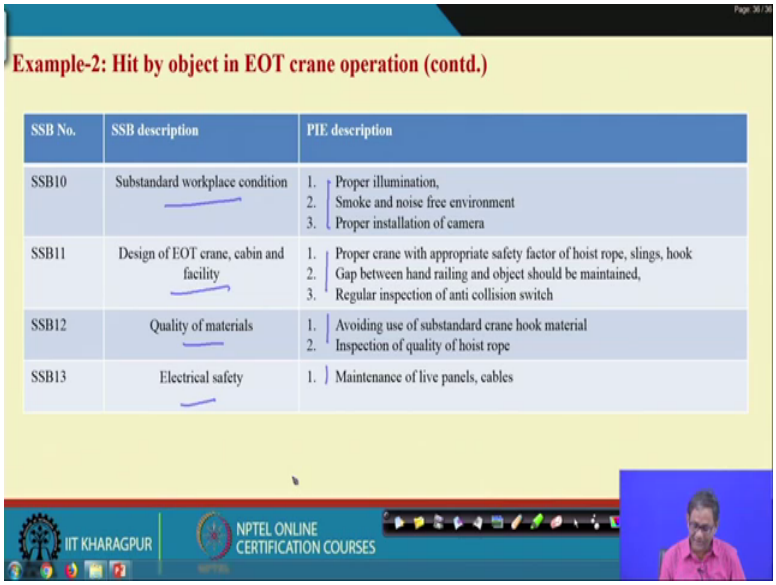

Then, how many substandard workplace condition, design of EOT crane cabin facility, quality of materials, electrical safety. So, we have identified PIE. Nutshell what I mean to say that you have to identify what you have to do for safety barrier analysis; you have to do these things first.

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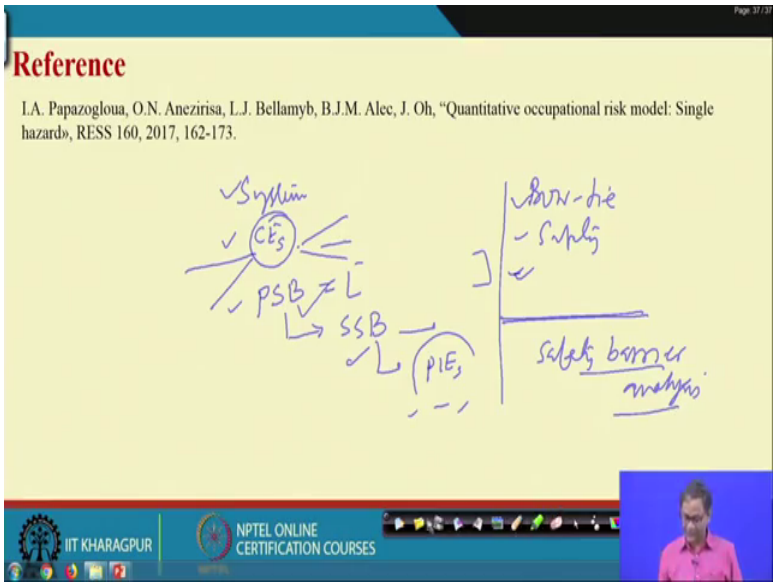

First you must know the system, for which you are going to do this. Then you basically have either design, you have design knowledge, hazard knowledge and your lesson historical records lessons run by which you know the centre events.

Once you know the centre events, you know the fault tree side as well as the event tree side. So, here I have shown you in terms of fault tree side, but in terms of event tree side also you have to see. So, what happened either in the fault tree or event tree then, for this centre events based on your design knowledge and hazard knowledge you will be able to find out primary safety barriers, it will be a number of number of barriers maybe one maybe more maybe many more.

Then for every PSB you find out SSB support safety barrier, it will be also quite a huge then for every SSB you find out PIE's. And then you will find out that for every centre event there will be a large number of PIE's. So, what is required then, that mean will you address all the PIE's or will you will you address when go for all SSB and should be there or will there be all PSB's how do you do it? So, that mean you will these identification is fantastic, but identification alone will not help you in taking actions you require to quantify it. That quantification will help you how many PIE's you should consider or what is the first PIE that should be taken into consideration or where your effort put in preventing the centre event to occur will be maximized or where for which PIE's you will be maintaining the status through.

So, all those things will come under safety barrier analysis. So, that mean what we have done you have leant today? You have learnt bow tie that revisit, then you have learnt the safety barriers in terms of three important concepts. And you finally, you have you are you are able to you got the methodology how to identify the PSB, SSB and PIE's.

And then what I want you say that we see that we have seen the two different examples and these two examples would be useful enough for you to develop the safety barriers for your own system. But this is not sufficient; you have to go for safety barrier analysis. Thank you for listening, I hope you enjoyed this lecture.

Thank you.