Engineering Hydrology
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Lecture 78
Hydrologic Design

Hello all participants, welcome back, we have completed six modules of this particular course. Today we are going to move on to the seventh module, that is the last module on hydrologic design. Different processes related to hydrology variables and hydrologic analysis and hydrologic statistics we have completed.

Now, this is the new topic of hydrologic design, this is very important whenever we are carrying out design of a hydraulic structure. I am not looking at the structural point of view of design, here what are the considerations to be taken care while carrying out a design of a hydraulic structure in hydrology perspective.

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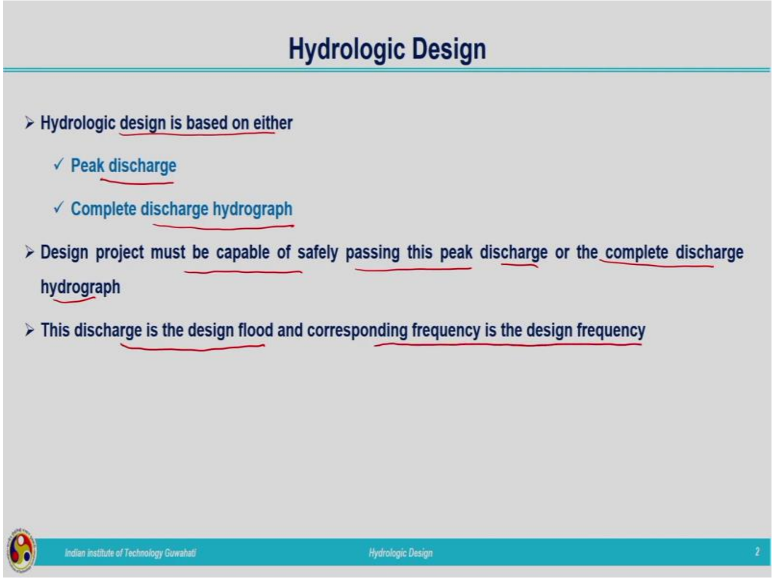

So, coming to hydrologic design. Hydrologic design is based on either on peak discharge or by means of complete discharge hydrograph. For any type of design related to hydrologic structure, we need to have the peak discharge value corresponding to a particular rainfall. What will be the value corresponding to that? We know already that these values are random variables, taking a single value corresponding to this peak discharge or suggesting a single value corresponding to this peak discharge is very difficult. So, there are different ways to find out the value corresponding to this peak discharge and different ways for the design purpose we consider single value of peak discharge or by means of considering complete discharge hydrograph. So, design projects must be capable of safely passing this peak discharge or the complete flow hydrograph. Once we have decided what is the peak discharge, the project should be able to withstand the peak discharge or if it is a hydraulic structure such as a dam or reservoir, in that case, it should be able to pass this discharge hydrograph. There should not be any instability conditions arising due to the value corresponding to a rainfall or discharge. So, these values should be accurately determined while designing the hydraulic structure. This discharge is commonly termed as design flood and the corresponding frequency is design frequency. So, whenever we are designing a structure, it will be designed for certain period of years. Certain return period will be considered while designing that structure. Depending on the importance of the structure, the period which we are considering for the return period will be very high or very small.

For example, if you are considering the case with a dam or any other kind of big hydraulic structures, we have to consider a long period of return period, because we have to consider the loss which are incurring due to the failure of the structure. So that the return period we will be considering will be very high based on that the discharge value which will be calculating will be high, so that the frequency of occurrence will be less in such cases. But there are certain structures such as urban drainage storm, drainage systems and all, even if certain failure occurs in that case, it is not going to affect human life in a very high manner. And the economic considerations to be taken care we cannot spend too much of money on the construction of those structures. In that case, by keeping in mind the economic considerations, we will be keeping the return period corresponding to the design of that structure very less.

So, in the case of dams and important structures, we will be keeping the return period to be very high or sometimes we will be assigning a very high peak value, design discharge for designing that particular structure rather than giving a return period for that, if it is beyond 100 years. And in the case of minor structures such as drainage systems and all we will be making use of 2 to 5 years or 5 to 10 years as the return period.

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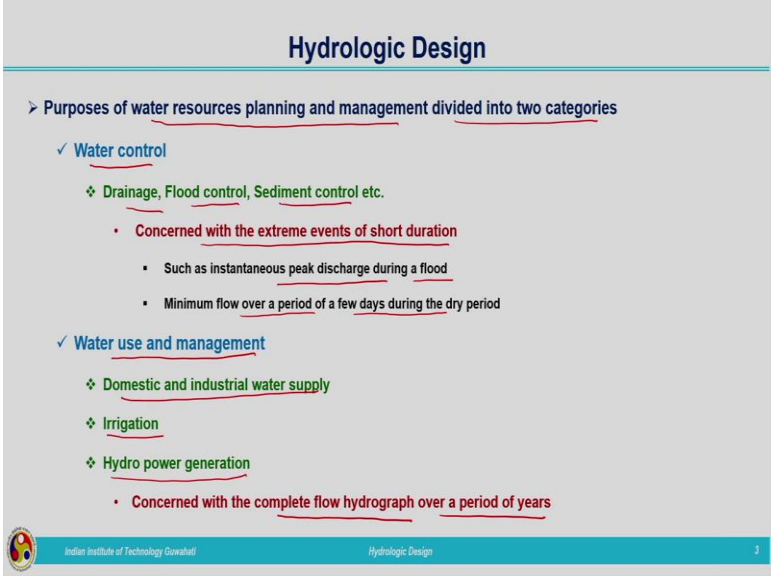

Before going to hydrologic design, we should understand the purpose of the water resources system clearly, that is we used to construct different types of projects, but the purpose will be different. Purposes of water resources planning and management divided into two categories that is one is for water control, and the second one is for water use and management. So, you should understand the difference between them. Water control means we need to regulate or control the flow or streamflow and the other one is for the water use and management. So, under water control the structures which are coming are drainage, flood control structures, sediment control structures, etcetera. So, here we are going to control certain things in that case we will be making use of extreme values. There we are considering the design discharge value based on the consideration of extreme values.

If it is a flood control structure, we need to go for the high value corresponding to the extreme value and if it is sediment control, we need to maintain certain minimal flow otherwise the sedimentation will be too much in such cases we will be going to the other extreme that is the lower extreme value. While coming to water use and management it is something related to domestic and industrial water supply, irrigation and hydropower generation. So, these are the difference between the purposes related to water resources projects. One is for water control other one is for the water use. Water control is concerned with the extreme events of short duration such as instantaneous peak discharge during a flood and minimum flow over a period of few days during the dry period. Dry period conditions, we will be looking at the minimum flow value corresponding to sediment control and similar kinds of projects and in the case of flood control drainage system type of projects will be looking into the extreme value or maximum value of the discharge. And in the case of water use and management we are concerned with the complete flow hydrograph over a period of years, because we need to provide water depending upon the demand for that we have to make use of the entire data of over the years and based on that the water supply, hydropower generation all these things will be carried out.

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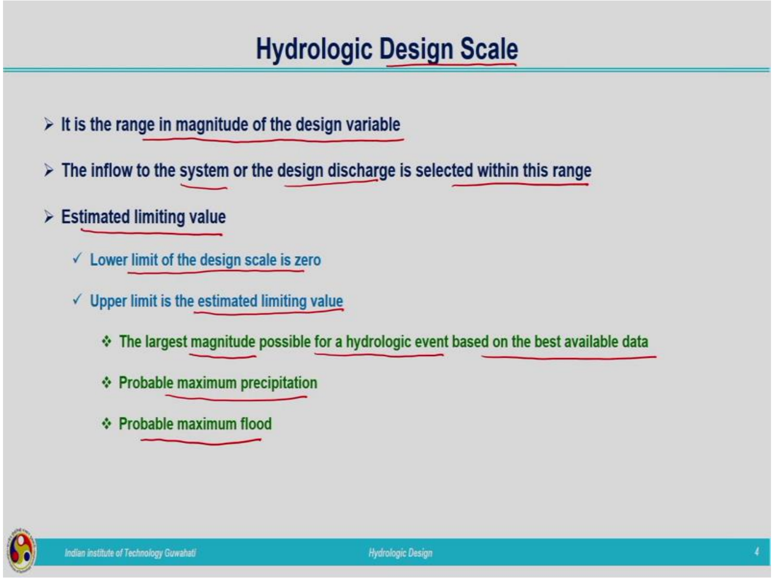

So, for this hydrologic design, we need to have a hydrologic design scale. It is the range in which magnitude of the design variables are considered. Since these variables are such as the rainfall value or the design discharge value, all these things are represented by means of random processes. So, in such cases we need to provide a range of design variables. The inflow to the system or the design discharge is selected within this range. Once the range is provided, we can choose a particular value of discharge for the design purpose which is termed as the design discharge. For that we will be making use of the concept of estimated limiting value. So, this as far as this limiting value is concerned it will be having the lower limit and also upper limit. For design purpose we can keep the lower limit as zero, we cannot go for negative values. But as far as the upper limit is concerned where we should keep the value that upper limit can go up to infinity, but based on the infinite value, we cannot carry out the design. So, for that we need to fix an upper limit value. So, lower limit of the design scale is zero and the upper limit is the estimated limiting value. So, we need to calculate a particular value for representing the upper limit of the limiting estimated limiting value.

The largest magnitude possible for a hydrologic event based on the best available data. For that what we will be doing, we will be considering the past data for so many years and based on that we will be finding out the largest magnitude of the hydrologic event, that will be kept as the upper limiting value, lower limit will be fixed at zero and the upper limit will be chosen based on the past data series. That may be probable maximum precipitation or probable maximum flood. As far as the limiting value is given in terms of precipitation, it is termed as probable maximum precipitation and if it is described in terms of discharge value it is termed as probable maximum flood.

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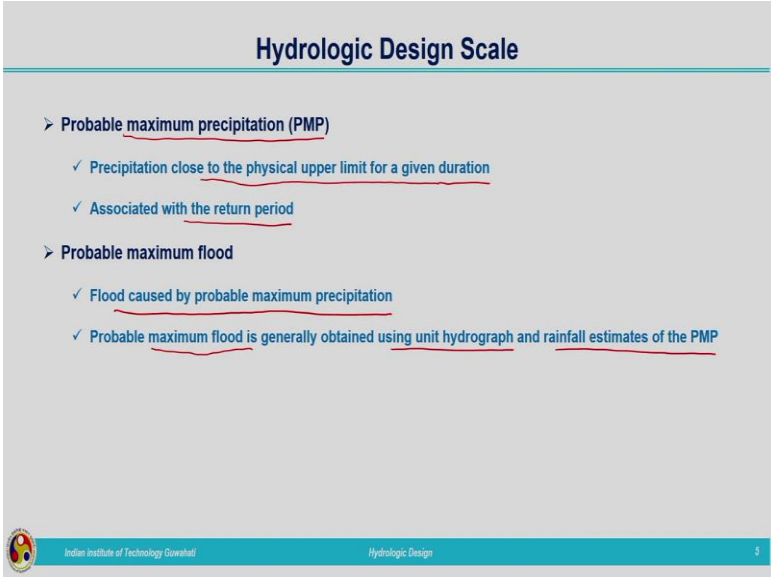

And what is this probable maximum precipitation? Probable maximum precipitation is the precipitation close to the physical upper limit for a given duration. For a given duration, what will be the highest value this precipitation can take, that is taken as the probable maximum precipitation. This is associated with a certain return period, because as I have explained in the previous slide regarding the return period related to minor structures such as drainage system and the major structures such as dam these return periods are different. So, if your considering probable maximum precipitation, we do not have to design urban drainage system for a maximum precipitation, which we will be using for the design of the dam or major important structure and the probable maximum flood is nothing but the flood caused by probable maximum precipitation. This probable maximum flood is generally obtained using unit hydrograph or rainfall estimates of the probable maximum precipitation. We can make use of unit hydrograph principles for determining this probable maximum flood that is based on unit hydrograph corresponding to probable maximum rainfall, we can find out the maximum discharge that value can be considered as the probable maximum flood.

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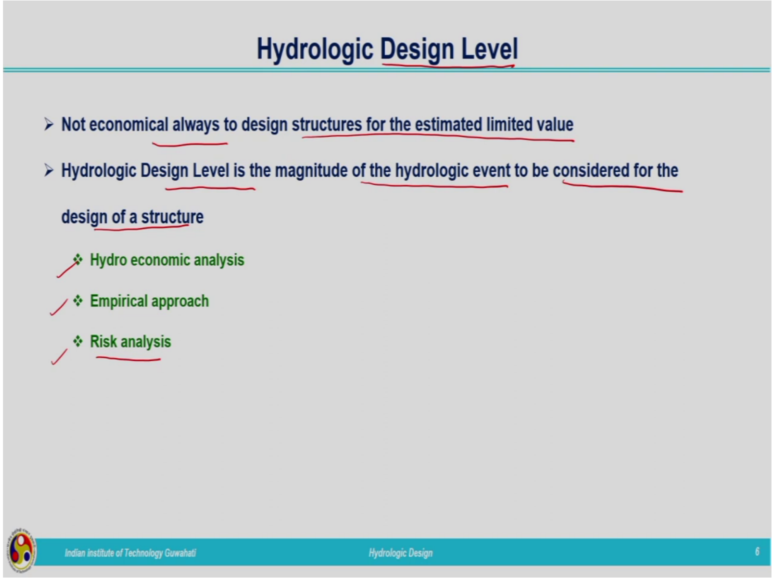

Now, coming to the upper limiting value, we need to have a hydrologic design level. How can we determine this upper limiting value and what should be kept as the hydrologic design level? It is not economical always to design structures for the estimated limiting value as I told you if I am keeping some 1000 years, 10,000 years return period, we are getting a probable maximum precipitation or probable maximum flood corresponding to that return period but always keeping a very high value of return period will not be leading to economical projects. Economical point of view we have to choose certain value of return period based on the importance of the structure. Hydrologic design level is the magnitude of the hydrologic event to be considered for the design of a structure. So, this is representing the magnitude of the event considered for the design of a particular hydrologic structure. That level will be different for different structures which we are going to design.

There are different methodologies for the determination of these hydrologic design level. First one is hydro economic analysis, second one is empirical approach and third one is risk analysis. So, three approaches are there: hydro economic analysis, empirical approach and risk analysis. So, out of these hydro economic analyses, it is such a lengthy topic, I will just give you a brief idea about that.

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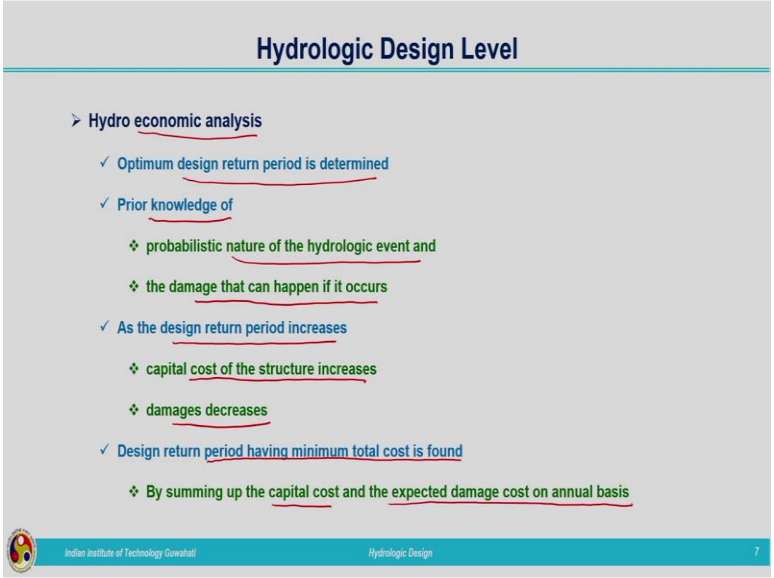

Let us see what is meant by hydro economic analysis. Optimum design return period is determined that is for a structure to be constructed, we will find out what should be the optimal value of return period because our probability everything depends on the return period which we are considering. We have seen probability of incidence is nothing but $\frac{1}{T}$, inverse of the return period. So, we need to find out the optimum value corresponding to the return period that is what is done under this hydro economic analysis. So, in this case, we need to have the prior knowledge of probabilistic nature of the hydrologic event considered. If it is rainfall, we need to study that particular event by making use of the previous data, previous data means it should be for long series long years data will be collecting and will be understanding the probability distribution function related to that particular variable and complete knowledge about the probabilistic nature of that particular hydrologic event will be attain. Also, we need to have the understanding about the damage that can happen if it occurs, if that kind of event is occurring, that is the extreme event is occurring and the structure is going to fail, in that case what will be the damage which may incur, that damage in terms of costs we should have the idea. And as the return period increases, capital cost of the structure increases because the return period 100 years if you are considering the magnitude of the event will be very high and the frequency of occurrence of that particular event will be less. So, related to that probability if you are calculating one by return rate value will be very less, probability of occurrence of that particular event will be very low. But if we are considering that particular value of return period, the capital cost incurred while constructing the structure will be very high.

If you are constructing a structure by making use of high capital cost, the damages will be decreasing. As the capital cost increases, the stability of the structure will be high, but at the same time the damages will be decreasing that is what we actually want. But always we will not be able to invest that much amount of capital cost. So, design return period having minimum total cost is found in this case by summing up the capital cost and the expected damage caused on annual basis.

Depending upon the importance of the structure, we can decide the capital cost and the cost related to the damages due to the failure of that structure, these two will be determined total sum we will be calculating. These two can be calculated by making use of different return periods. Depending on the type of the structure for which what should be the value of return period to be assumed that we should have some idea, based on that the capital cost can be calculated and what will be the cost which will be incurring due to the failure of the structure that will be calculated and these two should be added together to find out the optimum design return period. So, this is the fundamental principle which we usually follow under the hydro economic analysis. But if we want to solve problems or we want to make use of this method for the hydrologic design, we need to carry out so many calculations in depth and probabilistic analysis required, that I am not going to cover in this lecture.

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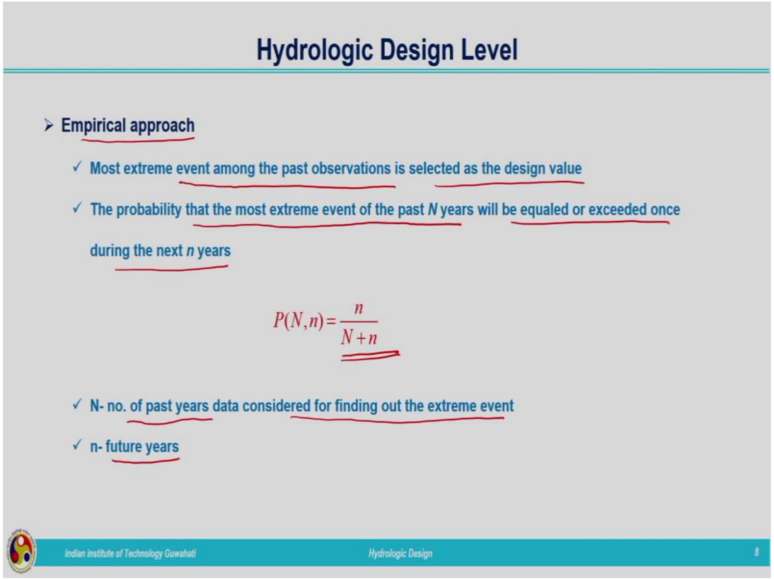

Now, let us move on to the second approach for determining the hydrologically design level that is the empirical approach. Empirical approach as we have done in the case of frequency analysis by making use of Weibull’s approach. In the similar way, we can design certain probability value by making use of empirical approach.

Most extreme event among the past observation is selected as the design value. In all these cases, what you should understand, we should have the accurate past data. You will need to collect long series of data for so, many years for understanding the maximum magnitude of the event, which is considered as the design value. The probability that the most extreme event of the past N years will be equaled or exceeded once during the next n years that need to be calculated. Based on the past N years data, magnitude of the extreme event will be calculated and we need to calculate the probability corresponding to that particular event equaled or exceeded in the coming n years. In the future coming years, we need to calculate the probability that can be calculated by using the formula

$$P(N,n) = \frac{n}{N+n}$$

N is representing the length of the data series, that is if it is a yearly data, n data points will be there. Depending on the data series which we have considered depending on n years number of data will be different. So, capital N is representing the length or the number of years considered when we were analysing the previous past data and small n is the number of years which we are considering for the future that is we need to find out the probability of occurrence of an event having specific magnitude which is equaled or exceeded in the coming small n years. That is the difference small n is representing the future years and capital N is representing the past years which we have considered as far as the data is concerned. That is capital N is the number of past years data considered for finding out extreme event and coming to a small n, it represents the number of future years. So, this is the way, we will be finding out the probability of the particular event having certain specified magnitude. And next important method is the risk analysis. That is the third approach which is used for finding out the hydrologic design level is risk analysis.

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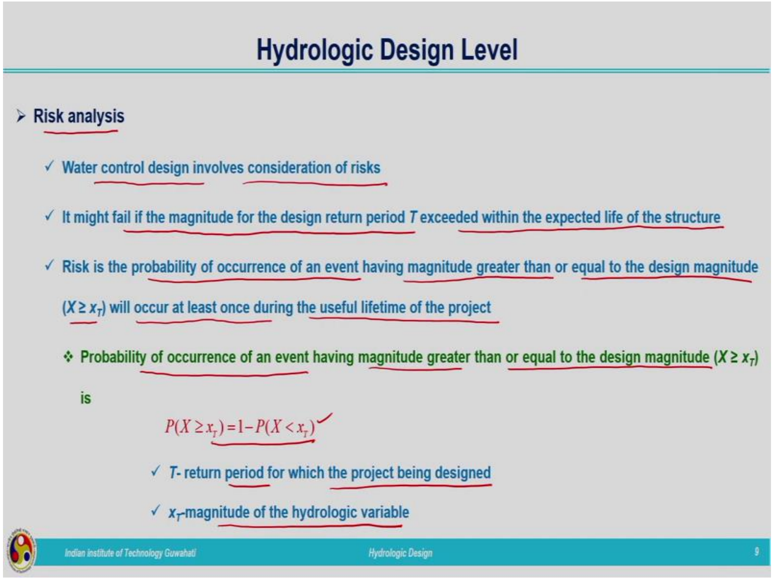

Whenever we are going to a particular hydrologic design, we need to carry out the risk and reliability analysis. What is meant by this risk analysis? We know already that water control design involves consideration of risks, this is mainly related to the water control, when we were discussing about the water resources projects, I told you these are of two types: one is related to water control and the second one is related to water use. So, when we are discussing about the water controls such as the dam structure, reservoir, control structures such as weir and spillways mainly when we talk about dams, the spillways come into picture. So, these control structures involve the consideration of certain amount of risk. The structure might fail, if the magnitude for the design return period T exceeded within the expected life of the structure, there is an expected life of the structure within that period the structure should be safe.

So, this structure might fail if the magnitude of the particular event corresponding to a return period exceeds that value, that is the thing which we associate with the risk. So, if we define risk, risk is the probability of occurrence of an event having magnitude greater than or equal to the design magnitude that is capital $(X \geq x_T)$ will occur at least once during the useful lifetime of the project. Any water control structure when we are designing there is a certain risk associated with that, that is defined as the probability of occurrence of an event having a certain maximum magnitude equaled or exceeded at least once during the lifespan of that particular structure.

So, the probability of occurrence of an event having magnitude greater than or equal to the design magnitude $(X \geq x_T)$ is calculated by making use of this formula that is

$$P(X \geq x_T) = 1 - P(X < x_T)$$

This we have discussed in the previous module related to hydrologic statistics probability of $X \geq x_T$, x_T is the threshold value which we are fixing, the event can take a value which is beyond this x_T that is what is represented by $P(X \geq x_T)$ that is given by $1 - P(X < x_T)$. T is the return period for which the project has been designed and x_T is the magnitude of the hydrologic variable that is the threshold value which we are fixing for the hydrologic variable.

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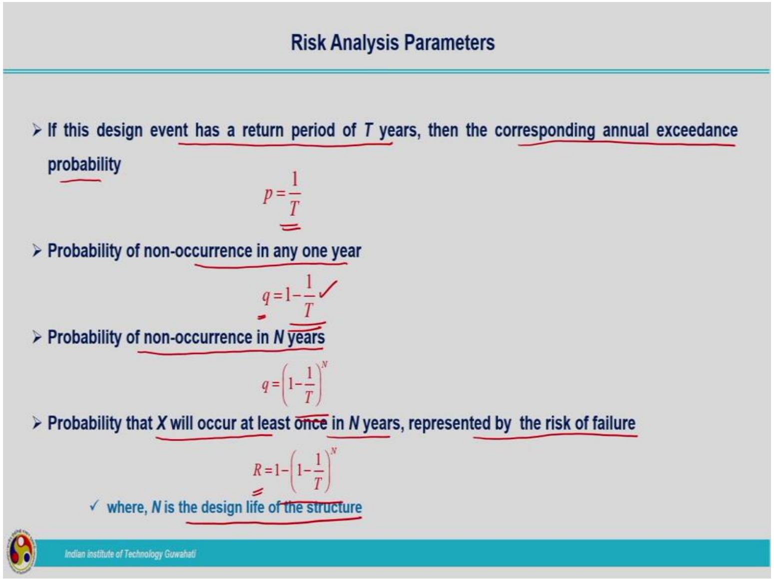

Now, how to calculate this in terms of return period? So, if this design event has a return period T year, then the corresponding annual exceedance probability can be calculated by using

$$p = \frac{1}{T}$$

How this $p = \frac{1}{T}$ is coming we have already derived in the previous module and the probability of non-occurrence of the event in any one year, probability of occurrence is capital X, that is the random variable value $X \geq x_T$, x_T is the threshold level then what will be the probability of non-occurrence? Probability of non-occurrence will be 1 minus that particular p value, it is the value corresponding to q that is given by

$$q = 1 - \frac{1}{T}$$

Probability of non-occurrence in N years this $1 - \frac{1}{T}$ is representing the probability of non-occurrence in one-year single year, if we are constituent capital N years, it can be represented as

$$q = \left(1 - \frac{1}{T}\right)^N$$

This derivation also we have covered this is only a repetition. Now, probability that X will occur at least once in N years will be represented by the risk of failure. So, the risk of failure of a structure is calculated by using the formula R is equal to

$$R = 1 - \left(1 - \frac{1}{T}\right)^N$$

that is probability of non-occurrence is $\left(1 - \frac{1}{T}\right)^N$ for N years and the risk is the case with a probability of occurrence that is equaled or exceeded corresponding to a particular maximum magnitude of that particular design event. So, it can be calculated by using the formula $1 - \left(1 - \frac{1}{T}\right)^N$. Here N is the design life of the structure.

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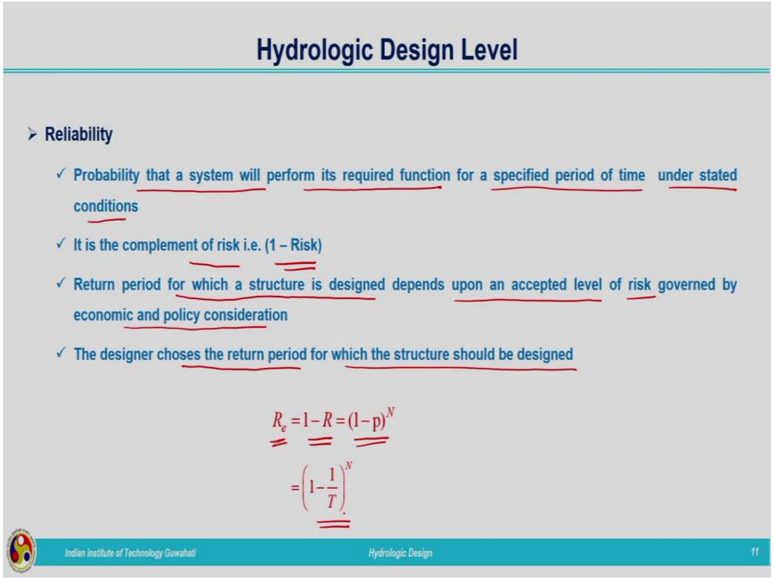

Now, related to risk analysis, another very important term which comes along with risk analysis is reliability. What is meant by reliability? Reliability represents the probability that a system will perform its required function for a specified period of time under stated conditions. What was risk it may fail, but in the case of reliability, it is the probability that the system will perform as we were expecting. It is the compliment of risk that is risk is representing the chances of failure, but reliability is representing the proper functioning of the structure. So, this reliability is the compliment of risk. So, we can write reliability as $(1-Risk)$, that is total probability is one risk plus reliability is equal to 1, if risk is known to us we can calculate reliability by taking $(1-Risk)$ value.

So, return period for which a structure is designed depends upon an accepted level of risk governed by economic and policy considerations. So, this return period we have to follow IS codes while designing certain structure, what should be the return period to be considered based on that we have to do. Simply we cannot provide a certain return period and we cannot construct a structure it may incur more capital cost. So, in order to avoid that, we have to choose the return period based on the certain codal provisions, which each and every country is following, that is the risk is governed by the Economic and Policy consideration. The designer chooses the return period for which the structure should be designed. We would not go for the design of a storm drainage system by considering the return period same as that of the return period which is used for a major structure such as dam. So, for each and every structure, there are certain return period provided by the authorities that has to be utilized. So, that return period will be chosen by the designer corresponding to that we will be choosing the design discharge. So, reliability R_e can be calculated by

$$R_e = 1 - R = (1 - \text{p})^N$$

So, in terms of return period capital T we can write as

$$R_e = \left(1 - \frac{1}{T}\right)^N$$

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So, this lecture I am winding up here related to the hydrologic design. In the next lecture, we will solve some of the numerical examples related to this particular topic and coming to the references these are some of the textbooks related to this topic of hydrologic design. Thank you.