Engineering Hydrology
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Lecture 80
Design Storm

Hello all, welcome back. In the previous lecture, we have discussed about risk and reliability and some of the problems related to that also we have solved and today we are going to move on to design storm. In the first lecture related to hydrologic design, we have discussed about the design scale. Instead of providing a single value for design variable, a scale has to be proposed and the lower value of that can be taken as 0, upper value is taken as the upper limiting value. That upper limiting value can be either described by means of a probable maximum precipitation or the flood which is caused due to probable maximum precipitation that is the probable maximum flood or it can be determined based on the frequency analysis, corresponding to a certain return period how much will be the magnitude of that particular variable. So, here in today's lecture, we are going to discuss about design storm.

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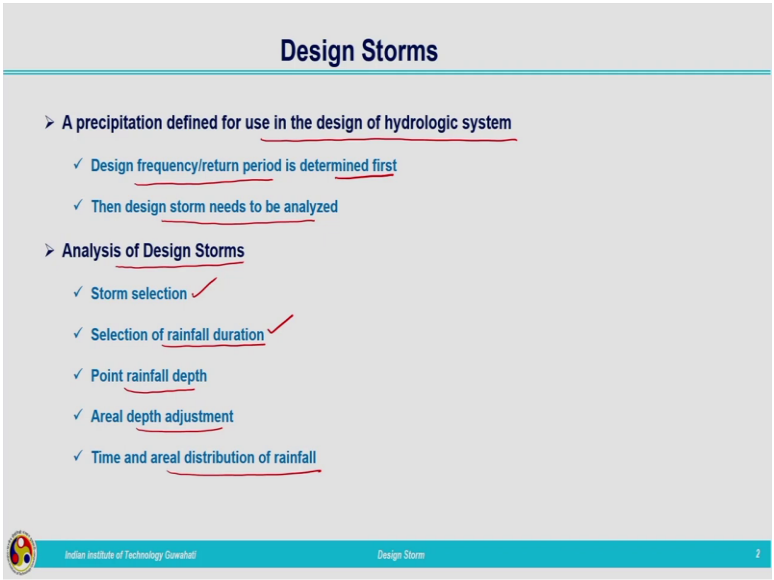

Design storm is that precipitation which is used for the design of hydrologic system, that is the precipitation which is defined for the design of a hydrologic system is termed as the design storm. So, that design storm can be chosen in different ways. It can be based on the historic data from a particular station or from stations which are having meteorologically similar characteristics and sometimes it can happen in such a way that data is not available to that particular catchment that is we are expecting heavy storm or maximum flood in a particular catchment, but related to that past data is not available in that particular catchment.

In such cases, we can make use of the storms from the neighboring catchments which are meteorologically similar to the catchment under consideration.

So, mainly we need to look into the design frequency or return period that has to be determined first. First, we need to determine the return period or the corresponding frequency of occurrence of the event that is depending upon the importance of the structure, return period considered will be different. For example, if you are talking about a major structure such as a bridge or a dam, the return period which will be considered will be of high value. It can be sometimes 50 years, it can be sometimes 100 years, but if it is related to a storm drainage work, we do not have to go for a high return period value like 50 years and 100 years, we will be limiting that within 5 to 10 years or sometimes 2 to 5 years.

So, depending upon the importance of the structure, we will be choosing the return period. So, first we need to finalize the return period or the corresponding frequency of occurrence of the event. After that we need to analyze the design storm. Regarding analysis of design storms first it comes to the selection of storm from the past data we need to choose the storm which can be considered for the design purpose. So, historic data will be checked and we will be finding out which storm has to be chosen. Then selection of rainfall duration. Duration is very important when we are talking about design storms. Then comes the point rainfall depth corresponding to the chosen rainfall duration from the selected storm and since it is acting on a certain area, areal depth adjustment needs to be calculated and time and areal distribution of the rainfall needs to be carried out. So, first step in deciding the design storm is that we need to choose the storm from the past data. Once the storm is decided, we need to find out the value corresponding to the duration. Duration has to be decided because in urban areas and all we will be making use of the rainfall intensity corresponding to short duration that is short duration high intensity rainfall is causing flooding in urban areas. So, in such cases duration is very important. So, we have to choose very short duration rainfall. So, depending upon the requirement we will be choosing the duration of the event. Once that point rainfall depth is determined, we can extend it to get the areal extent of that particular rainfall depth and temporal and areal distribution of that particular rainfall needs to be determined.

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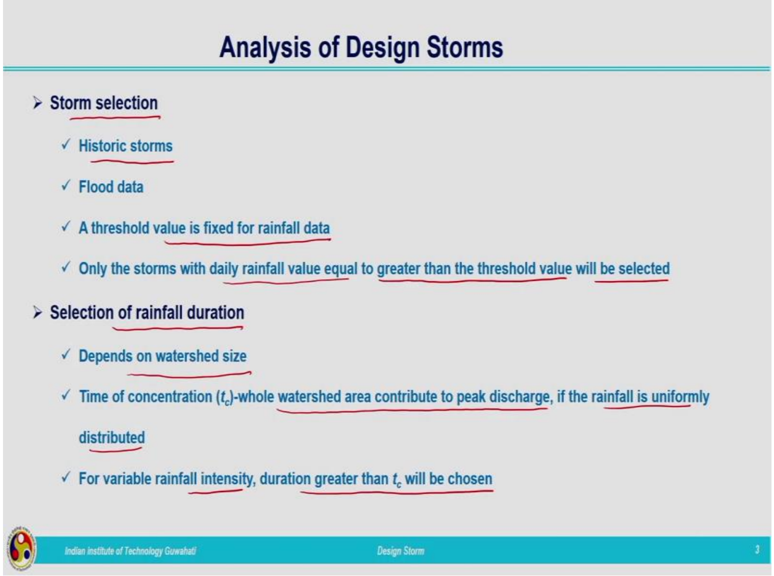

So, first step is the storm selection. Under storm selection, we will be analyzing historic storms. For the last so many years we will be collecting the data related to historic storms and the corresponding historic floods. In case of the catchments which are ungauged, we will not be having the flood data. If proper rain gauges are installed, we can have the rainfall data, storm data, but flood data may be lacking. So, mainly we will be collecting the storm data and the corresponding flood data. Then a threshold value is fixed for the rainfall data. Based on the past series of data, daily rainfall data, we will be fixing a threshold value. Above this threshold value will be considered for the flood analysis. For the modelling studies related to flooding, we have to consider the values which are coming above the threshold value which is fixed and in the study is related to drought we will be fixing a threshold value in the minimum range. So, below that minimum value will be considered for the analysis related to drought. So, only the storms with daily rainfall value equal to or greater than the threshold value will be selected for the analysis related to flooding.

Now, coming to the selection of rainfall duration. Rainfall duration is very important because short duration high intensity rainfall cases we have to identify that short duration based on the available data. So, corresponding to that duration we need to make use of rainfall data. Selection of rainfall duration is the second step. This depends on the watershed size. If size of the watershed is large, then the water which is reaching at the outlet point from the extreme point that is time of concentration will be large. But in the case of small watershed this time of concentration will be small. So, while deciding the duration of the storm, we will be considering it as equal to time of concentration. So, time of concentration is the time corresponding to whole watershed area contribute to peak discharge. If the rainfall is uniformly distributed in that case we will be considering the time of concentration as the duration of the storm that is constant value of rainfall we are considering and it is uniformly occurring in the catchment and entire catchment will be contributing water at the outlet point with a time value equal to time of concentration. But always we cannot assume a constant rainfall depth. In the case of variable rainfall intensity duration greater than t_c will be chosen, because it may be taking more time than that of the time of concentration for the entire watershed to contribute to the outlet point. Time of concentration is the time corresponding to the extreme point to contribute water to the outlet point. But in the case of rainfall having varying intensity this duration of the rainfall will be considered slightly more than that of t_c and in the case of urban catchments, we would not depend on all these things. We will be considering very short duration rainfall, it varies from 15 to 30 minutes. So, corresponding to that historic data has to be collected and based on that we need to choose the storm.

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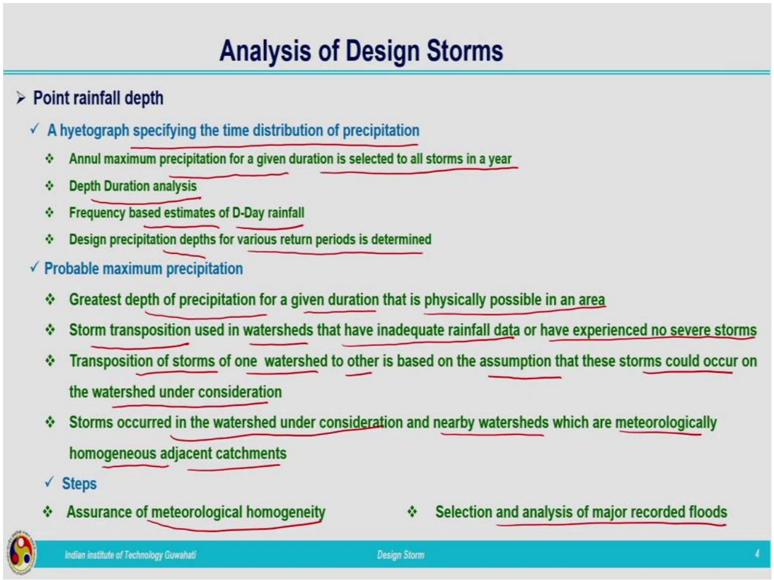

Coming to point rainfall depth, a hyetograph specifying the time distribution of precipitation from the historic data will be chosen which is representing a highest value above the threshold value which is chosen or below the value chosen for the drought analysis. So, this point rainfall depth includes the selection of the hyetograph. Annual maximum precipitation for a given duration is selected to all storms in a year. Entire series will be analyzed and annual maximum value will be chosen from that. Corresponding to that what is the hyetograph that will be chosen as the point rainfall depth. Then we can carry out the depth duration analysis, what will be the maximum depth corresponding to each duration. So, depth duration analysis will be carried out and we can develop the depth duration curves and frequency-based estimates of D-Day rainfall can also be calculated, D-Day means 1-day rainfall, 2-day rainfall, 3 days rainfall that way it can be chosen depending upon the historic rainfall data and design precipitation depths for various return periods have to be determined. We are going to design the structure corresponding to your particular return period. So, corresponding to that return period what will be the maximum rainfall depth or what can be the magnitude of the rainfall value that needs to be computed based on the historic data. So, sometimes in the case of very important structures, dams or some other structures, which are of great importance, if the failure happens for this structure, the losses will be very huge. In such cases, we will be going for probable maximum precipitation. 50 years return period, 100 years return period causing a value which may be lower than the probable maximum precipitation.

So, this probable maximum precipitation we will not prefer to use in all the cases because the design would not be economical, but some cases are the in which we cannot avoid the probable maximum precipitation. So, probable maximum precipitation is the greatest depth of precipitation for a given duration that is physically possible in an area. How to determine this probable maximum precipitation in the case of ungauged catchment or the catchment which has not experienced a maximum value of rainfall equivalent to this probable maximum which we are expecting. This can be done by storm transposition. Why do we want to go for storm transposition? Storm transposition is the process by which the value from a watershed which has experienced a very high value that is probably maximum precipitation can be used for the analysis of the ungauged catchment. So, storm transposition is used in watersheds that have inadequate rainfall data or have experienced no severe storms. But in such cases, you may think that why do we want to go for this much of high value of design storm. The reason behind is that this particular catchment is meteorologically similar to the other catchment, gauged catchment, which has already experienced a very high value of precipitation. So, we are expecting similar kind of maximum precipitation in this ungauged catchment where we do not have the data. So, in such cases we will be making use of the data from the gauged catchment which has experienced the maximum storm. So, transposition of storms of one watershed to other is based on the assumption that these storms could occur on the watershed under consideration. We are worried that the similar type of storm can occur in a particular catchment where we do not have the data and also, we have not experienced such a maximum storm.

But these catchments are meteorologically similar in nature. So, storms occurred in the watershed under consideration and nearby watersheds which are meteorologically homogenous adjacent catchments will be utilized. So, the catchment which is gauged in nature has experienced a maximum precipitation which is equivalent to probable maximum precipitation. So, the floods from the that particular catchment and also the catchment which is under consideration will be selected to finalize the design storm. So, these types of estimation of design storm is termed as based on storm transposition.

Different steps involved in this are assurance of meteorological homogeneity and selection and analysis of major recorded floods. The first step in storm transposition is that we need to clarify or we need to finalize that the catchment which is under consideration is meteorologically similar to that of the gauged catchment which has experienced a maximum precipitation. So, how can that be done? That is, we need to identify whether these 2 catchments are meteorologically similar. So, for that we have to analyze some of the atmospheric parameters which are causing the precipitation, wind velocity and the closeness to the coastal area, hilly catchments, similar kinds of hilly pattern are there and the very important factor is different atmospheric parameter or the moisture present in the atmosphere, humidity related parameters in both the catchments.

So, analysis based on these parameters will be deciding whether the catchments which are under consideration are meteorologically similar or not. Once it is finalized that these catchments are meteorologically similar, we will be collecting the existing storm data from the gauged catchment and also the minimal data which are available from the ungauged catchment. So, based on this analysis, we will be making use of the probable maximum precipitation which has occurred in the gauged catchment for the hydrologic design in the ungauged catchment.

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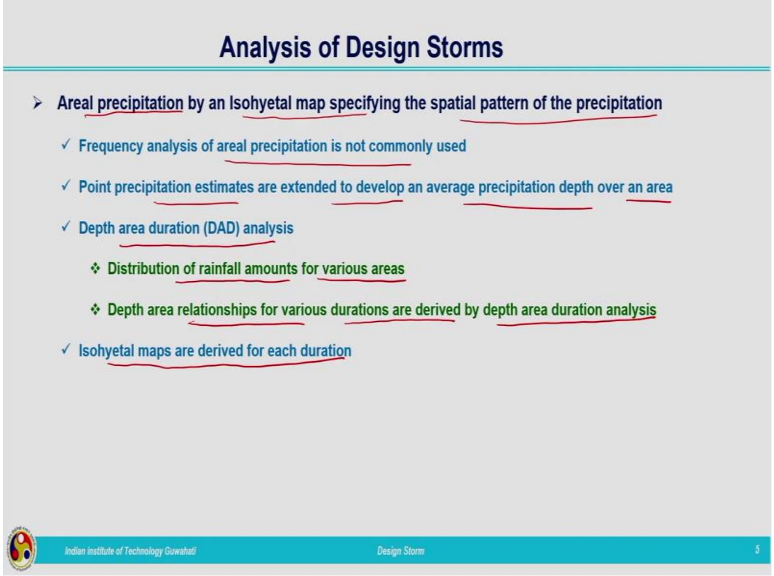

Now, coming to the areal precipitation. Till now, what we were talking about was related to point precipitation. Coming to areal precipitation, by means of Isohyetal maps, we will be identifying the spatial pattern of the precipitation. In the case of areal precipitation, it is not common to make use of the frequency analysis, that is applicable to the point rainfall data. So, frequency analysis of areal precipitation is not a common approach which we utilize. So, point precipitation estimates are extended to develop an average precipitation depth over an area. So, in that case also we will be making use of the point precipitation data at different locations in the catchment and that will be extended to the entire area by means of areal average precipitation. And in this case, what we will be doing? We will be carrying out the depth duration analysis and also depth area duration analysis. The rainfall depth corresponding to different durations that is the maximum rainfall depth corresponding to different durations will be identified and the relationship with the area is calculated or the relationship with the area will be graphically plotted. That way we can develop depth area duration curves by making use of depth area duration analysis, that is distribution of rainfall amounts for various areas corresponding to different durations can be obtained by using the depth area duration curves. Depth area relationships for various durations are derived by depth area duration analysis. So, the technique behind it I am not going to explore now, here you just understand that there are principles to identify the spatial variability of rainfall by making use of the point rainfall data that is done by understanding the depth duration relationship that is the maximum depth corresponding to different durations will be obtained and that is related to the correlation between the maximum precipitation depth corresponding to particular duration and the area of small, small watersheds for different areas will be found out. Those are giving us idea about the relationship between the rainfall and the area. So, depth area duration curves are derived by conducting depth area duration analysis. Then for each duration Isohyetal maps will be derived for the particular area under consideration.

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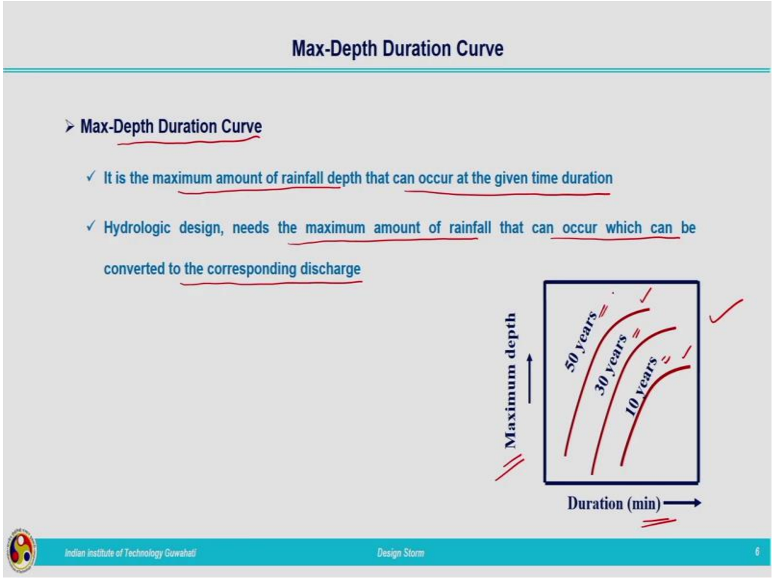

Now, we need to understand how to get the maximum depth duration curves that is required for carrying out the depth area duration analysis. So, maximum depth duration curve is representing the maximum depth corresponding to a particular duration which is identified from the past rainfall data. Historic data will be collected for varying durations and based on the data collected we can find out the maximum depth corresponding to each and every duration which we are considering. That maximum depth we will be plotting against the duration that is what is termed as the maximum depth duration curve. So, here you can see maximum depth is plotted along the y axis and duration in minutes or depending on your requirement, it can be in hours also. So, duration is plotted along the x axis and for varying return periods 50 years, 30 years 10 years or it can be from 10 to 100 years, so varying return periods will be considered. So, for different return periods, we will be plotting the depth duration curves. For each and every return period which we are considering separate curves will be plotted that is depth duration curves will be plotted and depending upon the requirement or for which the hydrologic design we need to carry out, we will be choosing the corresponding depth duration curve. If it is related to dams or bridges, it can be of 50 years or 100-year return period, if it is related to storm drainage network it can be 5 years. So, depending upon the requirement, we will be choosing the specific curve. So, the maximum duration curve represents the maximum amount of rainfall depth that can occur at that given time duration. We already know hydrology design needs maximum amount of rainfall that can occur, which can be converted to the corresponding discharge. What is the maximum rainfall which is occurring at a particular location corresponding to certain duration has to be identified for the hydrologic design. So, if we are having that depth duration curve from that we can select the storm or the precipitation depth, which has to be used for the design of hydrology structure. We can choose the corresponding precipitation depth from that depth duration curve which is needed for the hydrology design. So, that much about maximum depth duration curve. So, this is the curve representing the maximum depth duration curve. In this you can observe that 50 years return period curve is having maximum depth compared to 10 years return period. So, the depth is more in the case of higher return period that is as the frequency of occurrence is less then, than the intensity of rainfall or the depth of rainfall will be high, high intensity events will be occurring less frequently that is what we can understand from this curve, for the 50 years the maximum depth is at a higher value compared to 10 years.

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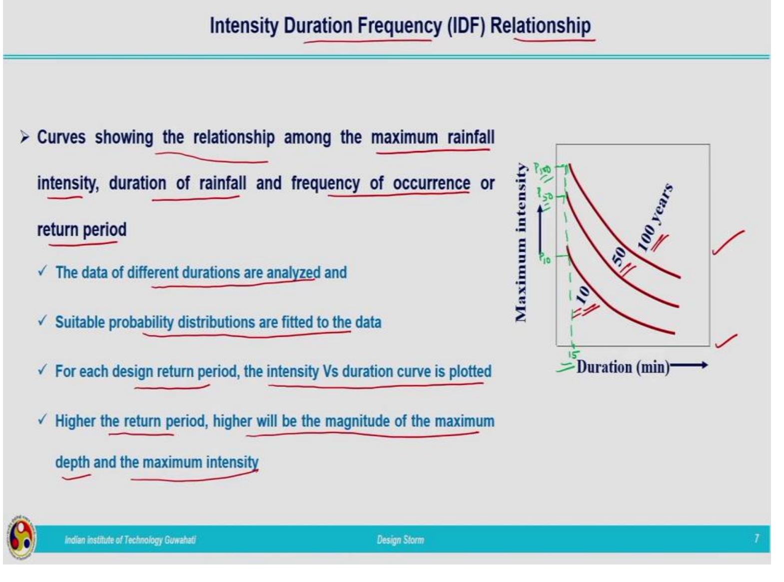

Now, next thing which you should have idea in related to this is the important curve that is intensity frequency duration curve. Whenever we are talking about hydrologic design especially in urban areas, we need to make use of intensity duration frequency curves, IDF curves in short form we will be naming it as IDF curves.

Let us see what is meant by IDF curve. Intensity duration frequency relationship, these are the curves showing the relationship among the maximum rainfall intensity, duration of rainfall and frequency of occurrence or return period. F is representing the frequency of occurrence or return period and I is representing the intensity and D is the duration. Corresponding to a particular duration what is the intensity of rainfall for a particular return period that relationship is represented by intensity duration frequency curve.

Schematically we can represent the IDF curve as shown in this graph. So, here also bottom curve is representing the IDF curve for return period 10 years, middle one is for return period of 50 years and the upper one is for a return period of 100 years. So, you can understand that as the frequency of occurrence is reducing or the return period is increasing the events are not very frequent, high intensity precipitation or the rainfall will be occurring very less frequently. So, that is why for very high values of return period we will be having less frequent events. Here in the case of 10-year return period, it is a very high frequency event, high frequency event will be having low intensity values, that is why it is coming at the bottom and 100-year return period curve will be coming at the higher side that is the magnitude of the events will be having high values for higher return period values.

The data of different durations are analyzed, previous series of short duration rainfall data will be collected. Short duration data is required, then only we can do derive the rainfall intensity curve corresponding to short durations. So, the data of different durations are analyzed and suitable probability distributions are fitted to the data and for each design return period the intensity versus duration curve is plotted that is what is shown over here in this graph. So, for each return period different curves will be derived, those curves are plotted as the intensity duration frequency curve and for the purpose of hydrologic design depending upon the type of the structure which we are considering under hydrologic design, suitable curve will be chosen from the intensity duration frequency curve corresponding to the specified return period. Higher the return period higher will be the magnitude of the maximum depth and maximum intensity and if the return period is having a lower value, high frequent values corresponding to maximum intensity and maximum precipitation depth. High frequent value of the variable means, it will be having less value as the frequency is high means, it is very commonly or routinely occurring one that will not be having a very high value. But less frequent event will be having very high value. Corresponding to 100 year, if we are considering a duration of 15 minutes, I can mark over here if this is representing 15 minutes, corresponding to this 15-minute duration 10-year return period is giving a value at this point this is P_{10} corresponding to 10 year return period and if you are talking about 50 years return period, this is representing P_{50} and if we are talking about 100-year return period P_{100}, it is a high value. So, duration is less, intensity will be high and the return period is less intensity will be less. So, you will look at the maximum intensity for 10-year return period corresponding to a duration of 15 minutes P_{10} is lower than P_{50} which is lower than P_{100}. Higher the return period higher will be the value that will be occurring less frequently.

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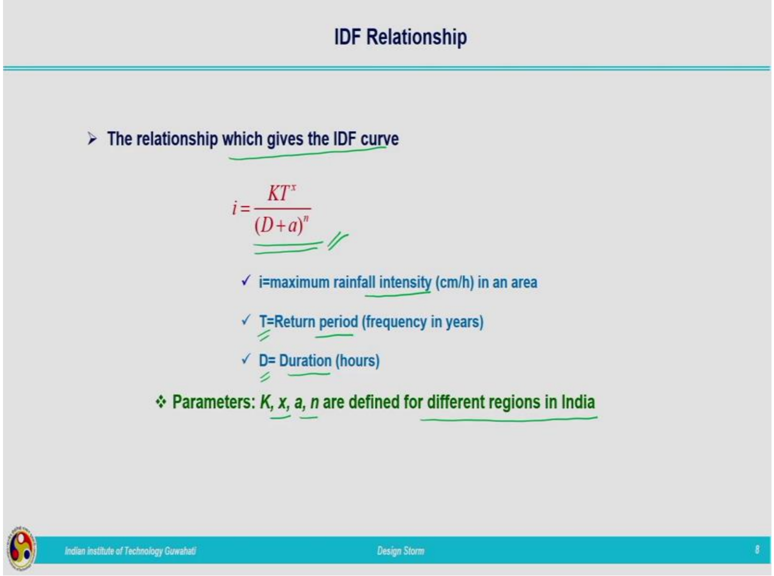

The relationship which gives the IDF curve is given by

$$i = \frac{KT^x}{(D+a)^n}$$

In this i is the maximum rainfall intensity, T is the return period which is representing the frequency in years, D is the duration and parameters K, x, a and n are defined for different regions in India.

This particular equation can be utilized for deriving intensity duration frequency curve for a particular region in India. For different, different regions, we can choose the corresponding parameters from the table corresponding to it, that table you can get from the textbook. So, this is the representation which can be utilized for deriving the intensity corresponding to a particular duration and also corresponding to particular return period that is T year return period, duration D hours. So, corresponding to that we can choose the intensity which is required for the hydrologic design.

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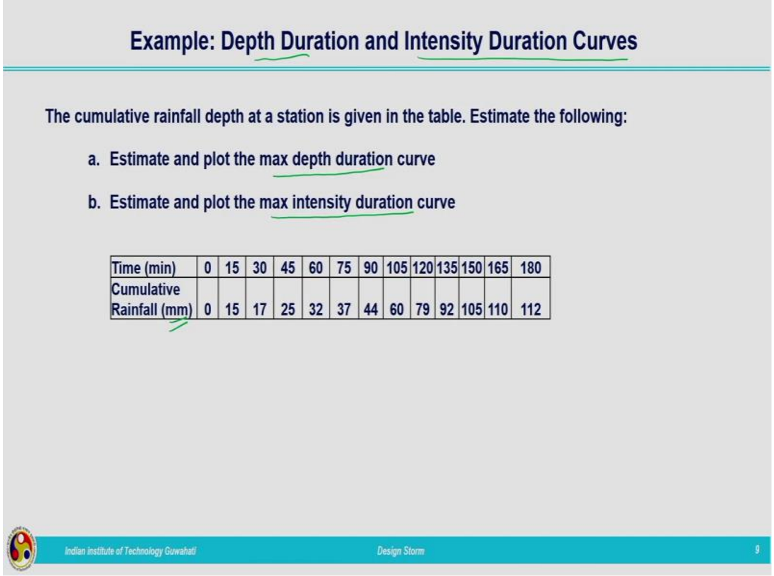

Now, let us solve one example related to depth duration and intensity duration curves. The cumulative rainfall depth at a station is given in the table. Estimate the following: estimate and plot the maximum depth duration curve, estimate and plot the maximum intensity duration curve.

Data given to you represents the cumulative rainfall data in millimeters, time is in minutes and cumulative rainfall data is given in millimeters. So, by making use of this data we need to derive the depth duration curve and also intensity duration curve. I am not calling it as IDF curve intensity duration frequency curve, because here we are going to derive only one curve. For different return periods, we can derive incorporating the frequency different curves can be derived then only we can tell that it is an IDF curve. IDF curve includes the intensity duration curve corresponding to different frequency or different return periods.

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Example: Depth Duration and Intensity Duration Curves

Time	Cum. Rainfall	Rainfall Depth	Incremental depth of rainfall for various durations (min)											
min	mm	mm	15	30	45	60	75	90	105	120	135	150	165	180
0	0	0	0											
15	15	15	15											
30	17	2	2	17										
45	25	8	8	10	25									
60	32	7	7	15	17	32								
75	37	5	5	12	20	22	37							
90	44	7	7	12	19	27	29	44						
105	60	16	16	23	28	35	43	45	60					
120	79	19	19	35	42	47	54	62	64	79				
135	92	13	13	32	48	55	60	67	75	77	92			
150	105	13	13	26	45	61	68	73	80	88	90	105		
165	110	5	5	18	31	50	66	73	78	85	93	95	110	
180	112	2	2	7	20	33	52	68	75	80	87	95	97	112

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So, these are the data given to us: time in minutes and cumulative rainfall in millimeters. So, from the cumulative rainfall we can find out the incremental depth of rainfall. Incremental depth of rainfall in millimeters is listed in this column. So, that is 0 times 0 rainfall, 15th minute it is 15-millimeter, 30th minute cumulative rainfall is 17 millimeters. So, 17 minus 15, 2 millimeter is corresponding to 30 minutes. 2 millimeter is the incremental rainfall depth corresponding to 30 minutes. That way when it comes to 45 minutes, 25 minus 17, that is coming out the be 8-millimeter. In that way we can find out the incremental depth of rainfall corresponding to each duration. Now, what we need to find out we need to find out the maximum depth and maximum intensity corresponding to different durations. So, for that we will make the table like this. Incremental depth of rainfall for various durations we are going to find out first, that is from the cumulative rainfall depth we have found out the incremental depth of rainfall. Now, we are going to find out the incremental depth of rainfall corresponding to each and every duration and after that from that data which we have determined, we can find out the maximum depth corresponding to each and every duration.

So, the data given is a 15-minute interval. So, we can make the duration as 15, 30, 45 up to 180 minutes. So, for 15 minutes if we talk about here, you look at the rainfall depth which we have determined from the cumulative rainfall depth that is representing a rainfall depth corresponding to 15 minutes duration. So, 15 minutes duration data is the same as that of which is calculated as the incremental rainfall depth. So, that way if we are calculating the rainfall depth corresponding to 30 minutes duration it will be coming out as listed in this column. So, 30 minutes will be 15 plus 2, 17, 2 plus 8, 10, 8 plus 7, 15, 7 plus 5, 12 that way we will be calculating. In the similar way next column is related to 45 minutes. 45 minutes it will be 15 plus 2 plus 8 that will be 25 and next will be 2 plus 8 plus 7 that is 17. So, the values corresponding to incremental depth of rainfall for various duration, 60 minutes 75 minutes, 90 minutes up to 180 minutes are tabulated here in this table. From this what we need to find out? We have found out the rainfall depth, incremental rainfall depth corresponding to each duration. Depth duration curve is representing the maximum depth corresponding to a particular duration versus duration. So, we need to find out or we need to identify the maximum depth of rainfall from this calculated incremental rainfall depth corresponding to different durations.

So, we can start that when we talk about 15 minutes duration data, this column the maximum value will be 19 millimeter and when it comes to 30 minutes duration maximum value is 35 millimeters and corresponding to 45 minutes duration it is 48 millimeters. In that way for 60 minutes it is 61, 75 minutes it is 68 millimeter and 90 minutes it is 73, corresponding to 105 minutes it is 80 and 120 minutes represents 88 millimeters of rainfall and for 135 minutes it is 93 millimeters, and for 150 minutes it is 105 millimeter and corresponding to 165 minutes it is 110 millimeters and last that is for 180 it is 112 millimeters. Now, we can make use of these maximum depth of incremental precipitation corresponding to each duration for plotting the depth duration curve.

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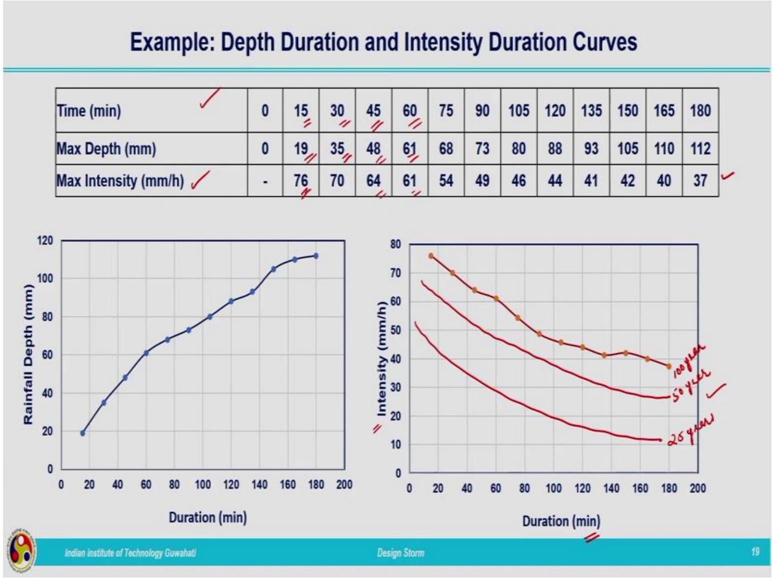

So, we can tabulate the maximum depth which are found out in the previous slide, it is tabulated over here in this table. So, corresponding to each duration we have found out the maximum depth. This can be plotted like this rainfall depth in millimeter versus duration in minutes is plotted to obtain the rainfall depth versus duration curve. This curve is the depth duration curve and depth duration curve are developed and the relationship with the area is found out in the case of depth area duration curves. Here I am not discussing about that.

Next, we will find out the intensity duration curve. So, here we are having the maximum depth corresponding to each and every duration. So, if the depth and the duration is known to us, we can calculate the corresponding intensity that is depth divided by the duration will give us the intensity. So, that intensity is calculated in this row corresponding to each and every duration: 15 minutes, 30 minutes. So, you are having a depth of 19 millimeter corresponding to 15 minutes. 15 minutes we are getting 19 millimeters. So, 60 minutes how much it will be? Multiplied by 4 that is 76. 30 minutes duration we are having 35 millimeters of rainfall. So, 60 minutes we will be having 70 millimeters of rainfall and in the similar way corresponding to 45, 60 minutes, all durations depths are calculated and corresponding intensities can be calculated by making use of the relationship with the depth and the intensity corresponding intensities are listed over here in this row.

Now, we can plot the intensity duration curve, intensity in millimeter per hour versus duration in minutes. So, the values which are tabulated here, maximum intensity and time in minutes are used over here to plot the intensity duration curve. Here we have not specified the return period. So, similar way, if this is for 100-year return period, we can derive another curve corresponding to 50 years return period and corresponding to 25 years it will be coming like this. But the rainfall data historic data should be available to us for different durations. By making use of the historic data, we can derive the intensity duration frequency curves for varying return periods. But here in this case, I have not specified anything about the return period, we were given the rainfall depth and the corresponding duration, based on that we have calculated the maximum depth and maximum intensity. By making use of those data, we have plotted the maximum depth duration curve and maximum intensity duration curve.

While deriving the intensity duration frequency curve, we have to make use of the probabilistic distribution, which will be the suitable distribution which can be fitted to the given data, based on that we will be finding out the frequency of occurrence and also the magnitude of the event corresponding to certain return period. So, by making use of the suitable probabilistic distribution, that distribution has to be fitted first and based on that we will be finding out the intensities corresponding to different return periods for varying durations. Then we can derive different number of curves corresponding to different return periods. So, these are the types of problems related to depth duration curve and intensity duration curve.

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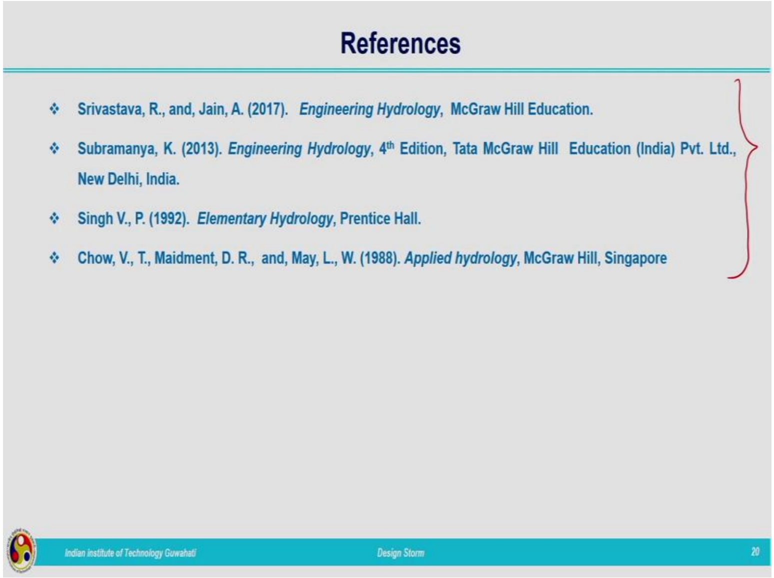

Related to this you can get so many exercise problems from these textbooks. These are some of the reference textbooks. Here, I am winding up today’s lecture. Thank you.