Course Name: Watershed Hydrology

Professor Name: Prof. Rajendra Singh

Department Name: Agricultural and Food Engineering

Institute Name: Indian Institute of Technology Kharagpur

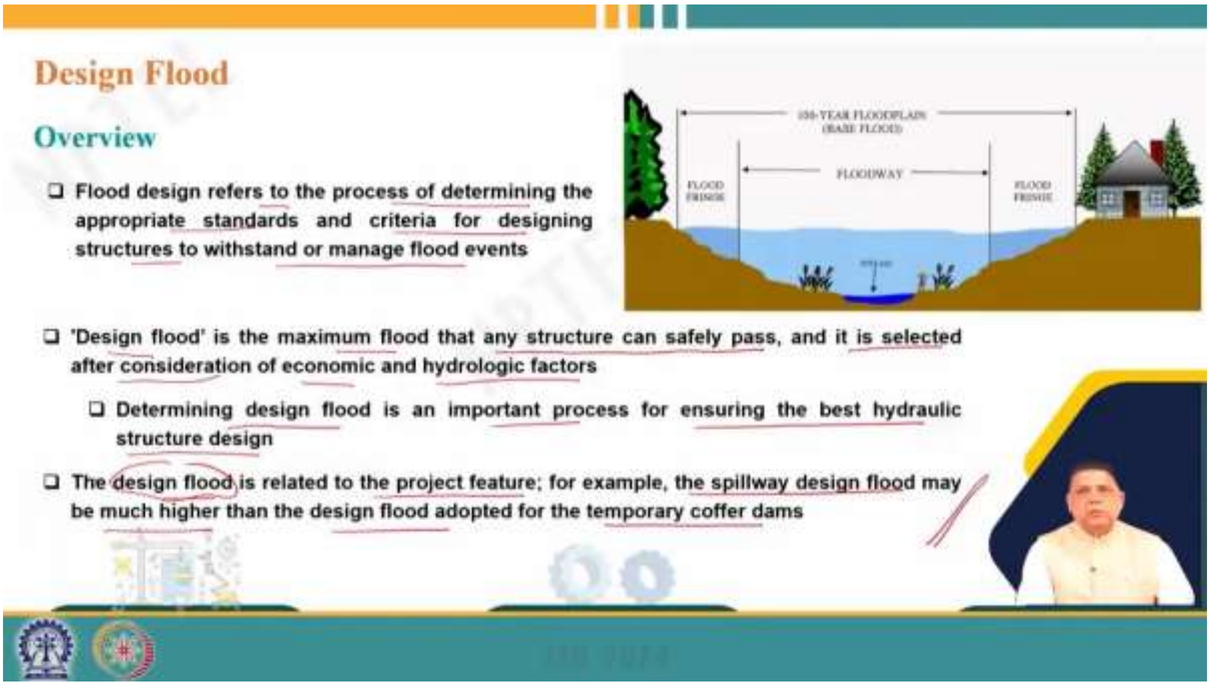
Week: 09

Lecture 42: Design Flood

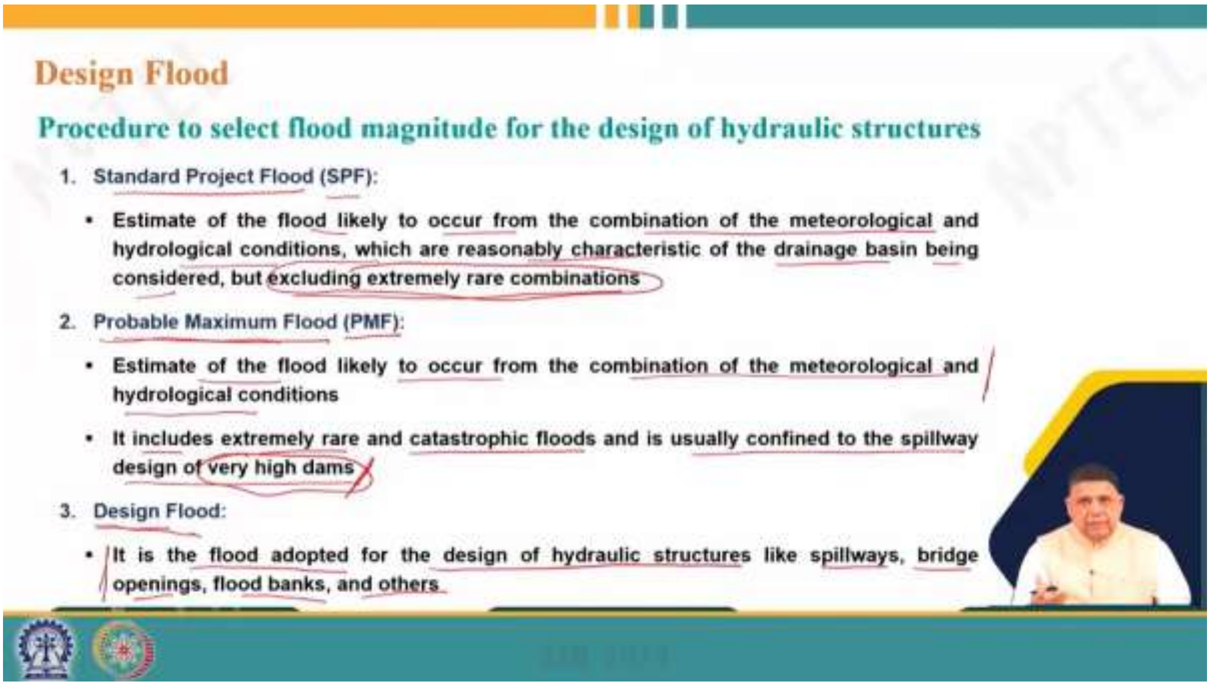
Hello friends, welcome back to this online certification course on Watershed Hydrology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are in Module 9, this is Lecture Number 2, and the topic is design flood.

In this lecture, we will be discussing design flood, methods for flood design, and we will also talk about design storm.

Now, coming to design flood, basically, design flood or flood design refers to the process of determining the appropriate standards and criteria for designing structures to withstand or manage flood events. So, obviously, if a flood occurs, then water levels and discharges in the streams will rise, and in order to manage them, we have to have structures around the entire watershed. And for designing those structures, we have to have certain standards and criteria, and of course, the magnitude of the flood is one major criterion, which is what we talk about when we refer to the design flood. So, the design flood is the maximum flood that any structure can safely pass, and it is selected after consideration of economic and hydrologic factors. So, obviously, there are two important concepts or factors here: economic and hydrologic. Hydrologic, because your structure should be able to handle the peak flood that is expected to occur, but at the same time, your design should be economical so that you do not overspend on the structure. So, that is why both the hydrologic and economic criteria have to be satisfied, and determining the design flood is an important process for ensuring the best hydraulic structure design. So, obviously, if we have a fair idea about the design flood, then only we will be able to ensure that our structure, which we have designed, is the best one to handle the design flood. And the design flood is related to the project feature. For example, the spillway design flood may be much higher than the design flood adopted for a temporary cofferdam. So, obviously, what the project is, what kind of structure you are going to design, even in the same watershed, will decide what kind of design flood magnitude you are going to adopt for designing a particular structure.



Now, coming to selecting flood magnitude for the design of hydraulic structures, basically, there are two major criteria. One is called the standard project flood, and the other is called the probable maximum flood. So, when we say a standard project flood or SPF, it is basically estimating the flood that is likely to occur from a combination of the meteorological and hydrological conditions, which are reasonably characteristic of the drainage basin being considered, but excluding extremely rare combinations. So, obviously, while deciding the SPF, or that is the standard project flood, or the magnitude of the flood, we do consider the meteorological and hydrological features of the basin. All the likely floods that are expected are taken into account, but we exclude the extremely rare combinations, the extremely rare phenomena, rare flood magnitudes that are likely to occur, which we neglect in the standard project flood. On the other hand, when we talk about the probable maximum flood or PMF, then it's an estimate of the flood likely to occur from the combination of meteorological and hydrological conditions. Up to that point, the definition remains the same for SPF as well as PMF. But in the case of PMF, it includes extremely rare and catastrophic floods, usually confined to the spillway design of very high dams. So, basically, here in this case of the probable maximum flood, we do consider extremely rare and catastrophic floods that have occurred in the history of that particular basin or particular region. Of course, it's expected that the magnitude of the PMF will be much, much higher than SPF because of this consideration of extremely rare or catastrophic floods. That is why this PMF is considered while designing very high dams or dams which are likely to handle large flows compared to the SPF. And the design flood is the flood adopted for the design of hydraulic structures like spillways, bridge openings, flood banks, and others. So, basically, a design flood is the one which we really use while designing a structure, be it a spillway, bridge opening, or flood bank, or whatever. Depending upon the type of structure and the magnitude of flow the structure is likely to experience, we may adopt SPF, PMF, or some other flood. So, whatever we adopt is referred to as a design flood. A design flood may be SPF, PMF, or some other magnitude decided on some other basis. So, all those things can change.

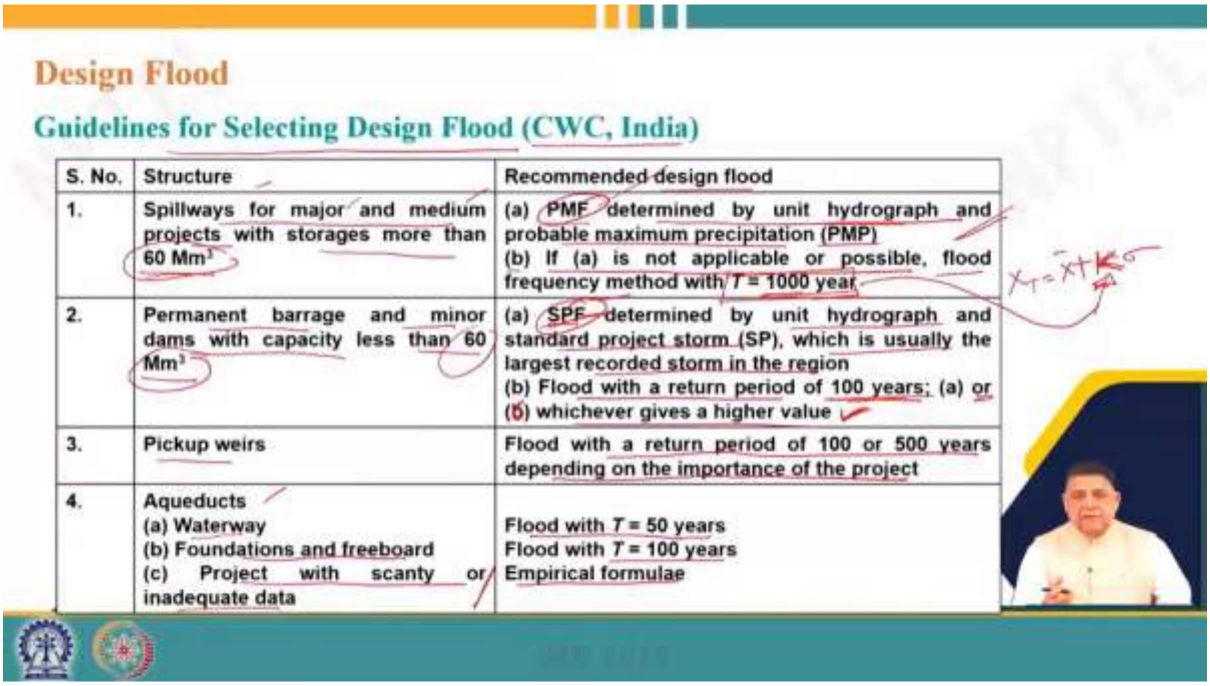


Now, let us talk about the guidelines for selecting a design flood, which are given by the Central Water Commission of India (CWC), which is the custodian of all the flow data and takes care of all the major streams in the country. So, they have guidelines for selecting a design flood. Of course, the recommendation is based on the structure. Spillways for major and medium projects with storages more than 60 million cubic meters. So, it is talking about the storage structure, meaning large dams, and even when large dams are there, there will be a reservoir, there will be storage available. So, if the storage magnitude is more than 60 million cubic meters for a given structure, which is likely to happen in medium and major projects, then the recommended design flood is PMF, the probable maximum flood determined by unit hydrograph and probable maximum precipitation. So, basically, this is the second part. We have to adopt PMF and how to determine PMF is being recommended here. That is, we have to use the unit hydrograph method using the probable maximum precipitation. We will discuss these methods a little later. Another alternative is that if PMF is not applicable or possible, suppose you do not have enough data to really calculate PMF, then the flood frequency method with a return period equals to 1000 years can be used. So, this also can be.

So, you remember Chow's method, where

$$x_t = \bar{x} + k\sigma$$

Basically, we decided that k depends on the probability distribution function and the return period. So, basically, that 1000-year return period will be taken into account here, and the magnitude of the frequency distribution function, whichever you are using, will be used to determine the k value here. So, either we use PMF or we use t equals to 1000 years, which is the return period of 1000 years for deciding the design flood. Then, if the structure is a permanent barrage and minor dams with a capacity less than 60 million cubic meters, so just smaller, then we go for SPF, which is determined by the unit hydrograph and the standard project storm, which is usually the largest recorded storm in the region. So, basically, the design flood is SPF, which stands for standard project flood. And of course, this is the second part here, also talks about the unit hydrograph method, where we have to use the standard project storm. Now, if option A is not possible, then we use the flood with a return period of 100 years, that is k corresponding to 100 years will be used, or C. It is C basically, C, whichever gives a higher value. So, out of these two, if we have both possible, then whichever gives a higher value will be adopted as the design flood. So, it is very clear that if it is major and medium projects where the storage is 60 million cubic meters, then we go for PMF or t equals to 1000 years. If the storage is less than 60 million cubic meters, then we go for SPF or t equals to 100 years, or whichever is higher. Then for other kinds of structures like pick up here, then flood with a return period of 100 or 500 years, depending on the importance of the project, that flexibility is given. In the case of aqueducts, if it is a waterway, then we use the flood with 50 years. For foundation and freeboard, we use the flood with 100 years. In projects with scant or inadequate data, suppose you are designing a structure where you do not have the available flow data or PMF or SPF, then we can even use empirical formulas. Of course, then you can say that the size of this structure is relatively small, that it does not endanger the lives or downstream area of the structure, and that is why we have this flexibility of using the empirical formulas. So, these are the guidelines for selecting the design flood given by the CWC.

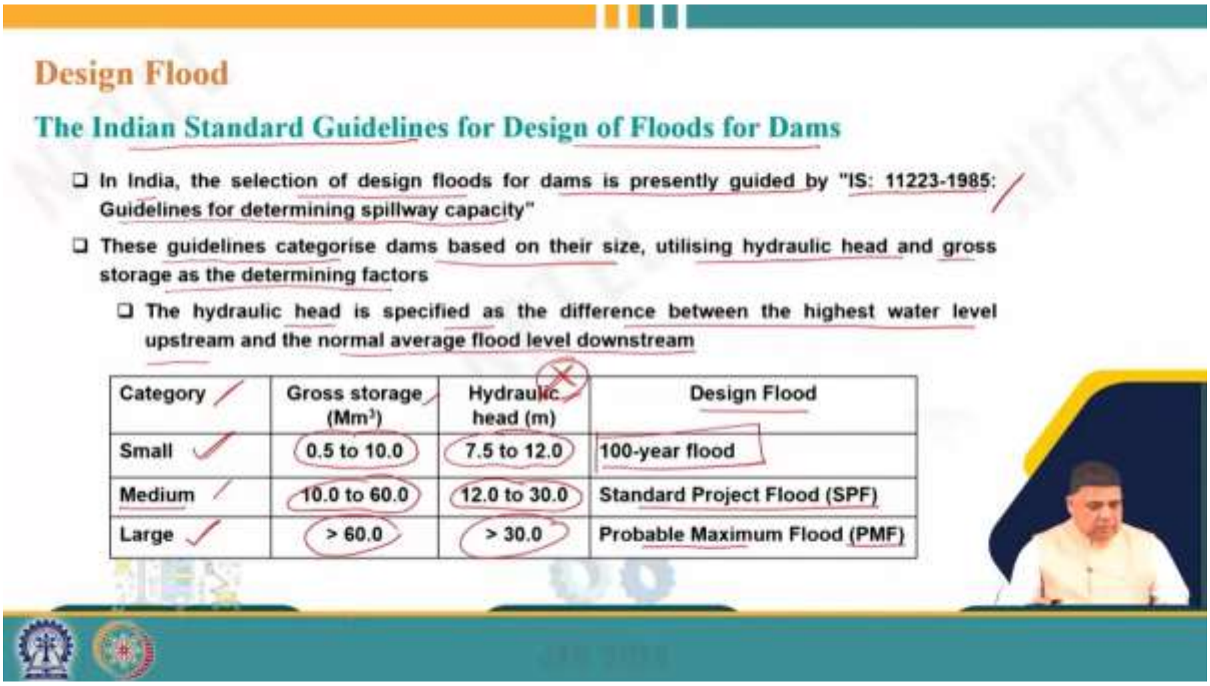


Design Flood

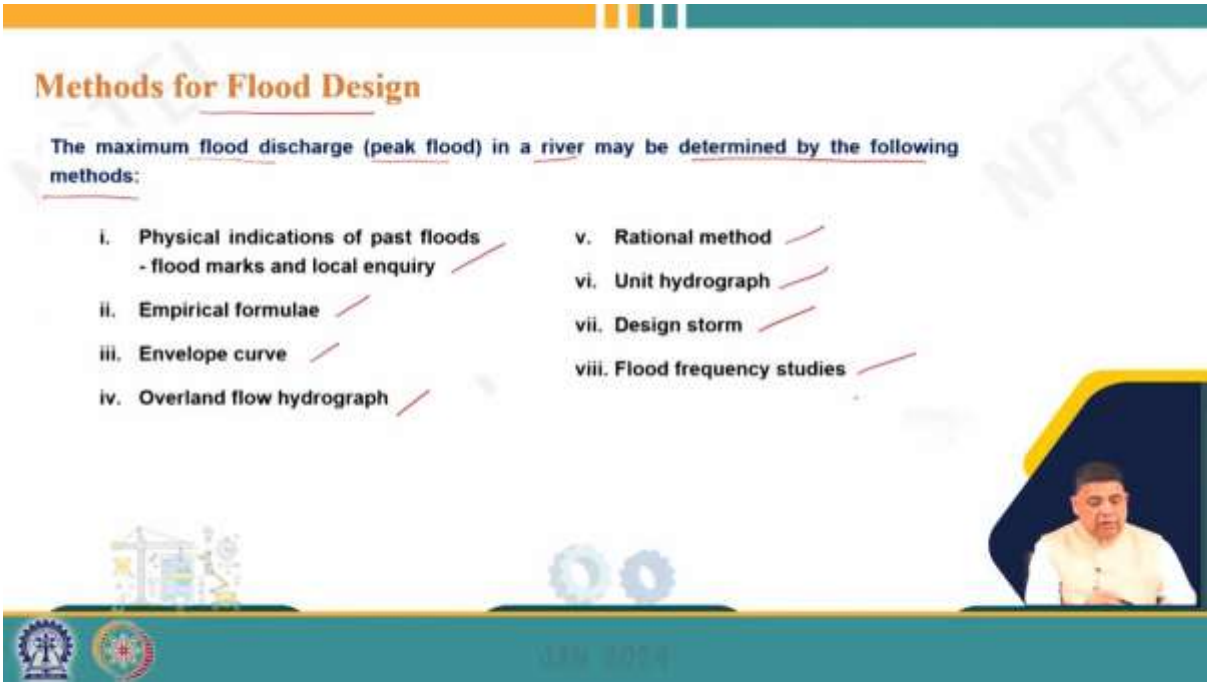
Guidelines for Selecting Design Flood (CWC, India)

S. No.	Structure	Recommended design flood
1.	Spillways for major and medium projects with storages more than 60 Mm³	(a) PMF determined by unit hydrograph and probable maximum precipitation (PMP) (b) If (a) is not applicable or possible, flood frequency method with T = 1000 year
2.	Permanent barrage and minor dams with capacity less than 60 Mm³	(a) SPF determined by unit hydrograph and standard project storm (SP), which is usually the largest recorded storm in the region (b) Flood with a return period of 100 years; (a) or (b) whichever gives a higher value
3.	Pickup weirs	Flood with a return period of 100 or 500 years depending on the importance of the project
4.	Aqueducts (a) Waterway (b) Foundations and freeboard (c) Project with scanty or inadequate data	 Flood with T = 50 years Flood with T = 100 years Empirical formulae

Now, there are also some Indian standard guidelines for the design of floods of dams. In India, the selection of design floods for dams is presently guided by Indian Standard 11223-1985, titled "Guidelines for determining spillway capacity." So, this IS standard is what we need to use for the design of floods. These guidelines categorize dams based on their size, utilizing hydraulic head and gross storage as determining factors. So, both head and gross storage are taken as determining factors here. The hydraulic head is specified as the difference between the highest water level upstream and the normal average flood level downstream. This is how you decide the hydraulic head, and the category of the structures could be small, medium, or large. Of course, the gross storage and hydraulic head also vary, as does the design flood. So, if it is a small structure where the gross storage is between 0.5 and 10 million cubic meters and the hydraulic head is between 7.5 and 12 meters, then we use the 100-year flood, meaning we calculate t equals to 100 flood for t equals 100 years. If it is a medium category structure where the gross storage is between 10 to 60 million cubic meters and the hydraulic head is 12 to 30 meters, then we use SPF. If it is a large structure where it is greater than 60 million cubic meters and the hydraulic head is greater than 30 meters, then we use the probable maximum flood (PMF). So, this is the IS guideline. If you compare the CWC recommendations and the IS recommendations, then we find that in the CWC recommendation, only the hydraulic head is missing, but otherwise, more or less things are the same; only the hydraulic head is not specified. In that case, it only goes by gross storage. So, that is the only difference; otherwise, both of them are almost similar.



Then comes the method for flood design. The maximum flood discharge or peak flood in a river may be determined by the following methods. There are several methods available: the first one is physical indications of past floods, such as flood marks or local inquiry; the second is empirical formulas; the third is envelope curve; the fourth is overland flow hydrograph; the fifth is the rational method; the sixth is the unit hydrograph method; the seventh is by design storm, and lastly, flood frequency study. So, all these methods are possible for designing a flood, and let us take a few of them one after the other.



So, let us talk about the first one, the simplest one, that is physical indications of past floods, like flood marks and local inquiry. So, obviously, in this case, as the name itself suggests, we take note of the flood marks as well as based on the local inquiries, depths, and fluxes, that is, the heightening of water at bridge openings and other factors actually at an existing bridge or on the weir in the neighbourhood. So, if we have an existing bridge or a weir, then obviously, there will be, if there are past floods, typically flood marks there. So, we go by the marks or we ask the local people about what was the depth they saw last time, what was the flow they expected, I mean the kind of flood they expected, and similar other information we generally inquire, and then the maximum flood discharge can be calculated using Manning's or Chezy's equation. So, obviously, if we know the head, then obviously, we estimate A, P, R, and S. For example, if I have to use Manning's equation, then we have to have

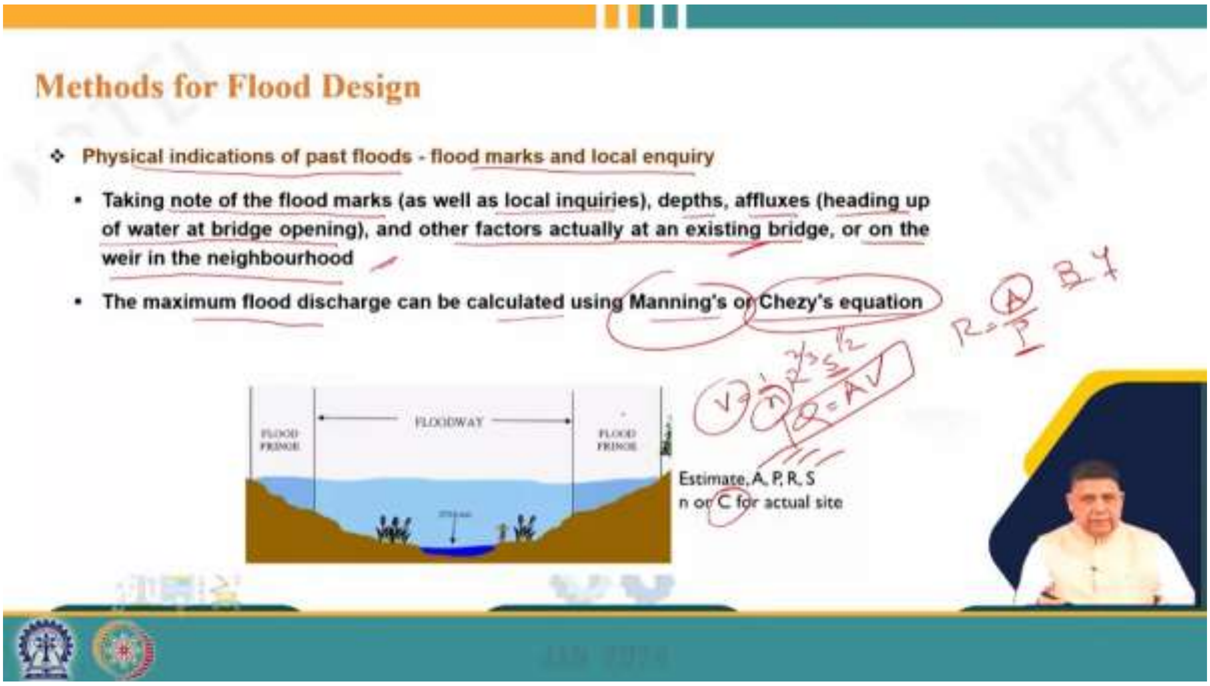
$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

$$\text{or, } Q = AV$$

that is what we know. So, obviously, then you have to use Manning's equation, Manning's roughness coefficient. You know the hydraulic radius R is A divided by P.

$$R = \frac{A}{P}$$

So, obviously, for calculating A, you need B and Y, the base width and the depth, also the type of cross-section that is being used. P is the weighted perimeter, and S is the bed slope. So, all this information we require, and then, I mean, based on the information, we can calculate A, P, R, S, and then we calculate the discharge Q equals to AV. So, we can use either Manning's equation or we can also use Chezy's equation where CC is the Chezy's coefficient. So, we can use any of the methods provided. So, basically, we get the idea of the head that the structure is likely to handle, and then we decide all other things based on that information.



Then, of course, we have several empirical formulas that are different, which are popular in India, and some of these we have already discussed while discussing runoff, like the Dickens formula

$$Q_P = C_D A^{3/4}$$

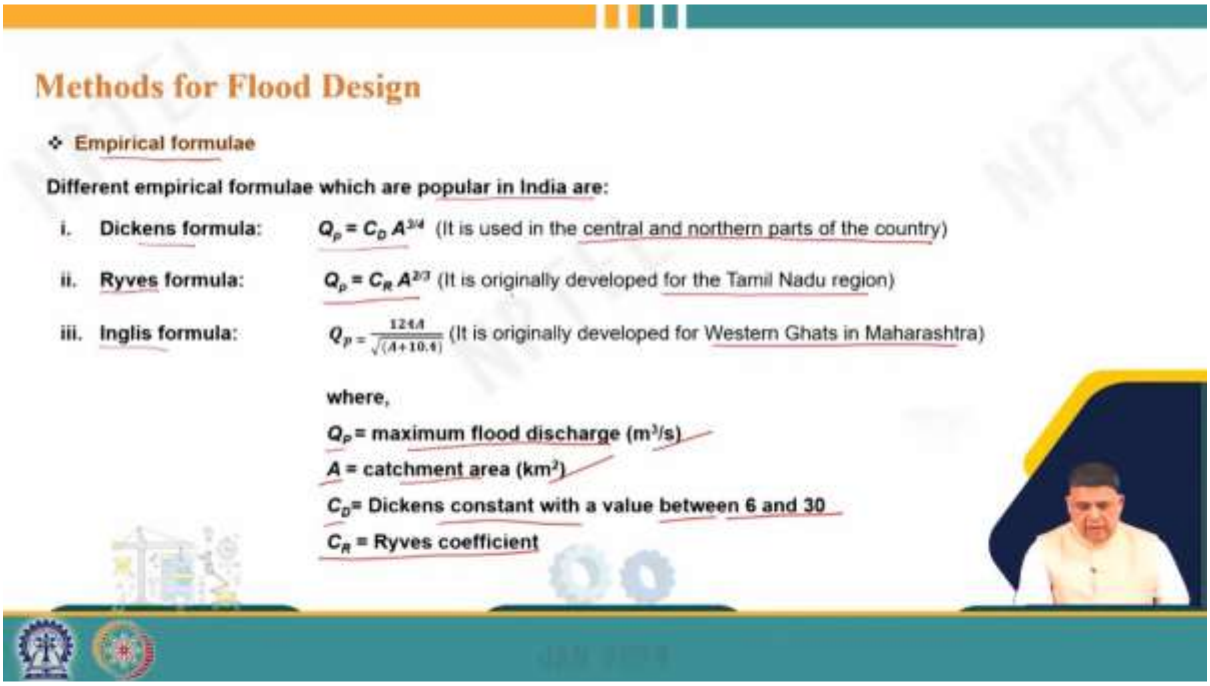
it is used in the central and northern parts of the country. Reeves formula, which is

$$Q_P = C_R A^{2/3}$$

originally developed for the Tamil Nadu region. English formula, which is

$$Q_P = \frac{124A}{\sqrt{(A + 10.4)}}$$

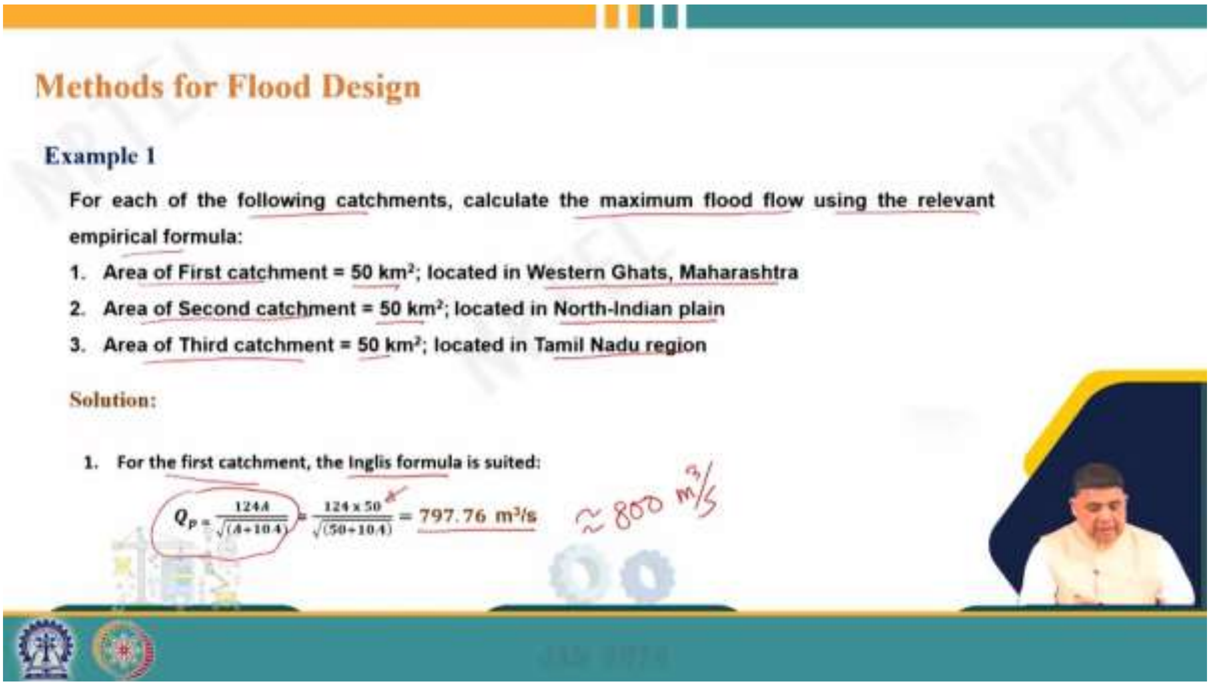
originally developed for the Western Ghats in Maharashtra. So, depending upon the region we are talking about, we can decide which formula to use, and then we can find out the peak discharge where Q_P is the maximum flood discharge in cubic meters per second, and A is the catchment area in square kilometres because these are empirical formulas. So, obviously, we have to be careful about the units. C_D is the Dickens constant with a value between 6 and 30, and C_R is the Reeves constant coefficient. So, these are the formulas which can be adopted for different parts of the country, depending on where your project lies, actually.



Let us take an example here: for each of the following catchments, calculate the maximum flood flow using the relevant empirical formula. The area of the first catchment is 50 square kilometres located in the Western Ghats, Maharashtra. The area of the second catchment is again 50 square kilometres and is located in the North Indian plain. The area of the third catchment is again 50 square kilometres located in the Tamil Nadu region. So, obviously, for the same area, the same size of the catchment, the example tries to demonstrate what happens or how the flow will change if we use any of the three formulas depending upon the region we are working in. So, obviously, for the first catchment in the Western Ghats, Maharashtra, we have to use the English formula, which was just now we saw is given by

$$Q_P = \frac{124A}{\sqrt{(A + 10.4)}}$$

So, obviously, we know the value of A is 50. So, we have to put the value of 50, and here we get a discharge magnitude of 797, or almost 800, cubic meters per second for this Western Ghats, Maharashtra, for a 50-square-kilometer catchment.



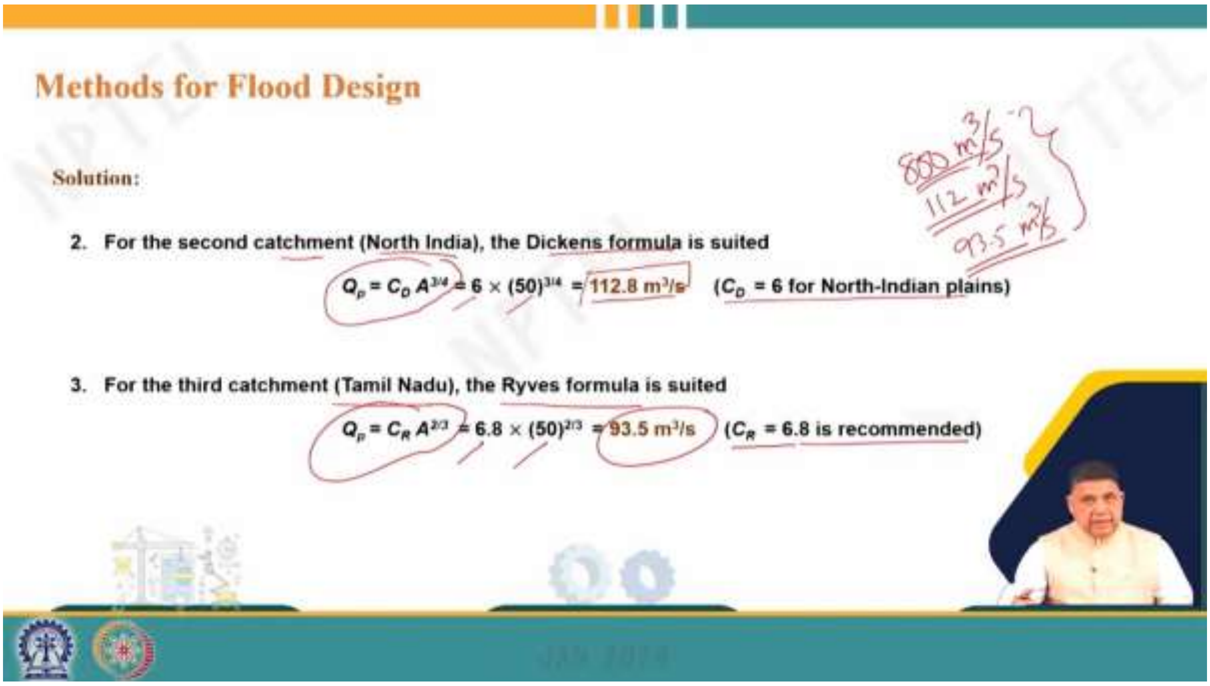
If we take the second catchment, which is in North India, where we will be using Dickens' formula, and the formula is

$$Q_P = C_D A^{3/4}$$

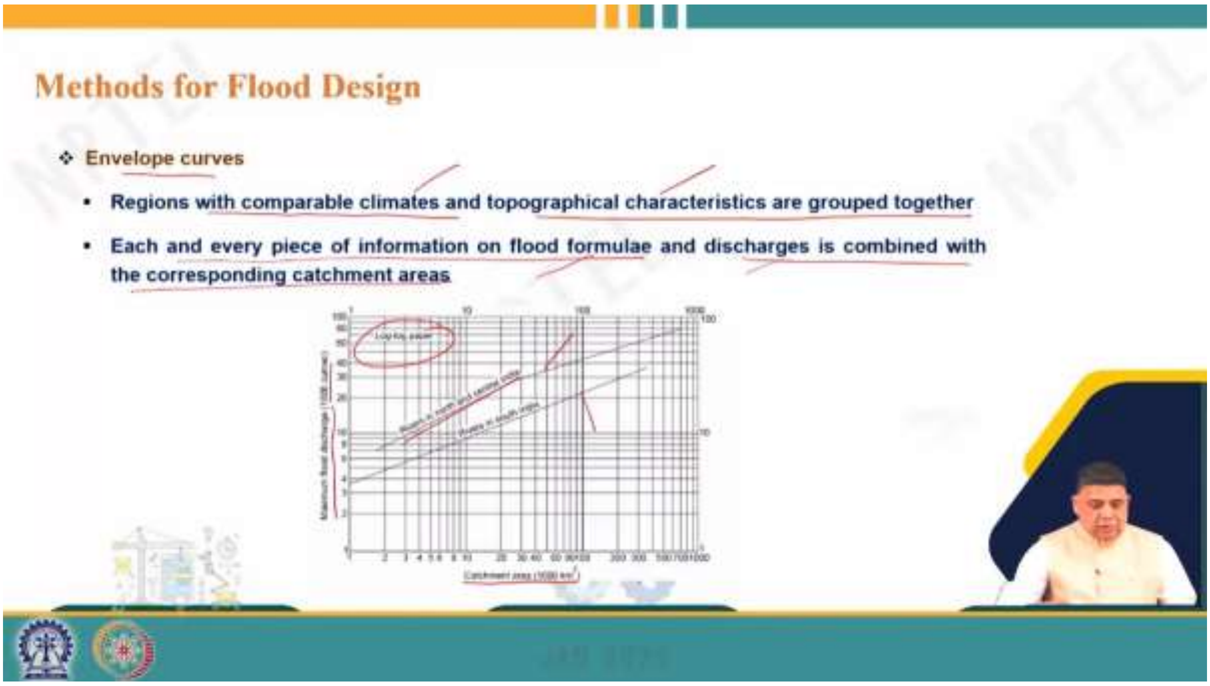
and for the North Indian plains, a C_D value of 6 is recommended. So, putting 6 and A equals to 50, we get a very low value of 112, so 113. So, the first one gave us 800 cubic meters per second, and now we are getting 112 cubic meters per second when we use Dickens' formula for Northern India. And the third catchment, which is in Tamil Nadu, which is you choose a huge formula,

$$Q_P = C_R A^{2/3}$$

we have to use this equation and a C_R value of 6.8 is typically recommended. So, putting the C_R value and A value, we get 93.5 cubic million meters per second. So, the third method gives us 93.5 or 94 cubic meters per second. So, you can see that depending upon where your study area is or which formula you are using, the magnitude Q could be drastically different, 94 to 112 to 800. So, obviously, your design structure design will also change accordingly. So, one has to be really careful in applying any of the formulas, and you have to ensure that that particular formula is applicable for a particular area or not, then only you can utilize the method.



Then, of course, we can go for envelope curves, that is, regions with comparable climates and topographic characteristics are grouped together, and each and every piece of information on flood formula and discharges combined with the corresponding catchment area. So, obviously, you can see here it is a maximum flood discharge in 1000 cubic meters per second, and this is the catchment area in 1000 square kilometres. Based on all the information you can gather about the comparable climates or topographical features or the formulas adopted or the discharge values which are available, we can have developed the envelope curves, and as you can see here, two curves are shown here: rivers in North and Central India, the top curve will be here, and rivers in South India, the bottom curve will be applicable. So, and say on log paper. So, one can really read the values if you do not have data available with you.

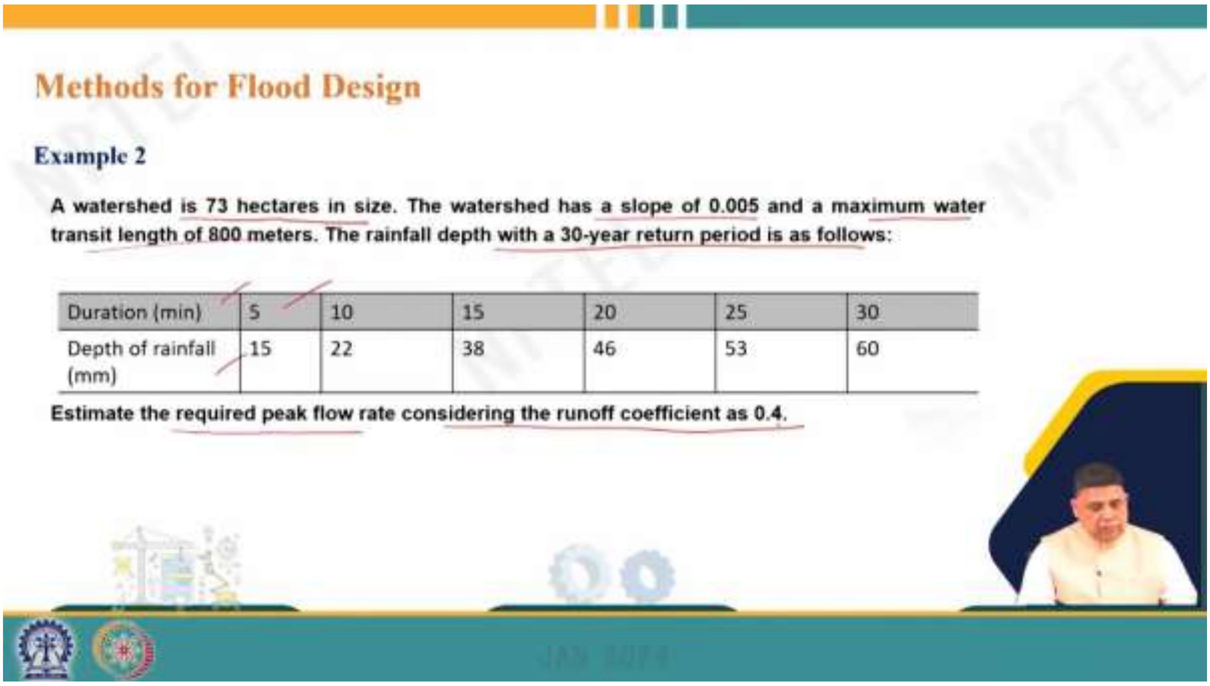


Then the next method is the rational method, which is

$$Q_p = CiA$$

which we have discussed in great detail earlier, you know, in our discussion on runoff, and where we know that Q_p is the peak discharge in cubic meters per second, C is the runoff coefficient, i is the mean intensity of precipitation for duration equal to the time of concentration t_c, and A is the catchment area in square meters. So, putting the values, we can find out what is the flood design or peak discharge.

And we will just take an example on this so that the method is refreshed in your mind. So, a watershed is 73 hectares in size, it has a slope of 0.05, and a maximum water transit length of 800 meters. Rainfall depth with a 30-year return period is given here, that is, for different durations, we have the depth of rainfall given here. Estimate the required peak flow rate considering the runoff coefficient is 0.4.



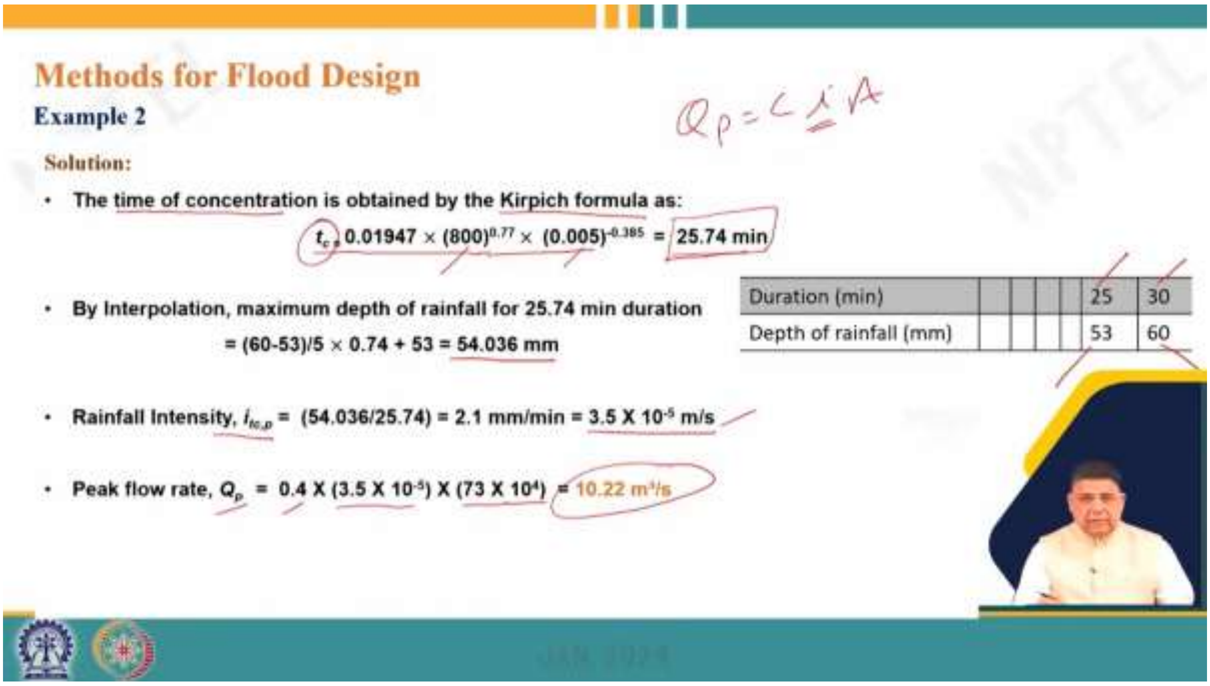
So, obviously, it is a fit case of using the rational formula, and this the first thing we know that in this method we have to determine the time of concentration, and for that, we read Kirpich formula which is

$$t_c = 0.01947 \times L^{0.77} \times S^{-0.385}$$

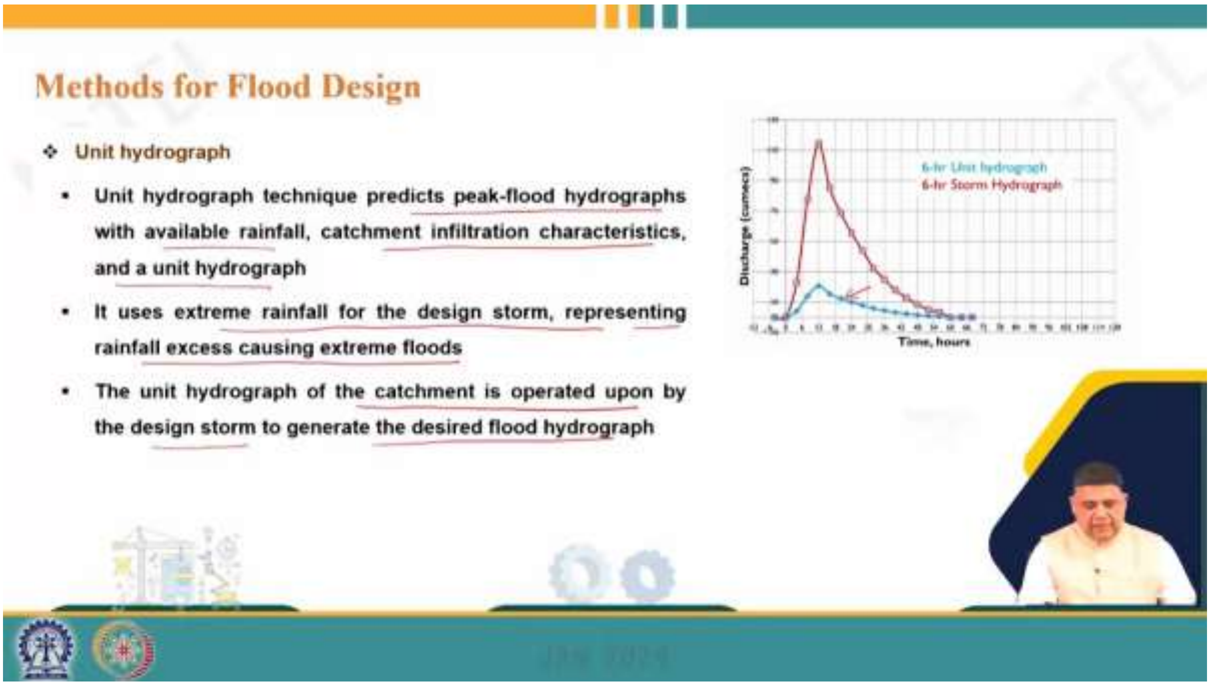
So, putting the value of L and S, we can calculate t_c, which comes out to be 25.74 minutes. And we know that the intensity of rainfall has to be taken.

$$Q_p = CiA$$

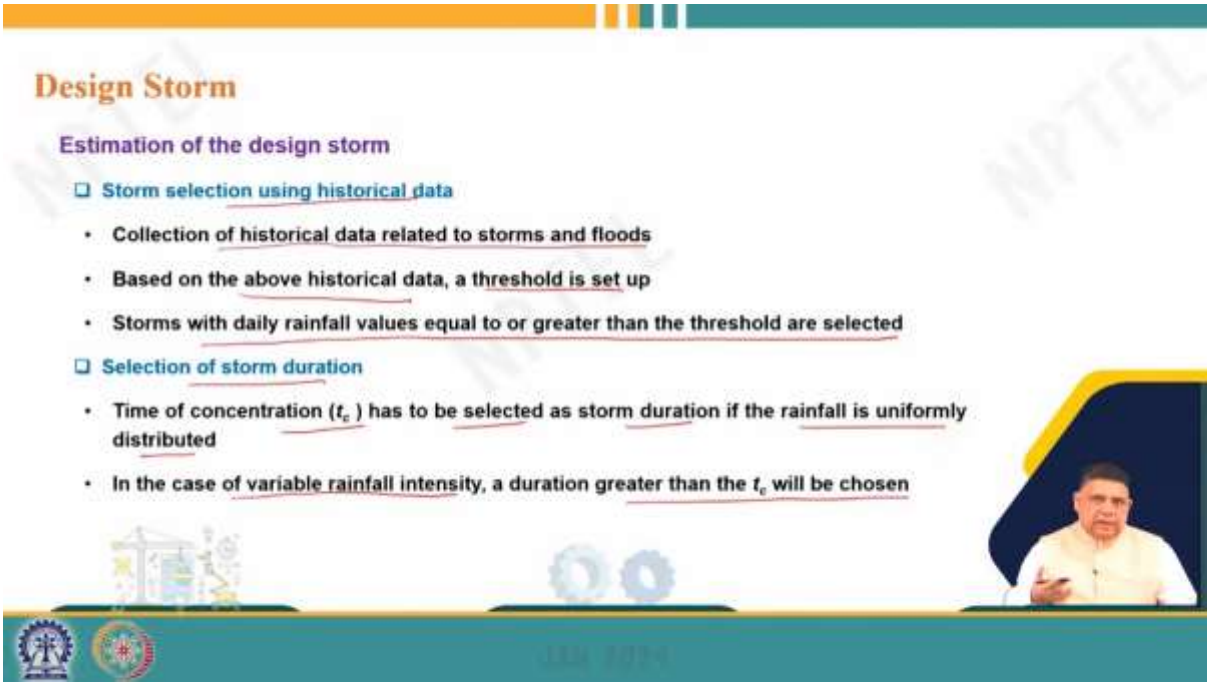
And in that, this intensity has to be taken corresponding to the time of concentration, and that is where we have to use the information given on the depth of rainfall. So, we have to interpolate the value for the desired. So, we are given values for 25 and 30 minutes and rainfall values of 53 mm and 60 mm. So, for 25.74 mm, we need to interpolate, and if you do that, we will get a value of 54.036 millimetres. So, that is the depth of rainfall corresponding to 25.74 minutes of time of concentration. So, obviously, we can convert that into intensity. So, 54.036 divided by the time into 60, of course, so, it gives us 3.5 into 10 to the power minus 5 meters per second. So, obviously, it is in millimetres. So, we have to convert the units; we want in meters per second, that is the unit we will be using here. And so, the peak runoff rate is Q_p, 0.4 C value is given as 0.4. Intensity we have calculated, and the catchment area is 73 hectares or 73 times 10 to the power 4 square meters. So, the Q_p value we get is 10.22 cubic meters per second. So, from using the rational method for this particular catchment, we get a peak discharge of 10.22 cubic meters per second.



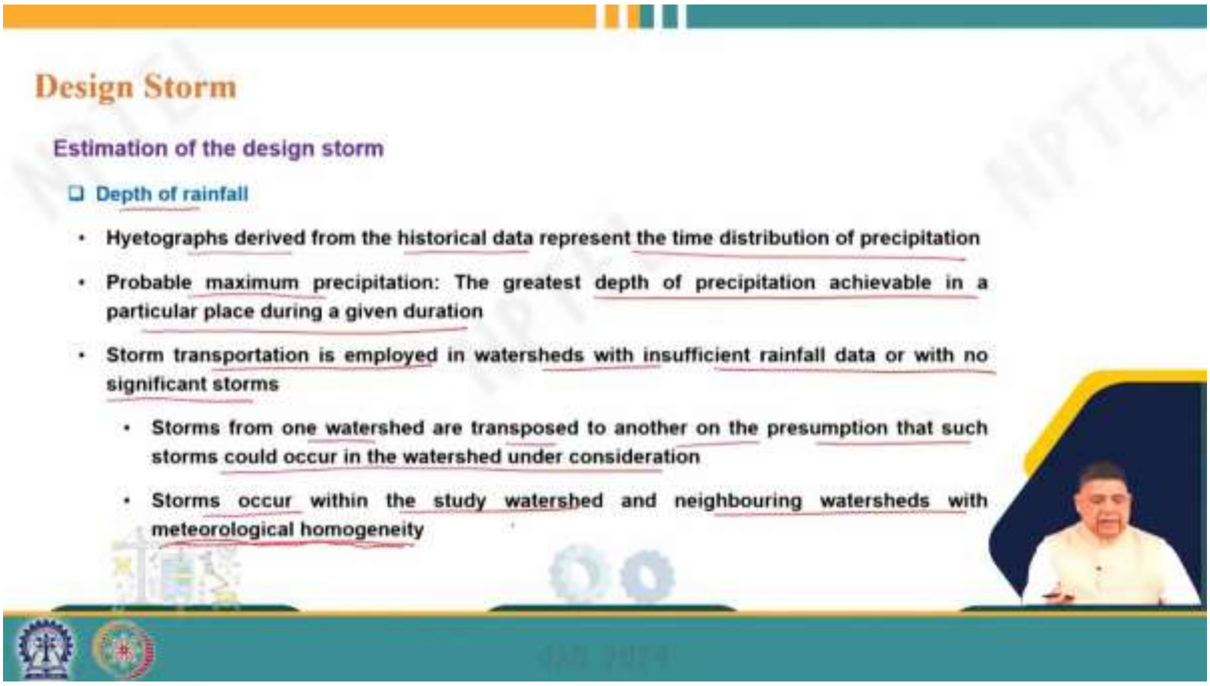
Now, we go to the next method, which is the unit hydrograph method. This method also we have discussed in great detail in hydrographs. So, it predicts a peak flood hydrograph with available rainfall catchment infiltration capacity and unit hydrograph. So, you have to have a unit hydrograph and you have to have effective rainfall magnitude. That means, for that, you have to have the rainfall data as well as the losses data, at least infiltration characteristics. And then we can multiply with the magnitude of rainfall to the unit hydrograph because the unit hydrograph is one unit depth of effective rainfall. So, if I know that I have 5 centimetres of effective rainfall, then I can get the peak discharge for the event. And, of course, it uses extreme rainfall for the design storm representing rainfall excess causing extreme methods. And if you remember, while discussing the CWC recommendation, it was mentioning all the time that PMF or SPF will be using the unit hydrograph method with PMP or that is probable maximum precipitation or standard precipitation. That was also mentioned. So, that is what it is trying to say. The unit hydrograph catchment is operated upon by the design storm to generate the desired flood hydrograph.



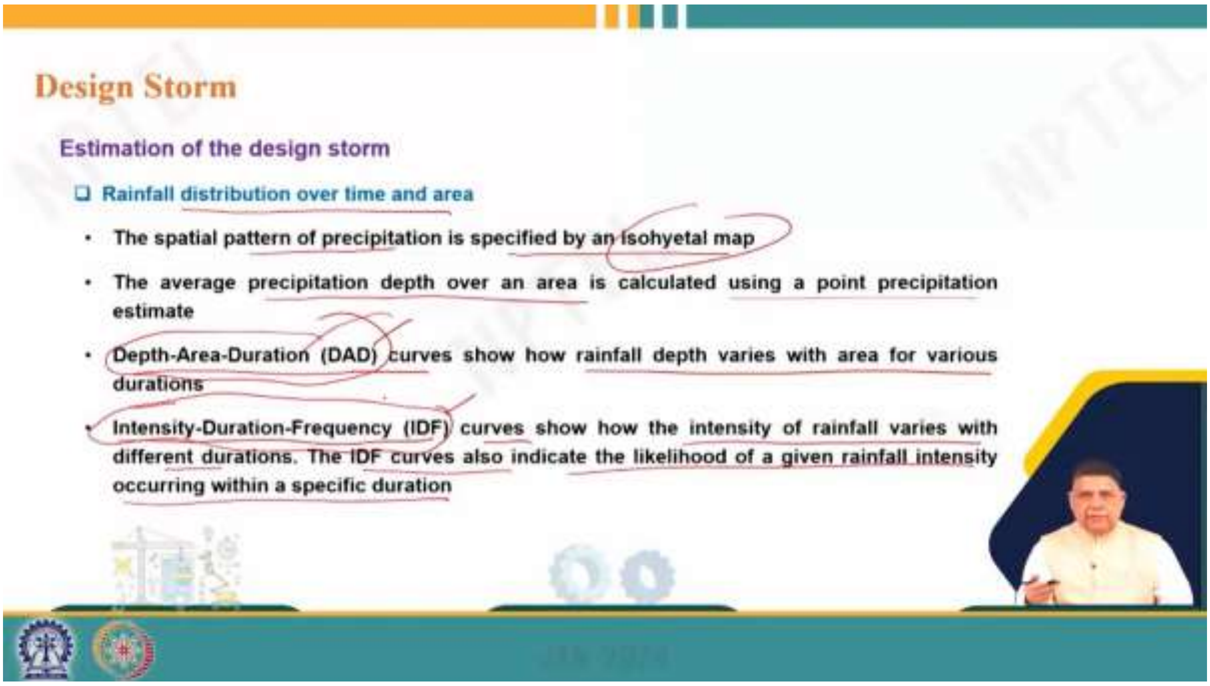
So, already we have discussed this in great detail. Now, we go to the design storm. Design storm, basically to estimate the design flood for a project by the use of unit hydrograph, we need a design storm. And this can be a storm producing probable maximum precipitation PMP for deriving probable maximum flood or a standard project storm for standard project flood calculation. And, of course, we know the difference between PMP and PMF and SPF. So, obviously, corresponding we can understand what will be the difference between PMP and SPF. And estimation of design storm, basically it includes storm selection using historical data, selection of storm duration, depth of rainfall, and rainfall distribution pattern over time and area. So, all this information is required for estimating the design storm. Now, coming to storm selection using historical data, the steps. So, obviously, collection of historical data related to storms and floods has to be done. And based on the above historical data, a threshold is set up. That means, for what kind of design again we are doing, based on that we will be setting up the threshold. And storms with daily rainfall value equal to or greater than the threshold are then chosen for analysis. Then selection of storm duration, the time of concentration has to be selected as a storm duration if the rainfall is uniformly distributed over the basin. And in the case of variable rainfall intensity, a duration greater than t_c will be chosen. So, obviously, depending upon the nature or distribution of rainfall over the spatial distribution of rainfall over the basin, we will choose at least t_c or greater than t_c duration that we have to make a decision.



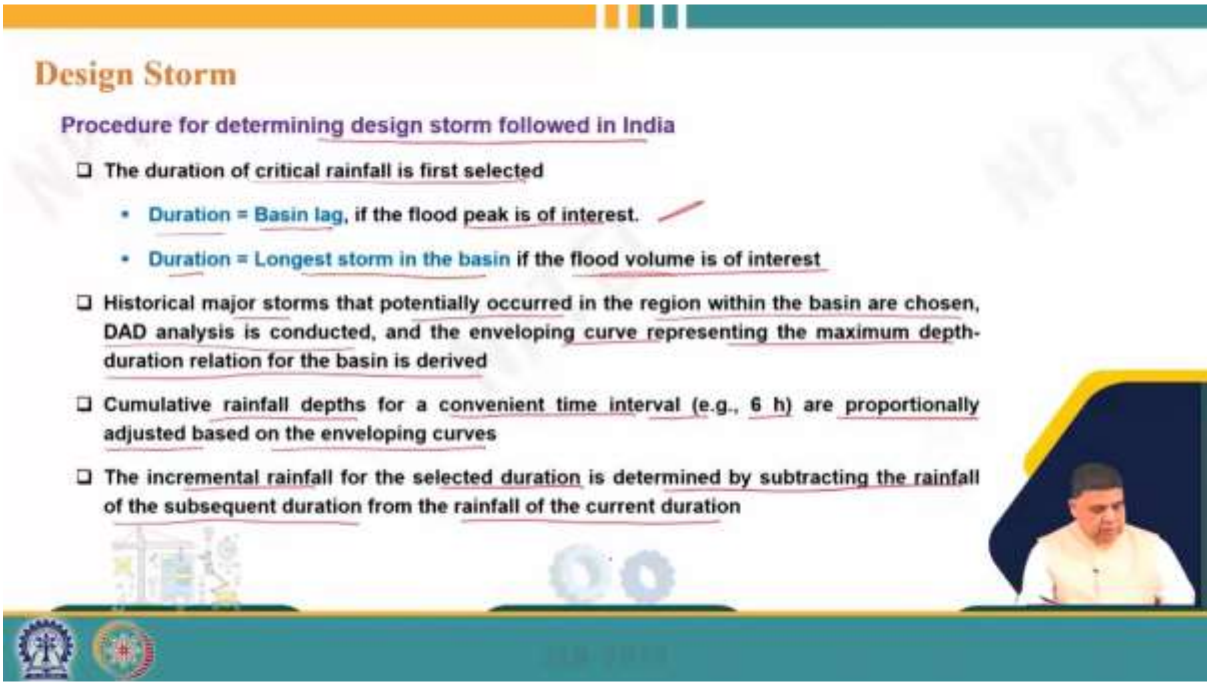
Then comes the depth of rainfall, then hydrographs derived from the historical data represent the time distribution of precipitation. Probable maximum precipitation is the greatest depth of precipitation achievable in a particular place during a given duration. So, that is, I mean, the rarest of rare values will also be used. And storm transposition is employed in watersheds with insufficient rainfall data with no significant storms. So, obviously, if you do not have data available with you, then also you have to take data from the neighbouring stations, neighbouring catchments within the hydrologically homogeneous region, and then you can use the data. So, storms from one watershed are transposed to another on the presumption that such storms could occur in the watershed under consideration. Storms occur within the study watershed and neighbouring watershed with meteorological homogeneity. So, the hydrological or meteorological homogeneity has to be assumed, and data can be transported.



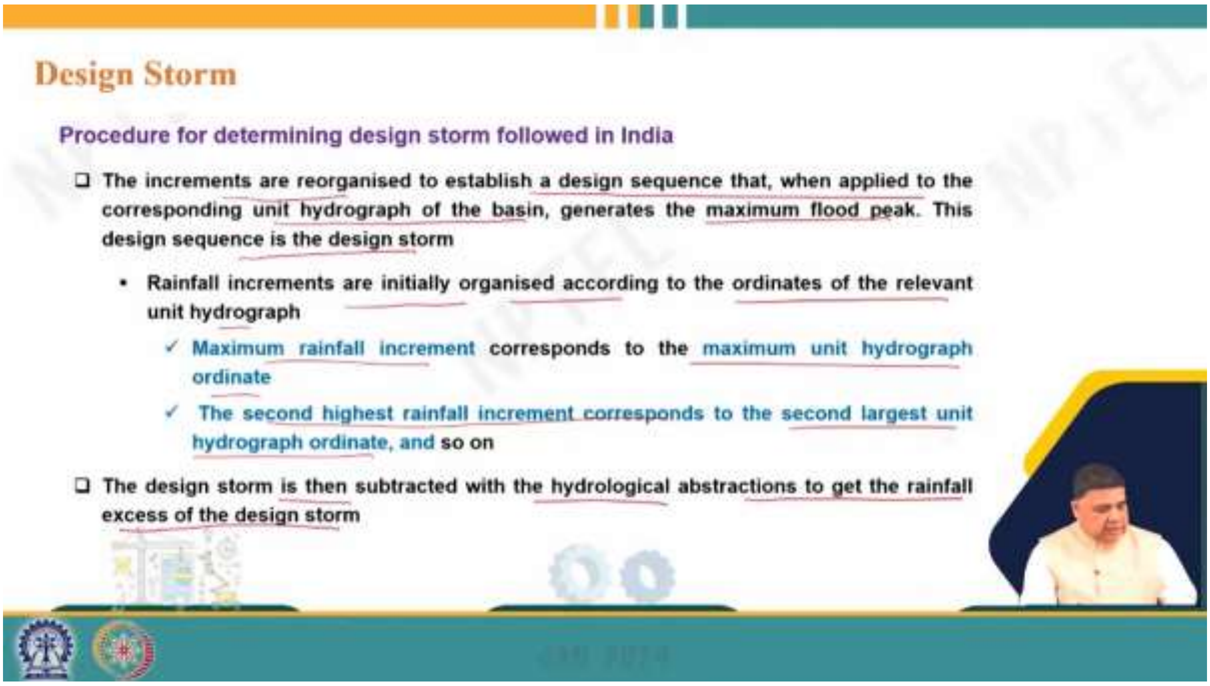
Then rainfall distribution over time and area, the spatial pattern of precipitation is specified by isohyetal map. The average precipitation depth over an area is calculated using the point precipitation estimate. So, here depth area duration curves can be used, which show how rainfall depth varies with area for various durations. Similarly, intensity duration frequency curves can be used, which show how the intensity of rainfall varies with different durations. And the IDF curves also indicate the likelihood of a given rainfall intensity occurring within a specified duration. So, of course, DAD, IDF, all those, and hydrograph, isohyetal map, all these terminologies if you remember, we have all discussed in great detail while discussing rainfall frequency or runoff. So, all these terms are recurring here in the case of flood because things remain more or less the same.



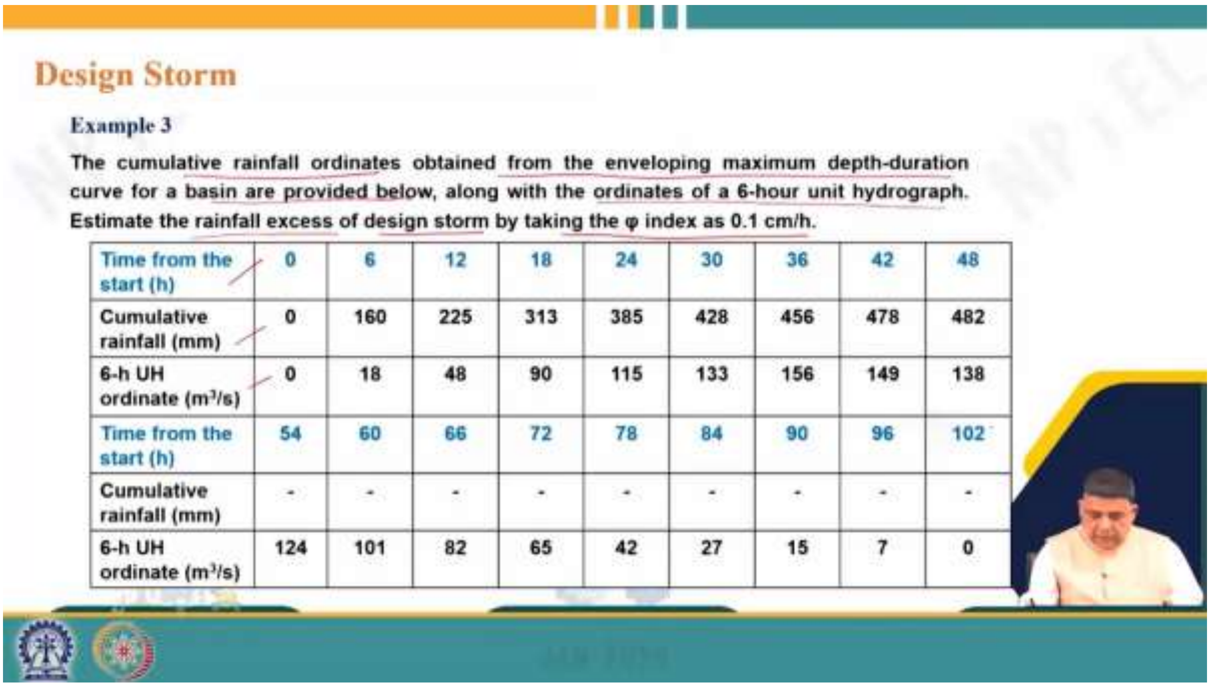
Now, coming to the procedure followed for determining design storm in India. So, the duration of the critical rainfall is first selected, and the duration could be equal to basin lag if the flood peak is of interest, and it could be equal to the longest storm in the basin if the flood volume is of interest. So, depending upon what kind of a structure it is, whether if it is a discharge structure like a spillway, then obviously, you will be interested in peak flow that has to be taken away, or if it is a storage structure, then obviously, you will be interested in flood volume, then the longest storm of the basin has to be considered. Then historical major storms that potentially occurred in the region within the basin are chosen, DAD analysis is conducted, and the envelope curves representing a maximum depth-duration relation for the basin are derived. Cumulative rainfall depth for a convenient time interval, say 6 hours, are proportionally adjusted based on the envelope curve, and the inclement rainfall for the selected duration is determined by subtracting the rainfall of the subsequent duration from the rainfall of the current duration. So, obviously, you may have cumulative data, but you want data for a particular duration.



Then, increments are reorganized to establish a design sequence that, when applied to the corresponding unit hydrograph of the basin, generates the maximum flood peak. This design sequence is the design storm, and rainfall increments are initially organized according to ordinates of the relevant unit hydrograph. The maximum rainfall increment corresponds to the maximum unit hydrograph ordinate, the second-highest increment corresponds to the second-largest unit hydrograph, and so on. And the design storm is then subtracted with the hydraulic abstraction to get the rainfall excess of the design storm. We will take an example, and things will be clearer, probably.



The cumulative rainfall ordinates obtained from the envelope, being the maximum depth duration curve for a basin, are provided below along with ordinates of the 6-hour unit hydrograph. Estimate the rainfall excess of the design storm by taking 5 indexes as 0.1 centimetre per hour. So, obviously, here you have time from the start given and cumulative rainfall value has been given, which is obtained from the maximum depth duration curve, and the corresponding 6-hour unit hydrograph is also given. So, this data is provided.

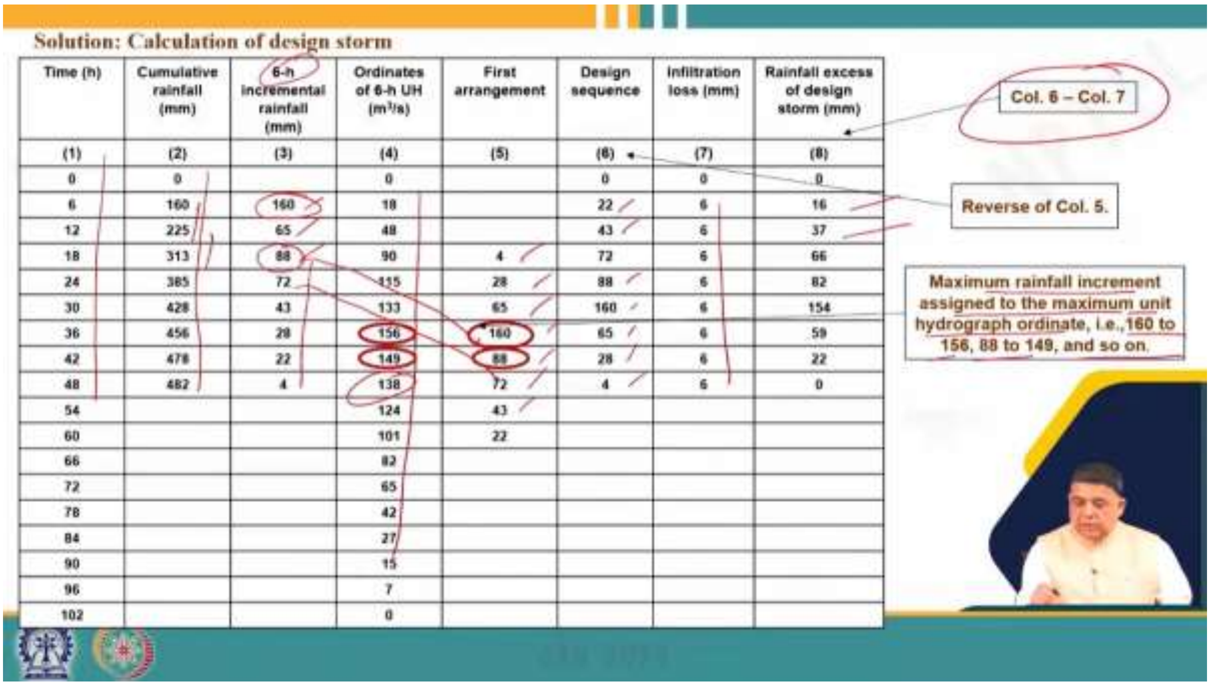

Design Storm

Example 3

The cumulative rainfall ordinates obtained from the enveloping maximum depth-duration curve for a basin are provided below, along with the ordinates of a 6-hour unit hydrograph. Estimate the rainfall excess of design storm by taking the φ index as 0.1 cm/h.

Time from the start (h)	0	6	12	18	24	30	36	42	48
Cumulative rainfall (mm)	0	160	225	313	385	428	456	478	482
6-h UH ordinate (m^3/s)	0	18	48	90	115	133	156	149	138
Time from the start (h)	54	60	66	72	78	84	90	96	102
Cumulative rainfall (mm)	-	-	-	-	-	-	-	-	-
6-h UH ordinate (m^3/s)	124	101	82	65	42	27	15	7	0

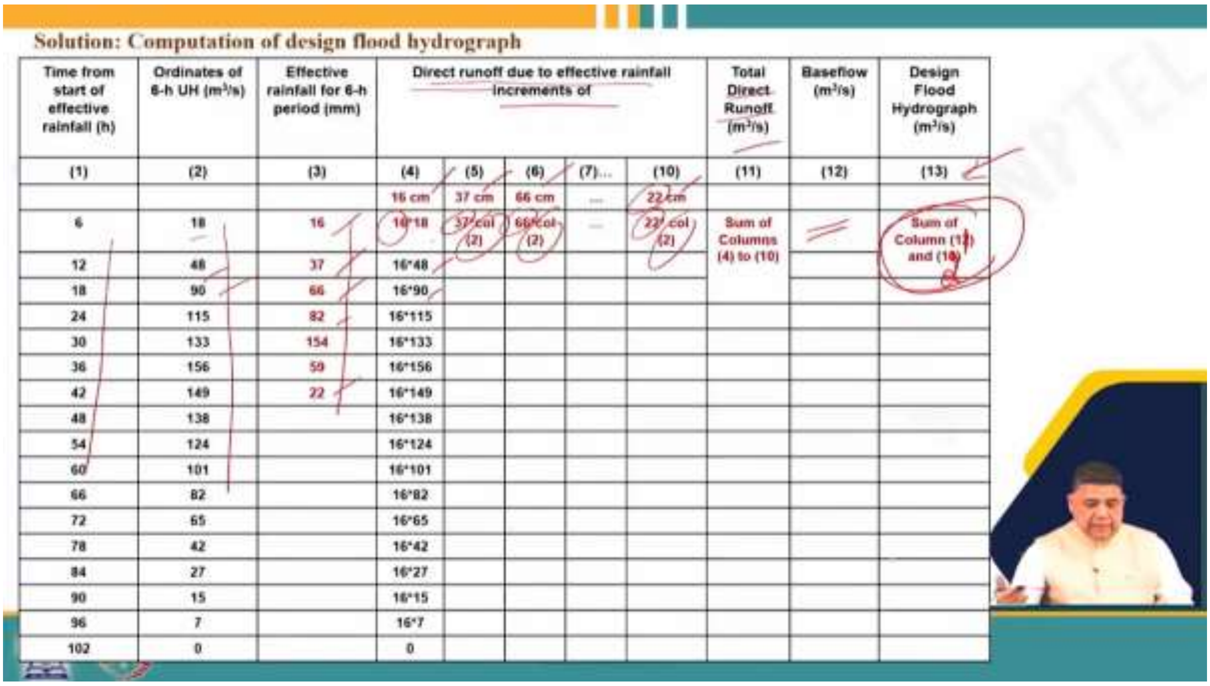
Now, we have to calculate the design storm. So, obviously, we have been given the cumulative rainfall value for over the duration, and we suppose we select 6-hour intervals. So, obviously, we have to have 6-hour incremental rainfall. For the first 6 hours, it is 160, for the second 6 hours it is 225 minus 160, which is 65, then 313 minus 225 is 88, and so on. Incremental rainfall will be obtained, and obviously, these are the ordinates of the unit hydrograph which are available to us. So, the first arrangement that we do is corresponding to the peak of the unit hydrograph. So, 156 is the peak that we match with the maximum incremental rainfall. So, 156 is matched to 160. Similarly, the next highest ordinate of the unit hydrograph is 149. So, the second-highest, 88, will be brought there. Similarly, the third-highest is 138. So, the third ordinate will be brought here. That is how it will be matched. So, the maximum rainfall increment assigned to the maximum unit hydrograph ordinate is 162, 156, 88 to 149, and so on. So, that is what we do. Then we have a design sequence where we will just use the reverse of this. So, 0, 22, 43, 72, 88, 160, 65, 28, and 4. And the infiltration loss value is given to us. So, we know the millimetre loss in millimetres. So, the rainfall excess of the design storm, we know that it is 22 minus 6, which is 16, 43 minus 6, which is 37, and so on. This is the rainfall excess of the design storm, that is column 6 minus column 7 we get here.



Solution: Calculation of design storm

Time (h)	Cumulative rainfall (mm)	6-h incremental rainfall (mm)	Ordinates of 6-h UH (m^3/s)	First arrangement	Design sequence	Infiltration loss (mm)	Rainfall excess of design storm (mm)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	0		0		0	0	0
6	160	160	18		22	6	16
12	225	65	48		43	6	37
18	313	88	90	4	72	6	66
24	385	72	115	28	88	6	82
30	428	43	133	65	160	6	154
36	456	28	156	160	65	6	59
42	478	22	149	88	28	6	22
48	482	4	138	72	4	6	0
54			124	43			
60			101	22			
66			82				
72			65				
78			42				
84			27				
90			15				
96			7				
102			0				

And then what we do is that we have this is the time, this is the UH ordinate, effective rainfall that we calculated in the last column there, the same is listed here: 16, 37, 66, 82, 16, 37, 66, 82. And then we calculate direct runoff due to effective rainfall increments. So, there will be many columns, the number of columns will be equal to the number of effective rainfall increments. So, we have 16. So, one column will be 37, the second column 66, the third column, and so on, and the last will be 22. And then for each column, we will calculate the direct runoff ordinate, which is a multiple of the UH ordinate and the effective rainfall ordinate. So, in this particular scenario, all these unit hydrograph values will be multiplied by 16. So, 16 times 18, 16 times 48, 16 times 90, and so on. The second column, that is column 5, will be 37 multiplied by column 2, then the sixth column will be 66 multiplied by column 2, and so on. And the last column, this is 22, is the effective rainfall. So, 22 times column 2. And then all these will be summed up; columns 4 to 10 will give us the total direct runoff, and then we will add the base flow value here to get the design flood hydrograph. So, this will give us the design flood hydrograph, the sum of these columns 11 and 12 will give us column 13 here. Column 11 and 12 together give us column 13, which is the design flood hydrograph, and that is what we will be using in our design.



Solution: Computation of design flood hydrograph

Time from start of effective rainfall (h)	Ordinates of 6-h UH (m^3/s)	Effective rainfall for 6-h period (mm)	Direct runoff due to effective rainfall increments of					Total Direct Runoff (m^3/s)	Baseflow (m^3/s)	Design Flood Hydrograph (m^3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)...	(10)	(11)	(12)	(13)
			16 cm	37 cm	66 cm	...	22 cm			
6	18	16	16*18	37*col (2)	66*col (2)	...	22*col (2)	Sum of Columns (4) to (10)		Sum of Column (11) and (12)
12	48	37	16*48							
18	90	66	16*90							
24	115	82	16*115							
30	133	154	16*133							
36	156	59	16*156							
42	149	22	16*149							
48	138		16*138							
54	124		16*124							
60	101		16*101							
66	82		16*82							
72	65		16*65							
78	42		16*42							
84	27		16*27							
90	15		16*15							
96	7		16*7							
102	0		0							

With this, we come to the end of this lecture where we have discussed the design flood, its significance, and the methods which can be used for deciding the design flood. We have also discussed the design storm and have seen the recommendations of the CWC as well as Indian standard recommendations for major structures. Thank you very much. Please give your feedback and feel free to raise any questions or doubts; we will be happy to answer them on the forum. Thank you very much.