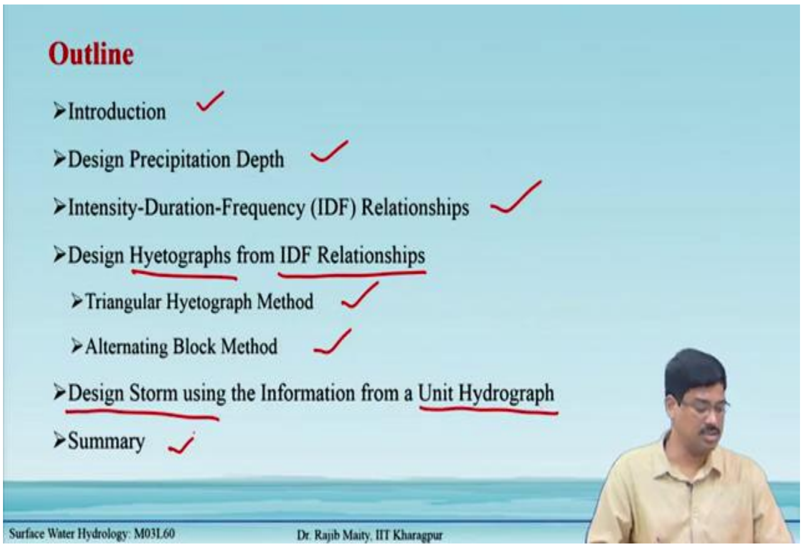
Surface Water Hydrology
Professor Rajib Maity
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 60
Design Storm

In this lecture, we will learn about the Design Storm that is utilized sometimes to develop the design flood.

(Refer Slide Time: 0:35)

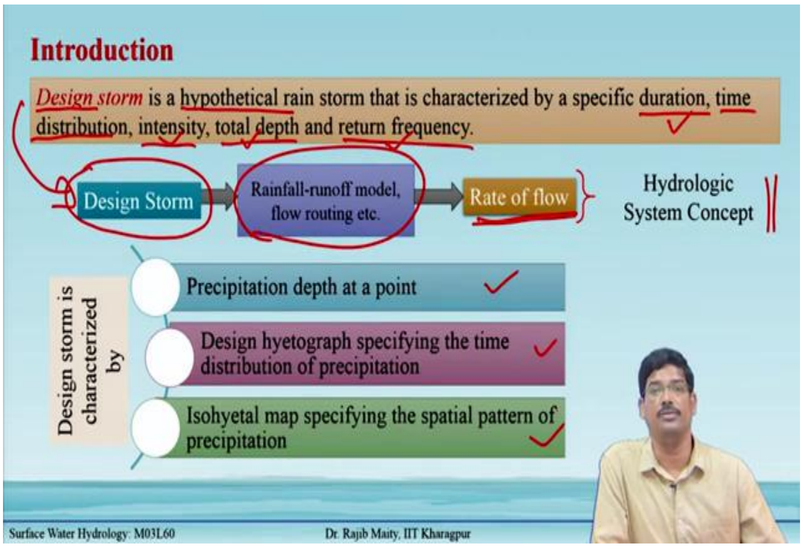
Under this concept covered, we will learn the concept of design storm and then there is some procedure for the development of design storm.

(Refer Slide Time: 0:45)



The outline of this lecture goes like this: first, we will give some basic introduction and then the design precipitation depth. But before that, the one theoretical discussion that we need to briefly recall is the relationship between intensity, duration and frequency. In total, we will learn three methods in this lecture. The first one is the triangular hyetograph method, then alternating block method and these two methods are related to the IDF relationship. There is also another method for the design storm that will utilize some information from the unit hyetograph. So, this is the third one to develop this design storm before we go to the summary of this lecture.

(Refer Slide Time: 2:14)



Introduction

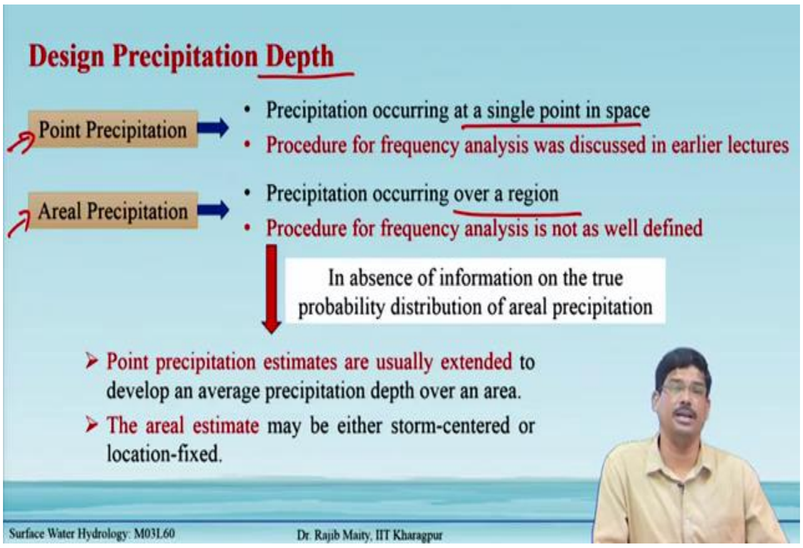
A design storm is a hypothetical rainstorm that is characterized by a specific duration, time distribution, intensity, total depth, and return frequency.

The design storm gives the time distribution, so time distribution is one of the major differences from that the earlier concept. The design storm we put into some models to get depending on that what we need to get out of that one. One typical example could be the rainfall-runoff model or the flow routing, etc. We need to get an output, i.e., the rate of the flow. Now, this rate of the flow provides the information on the peak flow or total duration of the flow or total flow volume.

Design storm is characterized by

- Precipitation depth at a point
- Design hyetograph specifying the time distribution of precipitation
- Isohyetal map specifying the spatial pattern of precipitation

(Refer Slide Time: 4:52)



Design Precipitation Depth

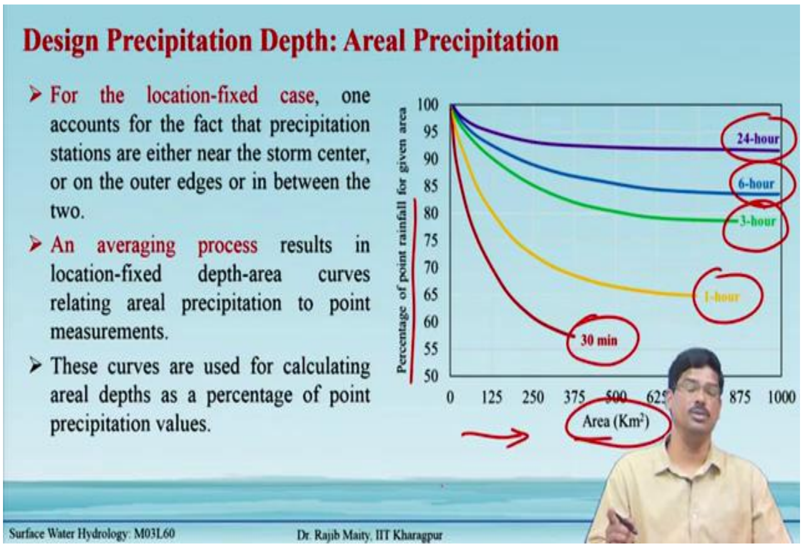
Point Precipitation

Precipitation occurs at a single point in the space and its procedure for the frequency analysis was discussed in the earlier lectures in the previous two, previous weeks when we are discussing the frequency analysis in detail.

Areal Precipitation

Aerial precipitation is the precipitation occurring over a region. The procedure for the frequency analysis is not very well defined for areal precipitation. However, the relationship between the point precipitation to the aerial precipitation can be developed. In the absence of the information on the aerial precipitation and we do not know what is the true probability distribution of the aerial precipitation. In that situation, the point precipitation estimates are usually extended to develop an average precipitation depth over an area and the aerial estimate may be either storm-cantered or location-fixed.

(Refer Slide Time: 6:00)



Design Precipitation Depth: Areal Precipitation

For the location-fixed case, one accounts for the fact that the precipitation stations are either near the storm centre or on the outer edge, or in between these two. Now, an averaging process that results in the location-specific depth area curves relating the aerial precipitation to the point measurement. These curves used for calculating the aerial depths as the percentage of the point precipitation values. Such typical plots are shown in fig.1.

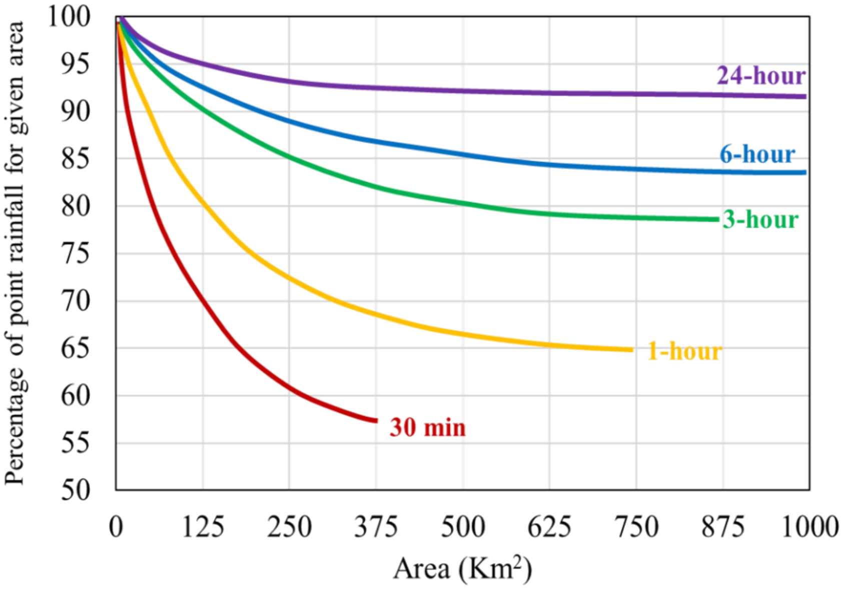
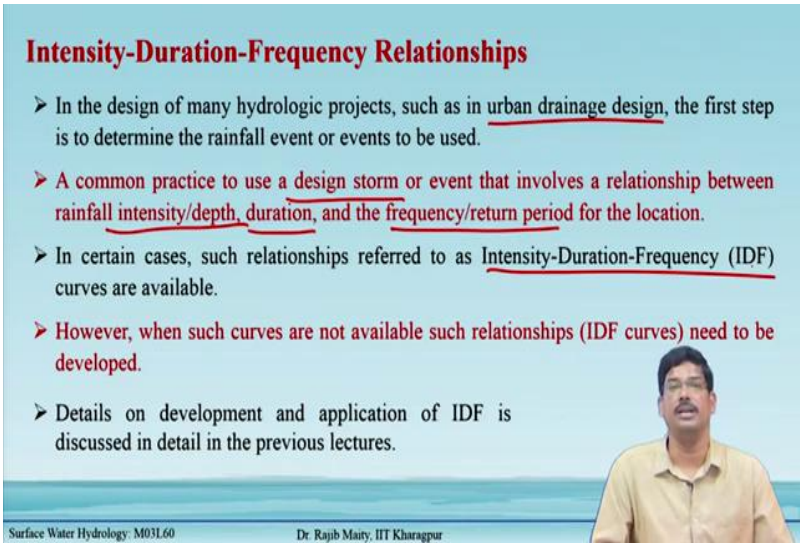


Figure 1: A typical DAD curves

In Fig. 1, you can notice that the x-axis is showing the area and y-axis shows the the percentage of the point rainfall for the given area. Different durations are shown in against different curves, such as 30 minutes or 1 hour or 3 hours 6 hours, 24 hours. The common thing is that these curves exponentially decrease as the area increases along this x-axis. So, we get some information from the point precipitation to the aerial precipitation.

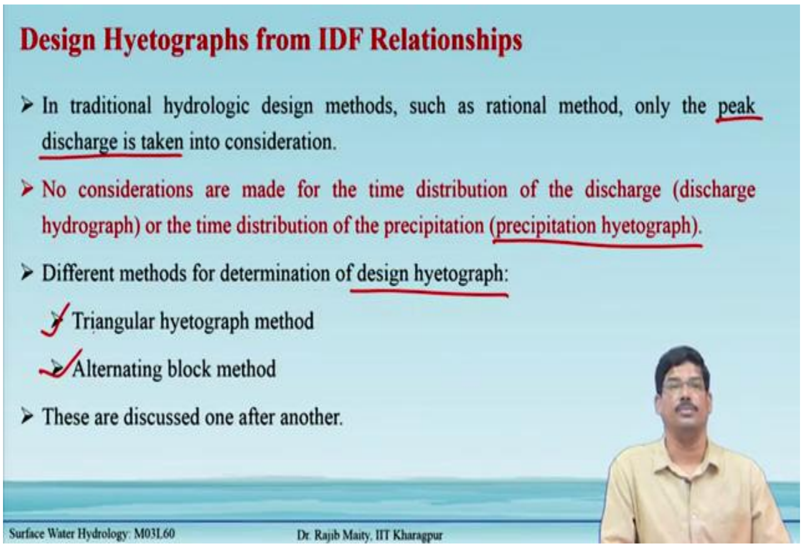
(Refer Slide Time: 7:12)



Intensity-Duration-Frequency Relationships

Now, coming to the IDF relationship, i.e., the Intensity Duration and Frequency relationship for the storm for a particular region. In the design of the many hydrologic projects, such as the urban drainage design, the first step is to determine the rainfall event or the events to be utilized in the design. A common practice is to use the design storm or event that involves the relationship between the rainfall intensity, depth and duration, and frequency of the return period of that location. In certain cases, such a relationship of this IDF relationship is available, but in some other cases, it may not be available. In that case, that relationship needs to be developed and the details were was discussed in earlier lecture.

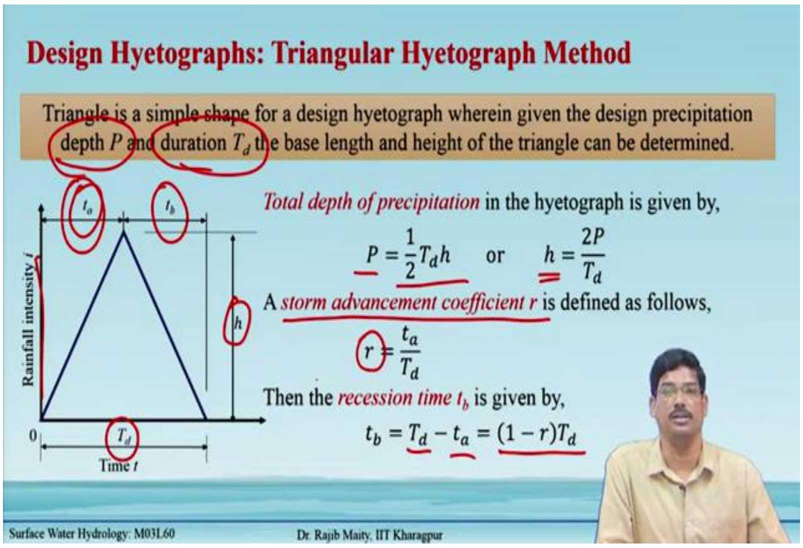
(Refer Slide Time: 8:44)



Design Hyetographs from IDF Relationships

In the traditional hydrologic design method, such as the rational method, this was also discussed earlier and as you know that only peak discharge is taken into consideration, No considerations are made for the time distribution of the discharge (discharge hydrograph) or the time distribution of the precipitation (precipitation hyetograph). There are two methods - one is the triangular hyetograph method and the other one is alternating block method. These two methods will be discussed one after another.

(Refer Slide Time: 9:42)



Design Hyetographs: Triangular Hyetograph Method

Triangle is a simple shape for a design hyetograph wherein given the design precipitation depth P and duration T_d the base length and height of the triangle can be determined.

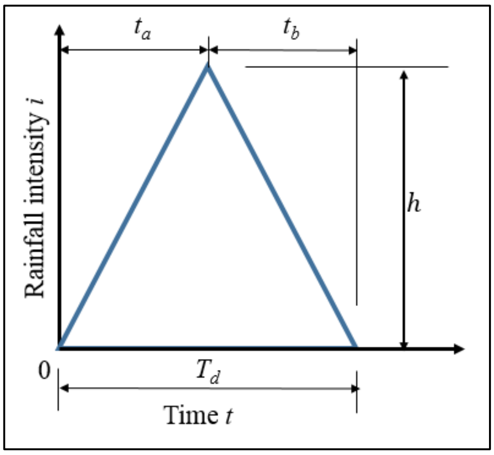


Figure 2: A typical triangular Hyetograph

The total depth of precipitation in the hyetograph is given by,

$$P = \frac{1}{2} T_d h \qquad \text{or} \qquad h = \frac{2P}{T_d}$$

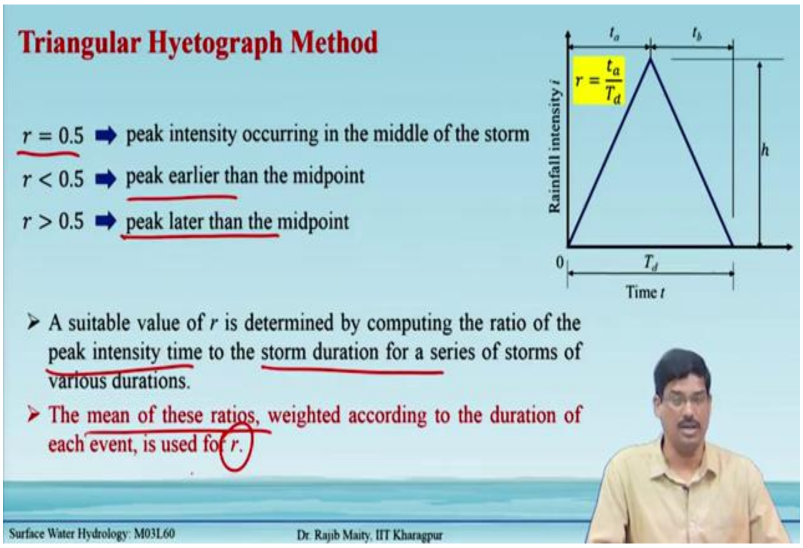
A storm advancement coefficient r is defined as follows,

$$r = \frac{t_a}{T_d}$$

Then the recession time t_b is given by,

$$t_b = T_d - t_a = (1 - r) T_d$$

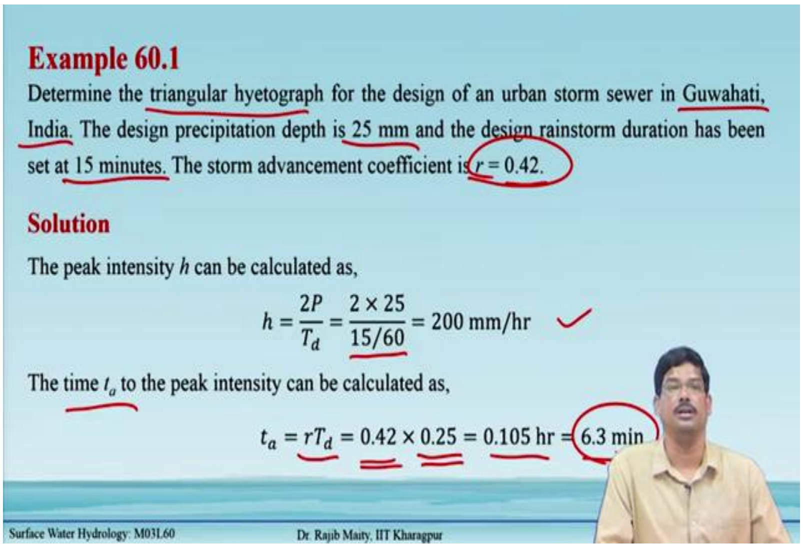
(Refer Slide Time: 11:26)



So, generally, r varies from 0 to 1. If r =0.5, the peak intensity occurs at the middle of the storm, and for r < 0.5, the peak occurs earlier than the midpoint, and for r > 0.5, the peak occurs after the midpoint of the total duration.

- ➢ A suitable value of *r* is determined by computing the ratio of the peak intensity time to the storm duration for a series of storms of various durations.
- ➢ The mean of these ratios, weighted according to the duration of each event, is used for *r*.

(Refer Slide Time: 12:55)



Example 60.1

Determine the triangular hyetograph for the design of an urban storm sewer in Guwahati, India. The design precipitation depth is 25 mm and the design rainstorm duration has been set at 15 minutes. The storm advancement coefficient is r = 0.42.

Solution

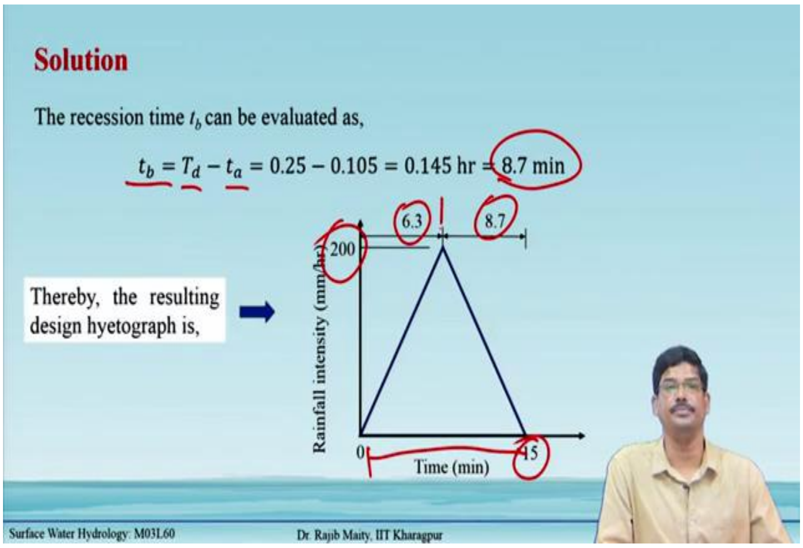
The peak intensity h can be calculated as,

$$h = \frac{2P}{T_d} = \frac{2 \times 25}{15/60} = 200 \text{ mm/hr}$$

The time t_a to the peak intensity can be calculated as,

$$t_a = rT_d = 0.42 \times 0.25 = 0.105 \text{ hr} = 6.3 \text{ min}$$

(Refer Slide Time: 14:21)



The recession time t_b can be evaluated as,

$$t_b = T_d - t_a = 0.25 - 0.105 = 0.145 \text{ hr} = 8.7 \text{ min}$$

Thereby, the resulting design hyetograph is,

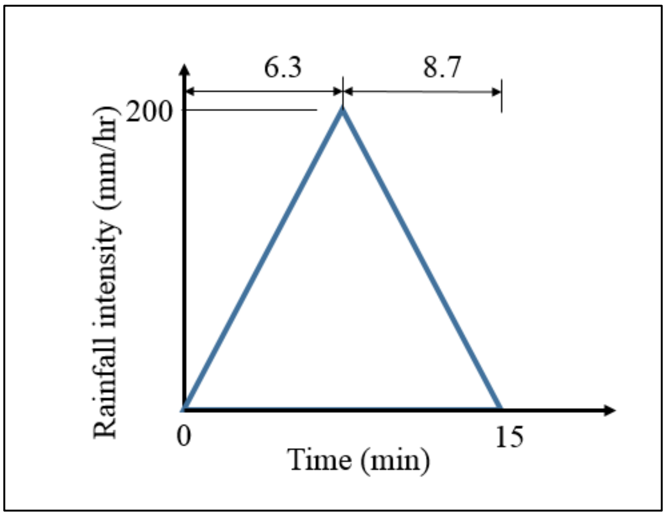
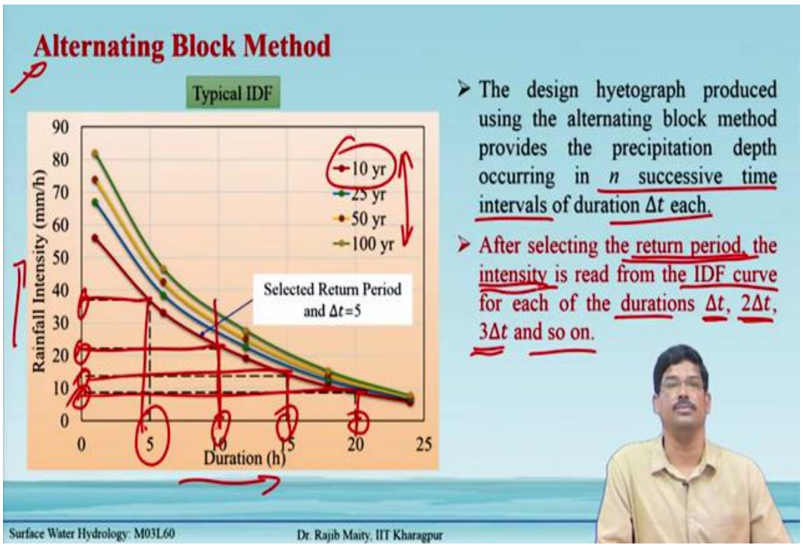


Figure 3: Triangular hyetograph (example 60.1)

(Refer Slide Time: 14:59)



Alternating Block Method

The next method is known as the alternating block method. For this alternating block method, we need the information of intensity-duration-frequency curve. It was discussed already in earlier lectures. A typical intensity duration frequency curve is shown in fig.4, where the duration is shown in the x-axis, and the rainfall intensity is shown in the y-axis. Different curves are shown for this different return periods.

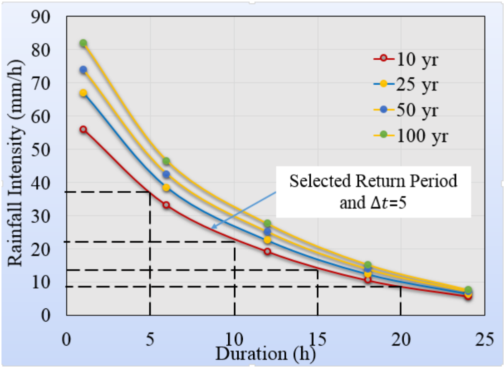
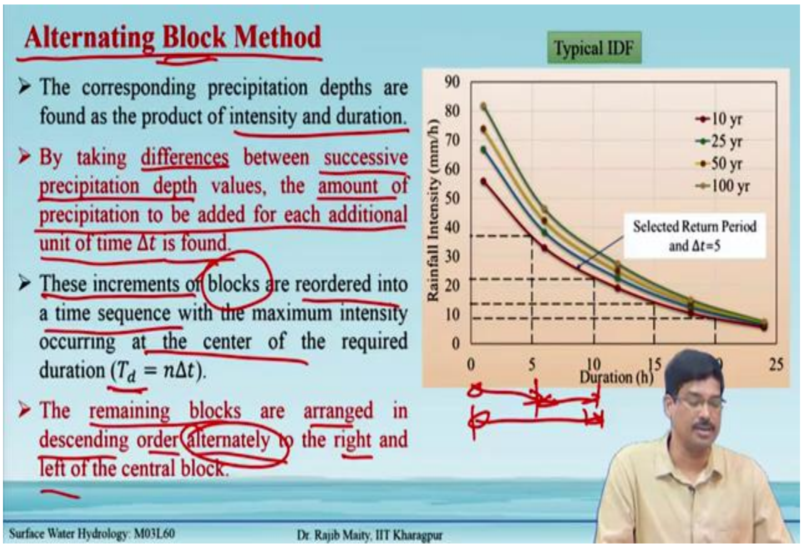


Figure 4: A typical IDF curves

Now, in the process, the design hyetograph produced using the alternating block method provides the precipitation depth occurring in n successive time intervals of durations Δt each. After selecting the return period, the intensity is read from the IDF curve for each of the durationsΔt, $2\Delta t$, $3\Delta t$ and so on.

(Refer Slide Time: 17:31)



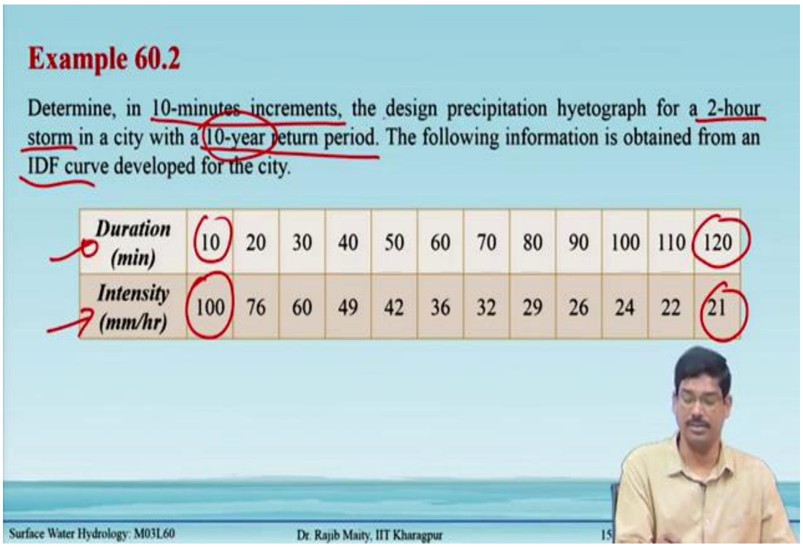
The corresponding precipitation depths are found as the product of intensity and duration.

By taking differences between successive precipitation depth values, the amount of precipitation to be added for each additional unit of time Δt is found.

These increments or blocks are reordered into a time sequence with the maximum intensity occurring at the centre of the required duration ($T_d = n\Delta t$).

The remaining blocks are arranged in descending order alternately to the right and left of the central block.

(Refer Slide Time: 19:29)

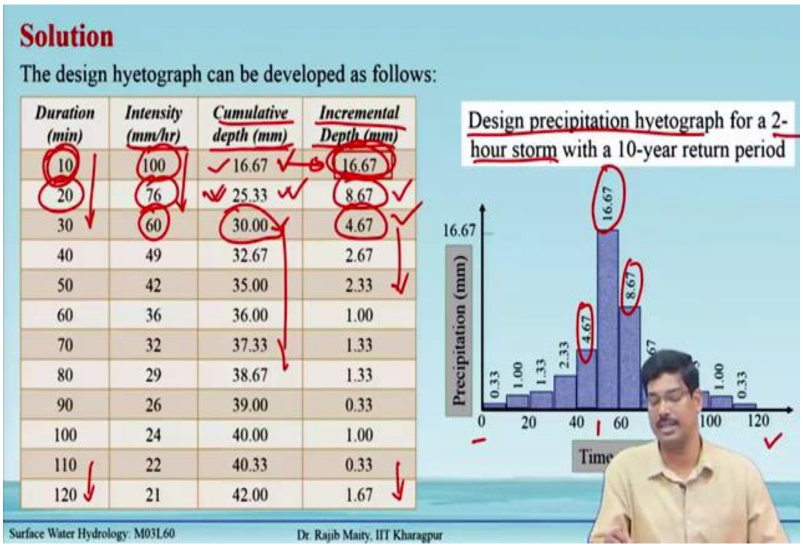


Example 60.2

Determine, in 10-minutes increments, the design precipitation hyetograph for a 2-hour storm in a city with a 10-year return period. The following information is obtained from an IDF curve developed for the city.

Duration (min)	10	20	30	40	50	60	70	80	90	100	110	120
Intensity (mm/hr)	100	76	60	49	42	36	32	29	26	24	22	21

(Refer Slide Time: 20:38)



The design hyetograph can be developed as follows:

Duration (min)	*Intensity (mm/hr)*	*Cumulative depth (mm)*	*Incremental Depth (mm)*
10	100	16.67	16.67
20	76	25.33	8.67
30	60	30.00	4.67
40	49	32.67	2.67
50	42	35.00	2.33
60	36	36.00	1.00
70	32	37.33	1.33
80	29	38.67	1.33
90	26	39.00	0.33
100	24	40.00	1.00
110	22	40.33	0.33
120	21	42.00	1.67

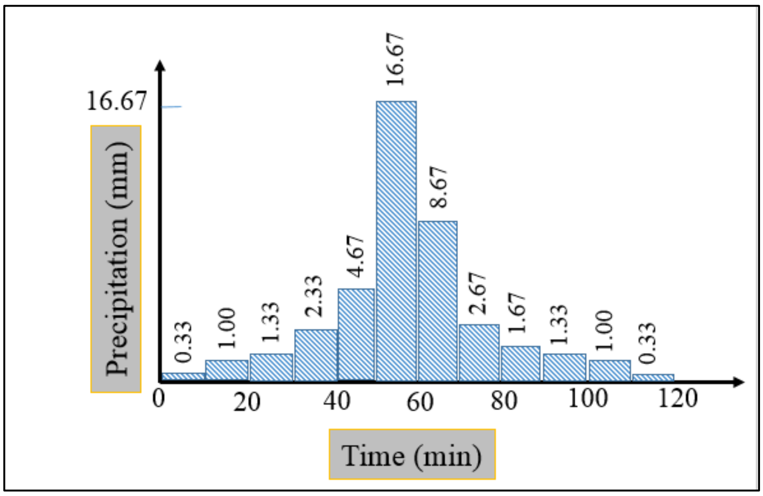
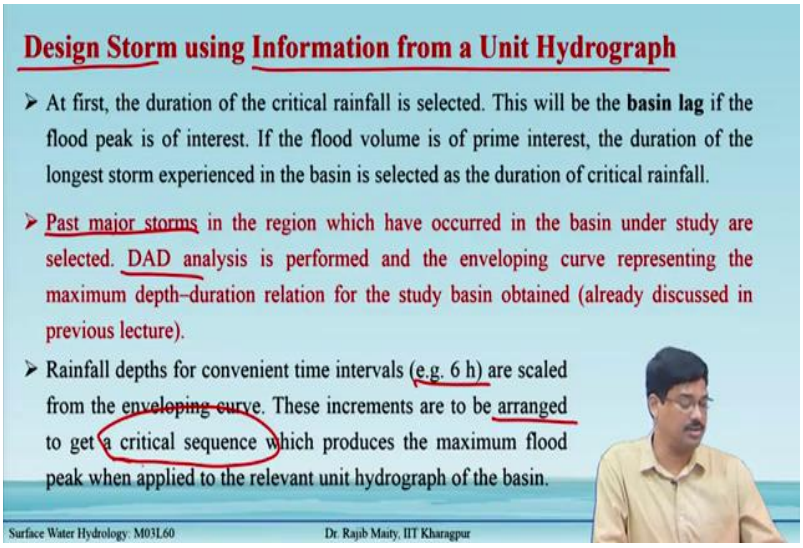


Figure5: The Design precipitation hyetograph for a 2-hour storm with a 10-year return period (Example 60.2)

(Refer Slide Time: 23:44)



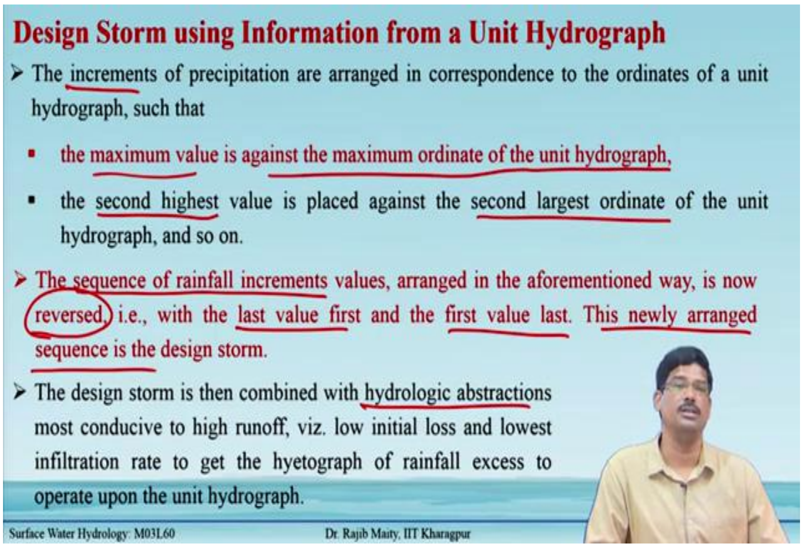
Design Storm using Information from a Unit Hydrograph

At first, the duration of the critical rainfall is selected. This will be the basin lag if the flood peak is of interest. If the flood volume is of prime interest, the duration of the longest storm experienced in the basin is selected as the duration of critical rainfall.

Past major storms in the region which have occurred in the basin under study are selected. DAD analysis is performed and the enveloping curve represents the maximum depth–duration relation for the study basin obtained (already discussed in the previous lecture).

Rainfall depths for convenient time intervals (e.g. 6 h) are scaled from the enveloping curve. These increments are to be arranged to get a critical sequence that produces the maximum flood peak when applied to the relevant unit hydrograph of the basin.

(Refer Slide Time: 25:45)



Design Storm using Information from a Unit Hydrograph

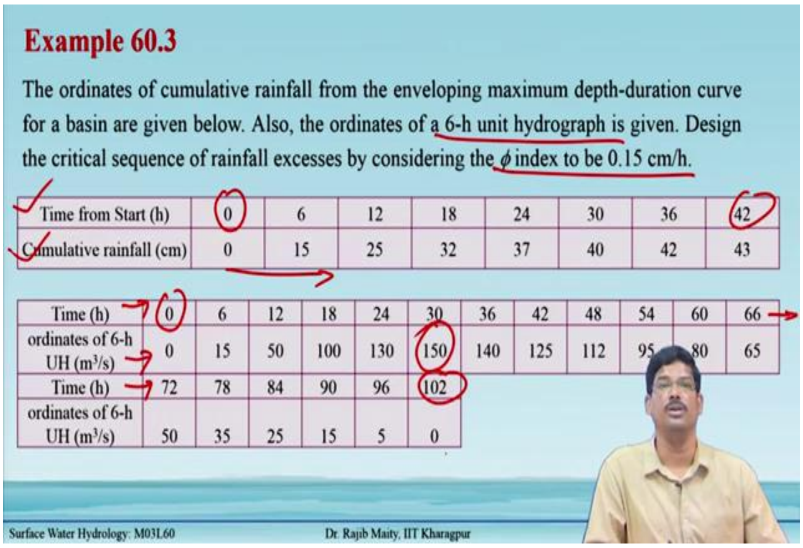
The increments of precipitation are arranged in correspondence to the ordinates of a unit hydrograph, such that

- The maximum value is against the maximum ordinate of the unit hydrograph,
- The second highest value is placed against the second-largest ordinate of the unit hydrograph, and so on.

The sequence of rainfall increments values, arranged in an aforementioned way, is now reversed, i.e., with the last value first and the first value last. This newly arranged sequence is the design storm.

The design storm is then combined with hydrologic abstractions most conducive to high runoff, viz. low initial loss and lowest infiltration rate to get the hyetograph of rainfall excess to operate upon the unit hydrograph.

(Refer Slide Time: 27:12)



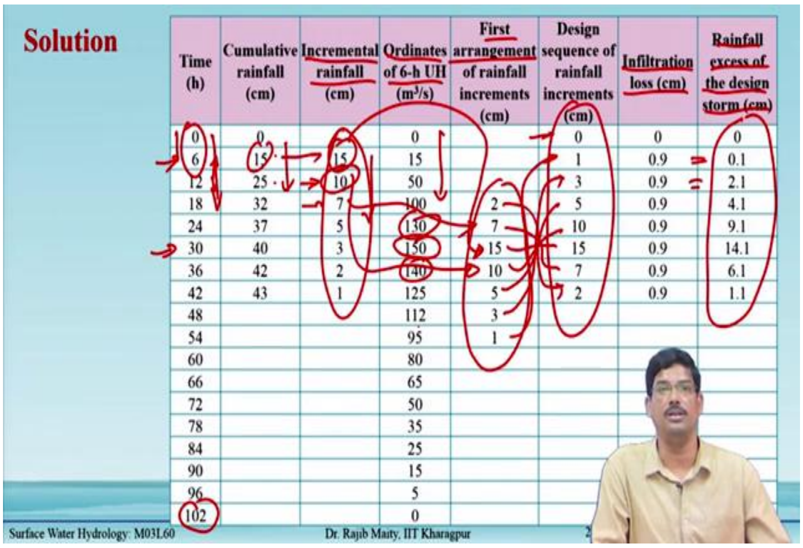
Example 60.3

The ordinates of cumulative rainfall from the enveloping maximum depth-duration curve for a basin are given below. Also, the ordinates of a 6-h unit hydrograph are given. Design the critical sequence of rainfall excesses by considering the ϕ index to be 0.15 cm/h.

Time from Start (h)	0	6	12	18	24	30	36	42
Cumulative rainfall (cm)	0	15	25	32	37	40	42	43

Time (h)	0	6	12	18	24	30	36	42	48	54	60	66
ordinates of 6-h UH (m^3/s)	0	15	50	100	130	150	140	125	112	95	80	65
Time (h)	72	78	84	90	96	102						
ordinates of 6-h UH (m^3/s)	50	35	25	15	5	0						

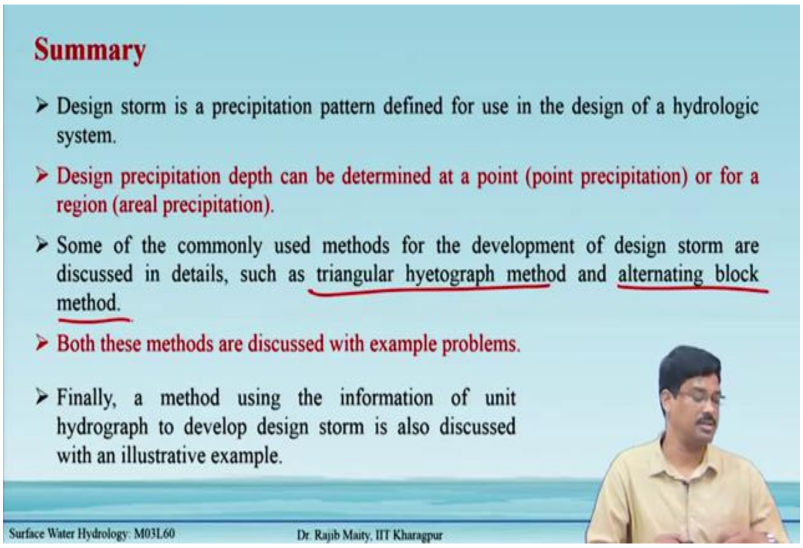
(Refer Slide Time: 28:28)



Solution

Time (h)	Cumulative rainfall (cm)	Incremental rainfall (cm)	Ordinates of 6-h UH (m^3/s)	First arrangement of rainfall increments (cm)	Design sequence of rainfall increments (cm)	Infiltration loss (cm)	Rainfall excess of the design storm (cm)
0	0		0		0	0	0
6	15	15	15		1	0.9	0.1
12	25	10	50		3	0.9	2.1
18	32	7	100	2	5	0.9	4.1
24	37	5	130	7	10	0.9	9.1
30	40	3	150	15	15	0.9	14.1
36	42	2	140	10	7	0.9	6.1
42	43	1	125	5	2	0.9	1.1
48			112	3			
54			95	1			
60			80				
66			65				
72			50				
78			35				
84			25				
90			15				
96			5				
102			0				

(Refer Slide Time: 32:05)



Summary

In summary, we learned the following points from this lecture:

- Design storm is a precipitation pattern defined for use in the design of a hydrologic system.
- Design precipitation depth can be determined at a point (point precipitation) or for a region (areal precipitation).
- Some of the commonly used methods for the development of design storms are discussed in detail, such as the triangular hyetograph method and alternating block method.
- Both these methods are discussed with example problems.
- Finally, a method using the information of unit hydrograph to develop a design storm is also discussed with an illustrative example.