Introduction to Transportation Engineering
Prof. Dr. Bhargab Maitra
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture – 16
Horizontal Alignment – Part III

Horizontal alignment part III.

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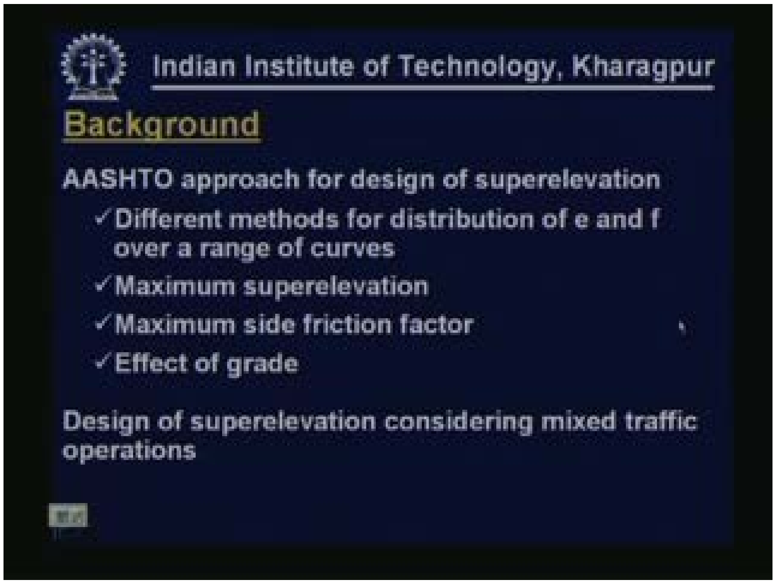

In the last lesson we discussed about the AASHTO approach for design of superelevation. In particular we talked about different methods for distribution of e and f over a range of curves. We also discussed about maximum superelevation rates which are described by AASHTO under different conditions. We talked about maximum side friction factors depending on the speed level and also discussed about the effect of grade on superelevation design.

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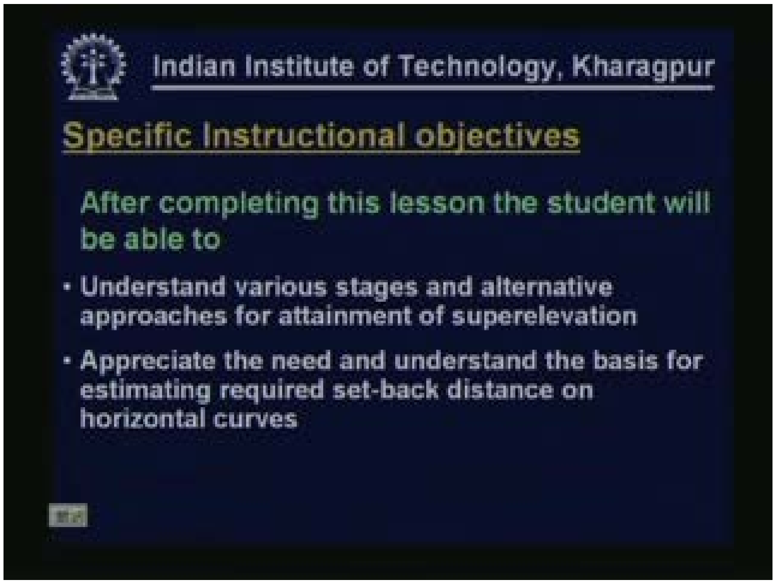

After completing today's lesson the student will be able to understand various stages and alternative approaches for attainment of superelevation. What are the stages and what are the alternative approaches for attainment of superelevation on roads. And also the student will be able to appreciate the need and understand the basis for estimating required set-back distance on horizontal curve. The student will be able to understand what set-back distance is, why it is necessary and how to calculate the required set-back distance on horizontal curves.

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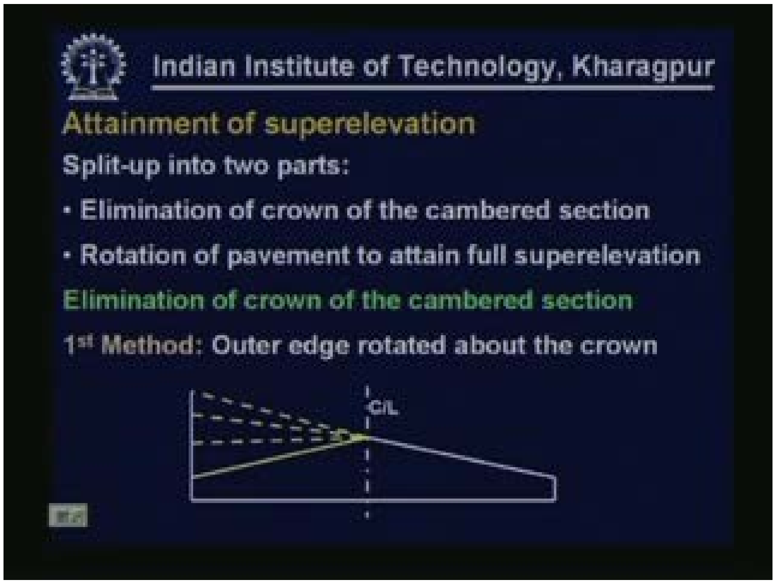

To start with, attainment of superelevation:
So far we have discussed various approaches, the approaches which are followed in India for design of superelevation under mixed traffic operations and also we have discussed the approaches given or recommended by AASHTO. But how to actually attain or get this superelevation in the field is the subject matter what we are discussing now.

In general, you have seen that roads are in cambered section they are in this shape if we assume straight line camber. But ultimately the superelevated design we expect something like this uniform slope equal to the required superelevation rate. So how the cross section is to be changed from normal cambered section to a fully superelevated surface or the cross section is the subject matter we are discussing.

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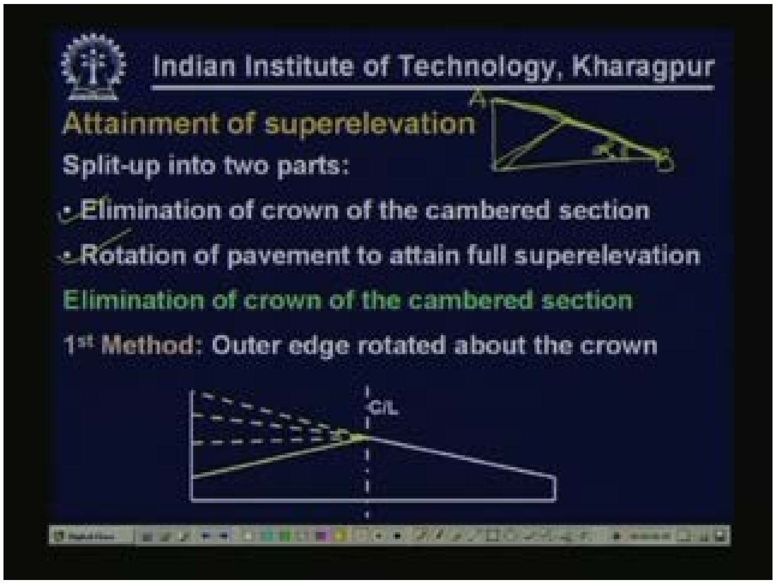

This can be split into two parts; one is elimination of crown of the cambered section that is part A. That means the original cambered section say it is like this. Elimination of crown means we have uniform clause cross slope equal to the camber. That means earlier the section was like this. After this part or after this stage we expect a section with uniform cross slope equal to the superelevation.

Then part two is rotation of pavement to attain full superelevation. That means end of stage 1 we have a surface where there is uniform slope equal to camber but actual superelevation we may need a much steeper slope than the camber. So, further rotating this surface if I call it AB and if this is the angle say alpha then rotation of AB further to have the required angle alpha is equivalent or which will give us the required superelevation. So these are the basic two parts; elimination of crown of the cambered section to have a uniform slope equal to camber and then further rotation of pavement to attain full superelevation.

Now there are alternative methods available for each of these two steps. Let us discuss first step one and the alternative methods.

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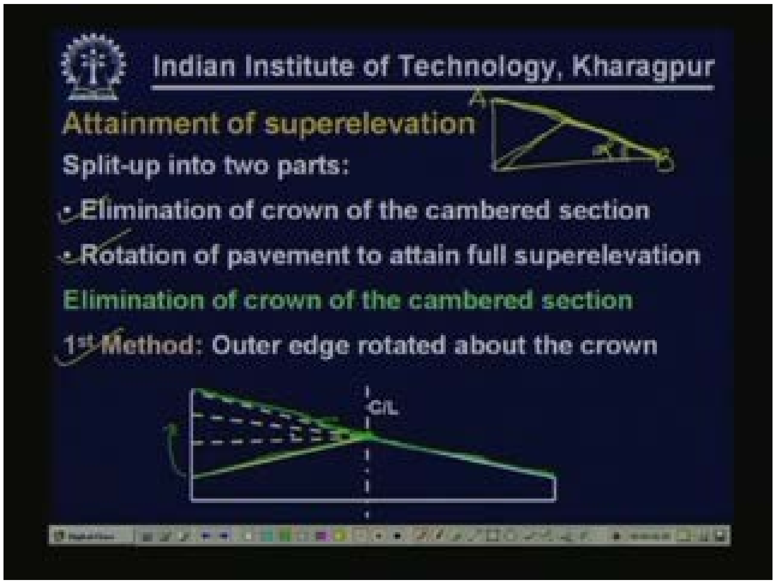

Step one as I indicated is elimination of crown of the cambered section. So first method is outer edge is rotated about the crown. Let us assume that this green line indicates the original cambered section and this is the center line. So we are actually rotating the outer edge of the pavement gradually over a length of road and then this outer edge is rotated like this. This yellow line shows the position at different lengths and finally now we get a slope which is equal to the slope of the inner edge. That means it forms a basic straight line.

What we are doing, the inner edge remains unchanged, the outer edge that is this portion (Refer Slide Time: 8:04) is rotated and it is rotated gradually over the length of the road and finally we get a slope of the outer edge which is in the line of the slope for the inner edge. That way we get a uniform section where the slope is equal to the slope or equal to the camber.

Now this obviously is done gradually over the length of the road, suddenly this cannot be done. Now this has primarily two disadvantages. You can see in this case the outer edge is rotated gradually. So if we take a position in the beginning before we rotate the outer edge then the outer edge has a slope equal to the required camber. After full rotation when we have uniform cross slope equal to the camber even for the outer edge then also we have slope at the outer edge which is equal to the camber.

But what happens in between?
In between actually the slope is lesser than the slope required in terms of the requirement of camber. We have already discussed why camber is required and why a particular minimum slope is recommended for the section. Therefore for that small portion of the road where outer edge is getting rotated the outer edge has a slope less than the required camber. In fact some point in time it will be absolutely horizontal because it is getting rotated gradually so at some point it will have exactly same flat surface. Therefore there

could be drainage problem at some part of the road where the outer edge is getting rotated.

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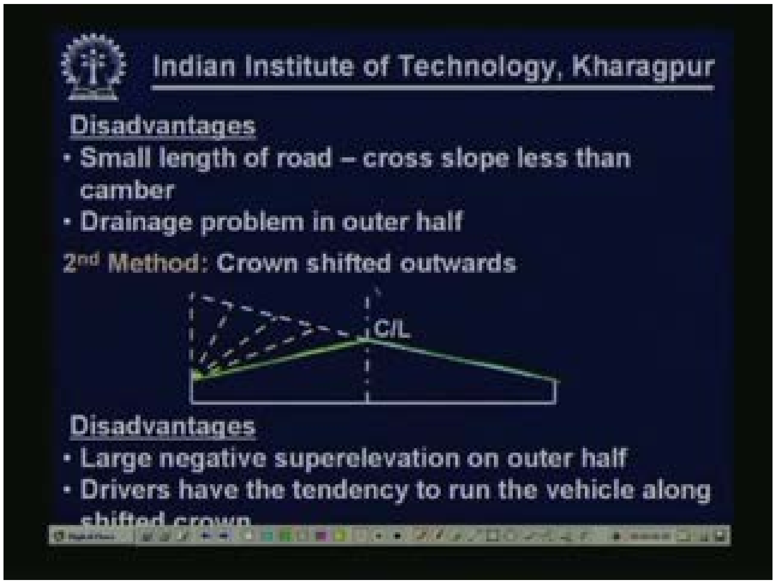

So if you see now the disadvantage basically is, small length of road will have cross slope less than the camber. Therefore there could be drainage problem in the outer half and one may find that outer edge or that portion may get damaged much early. Therefore, in order to overcome the problem associated with the first method the second method is sometimes adopted.

The second method what we do, look at this figure (Refer Slide Time: 11:12). Again originally this was the section as indicated by the green line. Now instead of rotating the outer edge with respect to the center line the crown itself is progressively shifted towards the outer edge like this.

Let me show it by another color, if this is the position of crown gradually the crown is shifted. This again is done over a length of the road. Gradually the crown is shifted and then end of the day we again get uniform cross slope for the outer edge as well as for the inner edge equal to the required camber. Now this yellow line shows the position of outer edge at different times and finally we get the required uniform slope equal to the camber. So in this case we overcome the disadvantages associated with the first method.

Particularly at no point the slope at the outer edge will be lesser than the required camber. Everywhere slope will be more than the required camber so there is as such no drainage problem under this condition. But this method has also got its own disadvantages. Number one large negative slope at the outer edge, we have a negative slope more in this case particularly at the outer edge. And the second thing is we are shifting the central line or the crown not really the center line but the crown. Now this crown is progressively shifted.

Now in most of the cases vehicles or drivers have a tendency to drive along the crown what we normally define as central seeking tendency of vehicles. They want to keep the crown in between and then move. So what happens, if we are shifting the crown itself drivers may not realize that because it is done very slowly. So what happens is unknowingly the vehicle is also shifted towards the outer edge and that sometimes may cause safety problems so it is also not flawless rather it has also got its own disadvantages.

Let us now see the major disadvantages.
1) Large negative superelevation on outer half.
2) Drivers have the tendency to run the vehicle along shifted crown.
We have discussed two methods. Each method has its own disadvantages. And one has to apply judgment looking at the ground situation, looking at the terrain, looking at the amount of rainfall in that area, pavement type about the suitability of a particular method for a given situation. Now let us go to stage II.

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Now we have got uniform slope equal to camber. Now that slope is to be further rotated to have the required amount of superelevation. Again there are two possible alternative methods. In method 1 rather there are three different methods.

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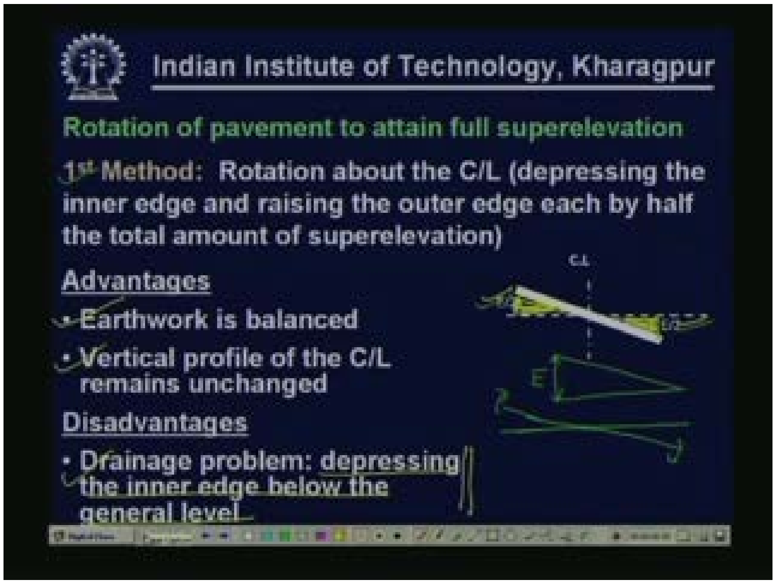

In method 1 that is the first method rotation is about the central line. That means say we have uniform slope like this. Now this line is rotated like this rotated further to have the required superelevation so it is rotated with respect to the central line. Thus the amount of depression for the inner edge and amount of raise for the outer edge should be equal. Hence finally suppose for uniform section if we need a difference of say 'E' between the outer edge and inner edge so this inner edge is depressed by an amount E/2 and the outer edge is also raised by an equal amount E/2 so that the way pavement's surface is rotated further to have the required superelevation as per the design standard.

Now it has certain advantages.
1) Because the pavement is rotated with respect to the central line the earthwork is balanced. Amount of cut and amount of fill they try to balance each other because this is also E/2 and the outer edge is also raised by E/2 so the cut and the fill are generally balanced. Also, because the rotation is with respect to the central line vertical profile of the central line remains unchanged. This is also another disadvantage. So, vertical profile of the road remains unchanged. But like every practical way of doing work it has its own disadvantages. So this method has also got its own disadvantage.

A major disadvantage is the depression of the inner edge which may invite drainage problem because the level for the outer and inner edge for a normal pavement section with camber and the crown at the central line may be decided often depending on the rainfall and other practical considerations. Hence by rotating the pavement with respect to the central line we are actually putting the inner edge below the earlier level. So this depression may invite drainage problem and water may be accumulated near the inner edge of the pavement. So there could be drainage problem particularly where terrain or the topography is like that and where the rainfall is also significant. So a major disadvantage is, drainage problem could occur because of depressing the inner edge below the general level. So inner edge is depressed below the general level and that may invite drainage problem.

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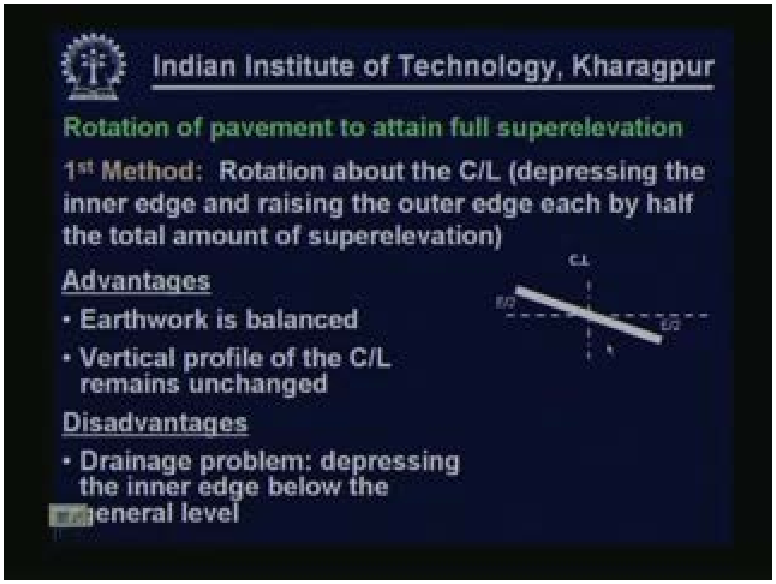

Now, in order to overcome this problem another alternative method is often used. It is also the rotation of the pavement because anyhow the pavement section with uniform cross slope equal to camber is to be rotated further in order to have the required superelevation. But in place of or instead of rotating it with respect to the inner edge with respect to the center line now in this method the pavement is rotated with respect to the inner edge. That means we do not change the level for the inner edge so, that is kept unchanged. And then with respect to the inner edge the pavement is rotated in order to have the required superelevation. Let us look at the sketch.

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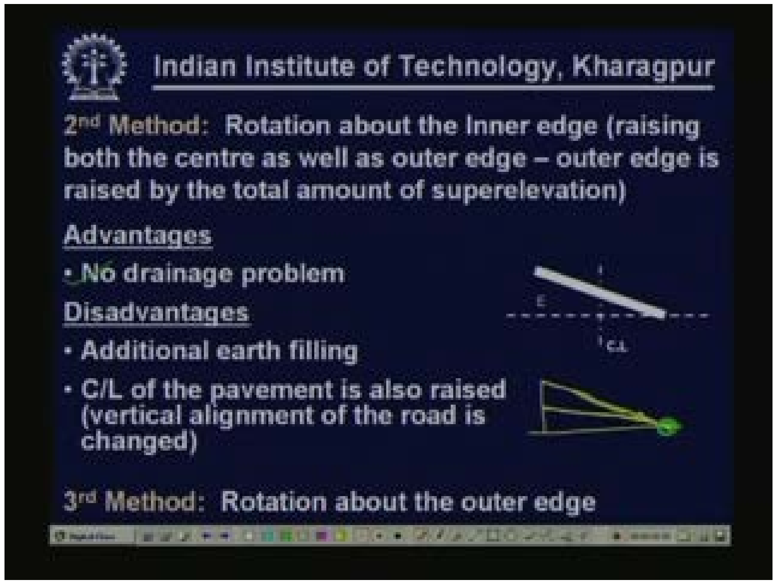

So may be in earlier case after the first stage it was like this. Now we don't change this inner edge, we now rotate the pavement further to have a cross slope like this. So what is happening is the pavement is rotated with respect to the inner edge. Now inner edge level is not changed so a major advantage with this method is there is no drainage problem now because we have not changed the level for the inner edge, it practically remains unchanged. However, this method has its own disadvantages.

The first thing is earthwork is no more balanced. So, additional earth filling is required because we are rotating the pavement now with respect to the inner edge. The second disadvantage is, for the center line vertical profile is changed. Because in first method we were rotating it with respect to the center line so level for the center line of the road was unchanged. But in this case since the rotation is with respect to the inner edge the vertical profile of the road is also altered which is also not very desirable. But of course every method has its own advantages and disadvantages.

So again looking at the particular condition, the rainfall, the terrain, the topography one has to make a decision as which will be a more appropriate solution or a more appropriate method for the given condition. There are also another alternative method which are not very common but sometimes may be used, that is the third method which is left.

We have discussed the rotation with respect to center line; second method was rotation with respect to the inner edge, now it is also possible to rotate the pavement with respect to the outer edge in order to have the required cross slope equal to the superelevation. So third method is, one can also rotate it with respect to the outer edge where for a very special reason or for a given side specific constraints where it’s not permissible or it is not practical to change the level for the outer edge only under that condition this method may be applied.

So there are three alternative methods; whether to rotate it with respect to the center line, whether to rotate it with respect to the inner edge or with respect to the outer edge. Now each method has its own advantages and disadvantages. One has to apply a judgment, case specific judgment and decide which will be the most appropriate method for a given situation. This completes our discussion about attainment of superelevation. Let me show you a typical superelevation diagram.

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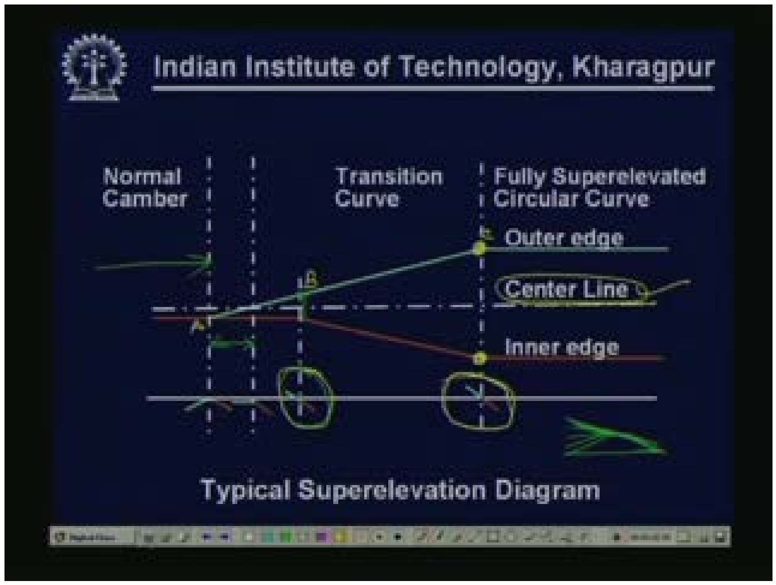

This is the normal cambered section, this portion up to this is the normal cambered section so you have level for the outer edge and the inner edge they are same, that is shown here by the red line, in fact the red and green line are going together. (Refer Slide Time: 25:45). Now this point onwards we are rotating the outer edge.

Method 1 of the first edge; rotating the pavement with respect to the inner edge or rotating the outer edge with respect to the center line. So, that is rotated and the crown or the center line remains unchanged, the inner edge also remains unaltered but gradually we are rotating the outer edge. So this portion actually indicates something like this as we have discussed, initially it was like this and now gradually this is rotated in order to have a cross slope finally equal to the camber.

Therefore at this point you can find that this distance and this distance are same. That means this is the position where you have uniform cross slope equal to the camber. That is what is indicated here by this cross section. After that the rotation is with respect to the center line. So from this point onwards inner edge is depressed shown by the red line, the outer edge is raised shown by the green line in order to attain the full superelevation. So at this point we have full superelevation available and please note that the center line remains unchanged, there is no change for the center line. Therefore initially only the outer edge is rotated with respect to the inner edge from point A to point B then at point B you have uniform cross slope equal to the camber then the pavement is rotated further with respect to the center line so center line remains unchanged as you can see it here (Refer Slide Time: 28:24).

So, with respect to the center line the pavement is rotated so outer edge is raised as shown by the green line goes up to a point C and at this point C you have a section like this uniform slope but equal to the required superelevation. So, at B also you have uniform slope and at C also you have uniform slope but at B the slope is equal to the camber and at C with further rotation we have obtained a slope equal to the required superelevation without changing the center line. That is a typical method what we have tried to indicate. Now that completes our discussion about superelevation.

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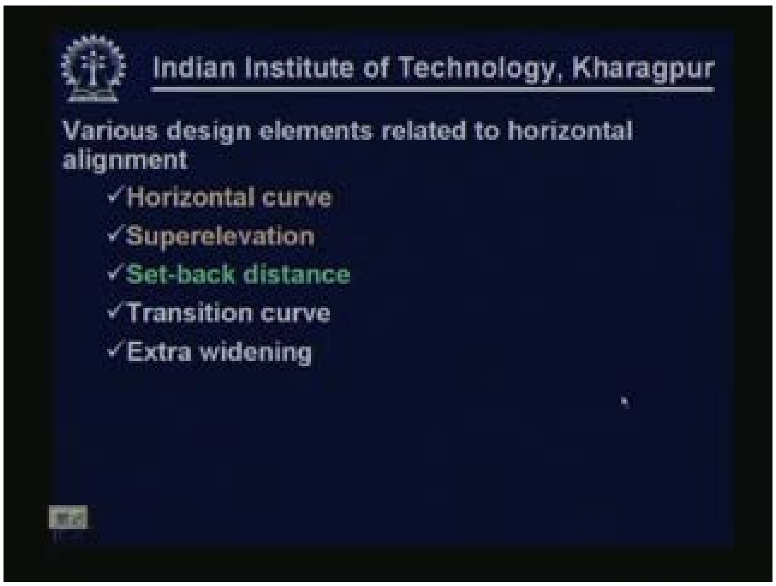

Now we shall go to the next element related to horizontal alignment that is the set-back distance.

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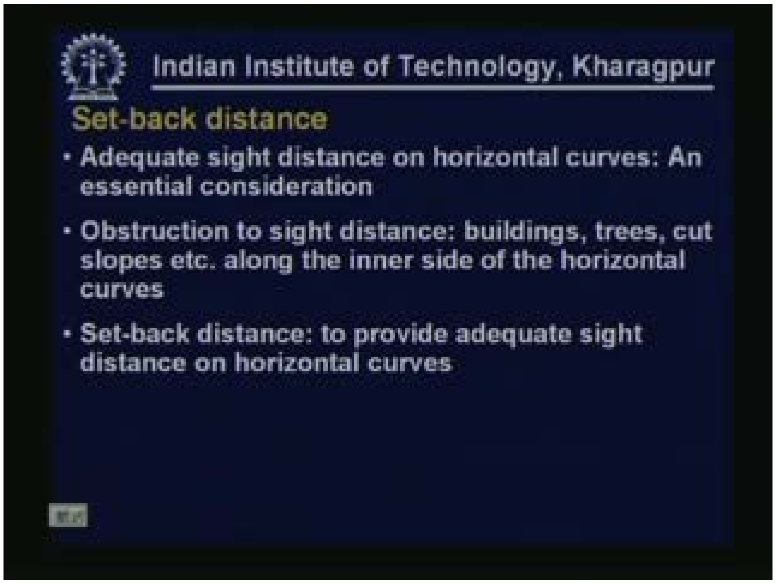

Now you know that at every point on highway adequate sight distance should be available. We have discussed about various types of sight distance. The minimum requirement is the Stopping Sight Distance or the SSD. The horizontal curve is a location where there could be problems of sight distance. So adequate sight distance must be ensured at all horizontal curves for safe and efficient movement of traffic and sight distance at horizontal curve is an essential consideration.

Why there could be a problem of sight distance at horizontal curves?
It is mainly due to the obstructions at the inner edge of the horizontal curve. So look at the sketch.

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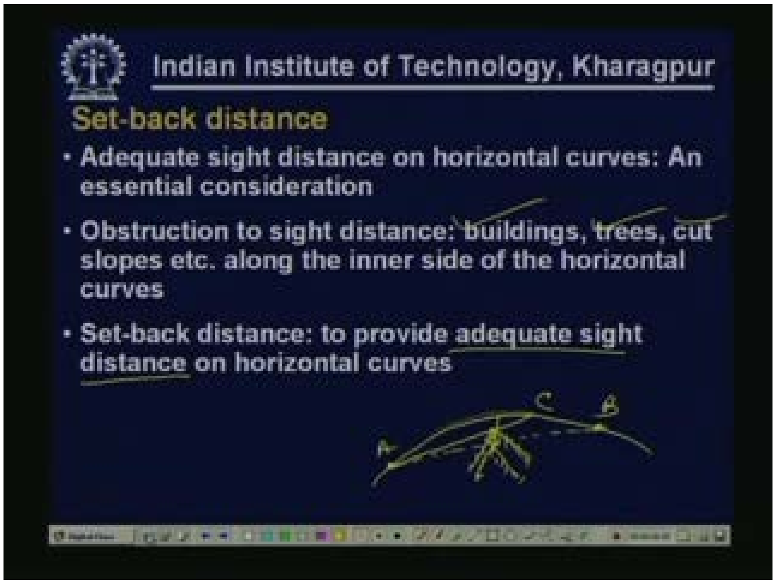

Suppose this is a curve say a vehicle is here the required sight distance may be along the road it is AB but the line of sight is like this. So if there is a building here then the line of sight is obstructed so up to point V visibility is not available so if this is the condition only up to point C the visibility is available. So the available sight distance along the road is AC where the requirement could be actually AB. So, restrictions to sight distance could be due to an obstruction in the inner side of the horizontal curve.

Now such obstructions could be like buildings, trees, cut slopes, etc and therefore we must ensure that if this is the line of sight and AB is the required sight distance then up to that point no building should be available or no obstruction should be there. So set-back distance is basically the clear distance in the inner side of the curve which must be available to make sure that adequate sight distance is available on horizontal curve.

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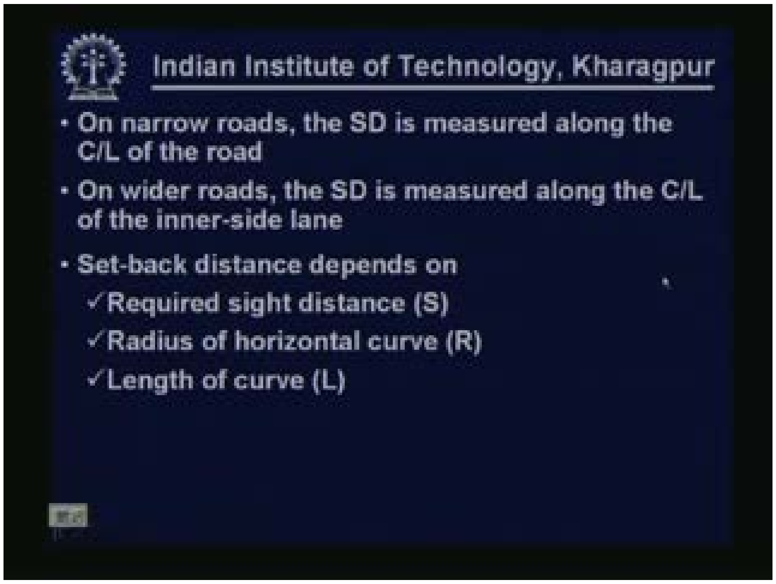

Now it is important to understand that on narrow roads Stopping Sight Distance is measured along the central line of the road. Narrow road means may be it is a single lane. So sight distance is measured along the center line of the road. For wider road the critical vehicle position could be different. For wider road the critical vehicle position would be when the vehicle is traveling in the inner side lane or when the vehicle is placed on the inner side of the curve, inner side lane because that would be the most critical position of vehicle. So when we are calculating the set-back distance also getting the idea about the sight distance we must consider a vehicle not along the central line of the road but the vehicle is placed towards the inner side lane of the road. Now this set-back distance depends on a number of factors.

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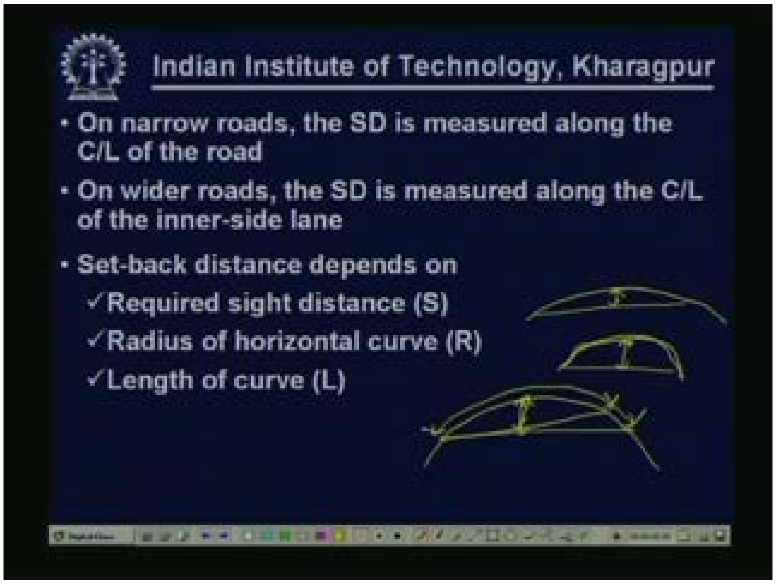

If this is the curve and this is the required line of sight and this is the required sight distance then the set-back distance will depend on the required sight distance. If the sight distance requirement is more obviously the set-back distance will be more. You need more distance here because instead of these if it is up to that then obviously line of sight goes like this so you find that now you need a distance which is higher. If our sight distance requirement is Stopping Sight Distance then it is something, if we talk about the overtaking sight distance or passing sight distance obviously more set-back distance will be required.

It will also depend on the radius of the horizontal curve. For sharper radius more set-back distance will be required. From the common sense also one can understand say a curve like this and a curve like this. So obviously for sharper curves sight distance requirement will be more. So here set-back distance requirement will be more, here may be it is like this and there for sharper curves it will be more. It will also depend on the length of the curve, length of the curve means length of the horizontal curve which could be again more or less than the required sight distance. So depending on that actually two different cases are considered.

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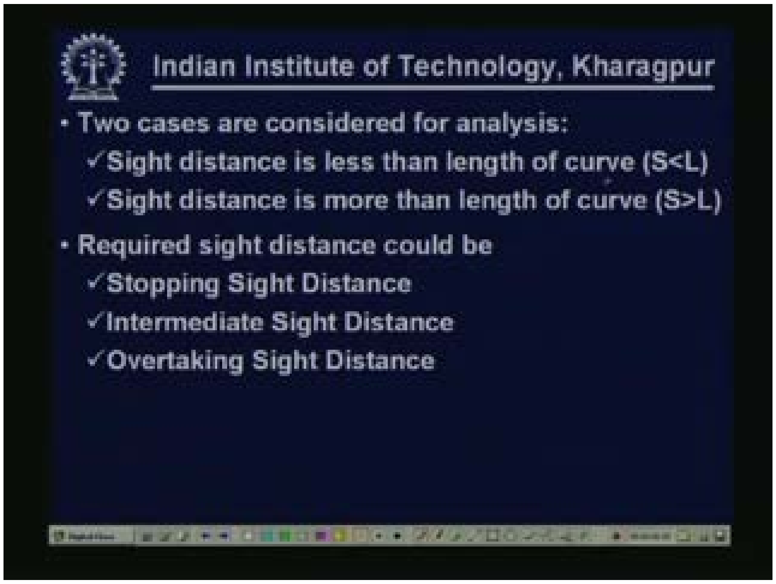

One is, sight distance is less than the horizontal length of the curve. That means if we denote sight distance as S and length of the curve as L then this S is lesser than L and the other case is S is more than the L. In both the cases analysis should be done separately. Now, required sight distance as I mentioned could be Stopping Sight Distance, it could be Intermediate Sight Distance. As per IRC we have discussed this concept or it could be even Overtaking Sight Distance. Hence sight distance what we are mentioning may be actually Stopping Sight Distance, it may be Intermediate Sight Distance and it may be also Overtaking Sight Distance. Now let us see how the sight distance or set-back distance can be calculated.

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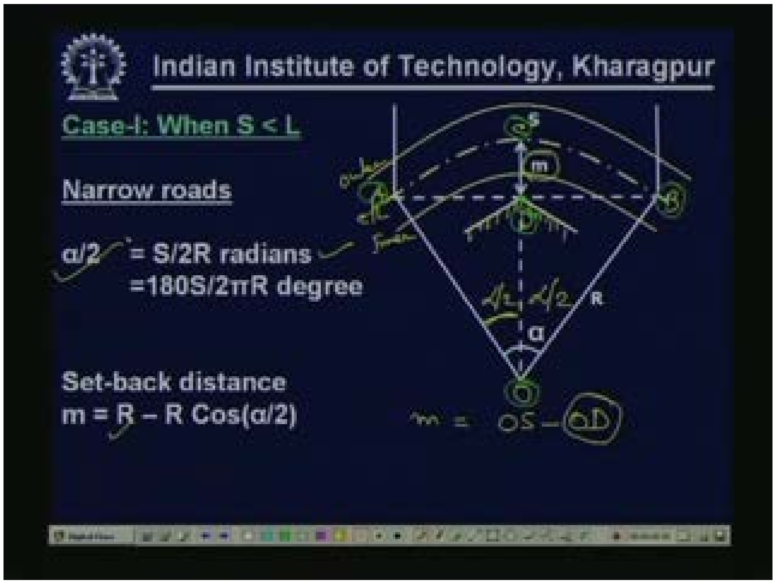

Let us consider a narrow road. So this is the centre line what I have tried to indicate, this is the outer edge of the road, this is the inner edge of the road. (Refer Slide Time: 37:30). Since it is a narrow road we are considering vehicle position at the centre of the road. So sight distance or the set back distance is also the distance from the center line of the road up to the building or any obstruction up to the building or any obstruction. So 'm' is the distance what we are trying to calculate.

Now in this case if this is A and this is B then AB is the line of the sight as shown by the dotted line. Now say the angle formed if it is alpha then this is actually alpha/2 and this is also alpha/2. Therefore sight distance is actually the length of the arc AB along the central line. So S/2 is this distance so alpha/2 = S/2/R or S/2/R radian. If I convert into degree you have to multiply by 180/pi so it becomes 180S/2piR degree.

Now, what is this set back distance?
Suppose if this point is 'C' in the middle and this is 'O' then set-back distance m is nothing but OS minus say this point is D. Let me circle it with some other color. So this is position O, this position B, this is position A, this is position C, this is position D this point. (Refer Slide Time: 39:40) So the sight distance or set-back distance m is OS – OD.

What is OS?
OS is nothing but the radius because OA = OB = OC are all equal to radius so that is nothing but this R – OD.

What is OD?
OD is nothing but OA cos alpha/2. I repeat, OD = OA which is nothing but R cos alpha/2 that's what gives you this distance. Therefore set-back distance is R – R cos alpha/2.
I have already indicated how the alpha/2 can be calculated.

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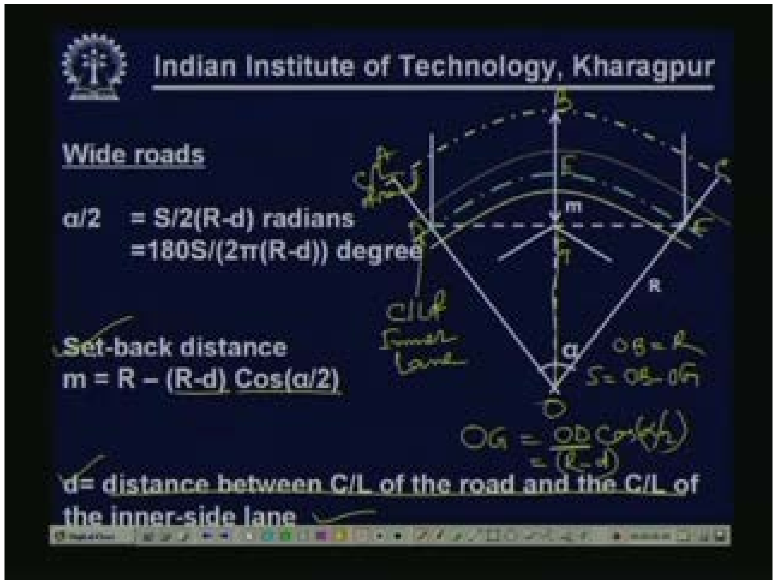

Suppose we consider a wider road, now in case of a wider road vehicle is placed towards the center line of the inner length. Now this is the center line of road and this green line indicates center line of inner length. So in this case set-back distance is from point this is A, this is B, this is C, this is D, say E, F, G and this is O. So principally or conceptually it is the same.

So what we get is this distance, what is this distance?
This is GO, OG, OG = OD cos alpha/2.

Now what is OD?
OD is nothing but OA – Ad. That means ‘Ad’ is nothing but the distance which is indicated here as ‘d’ the distance between the center line of the road and the center line of the inner-side lane. So it is basically OD is nothing but if R is the radius R is up to OA, OB, OC. So R – d where ‘d’ is the ‘Ad’ or indicated here as ‘d’ the distance between the center line of the road and the center of the inner-sight length. So in this case set-back distance becomes R – d cos alpha/2. So this is the distance we are trying to find out so overall OB is nothing but R. So set-back distance is nothing but OB – OG. So OB is r and OG = R – d cos alpha/2 and that's what gives you the set-back distance for wider road.

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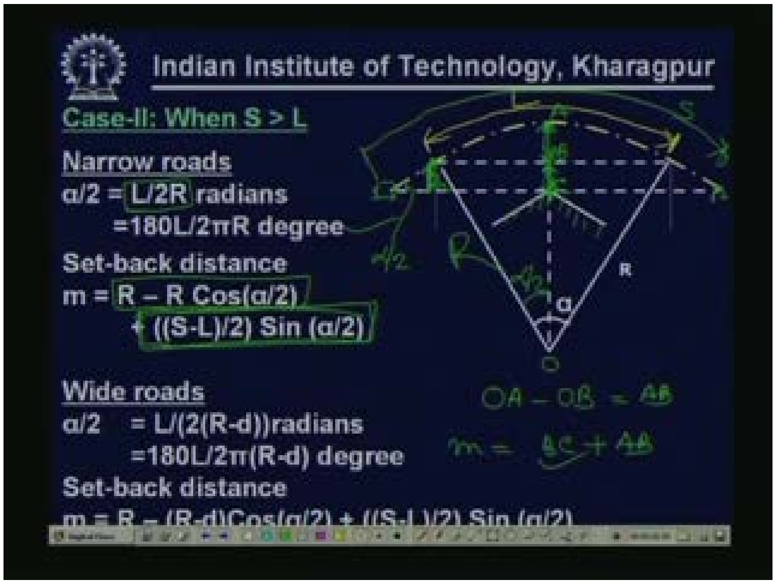

Now let us see the other case when S is greater than L. That means in this case S is greater than L. length of the curve is up to this, this is the length of the curve. Sight distance requirement is this and that's what is S. So 'S' is greater than curve. So vehicle position is here, line of sight is here. Now if we consider a point here then in the same manner alpha/2 = L/2R radian. Note that this is not S/2R in this case, this is L/2R radian, this distance is R so L/2R radian is converted into degree.

So the set-back distance the distance up to this part shown by this green line up to this part is nothing but as usual R – R cos alpha/2, that gives us set-back distance up to this point. But what we want is up to this building line or the building edge. So this additional distance is also to be considered. Now this additional distance is equal to this distance.

What is this distance, how we can calculate it?
If this angle is alpha/2 then this angle is also alpha/2 so this is also alpha/2. If this is alpha/2 that means this angle is also alpha/2 so this angle is also alpha/2.

So what is this distance then?
Overall it is 'S' from this point to that point, this is 'L' so this distance plus this distance is S minus L so this distance is actually S – L half of this so S – L/2. So S – L/2 sine alpha/2 gives us this distance which is equivalent to this distance the same distance. That's why we are adding this portion now. Hence S – L/2 sine alpha/2 is what is added. Hence in this case the set-back distance is R say 0 – A, this is B, this is C.

So how we are calculating?
It is 0A – R – R cos alpha/2 – 0B that gives us AB so OA – OB. Now we are also adding this part BC so total set-back distance m is BC + AB. So this part is actually AB and this remaining part is actually BC. Thus, for wider road a suitable adjustment is necessary. In this case it is actually given by R – R – d cos alpha/2

+ S – L/2 sin alpha/2 a very similar expression appropriately modified considering the distance ‘d’ the distance between the center line of the road and the center line of the inner lane, a similar adjustment.

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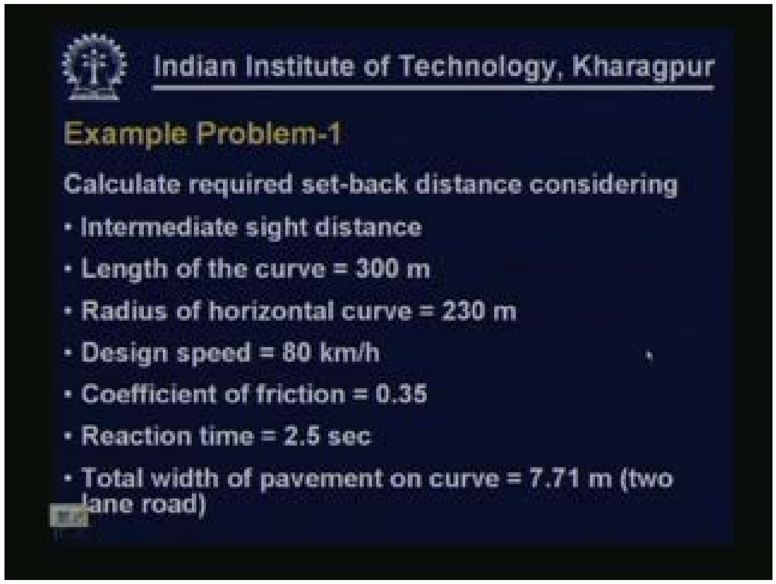

Now let me take an example; calculate the required set-back distance considering Intermediate Sight Distance:
Length of the curve is 300 m
Radius of horizontal curve is 230 m
Design speed as 80 Km/h
Coefficient of friction 0.35 as per IRC
Reaction time 2.5 seconds and
Total width of the pavement is 7.71 m, it is basically a two lane road.
So requirement sight distance is actually the Intermediate Sight Distance.

So what we have to calculate is Intermediate Sight Distance as per IRC Indian Roads Congress specification, it is twice the Stopping Sight Distance. So first we have to calculate Stopping Sight Distance then we will calculate Intermediate Sight Distance which is twice the Stopping Sight Distance then we check the sight distance requirement against the length of the curve as which one is higher and then accordingly try to calculate the set-back distance. Let us see the calculation.

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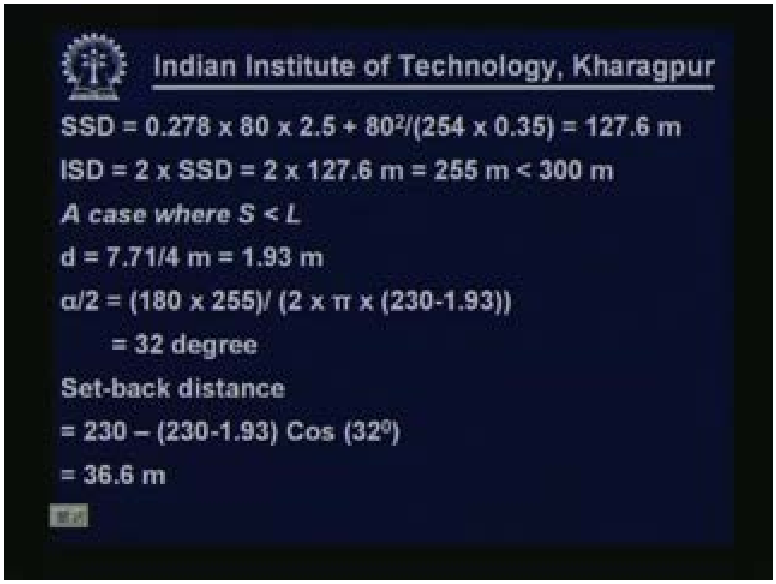

Stopping Sight Distance is 0.278 into V the speed in kilometer that's why it is 0.278 into t this the reaction time 2.5 second so this is the lag distance component plus the breaking distance V square/254f, it is 254f because V is in kilometer and f value is 0.35, speed is 80 Km. So we calculate this SSD as 127.6 m so ISD is twice as SSD. Therefore it becomes 255 m.

Now we find the length of the curve given as 300 m. So this is the case where S is less than L. That means required sight distance is less than the length of the curve. Now 'd' the total width of the pavement is 7.71 m it is a two lane so if you place the vehicle towards the center line of the inner lane then what is the distance 'd'?
Center line of the road to center line of the inner length it is 7.71 by 4 so 1.93 m. So alpha/2 is calculated and set-back distance is R – R – d cos 32 degree so 36 m. So that way we calculate the set-back distance.

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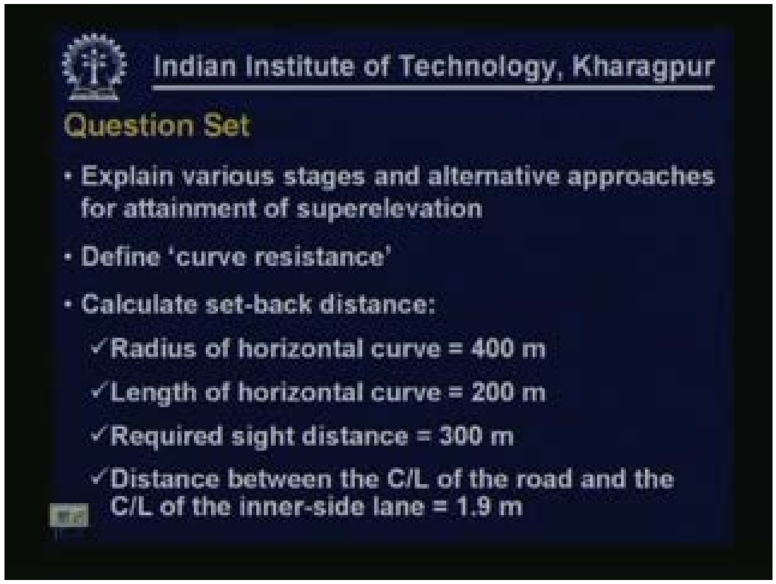

Question set:
Explain various stages and alternative approaches for attainment of superelevation:
2) Define curve resistance:
3) Calculate the set-back distance when the following data is given:
Radius of curve is 400 m
Length of horizontal curve 200 m
Required sight distance 300 m and
Distance between the center line of the road and the center line of the inner-side lane is 1.9 m.

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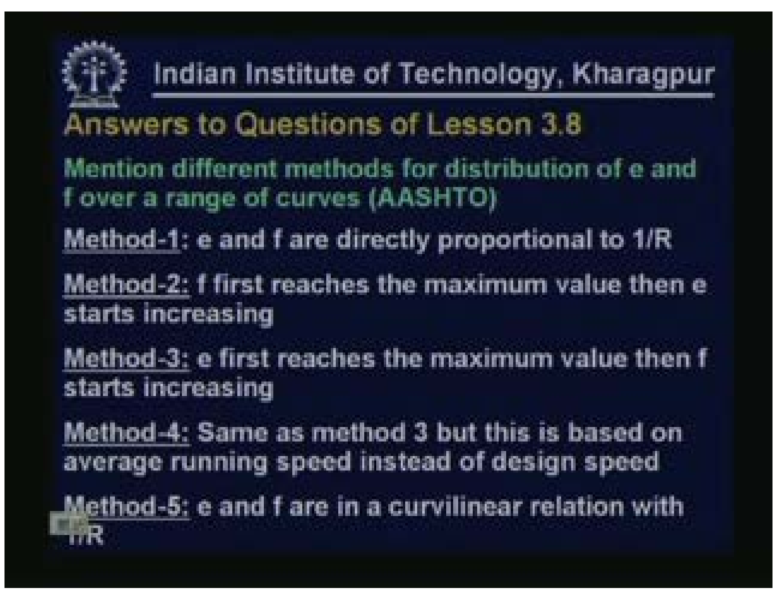

Now let me take up the questions which were asked in the last lesson and try to answer them. Different methods for distribution of e and f over a range of curves: There are five different methods:

Method 1:
Here e and f are directly proportional to 1/r, a very logical and rational method but it is suitable when all vehicles in the traffic stream travel at uniform speed even at tangent sections at intermediate curvature and even on circular curve portion which is not a very practical assumption because vehicles have a tendency to drive faster on tangents so therefore that raised a question on method 1.

Method 2:
Here f first reaches the maximum value and then ‘e’ starts increasing. So, for flatter curve we may not have ‘e’ value more suitable and practical for urban roads where providing superelevation at frequent intervals may be a problem. When ‘e’ starts increasing it increases very fast.

Method 3:
When e first reaches to its maximum and then only ‘f’ starts increasing so ‘e’ reaches maximum value and then whenever ‘f’ increases it increases very fast and this is corresponding to the design speed, ‘e’ is designed corresponding to the design speed. That indicates that vehicle which are traveling at average running speed may indicate a negative value of ‘f’ because ‘e’ is designed based on the design value. So e + f = V square/127R. So if ‘e’ is designed for design speed but the actual V is lesser than that the running speed that means f value is assumed negative. So f varies widely on different curves and that is a major disadvantage.

Method 4 is attempted to overcome this disadvantage by considering the same as method 3 but instead of design speed average running speed is taken. Therefore this overcomes the problem to some extent but has the same disadvantages but may be of lesser degree.

Method 5:
Here e and f are in a curvilinear relation with 1/R. Therefore in this case this tries to combine the advantages of method 1 and method 4.

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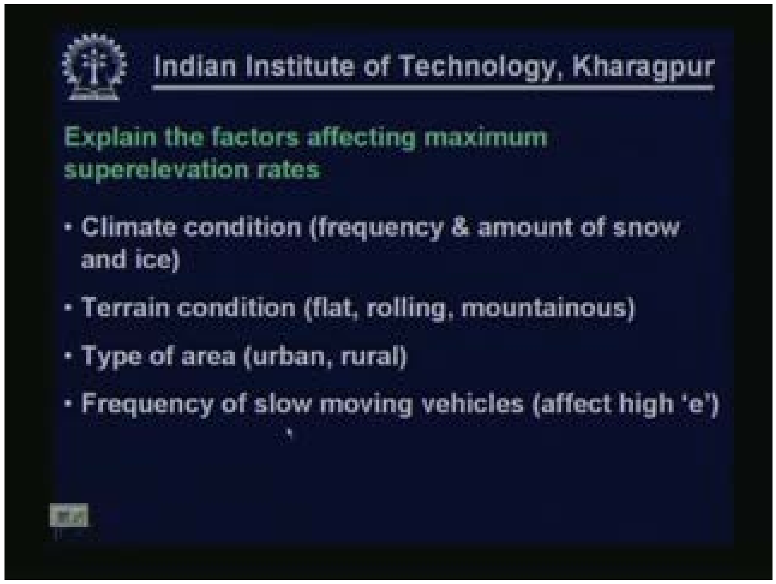

Factors affecting maximum superelevation rate:

- Climatic condition
- Terrain condition
- Type of area whether it is urban or rural and importantly
- Frequency of slow moving vehicle that affects the high value of 'e'

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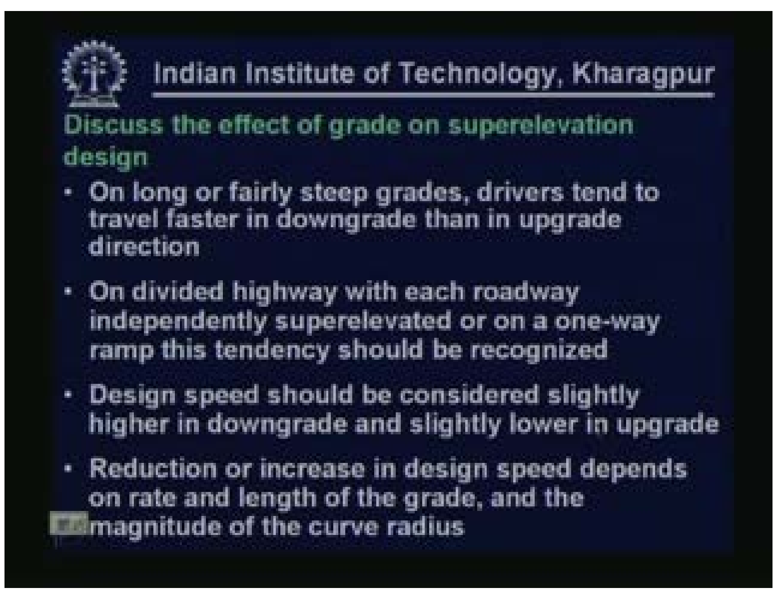

What is the effect of grade on superelevation?
On divided highway, long and fairly steep grades drivers have the tendency to drive fast on down grade than in upgrade. Therefore whether it is for divided road or one-way ramp

a separate design speed may be designed so may be reduction and design speed should be considered slightly higher on down grade and slightly lower on up grade. But a similar adjustment normally we don't do in practice for undivided roadways although theoretically it may be possible to have similar kind of adjustment even for undivided road but practically it is not done and it is not advisable also. Thank you.