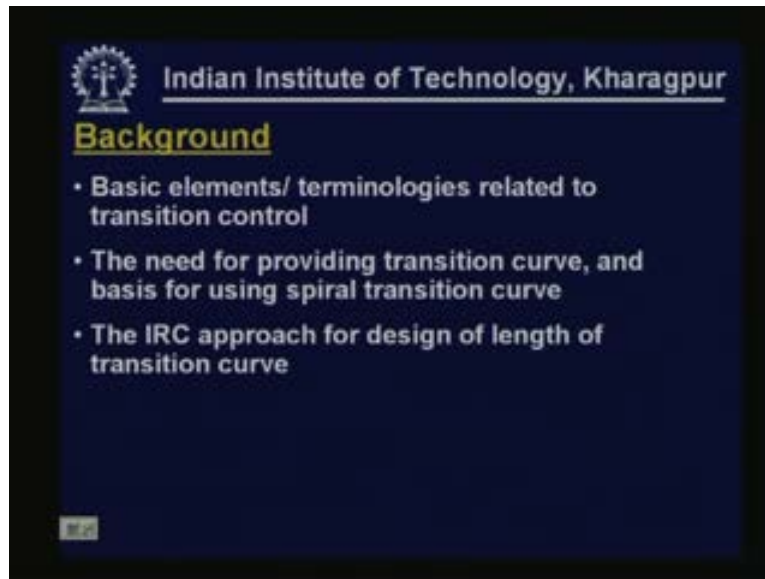


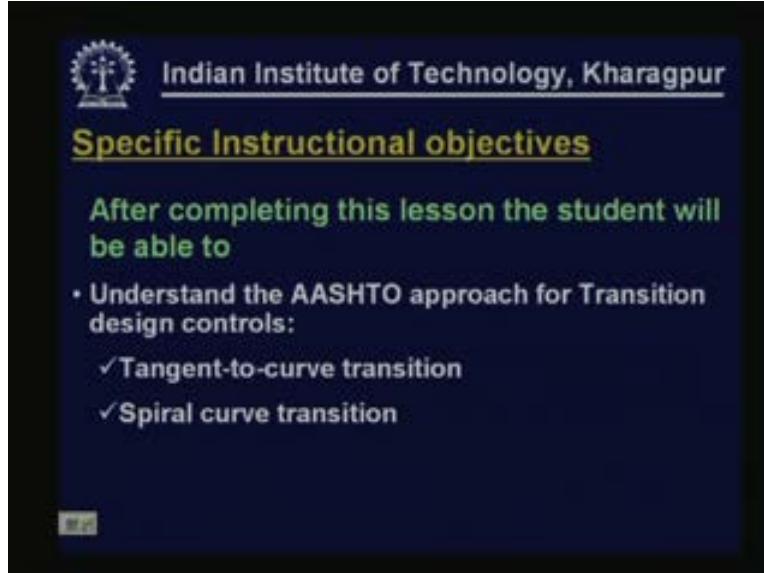
Introduction to Transportation Engineering
Prof. Bhargab Maitra
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture - 18
Horizontal Alignment – Part V

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Horizontal Alignment V, in lesson 3.10 we have discussed about various basic elements and terminologies related to transition control. We have discussed the need or the advantages for providing transition curve, what are the advantages if transition curve is provided and also the basis for using spiral transition curve, why spiral curve is used in horizontal alignment and so on. We have also discussed the Indian Roads Congress approach for design of length of transition curve. Thus we have discussed all these aspects in lesson 3.10.

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The slide is a presentation slide from the Indian Institute of Technology, Kharagpur. It features a dark blue background with white and yellow text. At the top left is the IIT Kharagpur logo. To its right, the text "Indian Institute of Technology, Kharagpur" is written in white. Below this, the title "Specific Instructional objectives" is written in yellow. The main content of the slide is in white text, stating "After completing this lesson the student will be able to" followed by a bulleted list of two objectives: "Understand the AASHTO approach for Transition design controls:" and two sub-points: "✓Tangent-to-curve transition" and "✓Spiral curve transition".

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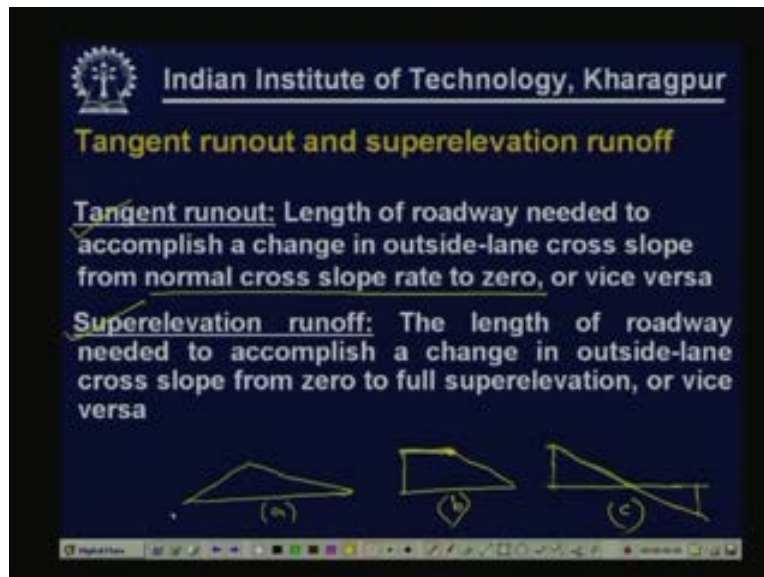
Specific Instructional objectives

After completing this lesson the student will be able to

- Understand the AASHTO approach for Transition design controls:
 - ✓Tangent-to-curve transition
 - ✓Spiral curve transition

After completing this lesson the student will be able to understand the AASHTO approach American Association of State Highway and Transport Officials for transition design control considering both tangent-to-curve transition and also spiral curve transition. In tangent-to-curve transition no transition curve is used, we have a tangent and then a circular curve directly. for spiral curve transition a transition curve which is basically a spiral curve is used in between the tangent and the circular curve. So under both cases we shall discuss about the AASHTO recommendations and approach for transition design control.

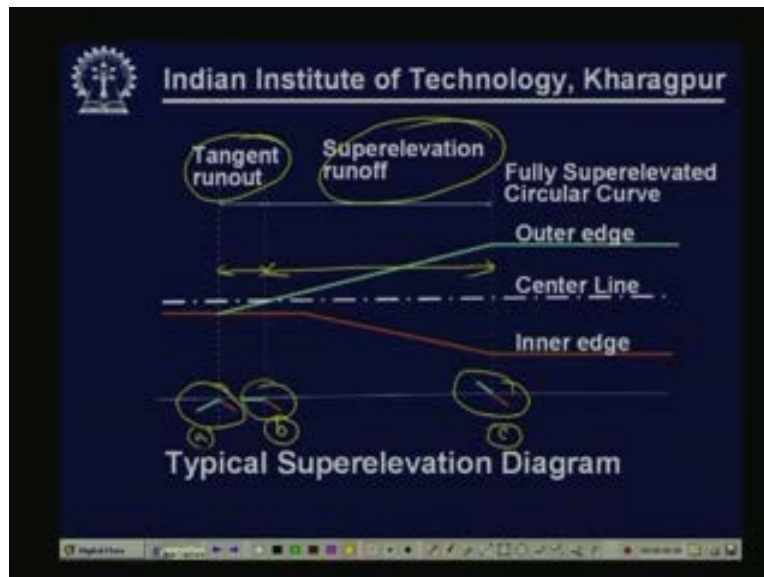
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Now let us again touch these two terminologies tangent runout and superelevation runoff. We have discussed these things earlier but again we shall talk about these two items. Tangent runout is basically the length of roadway needed to accomplish a change in outside-lane cross slope from normal cross slope rate to zero. So basically if we take a normal cross section a cambered cross section it looks like this. So from this position we want to get it like this if the rotation is with respect to center line so from 'a' to 'b' this is achieved over a length and from 'b' to final superelevation this is achieved say with respect to the rotation about the central line to attend the full superelevation so from 'b' to 'c'.

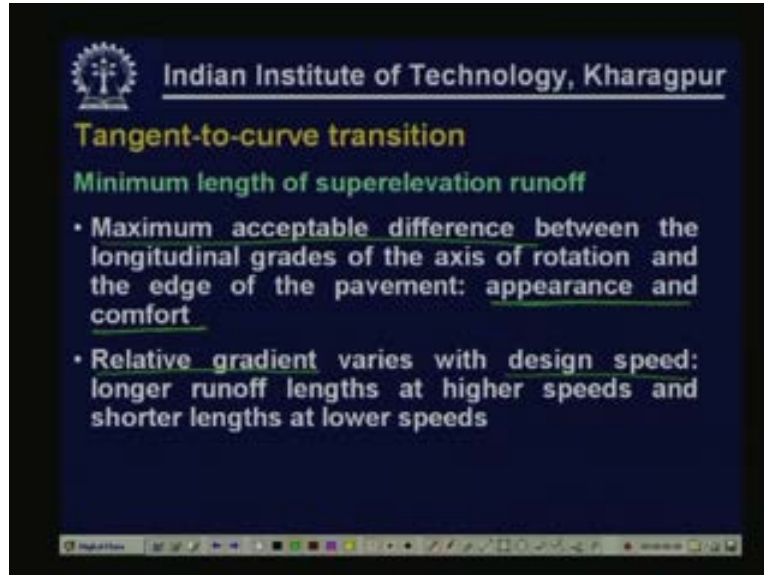
So 'a' to 'b' this portion is known as tangent runout outside cross slope from normal cross slope rate to zero so this is the normal cross slope to rate zero because it is flat outer edge. And superelevation runoff is the length of roadway needed to accomplish a change in outside length cross slope from zero to full superelevation, this is zero and this is the full superelevated cross slope from 'b' to 'c'. Hence the length which is required to change the cross section from 'b' to 'c' that is known as superelevation runoff. Now let us also see this sketch, this is the typical diagram of whatever we have discussed now.

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This is the normal cross section at this point. This is earlier 'a' to 'b' so this length is actually known as tangent runoff and then from this cross slope to the required cross slope for superelevation say this is 'c' so this is again achieved over a length which is known as superelevation runoff. Here the rotation is with respect to center line. Now, as I indicated we shall discuss the transition control for tangent-to-curve transition as well as for spiral curve transition. Let us talk first about the tangent-to-curve transition. Now in tangent-to-curve transition two elements are important for us; one is the length of superelevation runoff and the second item is the length of tangent runoff. Now let us see first length of superelevation runoff for tangent-to-curve transition. Let us look at these items.

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Considering the appearance and comfort there should be a maximum acceptable difference between the longitudinal grades of the axis of rotation and the edge of the pavement. Nearly a similar aspect we have discussed when we discussed the Indian Roads Congress approach for determining the length of transition curve. So there should be a maximum acceptable difference considering the appearance and comfort. Now in IRC a single value was recommended for a given terrain condition, it was 1 in 150. In this case **under** the AASHTO recommendations the relative gradient is recognized as a function of design speed so it is not the same rate or same relative gradient that is used. This relative gradient varies with design speed to provide longer runoff lengths at higher speed and shorter length at lower speed. So, relative gradient is not a fixed quantity this is a function of the design speed. Accordingly different values of relative gradients have been suggested.

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Design Speed (km/h)	Max. Relative Gradient (%)	Equivalent Max. Relative Slope
20	0.80	1:125
50	0.65	1:150
130	0.35	1:286

In AASHTO guideline ranging from design speed 20 to 130. Accordingly maximum relative gradients are 0.08 for 20 km/h design speed and 0.035 for 130 km/h design speed. Now the corresponding equivalent maximum relative slopes are 1:125 and 1:286. That means for higher speed and lower speed maximum relative gradient and the equivalent maximum relative slope values are different. Now limiting these two values means for 20 and for 130 for intermediate speeds the value of maximum relative gradient or equivalent maximum relative slope are interpolated from 0.08 to 0.035 similarly 1:125 to 1:286 say for example for a value of 50 Km/h maximum relative gradient becomes 0.65 and the corresponding equivalent maximum relative slope is 1:150.

You may recall our discussion about Indian Roads Congress provision for design of length of transition curve. The rate recommended for plain and rolling terrain is 1:150 which means that basically corresponds to 50 km design speed but IRC does not change this value the value of relative slope depending on speed but AASHTO recommends different value of maximum relative gradient or equivalent maximum relative slope as a function of design speed. So accordingly these values are to be taken for designing purpose. Intermediate values are also given by interpolating these two extreme values and those are given in AASHTO guideline.

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Minimum length of runoff:
$$L_r = \frac{(wn_1)e_d}{\delta} (b_w)$$

n_1 = No of lane rotated

w = Width of one traffic lane, m

e_d = Design superelevation rate, percent

δ = Maximum relative gradient

b_w = Adjustment factor for number of lane rotated

The slide also includes a small diagram of a road cross-section showing the transition from a flat surface to a superelevated surface, with a vertical curve length L_r indicated.

Now considering these aspects the minimum length of runoff is decided using this formula. This is the equation what is used $L_r = wn_1$ into e_d by δ multiplied by b_w . Now let us try to understand this equation first excluding this term b_w . That means initially without considering b_w . Now w is the width of one traffic lane expressed in meter and n_1 is the number of lanes rotated. So, if we consider a two lane road and the rotation is with respect to the center line then $n_1 = 1$. Similarly if it is a four lane undivided road and the rotation is with respect to the center line then $n_1 = 2$. If it is a six lane divided road and the rotation is with respect to the center line then the value of $n_1 = 3$. So accordingly wn_1 gives us the total length width that is going to be rotated. This term is multiplied by e_d , e_d is nothing but the designed superelevation rate in percentage.

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Minimum length of runoff:
$$L_r = \frac{(wn_1)e_d}{\delta} (b_w)$$

n_1 = No of lane rotated

w = Width of one traffic lane, m

e_d = Design superelevation rate, percent

δ = Maximum relative gradient


b_w = Adjustment factor for number of lane rotated

The slide also includes a small diagram of a road cross-section showing the transition from a flat surface to a sloped surface with a gradient δ .

So what it gives us basically is suppose this is the rotation with respect to center line say this is the center line then wn_1 into e_d gives us this distance. Now this is the wn_1 and e_d is the designed superelevation rate. Now this much change is to be achieved over a length with delta maximum relative gradient. So delta is the maximum relative gradient. So what is the length required? Length required would be then wn_1 into e_d by delta so that much length will be required to achieve this required superelevation with maximum relative gradient.

Now if we use only this part of the equation then whatever will be the required length for a two lane divided road rotated with respect to center line the requirement for a four lane undivided road all are undivided road so two lane undivided road and again four lane undivided road with respect to rotation with respect to center line the required length in the second case will be twice the length required in the first case. Let us consider that all are undivided roads, and similarly if we consider a six lane undivided road the required length will be three times than what was the requirement for a two lane undivided road. So it will be just proportional to the number of lengths rotated. Now practically or say from theoretical point of view that much length may be desirable but it may not be practical to consider that much requirement of length.

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Minimum length of runoff:
$$L_r = \frac{(wn_1)e_d}{\delta} (b_w)$$


n_1 = No of lane rotated

w = Width of one traffic lane, m

e_d = Design superelevation rate, percent


δ = Maximum relative gradient

b_w = Adjustment factor for number of lane rotated



Therefore this value b_w is used to adjust this length requirement. So b_w is multiplied which is known as adjustment factor for number of lanes rotated.

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 **Indian Institute of Technology, Kharagpur**

$$L_r = \frac{(wn_1)e_d}{\delta} (b_w)$$

No of lanes rotated	Adjustment factor	Length increase relative to one lane rotated
1	1.00	1.0
3	0.67	2.0

Runoff lengths are adjusted downward on a purely empirical basis to avoid excessive lengths for multilane highways

Therefore this b values or b_w values of this factor is suggested. AASHTO guidelines again give us or indicate the factors for different number of lanes rotated starting from 1, 1.5, 2, 2.5, 3, 3.5 and so on. Say for 1 the adjustment factor is 1 so length increase relative to one lane rotated is also 1 there is no change. But as the number of lanes rotated is increasing say for 3 this b_w factor is suggested as point six seven. So, actual length increase relative to one length rotated becomes 2. That means for three lanes rotated the length is not three times as compared to the first case

here but it is basically two times. Therefore runoff lengths are basically adjusted downward this is important.

The runoff length is adjusted downward on a purely empirical basis to avoid excessive lengths for multilane highways. So to avoid excessive lanes for multilane highways this factor b_w adjustment factor is used to have downward adjustment in road length runoff length and to avoid excessive length for multilane highways. That's about the runoff length as what should be the length of runoff. Now the other component for tangent-to-curve transition what will be the length of tangent runout. Now for tangent runout the length will depend on what is the normal cross slope that is to be removed. Because if you remember correctly the tangent runout length is required to have a cross section from the normal cambered section to the outer edge which is flat. That means how much crown or how much negative slope is to be removed, number one and at which rate it is to be removed. These are the two principle considerations that will decide the length of tangent runout.

Now whatever relative gradient is used it is same as whatever is used for the calculation of superelevation runoff. That means for superelevation runoff whatever relative gradient is used the same amount of relative gradient is used for the calculation of tangent runout. And considering similar triangles this calculation can be done.

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Minimum length of tangent runout

- Depends on amount of adverse cross slope to be removed and the rate at which it is removed
- Relative gradient: same as used for superelevation runoff


$$L_t = \frac{e_{NC}}{e_d} L_r$$

L_t = Min. length of TR, m
 L_r = Min. length of SR, m
 e_d = Design superelevation rate, %
 e_{NC} = normal cross slope rate, %

The diagram shows a cross-section of a road with a normal cambered section (red line) and a flat outer edge (blue line). The tangent runout length L_t is the horizontal distance from the start of the flat section to the start of the cambered section. The superelevation runoff length L_r is the horizontal distance from the start of the cambered section to the end of the cambered section. The diagram illustrates the relationship between these lengths and the slopes e_d and e_{NC} .

As I indicated minimum length of tangent runout depends on amount of adverse cross slope that is to be removed and also number two the rate at which it is removed. So now as far as the rate is concerned this relative gradient used is same as whatever is used for superelevation runoff. So look at this sketch now.


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 **Indian Institute of Technology, Kharagpur**

Minimum length of tangent runout

- Depends on amount of adverse cross slope to be removed and the rate at which it is removed
- Relative gradient: same as used for superelevation runoff


$$L_t = \frac{e_{NC}}{e_d} L_r$$



L_t = Min. length of TR, m
 L_r = Min. length of SR, m
 e_d = Design superelevation rate, %
 e_{NC} = normal cross slope rate, %

if L_r is the length of runoff that is required to achieve design superelevation e_d then to remove this normal cross slope e and c indicated here this is the normal outer edge position whatever length is required that is nothing but the tangent runout. So L_t is e_{NC} by e_d multiplied by L_r this basically means that the same relative gradient is used. One can also consider this. These are the two similar triangles, this is one and this is another one. So if this is the length required for e_d design superelevation then whatever is the length required for or to remove this normal cross slope that length is decided that is L_t so that way one can calculate the minimum length of tangent runout.

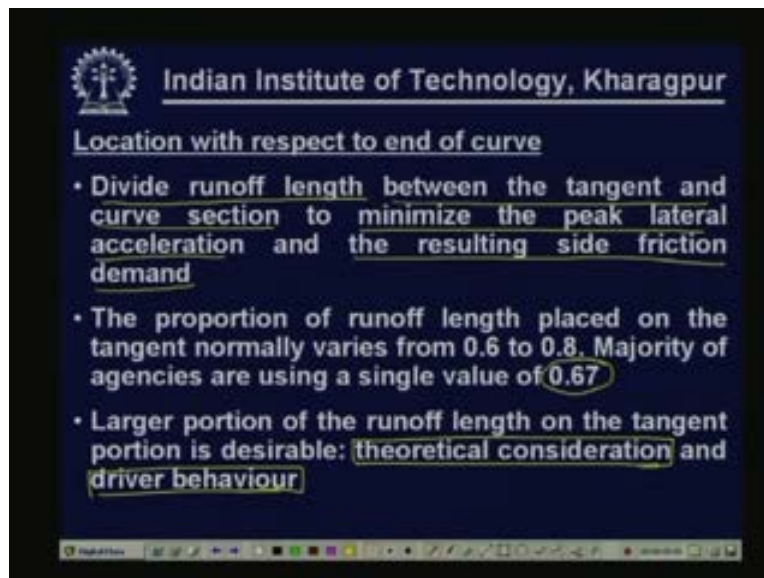
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Design Speed (km/h)	Minimum runoff length (m) (Based on 3.6m lane, 2% normal camber and one lane rotated)				Runout (m)	
	Superelevation (%)					
	2	4			12	Any
20	9	18			54	9
130	21	41			124	21

We have discussed two aspects; minimum runoff length and minimum runout length. Now both aspects and both minimum runoff length and runout length predominantly are a function of the design speed. So, for different design speed the values can be estimated 20 km/h to 130 km/h and also it depends on the maximum superelevation rate starting from 2% it goes up to 12% because AASHTO allows maximum superelevation rate up to 12% to 2%, 4, 6, 8, 10 and 12. Now for all these conditions depending on speed number one depending on maximum superelevation is permissible and the value of minimum runoff length and the runout can be estimated. So those values are estimated and are given in tabular form. So, one can pick up the appropriate value from the table. All these values are given in AASHTO guideline.

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Location with respect to the end of curve: Remember that we are discussing superelevation runoff length for a situation which is tangent-to-curve transition. That means there is no transition curve or spiral curve in between the tangent and the circular curve. So now the question comes we know what is the length of superelevation runoff should we provide the whole superelevation runoff length on the tangent portion itself or we provide the whole superelevation runoff length on a circular curve portion. Now for tangent portion actually the radius is infinity and as such there is no need of superelevation. So, if we provide the complete superelevation on tangent then that superelevation may not be necessary at all considering the radius and considering the movement on tangent portion.

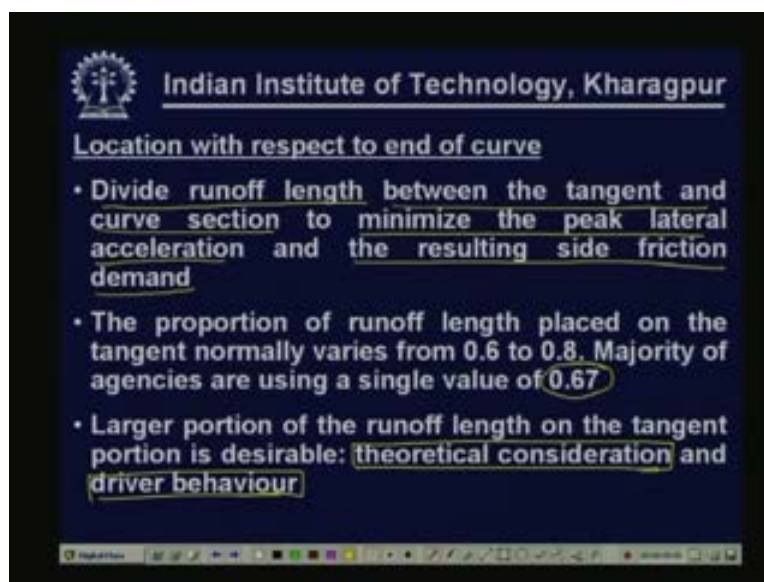
However, if we start introducing the superelevation from tangent portion onwards and the superelevation runoff length completely comes on the circular curve portion then once the vehicle enters into circular curve portion the required superelevation corresponding to the radius of curve for the circular curve portion will not be available to vehicles so that's again is not desirable. So it is neither preferable to have the complete runoff length on tangent nor it is required or nor it is desirable to have the complete runoff length on the circular curve portion. Both have their own disadvantages. So what is normally done or what is normally preferable is to divide runoff length between tangent and the curve section to minimize the peak lateral

acceleration and the resulting side friction demand, that's what is indicated. So, divide the runoff length between the tangent and curve section instead of providing the whole runoff length either on tangent or on curve section and this is done to minimize the peak lateral acceleration and the resulting side friction demand.

Then immediately the question comes at what proportion? How much then on tangent and how much on the circular transportation portion? Many agencies actually follow different standards, different proportions etc, and it varies from 0.6 to 0.08 on the tangent portion. That means 60 to 80% of the runoff length is provided on the tangent portion itself, it varies from 60 to 80 that means from 0.06 to 0.08 that's the factor and a large number of agencies are using point six seven which is nothing but two third. So two third of the superelevation runoff length is on tangent and the remaining one third on circular curve. Now here we can recall our discussions about the Indian Roads Congress specification where I have mentioned that as per IRC the distribution recommended is **one third** that means 67% and 33%. So again there is a similarity and there is a kind of compatibility between AASHTO recommendations and the recommendations given by the Indian Roads Congress so it may vary from 0.06 to 0.08 and a large number of organizations are actually using a single value which is 0.067.

Now from theoretical considerations that is this peak lateral acceleration and also considering the driver behavior. So one is theoretical consideration the other aspect is the driver behavior. I have mentioned it earlier also, the natural path of driving is spiral and that itself follows a transition curve. So, even if no transition curve is present in reality the natural path of driving is transition and more specifically it is spiral transition. Thus considering this theoretical aspect and considering the natural path of driving it is desirable to place a longer proportion of the runoff length on the tangent portion itself as indicated here.

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Larger portion of the runoff length on the tangent portion is desirable from theoretical consideration and also from the consideration of driver behavior.

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Design Speed (km/h)	Portion of runoff located prior to the curve			
	No. of lanes rotated			
	1.0	1.5	2.0-2.5	3.0-3.5
20-70	0.8			0.9
80-130	0.7			0.85

- Existing practice indicates that 10 percent variation does not lead to any major operational problems
- A single value (say, 0.67) may also be adopted

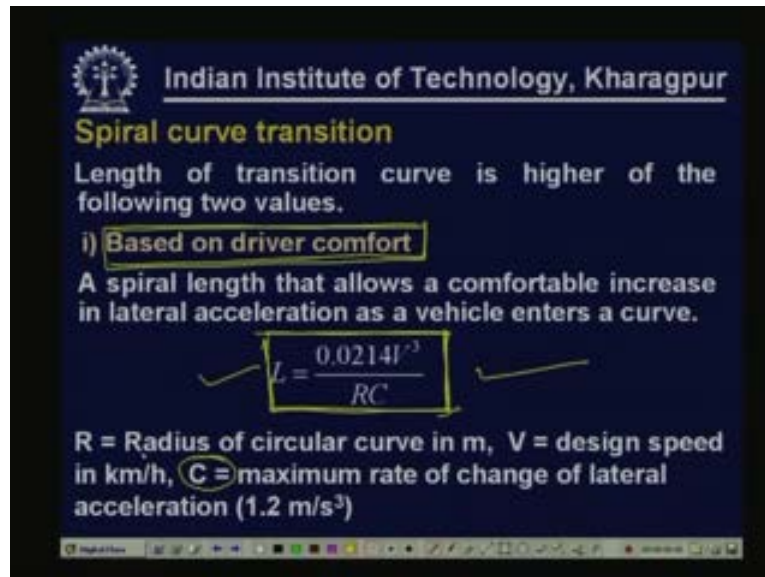
Accordingly AASHTO suggests the portion of runoff length located prior to curve or on tangent portion making it a function of the design speed range. One is used as 20 to 70 km/h and another is in the range of 80 to 100 and 30 km/h. So we can say that this one is a lower speed range and 80 to 130 may be used for higher speed range and also it depends on the number of lanes rotated. so making it a function of the design speed range and the number of lanes rotated the portion of runoff length which is to be located on the tangent portion is decided and that proportion varies from 0.7 to 0.9 and accordingly for different number of lanes rotated 1.5 and 2 to 2.5 these intermediate values are suggested. All these values are available in AASHTO guidelines. I have indicated a few values just to indicate the trend or explain the trend.

Now with all these if we again look at the existing practice that means most of the agencies or a large number of agencies at least they are using 60 to 80% superelevation runoff length on tangent portion and a large number of agencies they are actually using 0.067 that means two third of the total superelevation runoff length on tangent portion. If we look at the existing practice in the light of these theoretical considerations or the values which are recommended by AASHTO guideline and as I have indicated a few minutes back it is found that a minor variation say ten percent variation does not really affect the overall operation to that extent. That means existing practice indicates that ten percent variation does not lead to major operational problem. Therefore although these are recommended as I have shown here in tabular form a single value say 0.67 may also be adopted.

However, wherever situation permits, wherever condition permit a more refined design standard may be adopted as indicated in this table. That means different proportion depending on the number of lanes rotated and also depending on the design speed. So that is a more refined design consideration but a single value is also accepted. That completes our discussion about tangent-to-curve transition. we have discussed what should be the minimum length of superelevation runoff, what should be the minimum length of tangent runout and the location, that is how to distribute

the superelevation runoff length between the tangent length and also the length of the circular curve.

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Indian Institute of Technology, Kharagpur

Spiral curve transition

Length of transition curve is higher of the following two values.

i) **Based on driver comfort**

A spiral length that allows a comfortable increase in lateral acceleration as a vehicle enters a curve.

$$L = \frac{0.0214V^3}{RC}$$

R = Radius of circular curve in m, V = design speed in km/h, C = maximum rate of change of lateral acceleration (1.2 m/s³)

Now let us talk about the spiral curve transition. In spiral curve transition two aspects are generally considered and whatever lengths are calculated based on strong two different aspects the larger value is accepted as the minimum required length of spiral curve. The first criteria is based on driver's comfort and the second one is based on the lateral shift. now this first criteria based on driver's comfort is similar to what we have already discussed when we discussed about the Indian Roads Congress provision, a maximum value of the rate of change of centrifugal acceleration, so if length is known, velocity is known then we have to know the time taken to cover the length of transition curve. Now the maximum lateral acceleration V^2/r is introduced in that time so what will be the lateral acceleration that can be estimated and accordingly we calculated the required length of the transition curve, the same basis is used here.

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Indian Institute of Technology, Kharagpur

Spiral curve transition

Length of transition curve is higher of the following two values.

i) **Based on driver comfort**

A spiral length that allows a comfortable increase in lateral acceleration as a vehicle enters a curve.

$$L = \frac{0.0214V^3}{RC}$$

R = Radius of circular curve in m, V = design speed in km/h, C = maximum rate of change of lateral acceleration (1.2 m/s³) (0.5 - 0.8)

Let us look at the formula; it is $0.0214V^3$ by RC , L is the required length of transition curve, V is the design speed in km/h, R is the radius of circular curve in meter and C is the maximum rate of change of lateral acceleration. So the basic formulation this equation what I am showing here this is similar to what was discussed and what was mentioned when we talked about the IRC recommendations. The only difference was that the value was $0.0214V^3$ by RC and here it is $0.0214V^3$ by RC that's the only difference but basically it is the same equation.

Now the difference is basically in the consideration of C that is the maximum rate of change of lateral acceleration. In Indian Roads Congress guideline an empirical formula was suggested for the calculation of the design C value and also there was an upper limit a lower limit. C was recommended to be between 0.5 to 0.8 although there was an empirical equation formula for the calculation of C but this lower and upper limit also should be changed as per IRC and that value was point five to point eight in between 0.5 and 0.8.

In this case as per AASHTO the value what is normally used is 1.2 m per second cube and that's the major difference. In IRC it was 0.5 to 0.8 if I remember correctly this value was 0.5 to 0.8 and in this case 1.2 meter per second cube is allowed so that's the value of C what is normally used. Of course there are many agencies which are using a value other than 1.2, lesser values are also used. Sometimes values in this range 0.5 to 0.8 are also used by many agencies. This is also used but the recommended value is 1.2 meter per second cube.

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The slide is from the Indian Institute of Technology, Kharagpur. It is titled 'ii) Based on lateral shift'. The text explains that to ensure a spiral curve is sufficiently long, it must provide a shift in a vehicle's lateral position within its lane that is consistent with that produced by the vehicle's natural spiral path. The formula for the minimum length of the spiral curve is given as $L_{s \min} = \sqrt{(24p_{\min} R)}$. The minimum lateral offset p_{\min} is defined as the minimum lateral offset between the tangent and circular curve, with a value of 0.2 m. It is noted that 0.2 m is consistent with the minimum lateral shift that occurs as a result of natural steering behaviour of most drivers.

Indian Institute of Technology, Kharagpur

ii) Based on lateral shift

To ensure that a spiral curve is sufficiently long to provide a shift in a vehicle's lateral position within its lane that is consistent with that produced by vehicle's natural spiral path

$$L_{s \min} = \sqrt{(24p_{\min} R)}$$

p_{\min} = Minimum lateral offset between the tangent and circular curve (0.2 m)

p_{\min} as 0.2 m is consistent with the minimum lateral shift that occurs as a result of natural steering behaviour of most drivers

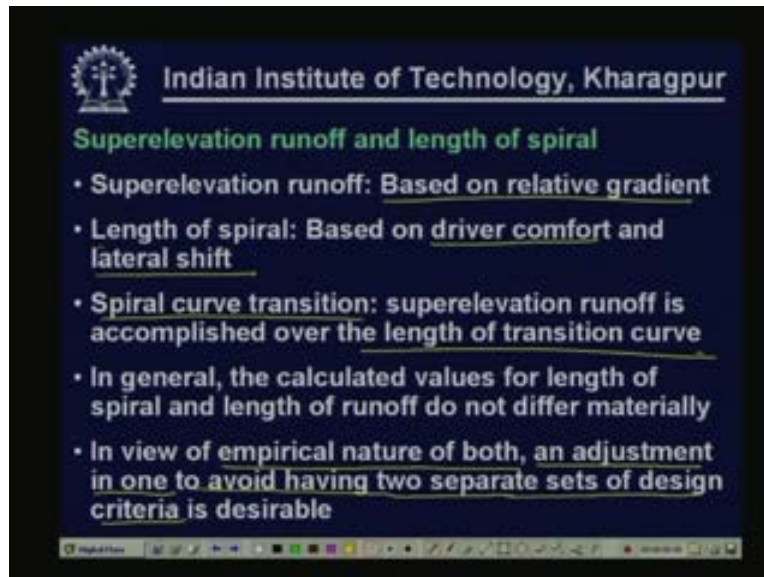
Now the other consideration is based on lateral shift. This was not covered while we discussed about the Indian Roads Congress provision. Now this is basically to ensure that a spiral curve is sufficiently long to provide a shift in a vehicle's lateral position within its lane that is consistent with that produced by vehicle's natural spiral path. So vehicles take a natural spiral path which is the normal behavior. So considering the vehicle's natural path we are considering this lateral shift as criteria to ensure that spiral curve length is sufficiently long to provide a shift in a vehicle's lateral position within its length. That means it does not encroach the adjacent length within its length that is consistent with that produced by vehicle's natural spiral path.

Now while talking about this spiral curve and its different properties we gave a formulation how to calculate the shift. That shift was calculated using the formula L_s square by $24R$ this was mentioned in lesson 3.10. Using the same basis we are now actually calculating the required minimum length for a given design value of p minimum. So this is the formula what is used; L_s minimum is root over $24p_{\min}$ multiplied by R and the value of p_{\min} that is minimum lateral offset between the tangent and the circular curve is used for design purpose and the value we used is 0.2 m. So 0.2 m value is taken for design for the calculation of minimum length of spiral considering the lateral shift and to ensure that spiral curve is sufficiently long to provide a shift in a vehicle's lateral position within its length that is consistent with what is produced by vehicle's natural spiral path.

Now it may be mentioned here that the value design value of 0.2 m what is taken as for the value of p minimum it is consistent with the minimum lateral shift. This value of p minimum as 0.2 m is consistent with the minimum lateral shift and that occurs as a result of natural steering behavior of most drivers, not all drivers but most drivers. Considering most drivers whatever the minimum lateral shift is I will emphasize on this part minimum lateral shift so it is consistent with the minimum lateral shift that occurs as a result of natural steering behavior of most drivers then we can get the value of L_s minimum.

Now considering both these aspects that means considering the driver's comfort we calculate the length of curve, considering the lateral shift we calculate the length of curve and whatever gives us the higher value that is to be taken as the minimum acceptable length of spiral.

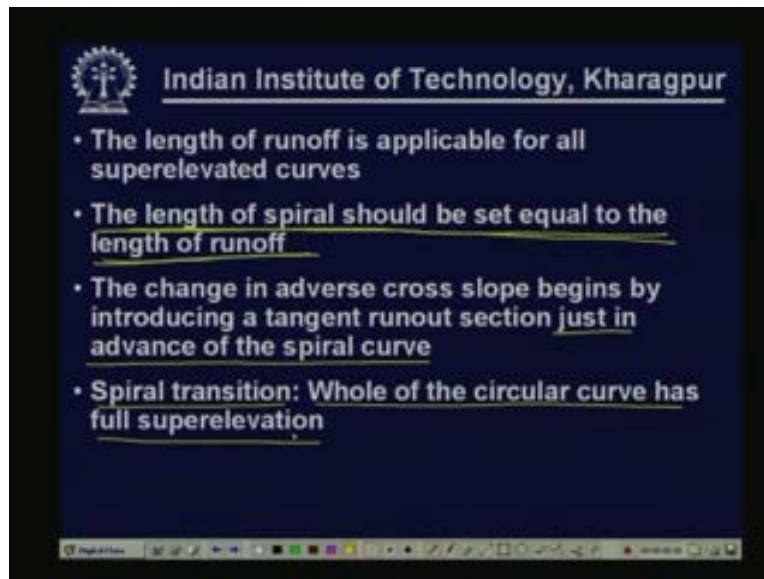
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Now we again look at superelevation runoff and length of spiral. The superelevation runoff is provided based on relative gradient, we have discussed it already. So superelevation runoff is calculated based on relative gradient and length of spiral is calculated based on driver comfort and lateral shift. Now, wherever there is a spiral curve transition the superelevation runoff is accomplished over the length of transition curve. That means superelevation runoff is accomplished over the length of transition curve. Now this raise a question that means there is a necessity that length of spiral and superelevation runoff they must be compatible to each other, compatibility it is required. It is because for spiral curve transition the superelevation runoff is accomplished over the length of transition curve.

Now in general the calculated values for length of spiral and length of runoff do not differ materially they are nearly same in most of the cases. However, as both of them are calculated using empirical basis or in view of empirical nature of calculation it is desirable to have an adjustment in one to avoid having two separate sets of design criteria. That means basis for superelevation runoff calculation and basis for length of spiral calculation they are not same they are different and we are saying for spiral curve transition superelevation runoff is accomplished over the length of transition curve so there has to be compatibility between the two. In most of the cases they are not different but because they are basically empirical in nature the calculation therefore it's better to have an adjustment in one to avoid having two separate sets of design criteria.

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Now the length of runoff applicable is applicable for all superelevated curves whether it is spiral transition or it is tangent-to-curve transition in both cases it is valid. Therefore what is recommended normally is the length of spiral should be set equal to the length of runoff. I repeat this part, the length of spiral should be set equal to the length of runoff then there won't be any compatibility problem. So two different design criteria will not appear, there will be over all compatibility.

Now obviously before we do that the change in adverse cross slope is done by providing tangent runout and this change in adverse also begins by introducing a tangent runout section just in advance of the spiral curve and in following this design standard wherever we are using spiral transition and following this basis the whole of the circular curve will have full superelevation.

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Maximum length of spiral

- Safety problems occur on spiral curves that are very long (relative to the length of circular curve)
- Mislead the driver about the sharpness of the approaching curve

$L_{s \max} = \sqrt{24p_{\max} R}$

p_{\max} = Maximum lateral offset between curve and tangent (1.0 m)

p_{\max} as 1.0 m is consistent with the maximum lateral shift that occurs as a result of natural steering behaviour of most drivers – also provides a reasonable balance between spiral length and curve radius

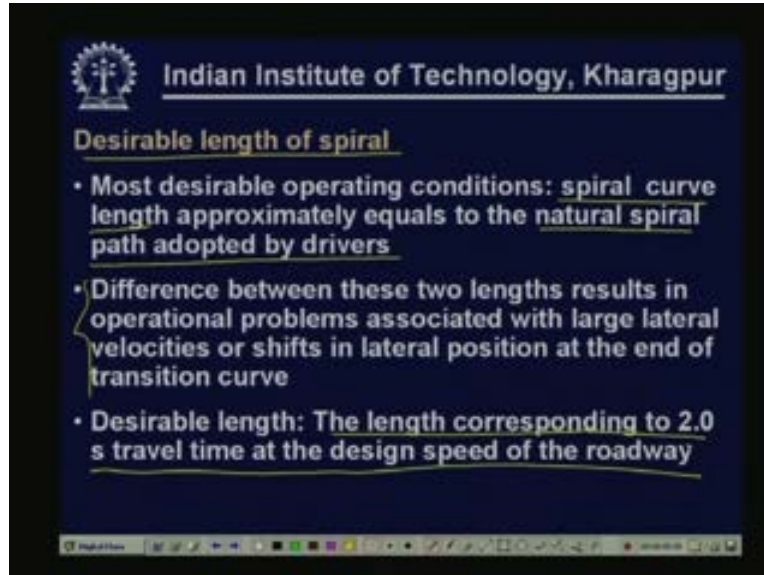
Now there is also a provision for maximum length of spiral, why it is so?

We have discussed about the minimum required length of spiral, what happens if we provide a longer length. Let us **stretch ourselves** our thinking, if we provide a very long length there are problems and that's what indicates the need for deciding a maximum length of spiral. Now there could be safety problems on spiral curves that are very long very long relative to the length of circular curve. So we are talking about conditions where spiral curves are there but length of the spiral curve the lengths are very long as compared to the length of the circular curve.

Now what is the problem? Why we are talking that there could be safety problems. Because those conditions may mislead the driver about the sharpness of the approaching circular curve because circular curve has a designated radius and if the transition length is too long then that may mislead the driver about the sharpness of the approaching curve and eventually there would be safety problem. So again a maximum length is suggested using this formula. Already the basis is known but here it is L_s max instead of L_s minimum and instead of p minimum it is p max, the equation is same. And p max is nothing but the maximum lateral offset between the curve and the tangent.

In earlier case when we were calculating the minimum length this was minimum lateral shift between the curve and tangent. In this case it is maximum lateral shift between the curve and the tangent and for design purpose the value is taken as 1 m. Now here also p max as 1 m is consistent with the maximum lateral shift. In earlier cases when we talked about the L_s minimum considering the lateral shift there the recommended value of p minimum was based on minimum lateral shift that occurs. In this case it is based on the maximum lateral shift that occurs as a result of natural steering behavior of most drivers and it also provides this p max as 1.0 m and it also provides a reasonable balance between the spiral length and curve radius. So this equation will give us a maximum limit of the spiral length.

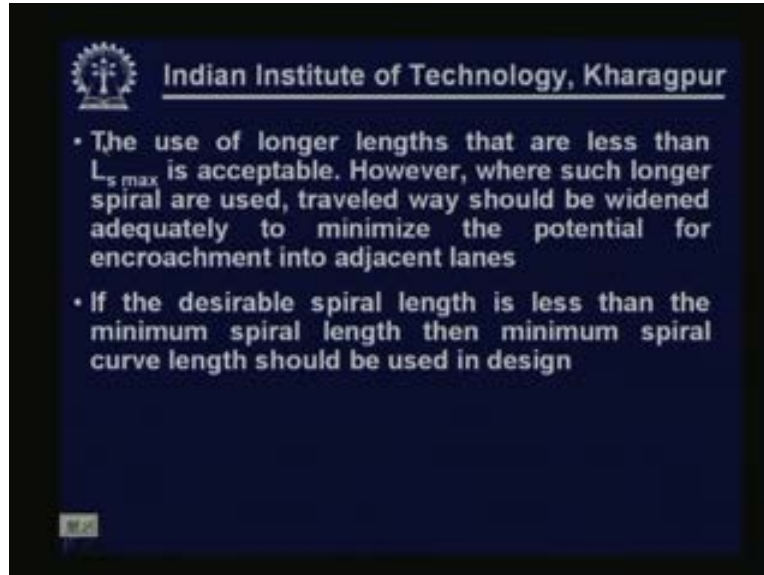
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Now there is something called desirable length of spiral. So we have talked about minimum maximum now it is the desirable length of spiral. Why this desirable length? Most desirable operating conditions are where spiral curve length approximately equals to the natural spiral path adopted by drivers. I have indicated it a number of times that the driver's natural driving path is also spiral. So one is whatever be the driver's natural path for spiral and whatever length the spiral is we are providing those for the design purpose. If both these things are matching that is the most desirable operating condition.

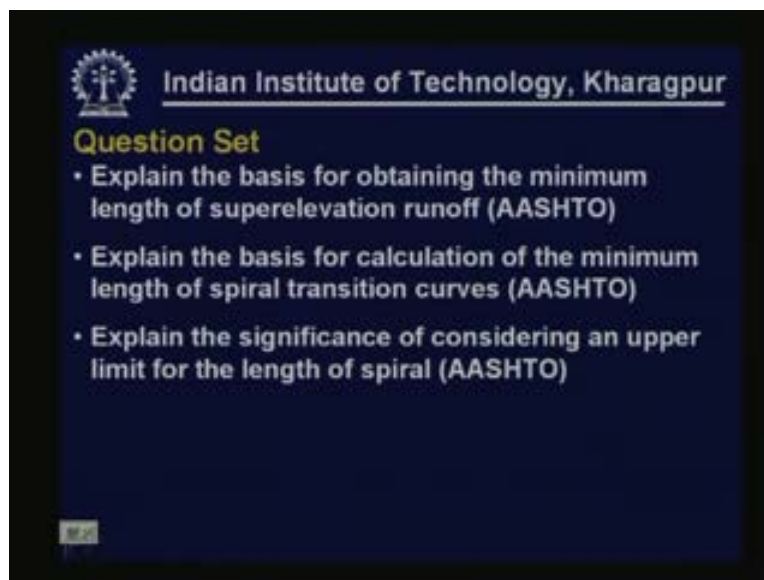
Now difference between these two lengths may result in operational problems associated with large lateral velocities or shift in lateral position at the end of transition curve, that's what tells us the problem. So most desirable condition is spiral curve length equal to the length of natural spiral path adopted by the drivers that is the desirable spiral length and AASHTO recommends that a length corresponding to two seconds travel at the design speed of the roadway will generally give the desirable length of spiral. So desirable length of spiral is two seconds travel at design speed of the roadway and whatever length is covered in two seconds time at design speed that will give us the desirable length of spiral.

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Now if we use the longer lengths which is less than maximum length of spiral then it is fine it is acceptable. However, where such spiral is used traveled way should be widen adequately to minimize the potential for encroachment into adjacent lanes. So longer lengths are fine but adequate widening should be done. If desirable spiral length is less than minimum spiral length then minimum spiral length curve should be used in design. So whatever we are saying as desirable length that is to be checked against the minimum required length and minimum required length must be satisfied.

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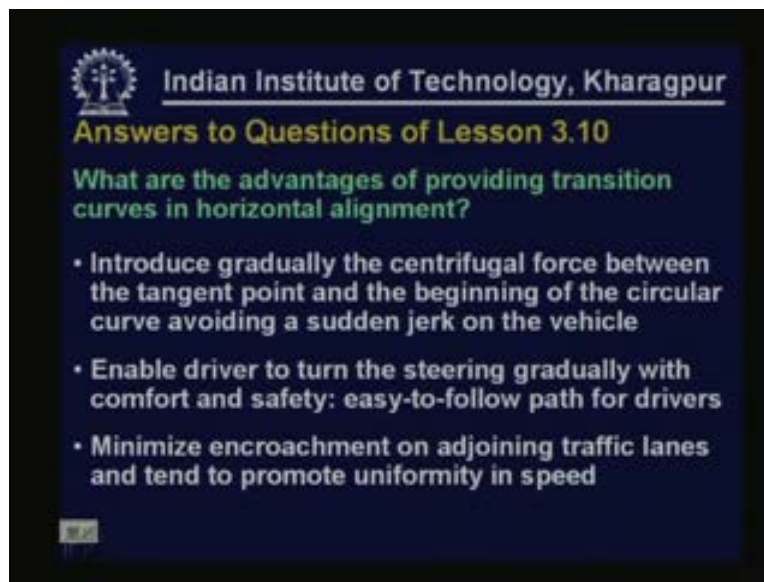


Now let me put some questions.

- 1) Explain the basis for obtaining the minimum length of superelevation runoff as per AASHTO procedure.
- 2) Explain the basis for calculation of the minimum length of spiral transition curves, again as per AASHTO recommendations or AASHTO approach.
- 3) Explain the significance of considering an upper limit for the length of spiral, why an upper limit is suggested in AASHTO design guideline.

Try to answer to these questions.

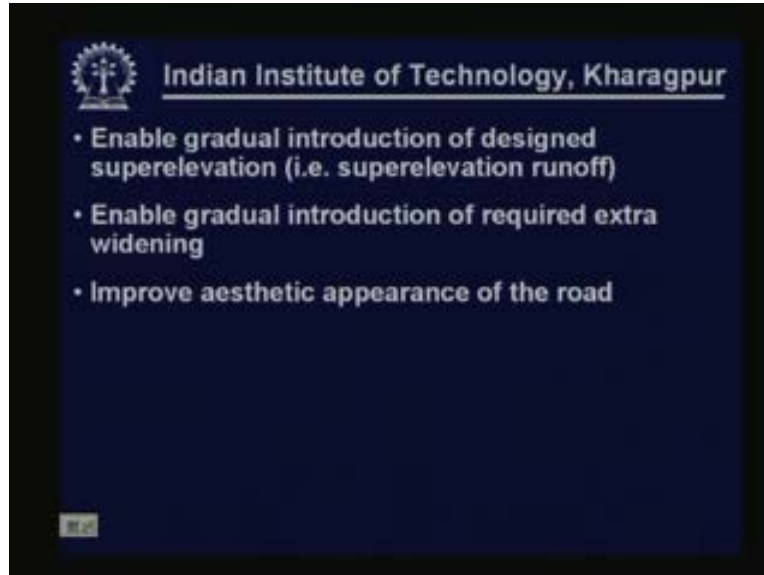
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Now let me try to answer the questions of lesson 3.10. The first question was:

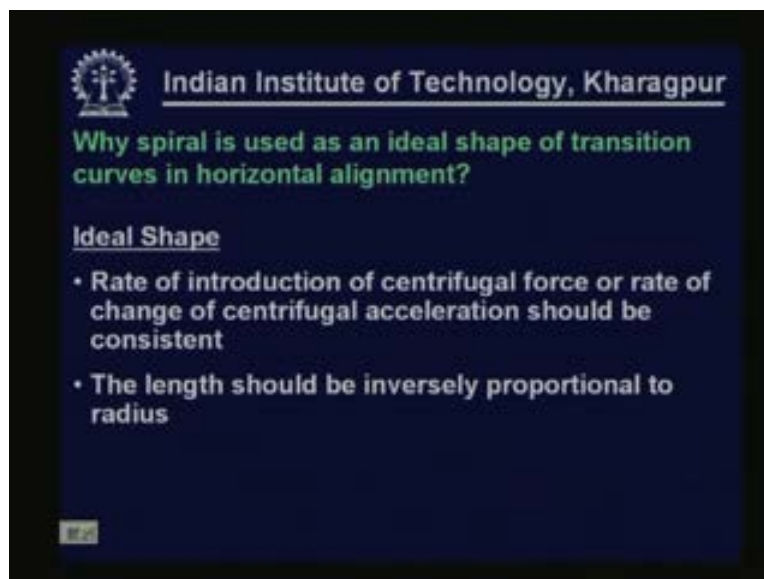
What are the advantages of providing transition curves in horizontal alignment? There are several advantages: it helps us to introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve avoiding any sudden jerk on the vehicle. Enables driver to turn steering gradually with comfort and safety that means we have to give easy-to-follow path for drivers. Minimize encroachment on adjoining traffic lanes and tend to promote uniformity in speed.

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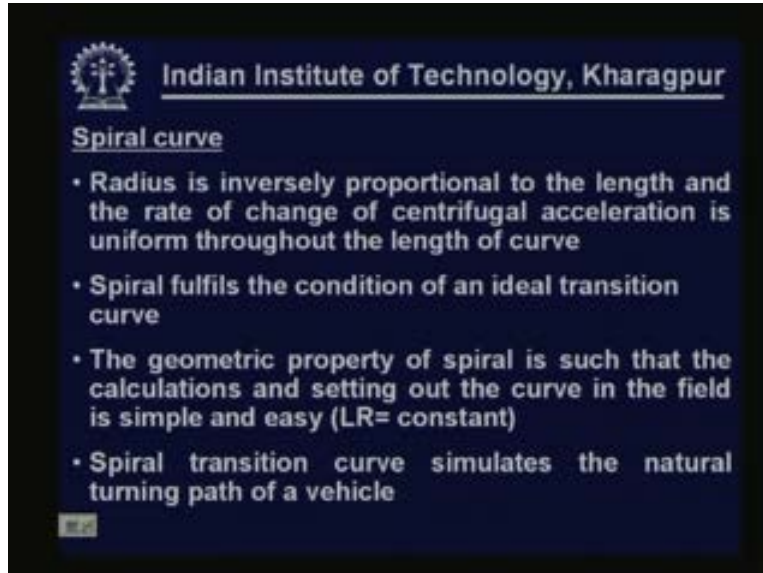
Enabling gradual introduction of design superelevation that is superelevation runoff particularly this length and also enable gradual introduction of required extra widening and finally it improves the aesthetic appearance of the roads. So those are all the advantages of using transition curve.


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Now why spiral is used as an ideal shape of transition curve in horizontal alignment? It is because for ideal shape rate of introduction of centrifugal force or rate of change of centrifugal acceleration should be consistent which means that the length should be inversely proportional to radius.

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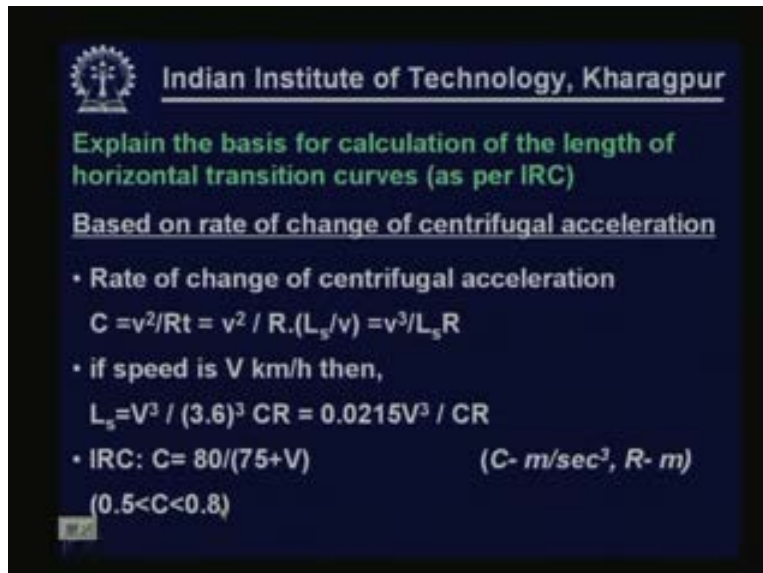
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Spiral curve

- Radius is inversely proportional to the length and the rate of change of centrifugal acceleration is uniform throughout the length of curve
- Spiral fulfils the condition of an ideal transition curve
- The geometric property of spiral is such that the calculations and setting out the curve in the field is simple and easy ($L_R = \text{constant}$)
- Spiral transition curve simulates the natural turning path of a vehicle

Now if you look at the spiral for spiral the radius is inversely proportional to the length and the rate of change of centrifugal acceleration is uniform throughout the length of the curve. That means it tells us that spiral fulfills the condition of an ideal transition curve. Moreover the geometric property of spiral is such that the calculations and setting out the curve in the field is simple and easy because the equation is simple L_R equal to constant. Also, spiral transition curve simulates the natural turning path of a vehicle which is a very important consideration. Therefore spiral is used as an ideal transition curve.

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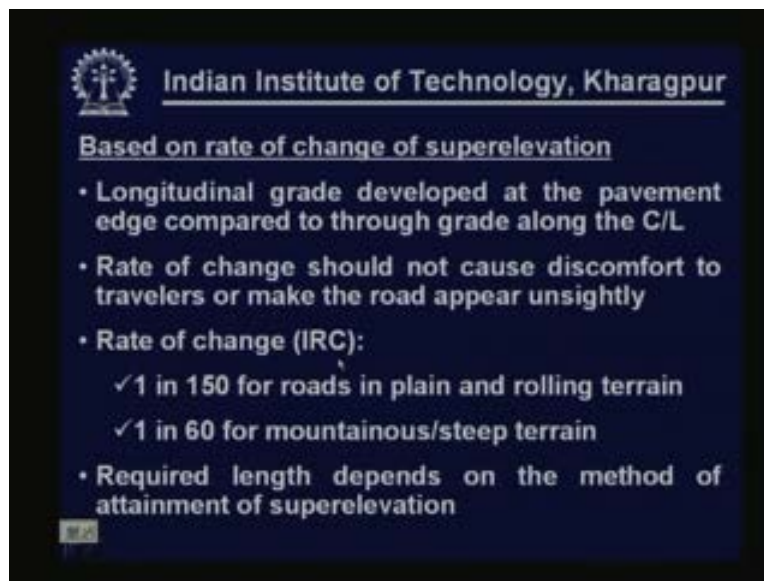
Explain the basis for calculation of the length of horizontal transition curves (as per IRC)

Based on rate of change of centrifugal acceleration

- Rate of change of centrifugal acceleration
$$C = \frac{v^2}{Rt} = \frac{v^2}{R \cdot (L_s/v)} = \frac{v^3}{L_s R}$$
- if speed is V km/h then,
$$L_s = \frac{V^3}{(3.6)^3 CR} = 0.0215 \frac{V^3}{CR}$$
- IRC: $C = 80/(75+V)$ (C - m/sec³, R - m)
($0.5 < C < 0.8$)

Now explain the basis for calculation of the length of horizontal curve as per IRC. one is based on the rate of change of centrifugal acceleration which gives us this basis $L_s = 0.0215V^3$ by CR we have also discussed this basis today and IRC gives this empirical formula $C = 80 \sqrt{75 + V}$ where C is in meter per second cube and V is in km/h so that gives us the design value C and it is to be checked against the lowest and highest value that is 0.5 and 0.8.

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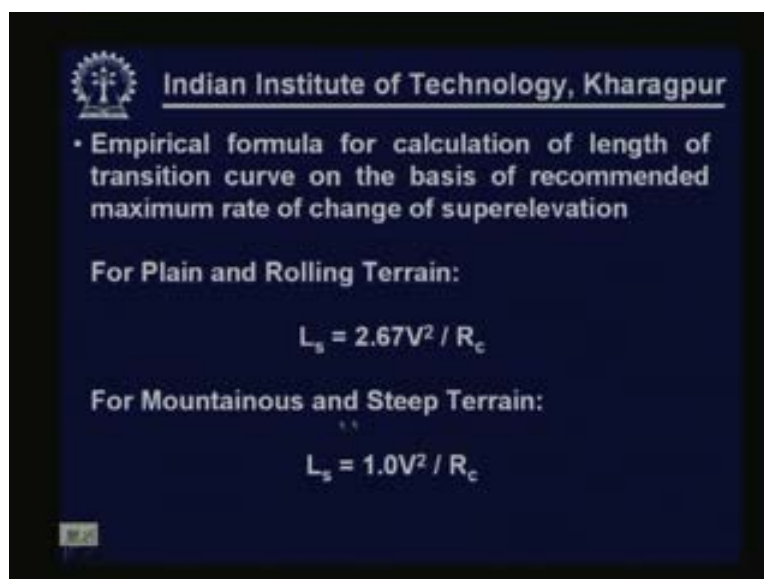
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Based on rate of change of superelevation

- Longitudinal grade developed at the pavement edge compared to through grade along the C/L
- Rate of change should not cause discomfort to travelers or make the road appear unsightly
- Rate of change (IRC):
 - ✓ 1 in 150 for roads in plain and rolling terrain
 - ✓ 1 in 60 for mountainous/steep terrain
- Required length depends on the method of attainment of superelevation

And also based on the change of superelevation the rate of change suggested is 1 in 150 for plain and rolling terrain and 1 in 60 for mountainous and steep terrain. So considering this two the higher value is to be adopted.

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- Empirical formula for calculation of length of transition curve on the basis of recommended maximum rate of change of superelevation

For Plain and Rolling Terrain:

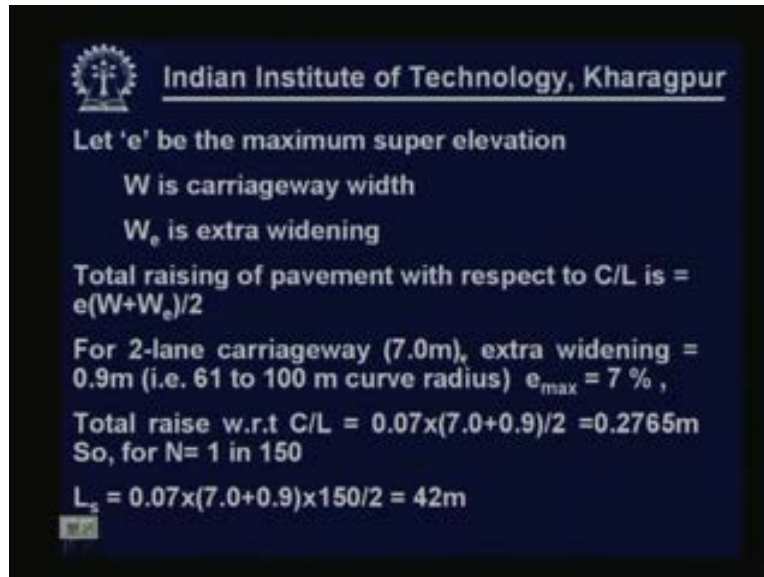
$$L_s = 2.67V^2 / R_c$$

For Mountainous and Steep Terrain:

$$L_s = 1.0V^2 / R_c$$

Also, based on the second consideration the rate of introduction of superelevation IRC suggests two empirical formulas one for plain terrain and one for mountainous and steep terrain so these empirical formulas are also sometimes used as an alternative to the second criteria because it is basically coming from the same basis.

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Let 'e' be the maximum super elevation
W is carriageway width
 W_e is extra widening

Total raising of pavement with respect to C/L is = $e(W+W_e)/2$

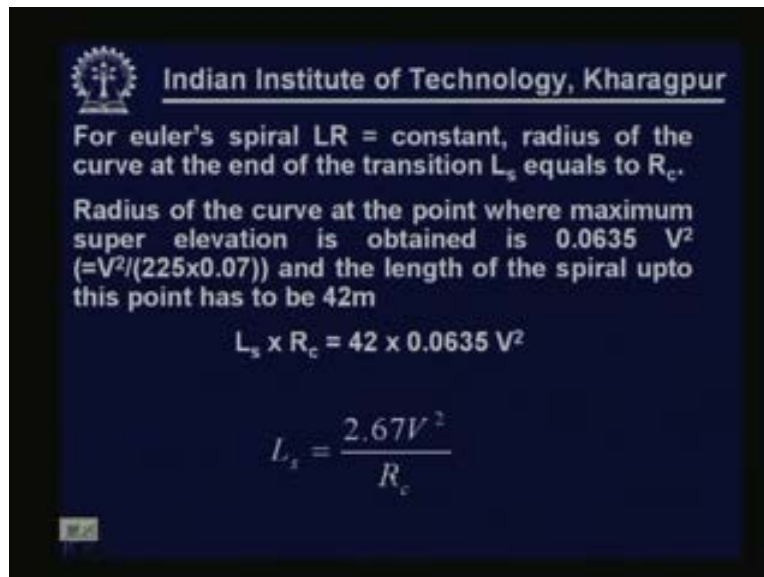
For 2-lane carriageway (7.0m), extra widening = 0.9m (i.e. 61 to 100 m curve radius) $e_{max} = 7\%$,

Total raise w.r.t C/L = $0.07 \times (7.0 + 0.9) / 2 = 0.2765m$
So, for N= 1 in 150

$L_s = 0.07 \times (7.0 + 0.9) \times 150 / 2 = 42m$

Now let us also quickly see how these empirical formulas are derived. If 'e' is the maximum superelevation, W is the carriageway W_e is the extra widening then the total raise of pavement with respect to center line is e into W into W_e divided by 2 why divided by 2 is because rotation is with respect to center line therefore for two lane carriageway it is assumed that the carriageway is two lane with 7m and extra widening is 0.9m so e max is 7% accordingly total raise is 0.2765 so N = 1 in 150 means it is 42m length.

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For Euler's spiral $LR = \text{constant}$, radius of the curve at the end of the transition L_s equals to R_c .

Radius of the curve at the point where maximum super elevation is obtained is $0.0635 V^2$ ($=V^2/(225 \times 0.07)$) and the length of the spiral upto this point has to be 42m

$$L_s \times R_c = 42 \times 0.0635 V^2$$
$$L_s = \frac{2.67 V^2}{R_c}$$

Now because L_r is constant, radius of the curvature at point where maximum superelevation is obtained is $0.0635V$ square this is obtained considering seventy five percent of the design speed IRC provision so V square by $225R = V$ square by $225R$ so $r = V$ square by 225 into e this e value is seven percent so that means L_s into RC equal to this one and $L_s = 2.67V$ square by RC . So you must be careful when you are using this empirical formula because lot of assumptions are involved and has gone inside it, thank you.