Introduction to Transportation Engineering
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Lecture - 19
Horizontal Alignment - Part VI

Horizontal Alignment VI; In lesson 11 we discussed about the AASHTO approach for transition design control considering both tangent to curve transition that means without any transition curve in between and spiral curve transition that is a spiral curve in between the tangent and the circular curve.

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After completing this lesson the student will be able to appreciate the need for extra widening of pavement on horizontal curves, understand the IRC as well as AASHTO approaches for design of extra widening of pavement on horizontal curves and also the student will be able to understand the general controls for highway alignment.

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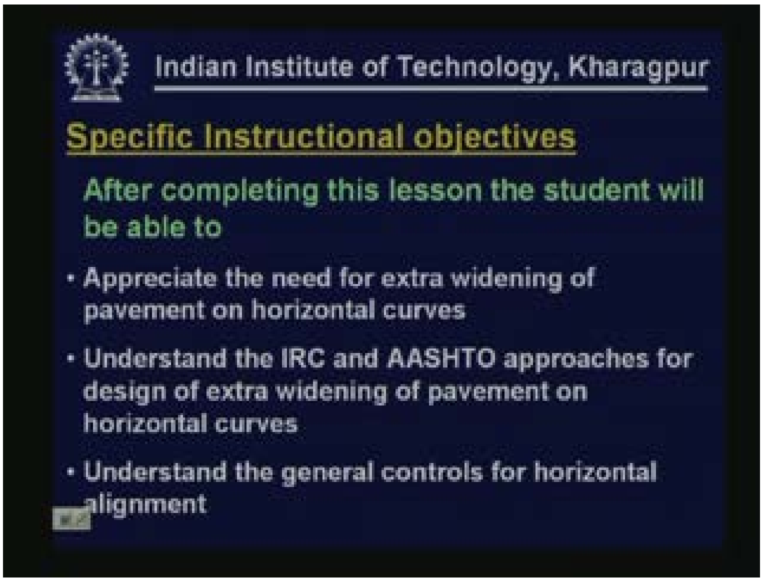

Let us start with the need for extra widening on horizontal curves. Why it is necessary to provide extra widening on horizontal curves. There are primarily two broad reasons; one is off-tracking of vehicles and number two is the psychological reasons. So there are two aspects one is off-tracking of vehicles and the second is psychological aspects. Broadly because of these two reasons it is necessary to widen the road pavement on horizontal curves.

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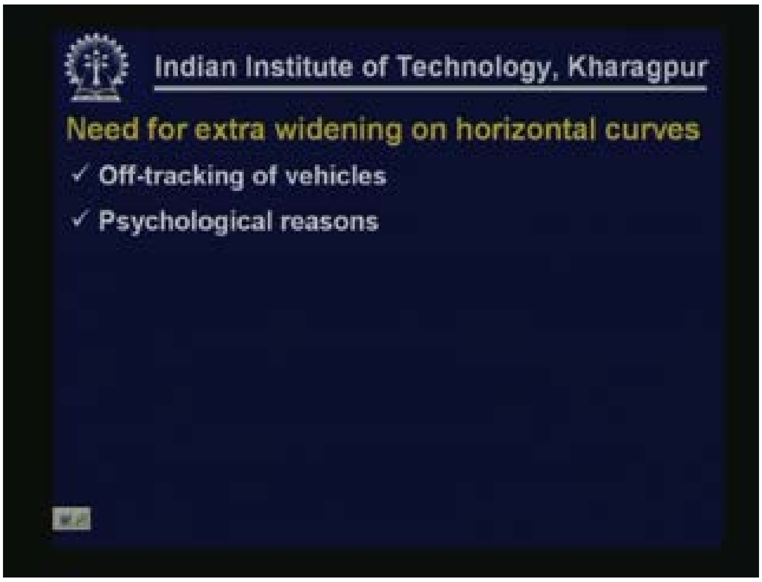

Now let us try to understand these two aspects; first, off-tracking of vehicle and then psychological aspects or psychological reasons. Automobiles have rigid wheelbase and for all these vehicles only the front wheels are turned. When these vehicles negotiate horizontal curve the rear wheels do not follow the same track as that of the front wheels. That means for all these vehicles with rigid wheel base when they negotiate horizontal curves the path followed by rear wheels and the front wheels are different. This is known as off-tracking of vehicles. Off-tracking means rear wheels and front wheels they do not follow the same track.

Obviously for a tangent section we expect rear wheels and front wheels that is, the tyres should follow the same track but on curves they do not follow the same track. A road system is designed for the design speed so when the vehicles are travelling at low speed and may be up to the design speeds we do not expect any lateral slips for the rear wheels because the road system is designed to support up to the design speed so we don't expect any lateral slips of the rear wheels.

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In this case the rear wheels normally will follow the inner side of the curve. That means whatever path will be followed by the front wheels the rear wheel will follow the inner side path. That means if we consider the front inner wheel on the edge of the pavement then the rear inner wheel will be on the shoulder. Basically this means that off-tracking is occurring and the inner wheels or the rear wheels follow the inner path of the curves as compared with corresponding front wheels.

Now, suppose the vehicle travels at a speed higher than the design speed now obviously the road system is designed for the design speed so we normally we do not expect vehicles to travel at a higher speed but if vehicle travels at speed higher than the design speed then the superelevation and the designed side friction will not be adequate to support the centrifugal force which are in operation or which are effective on vehicles on horizontal curves. In that case transverse skidding is possible and rear wheels may follow the outer path as compared with corresponding front wheels. So in this case if the vehicle is travelling at a speed higher than the design speed we do not expect the rear wheels to follow the inner path as compared with corresponding front wheels. Rather in this case the rear wheels may follow the outer part as compared with front wheels. That means altogether whether the rear wheels follow the inner part or the rear wheel follows the outer path one thing is very clear that when the vehicle negotiates with horizontal curves rear and front wheels do not follow the same track and that means off-tracking of vehicles will occur.

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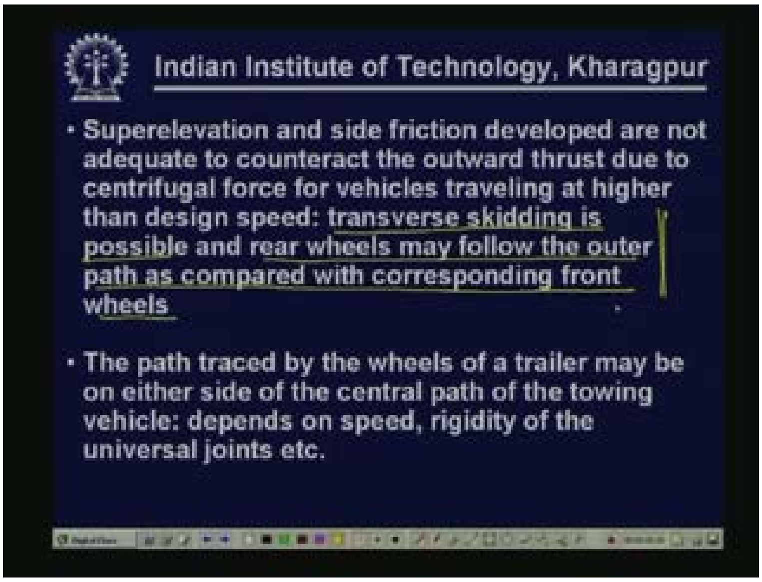

Now what happens when there is a trailer? In case of a trailer the path traced by the wheels of a trailer may be on either side of the central path of the towing vehicle, it may be on the inner side it may be on the outer side with respect to the central path of the towing vehicle depending on speed, rigidity of universal joints and other factors. So in this case also we expect off-tracking. That means off-tracking is a phenomena which is expected to happen for almost all vehicles which are travelling at a lower speed than the design speed, which are travelling also at a higher speed than the design speed and even for trailers off-tracking is expected so the design aspects or the design of curves or road design must consider these aspects and accordingly there is a necessity to widen the road pavement on horizontal curves. Now this is one aspect or it is happening due to off-tracking.

There are psychological reasons also. When the vehicle is on tangent we expect the vehicle to follow the central path. When the vehicle is moving on tangent we expect the vehicle to follow the tangent path. But when vehicles are negotiating a horizontal curve drivers have a tendency to follow or take the outer side of the lane, this is predominantly for two reasons; one is basically to take a path with larger radius so while turning the vehicle the drivers want to feel comfortable and also to have greater visibility. You know that visibility is a problem when vehicles are negotiating horizontal curves so side distance restriction to visibility occurs when at horizontal curves. Therefore vehicles tend to take the outer side of the lane when they are entering into horizontal curves.

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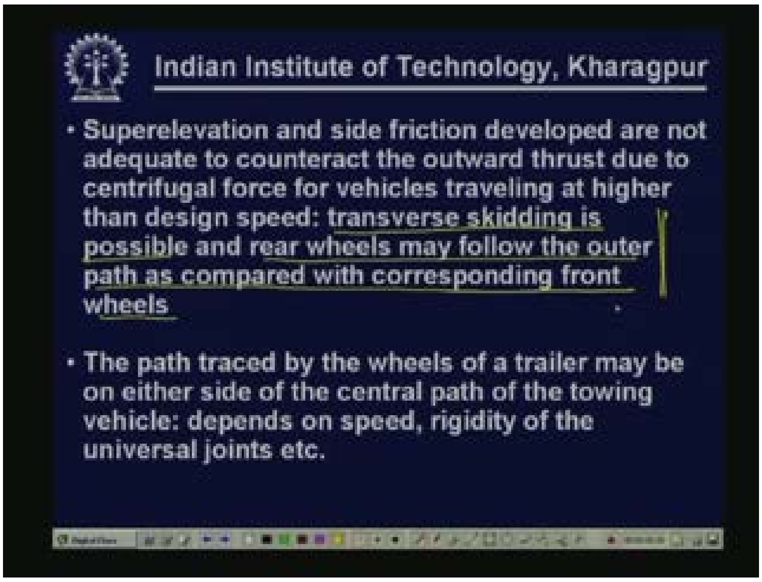

Number two; even on tangent vehicle keeps some lateral clearance. When two vehicles are crossing or passing each other they keep some minimum lateral clearance. This lateral clearance requirement or drivers when they are crossing or overtaking two vehicles or when two vehicles are overtaking the drivers tend to keep more lateral clearance on horizontal curves for psychological reasons. Therefore it is also necessary to consider these psychological aspects of drivers in the design process.

Therefore to summarise widening of road pavement is necessary primarily for two reasons; one is the off-tracking of vehicles that is rear wheels and front wheels they do not follow the same track therefore it is necessary to widen pavement to account for the off-tracking.

Number 2; also for psychological or behavioural aspects of drivers it is necessary to have an extra width. Therefore the design process the off and psychological aspects must be considered and pavement should be widened enough to have safe and confluent operation and operation of traffic to the same standards as it happens on the tangent section.

Now let us see how these aspects are taken into design consideration or what the basis is for design. Now obviously we shall discuss two approaches the approaches considered by the Indian Roads Congress and the approaches considered by AASHTO.

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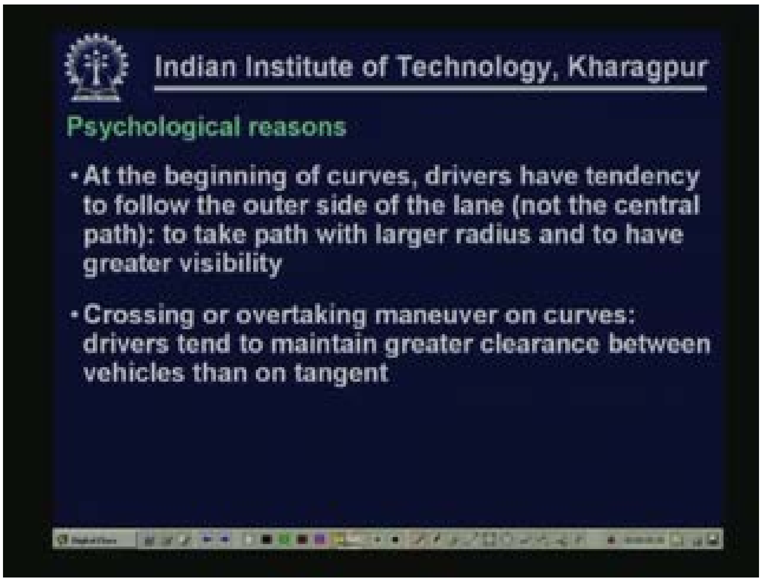

Therefore design of extra widening first let us discuss about the IRC approach or the approach which is recommended by Indian Roads Congress or which are normally in practice in India IRC considers two aspects; one is called mechanical widening and the other is called the psychological widening. so the total required widening is divided into two parts; one is called as mechanical widening or the component of widening which is required to due to mechanical reasons that is nothing but off-tracking and the other part is psychological widening that means the amount of widening which is required for psychological reasons of drivers and that component is known as psychological reasons.

Off-tracking is due to rigidity of wheel base and so this aspect is considered and accordingly the required widening is estimated which is known as mechanical widening and for psychological widening we consider greater manoeuvrability of steering at higher speeds this is one aspect. Also it is the extra space requirements for the overhangs of vehicles which are basically projected. If we take the axles and the tyres and the body there is an overhang portion so it is the extra space requirement for the overhangs of vehicles and also considering the greater clearance for crossing and overtaking of vehicles on horizontal curves. So considering all these aspects we take into account this psychological widening.

Now what should be the values, we know the basis but what should be the values, how much widening should be done considering this off-tracking or mechanical aspects and how much should be done to account for these psychological aspects.

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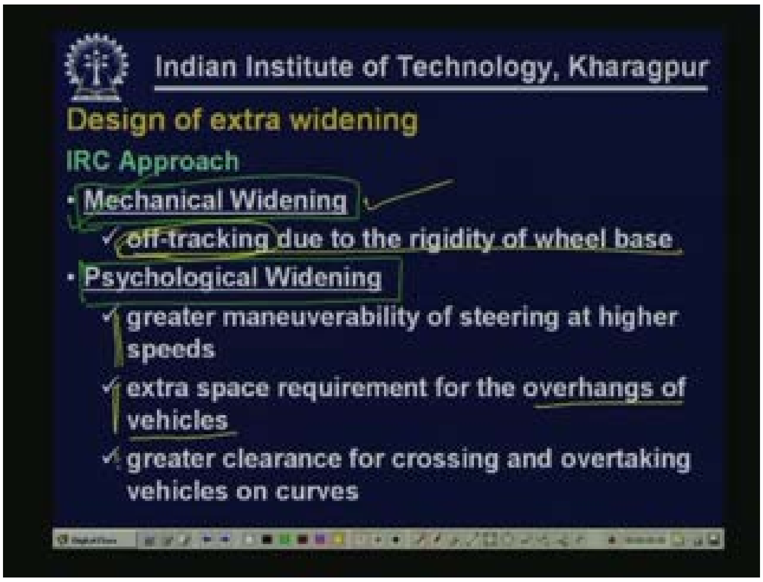

Now one can actually calculate the requirement of mechanical widening and simple equations are possible and can be derived. Let us see the sketch here. This is the line which is the path traced by the outer front wheels. I am showing it by the yellow line. Similarly let us take that path traced by the outer rear wheels that is shown by this green line. We have already understood the off-tracking mechanism that is the rear and front wheels they do not follow the same track so yellow line indicates the path traced by the outer front wheel and the green line indicates the path traced by the outer rear wheel.

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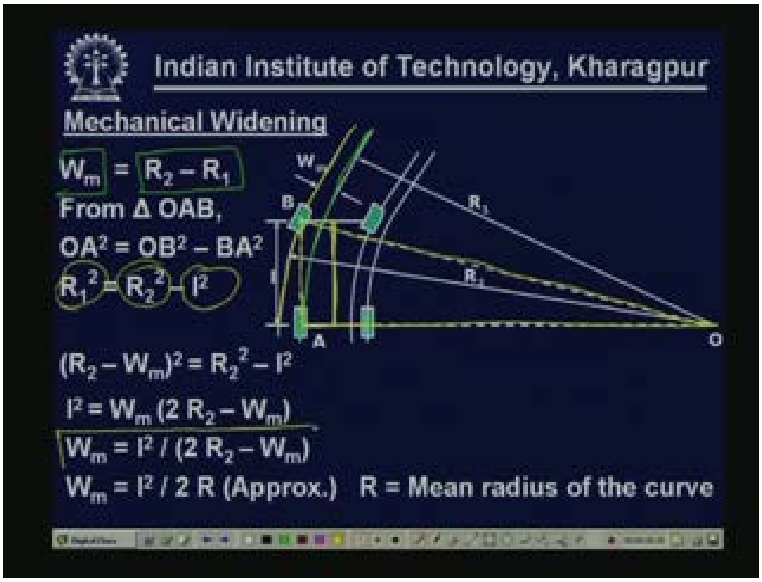

So obviously if R_1 is the radius of curve considering the path traced by the outer rear wheels and R_2 is the radius of the curve considering the path traced by the outer front wheel then the requirement of extra widening Wm is nothing but the difference between the two $R_2 - R_1$. Now if we consider this triangle OAB may be again shown by the yellow line OAB so if we consider this triangle A is the position of the outer rear wheel, B is the position of the outer front wheel and O is the centre of the curve then OA square this distance is nothing but OA square – BA square. Now OA square is nothing but R_1 square because OA is nothing but the radius of the curve considering the path traced by the outer rear wheels so this R_1 square. Similarly OB is nothing but R_2 the radius of the path traced by the by the outer front wheels so this is R_2 square and AB is nothing but this length of the wheel base it is nothing but this distance same as the length of the wheel base.

Therefore R_1 square equal to R_2 square minus l square. Now R_1 again is nothing but R_2 minus Wm where wm is the extra widening. So what we find here from this basic equation is we find wm equal to l square by two R_2 minus wm this is the equation we can get. Now this is approximately equal to l square by 2R because instead of considering R_1 and R_2 separately we take R as the mean radius of the curve. therefore extra widening wm equal to l square by two r instead of considering R_1 R_2 separately we are now considering a single radius what we can call as mean radius. So now it is l square by 2R. Now this l square by 2R is the requirement or the required extra width considering a single vehicle on a particular lane.

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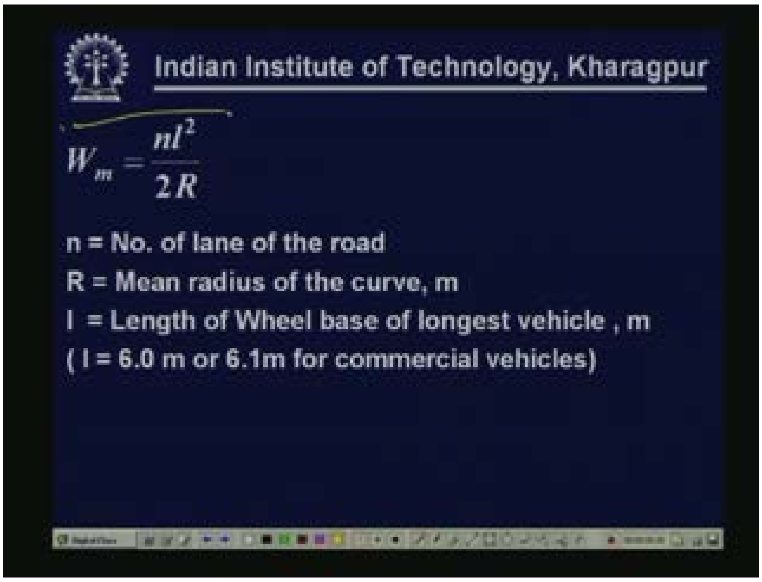

Therefore if we have a multi lane or multiple lanes are there in that case requirements are also to be multiplied. So, if we have n lanes then this requirement is to be multiplied by n. Therefore for a multi lane system this requirement is nothing but nl square by 2R and this is the final formula where n is the number of lane of the road, R is the mean radius of the curve may be in meter, l is the length of wheel base or the design vehicle in Indian condition it may be 6m or 6.1m for commercial vehicles so that way we can get the required extra width considering the off-tracking of vehicles. Of course it's a very simple derivation.

Now for psychological widening it is difficult to derive an expression logically so therefore for most of the cases in India empirical formula is popularly used for calculation of the requirement considering psychological aspect or what we call as psychological widening.

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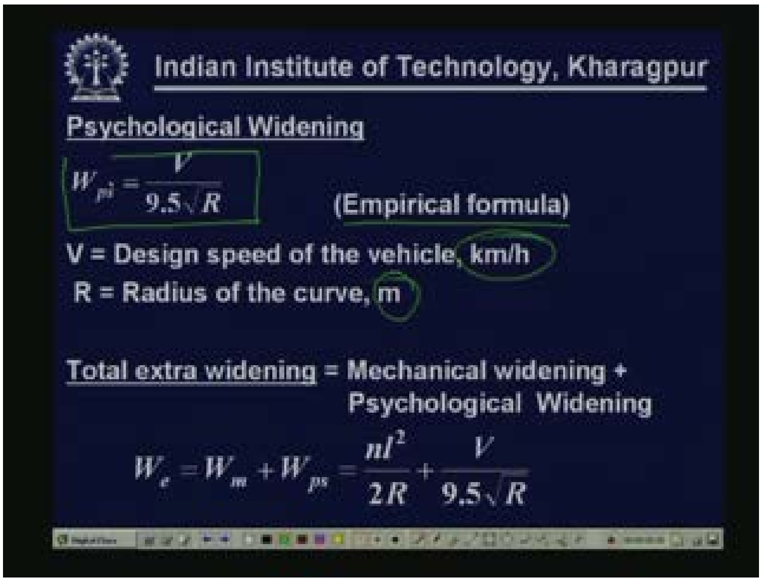

For psychological widening the required extra width is calculated like this; W_{ps} is the psychological component, V by 9.5 root R is the empirical formula here, V is the designed speed of the vehicle in kilometre per hour and R is the mean radius of the curve that is expressed in meter. And in this case the required psychological widening can be obtained in meter. Therefore total extra widening is nothing but mechanical widening plus psychological widening so that is nothing but nl square by 2R + V by 9.5 root R. Thus one actually calculates the required extra widening on curve depending on the design speed and also depending on the number of lanes and the radius of curve. So these are the three major components or influencing factors.

Now considering these aspects that means considering the requirement of off-tracking that is nothing but the mechanical widening and also considering the component that is known as psychological widening Indian Roads Congress have given the required total widening on curves and the design table is available. Now extra widening is expressed as a function of the number of lanes and the radius of curve. so for two lanes and single lane also the values are given depending on different radius up to 20m, 21 to 40, 40 to 60 etc and the design values for different ranges of radius are also given. Now these values are calculated considering mechanical widening and the psychological widening.

Now it is worthwhile to mention that for single lane road only mechanical widening is sufficient or why mechanical widening is considered because during crossing manoeuvres outer wheels of vehicles anyhow have to use the shoulder irrespective of whether the vehicle is on the straight or on the curve. So, whether on straight or tangent or whether it is on curve anyhow the outer wheels of vehicle have to use the shoulders. Therefore for single lane road it is normally not required to consider the psychological widening component and therefore only mechanical widening component is adequate.

For multilane roads the pavement widening may be calculated by adding half the widening for two lane roads for each additional lane because values are given in the IRC table for two lane road therefore for three lane, four lane and so on. For multilane roads the pavement widening may be calculated by adding half the widening for two lane road for each additional length. So that way one can calculate the adequate widening for any conditions as per the (IRC) Indian Roads Congress procedure.

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Now let us see the AASHTO approach for calculation of extra widening. As per AASHTO approach travelled way width needed on curve is normally denoted as W_c. It depends on a number of factors or a number of aspects. One is track width on curve, how much track width is required this is denoted by (U) then it considers the lateral clearance allowance (C) it depends on the width of front overhang of inner lane vehicle, carefully observe this part inner lane vehicle denoted as F_a and also the extra width allowance considering all these components the required travelled way width on curve is estimated.

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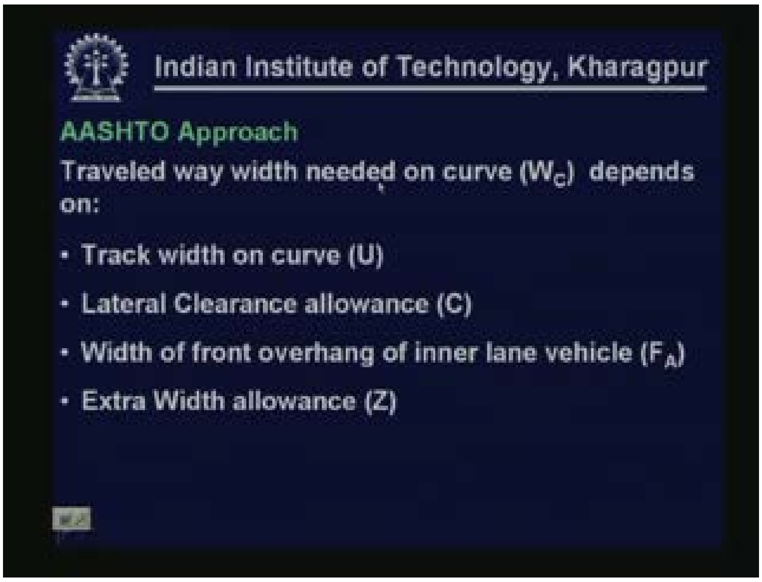

Now let us try to understand each of these components and see how the total travelled way width on curves is calculated. First is the track width; now the track width is nothing but on tangent, on tangent the track width is nothing but out to out of tyres the distance between out to out of tyres. The track width on curve is nothing but sum of the track widths on tangent plus the amount of off-tracking. So whatever width is normally required on tangent that component plus the amount of off-tracking and that together can give us the required track width on curve.

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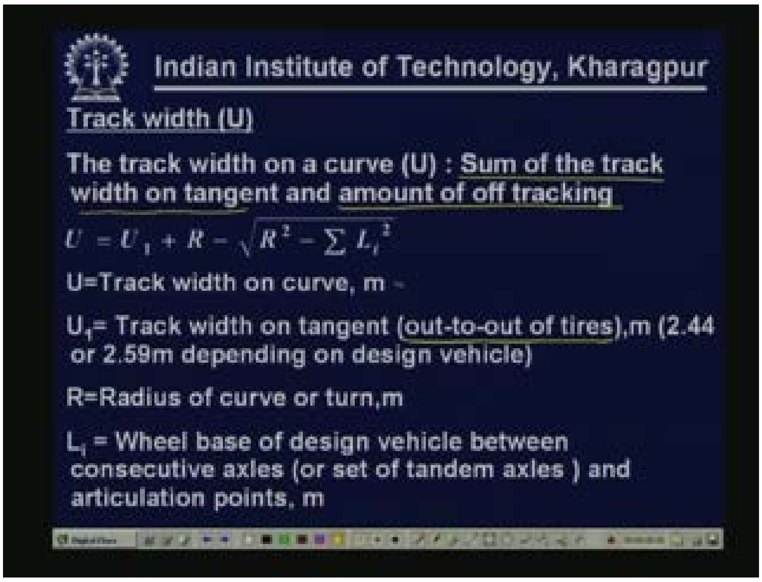

So it can be expressed by simple equation like this; $U = U_1 + R$ – root over R square – sum of L_i square where U is the track width on curve, U_1 is track width on tangent as per AASHTO procedure it is 2.44 or 2.59m depending on the design vehicle, R is the radius of curve or turn in meter and L_i is the wheel base of design vehicles between consecutive axles and articulation points this is also expressed in meter.

Now how to calculate the wheelbase for a normal vehicle say a standard truck or may be a bus even for a car it is easy to calculate this length of wheel base. Obviously the procedure may not be so simple if you consider the articulated vehicles. In that case there are procedures available, one can refer to standard textbooks or the AASHTO manual to understand the details how exactly L_i is calculated. But L_i is nothing but basically the wheel base of design vehicles between consecutive axles and articulation points. So that way using this equation one can easily calculate the requirement or what could be the width on curve and tangent.

Now this component the track width on tangent is also simple and the way we have shown you the derivation for required widening, when we were discussing about the IRC approach exactly following the similar procedure one can actually calculate the required component. But AASHTO has also made the thing simpler. This is the basis what we discussed. Considering this basis AASHTO has already given or produced design charts for calculation of track width on curves.

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And this track width is a function of design vehicle because vehicle property this L_i value is very much dependent on the property of the design vehicle and also it depends on the radius of the curve. So considering different design vehicles that means what are the different design vehicles and what could be the requirement for them and also considering the radius of curve AASHTO gives design charts for calculation of track width. So track width is a function of the design vehicle and the radius of curve.

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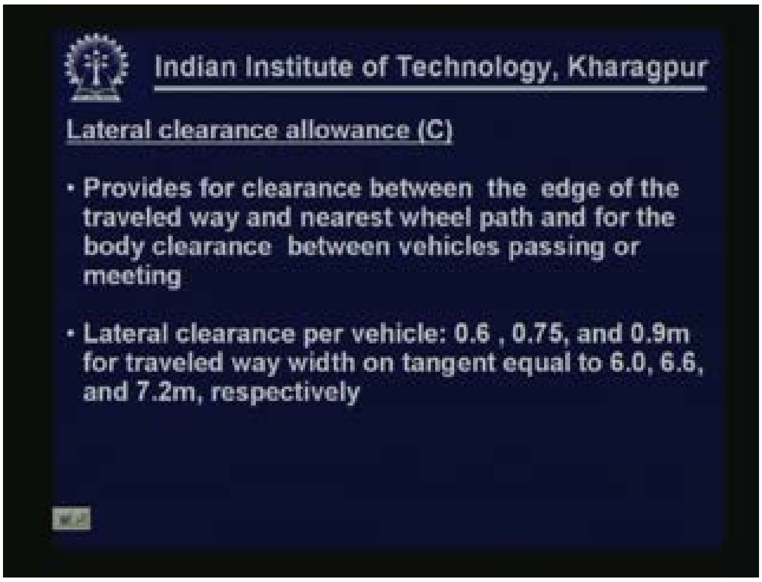

Lateral clearance allowance (C): Now this lateral clearance allowance provides for clearance between the edge of the travelled way and nearest wheel path and also for the body clearance between vehicles passing or meeting. We have already discussed the requirement of lateral clearance when vehicles are crossing or passing each other. AASHTO has given specific values and now for this lateral clearance per vehicle it should be taken as 0.6m, 0.75m, 0.9m respectively for different travelled way width on tangent equal to 6m, 6.6 and 7.2. So depending on the travelled way width on tangent which may be 6m, 6.6m, 7.2m the lateral clearance per vehicle can be calculated. It is already given in AASHTO.

Width of front overhang: What is width of front overhang?
It is basically the radial distance between the outer edge of the tire path of the outer front wheel and the path of the outer front edge of the vehicle body. Let us see it again. It is the radial distance between the outer edge of the tire path of the outer front wheel and the path of the outer front edge of the vehicle body. Normally if this is the vehicle body let us consider a bus then in the actual vehicle body there is normally some level of projection. So what we are saying is when vehicle is negotiating the curves suppose the wheel follows this path then this edge or this corner will also follow tracer path like this. So it is this radial distance, this difference up to this and up to this. That means basically this difference. So the radial distance between the outer edges of the tire this is the outer edge of the tire of the outer front wheels and this is the path of the outer front edge of the vehicle body. Hence the difference in radial distance is basically the width of front overhang.

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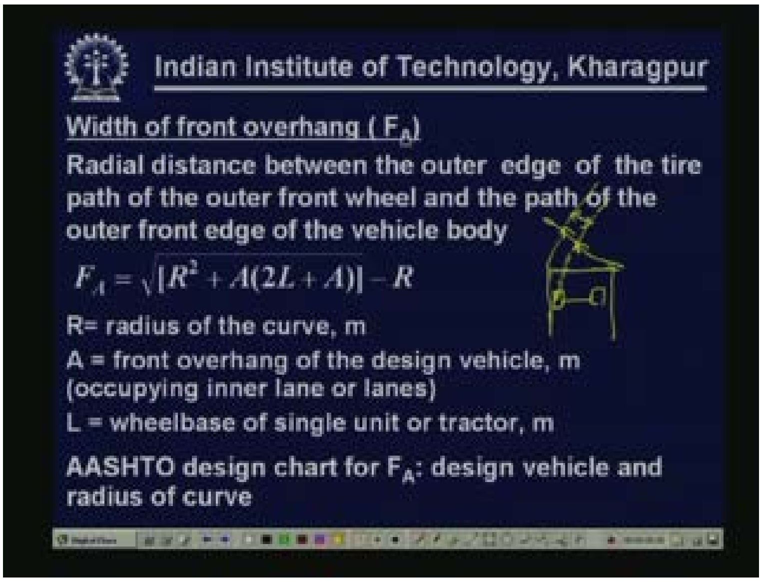

Now this again can be calculated by this formula as indicated here considering or making it as a function of the radius of curvature front overhang of design vehicles occupying the inner lanes or inner lane and length of the wheel base. Why it is taken as inner lane or lanes is because the vehicle which is occupying the outer most lanes for that vehicle the overhang portion need not be considered because there is no travel lane or no additional lane beyond that particular lane. Even if the overhang portion occupies some part of the shoulder it is still acceptable because that is not another lane that may be occupied by another vehicle. Therefore this front overhang portion is considered only for the inner lane or inner lane's vehicle. Now, again for this part also AASHTO has given design chart for F_A making it a function of design vehicle and the radius of curve. So, for different design vehicles and for different radius of curve what should be the value of F_A that may be obtained directly from AASHTO design chart.

The last component probably is the extra width allowance. It is again basically nothing but considering the psychological aspects or the behavioural aspects. This is the additional radial width of pavement to allow for the difficulty of manoeuvring on a curve and the variation in driver operation. So driver behaviour and the variation in driver behaviour is also considered and the difficulty of manoeuvring of a curve is recognised.

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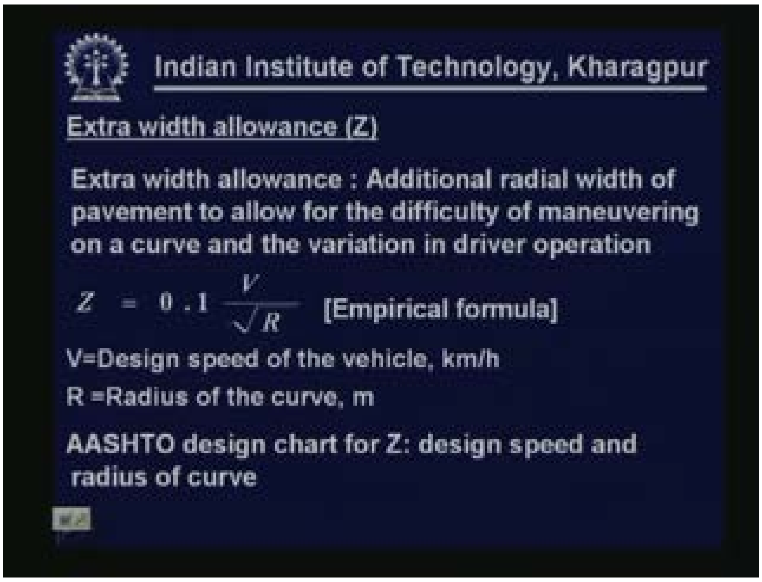

But here again empirical formula is given. The formula what we have mentioned earlier when I was discussing about the practice in India for calculation of the psychological widening I indicated another formula of similar nature. Basically they will give you a very close value that was V by 9.5 root R and here in this case zero point one v by root r this is again the empirical formula where V is the design speed of vehicle in kilometre per hour and R is the radius of the curve.

In this case also that is for extra width allowance AASHTO design chart is again available. But in this case this extra width allowance is a function of design speed and radius of curve. because you can see clearly this z is the function of V and R where V is the design speed R is the radius of curvature so radius of curve so for various design speeds and also considering different radius of curve the required value of Z there can be obtained directly from AASHTO design charts. So that way one can get the value. So now we know the entire individual component. So what could be the required widening of pavement on travelled way on curve? it is nothing but $W_c – W_n$ where W_c is the width of travelled way required on curve and W_n is the width of travelled way on tangent. Basically it is the difference between W_c and W_n what is the width required on curve and what is the width required on tangent. Now W_c we have told that it is the function of track, width function of lateral clearance allowance, width of front overhang of inner lane vehicle and the extra width allowance. Now considering these four aspects the width of travelled way on curve can be calculated like this; $N(U + C) + (N – 1) F_A$.

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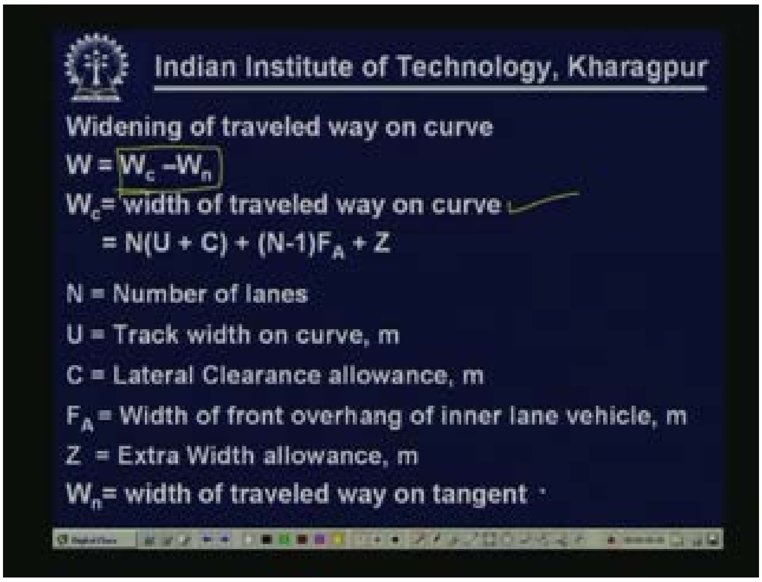

Now this U and C on per vehicle basis or per lane basis are multiplied by N the number of lanes and this F_A I have already explained is the width of front overhang is only effective and it is meaningful to consider this aspect for all the inner lane or lanes not the extreme outer lane. Hence excluding the outermost lane for all other lane this component is considered and that is why it is (N – 1) F_A + Z is coming from empirical formula so it is on a total width basis that means not on a lane or vehicle basis.

Based on this we can calculate what is the required extra widening on horizontal curve following the AASHTO approach. AASHTO has also given tables. So these are some of the values for two lane one way or two way highways. It depends on the radius of curve 300, 200, 100 etc and also the roadway width, travelled way width as I indicated earlier it may be 6m, 6.6m, 7.2m the width on tangent and so on. Then again for different design speed what would be the actual total required extra widening? This is just making the extra widening as a function of radius of curve the travelled way width on tangent and also the design speed. Now normally for a value less than 0.6m it is not necessary to consider the widening. So these table values as we discussed also depends on vehicle type or design vehicles what is the type of design vehicle and so on. These AASHTO tables or the values whatever I have indicated are basically for a particular type of design vehicle that is WB-15.

Now, for other type of design vehicle AASHTO again gives the required adjustment factor. If it is other type of design vehicle then what adjustment factors are to be applied are also given by AASHTO. This is for two lane. Therefore for three lane highway these values are to be multiplied by 1.5 and for four lane highways these values are to be multiplied by 2 and so on so that way for different conditions different design vehicle, different travelled way width on tangent, different design speed and different radius of curve the values or the required extra widening on horizontal curves can be calculated following AASHTO approach.

Now let us see the application of widening on curves. You have understood the basis for design. Now let us see how those things can be applied. Curve widening should transition gradually over a length sufficient to make whole travelled way usable. That means it should be introduced gradually in such a manner that the whole travelled way becomes usable. This is one consideration. The whole travelled way should be made usable. That means the driver behaviour or the path of driving should be recognized and that should be considered in the overall process.

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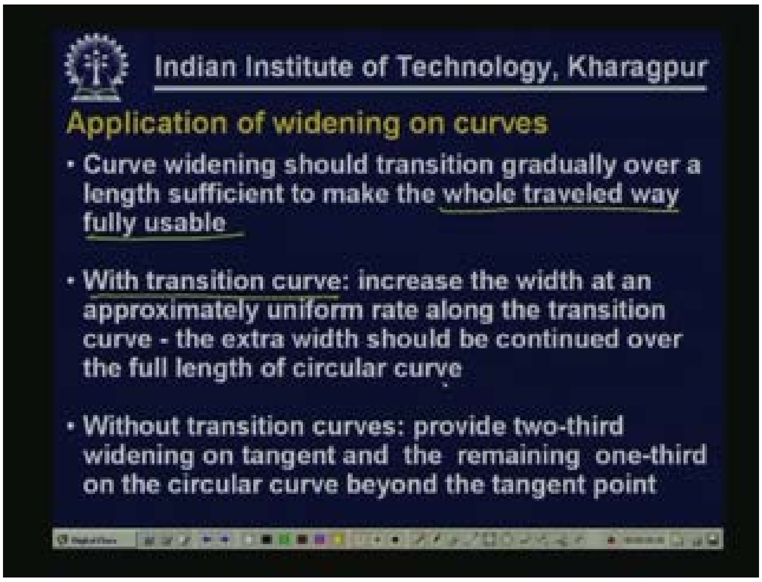

Then when a transition curve is used increase the width at an approximate uniform rate along the transition curve and then the extra total width should be continued over the full length of circular curve. In that case the whole circular curve will have the complete extra widening. When no transition curve or the spiral curve is used in that case provide two third of the widening on tangent and the remaining one third on the circular curve beyond the tangent point for superelevation. Also, a similar approach was taken so here also two third or one third and sometimes it is fifty percent so that kind of distribution is done.

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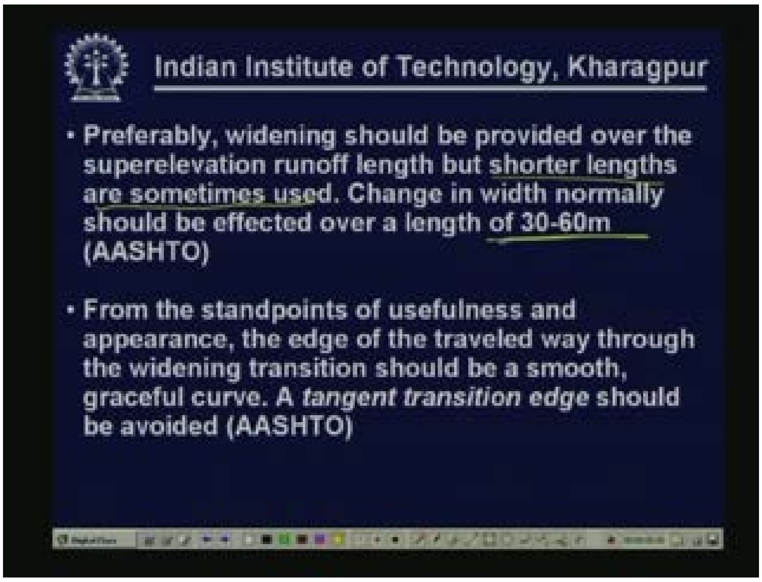

Now, preferably widening should be provided over superelevation runoff length but sometimes shorter lengths are also used. Now change in width normally should be affected over a length of 30 to 60m as per the recommendation of AASHTO. AASHTO states that it should be done over a length of thirty to sixty meter neither too long nor too short a length. From the stand point of usefulness and appearance the edge of the travelled way through the widening transition should be a smooth graceful curve. This is very important which is often an overload because we provide transition curve for a specific reason and transition curve is a curve. Therefore when extra widening is also introduced it is necessary to have a smooth graceful curve at the outer edge the appearance should be like a smooth graceful curve but not a tangent transition edge. Now with transition curve widening is generally applied equally on both sides of the carriage way fifty percent on the outer side and fifty percent on the inner side. Without transition curve the entire widening should be done only on inner side and also on sharp curves on hill roads. There are other practical constraints also, the entire widening may be done on the inner side.

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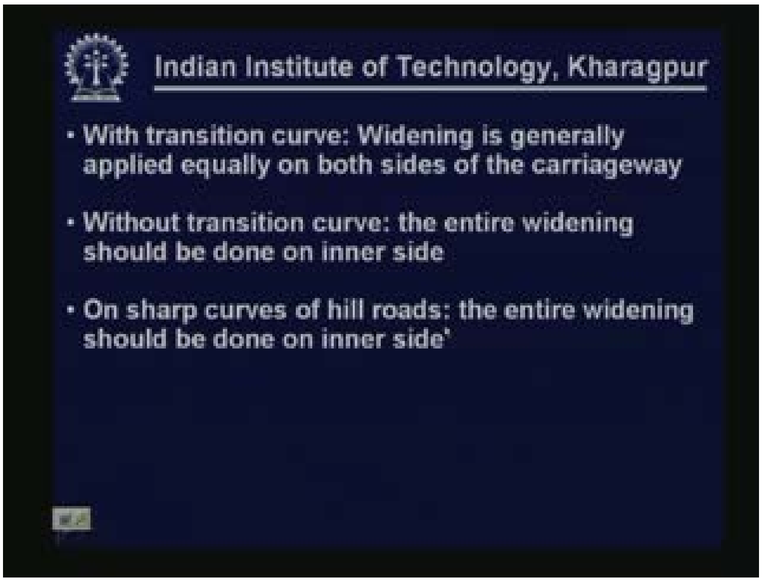

Now let us quickly say some of the general controls of horizontal alignments. many of these things we have also discussed earlier when we talked about the design of other components, horizontal curves, transition curves and other things but related to horizontal alignments what are the general controls that should be kept in mind. first alignment should be as directional as practical but consistent with topography, number of short curves should be kept minimum, however, long tangents are also needed because we have to provide adequate passing sight distance particularly for two lane undivided roads or highways therefore long tangents are also necessary.

In alignment developed for design speed attempt should be made to use short curves saving the minimum radius for the most critical condition. not that we shall design the curve minimum radius acceptable radius but you should try to provide flatter curves and keep the absolute minimum or the sharpest curve for critical conditions or critical situations.

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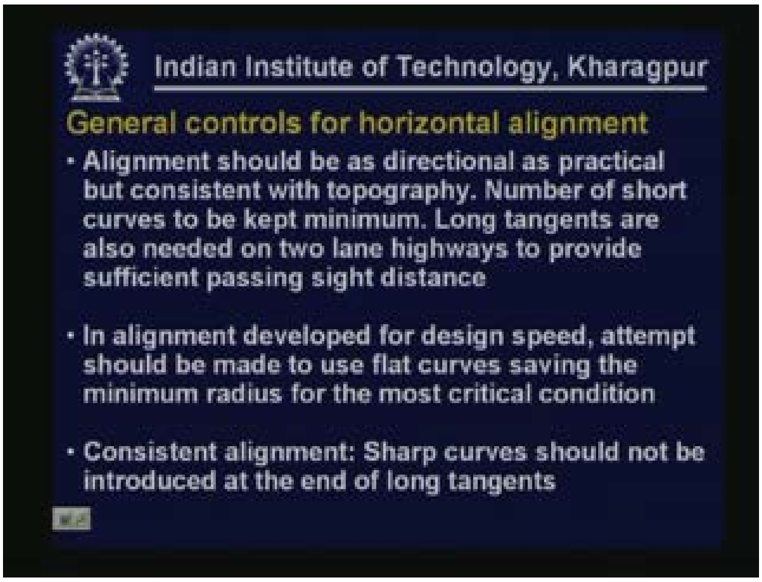

The alignment should be consistent. That means sharp curves should not be introduced at the end of long tangents, we have mentioned it earlier also. For small deflection angle less than five degree curve should be sufficiently long to avoid the appearance of kinks. This appearance part is also very important. We must try to avoid the appearance of kinks so both AASHTO and IRC recommends that curve length should be at least 150m for a deflection angle of five degree which is what we are calling as small deflection angle and this should be increased by 30m for each 1 degree increase or for each one degree decrease in deflection angle. That means for small deflection angle up to 5 degree that means for 5 degree it is 150m and for each one degree decrease in deflection angle at thirty meter extra length just to avoid the appearance of kinks.

Caution should be exercised in the use of compound circular curve, you should try to avoid it but for safe and smooth transitions from one curve to another the radius of the flatter curve should not be disproportional to the radius of sharper curves and there has to be some sort of compatibility. therefore a ratio of one point five is to one should be considered as the limiting value when compound circular curves are used where one is flatter and another is sharper so that should be the limiting ratio.

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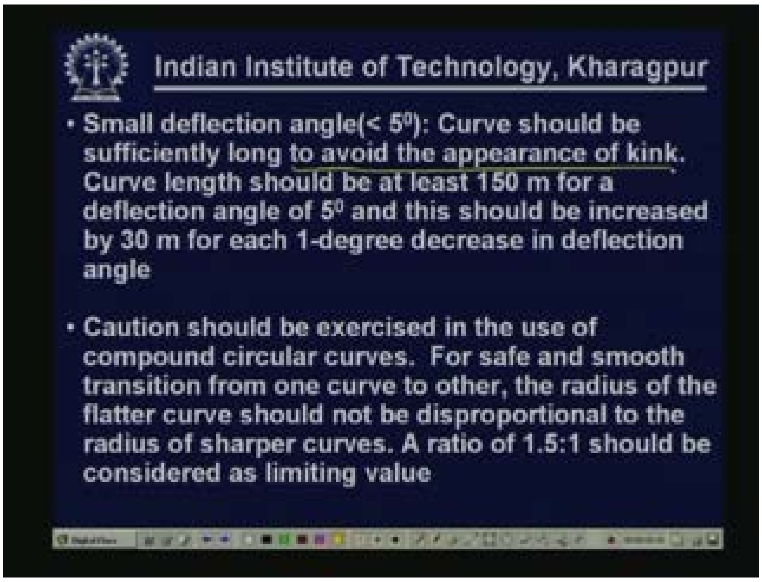

Reverse curve normally should be avoided but wherever situation demands one has to accept reverse curves especially in difficult terrain but it should be ensured that there is sufficient length between the two curves for introduction of requisite transition curve.

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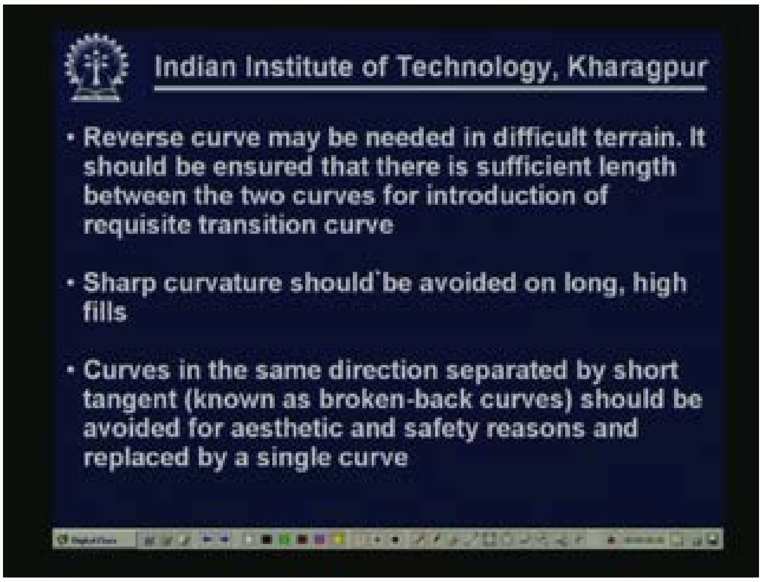

Sharp curves should be avoided or long high fills and curves in the same direction separated by short tangent known as broken back curves should be avoided for aesthetic as well as for safety reasons and they should be replaced by a single curve. Now I have mentioned that we need long tangents particularly on two lane two way roads to have adequate passing side distance but very long tangent sections also should be avoided, very long means exceeding 3 km length.

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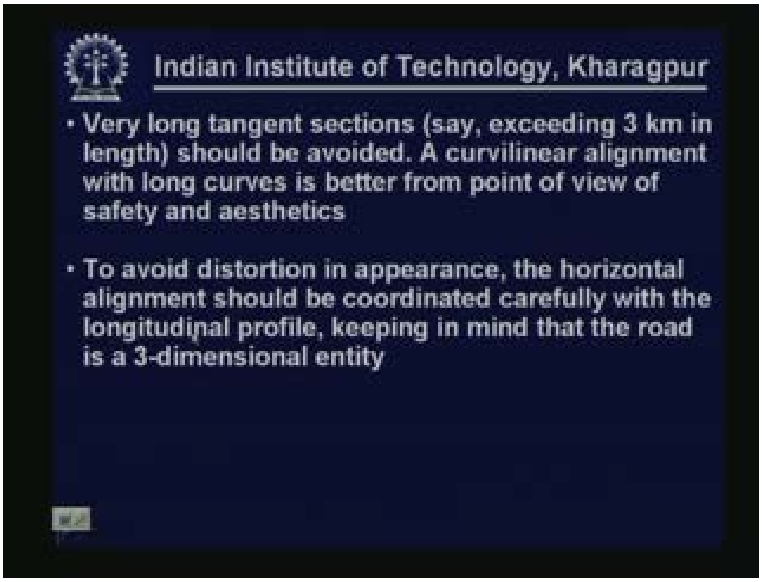

A curvilinear alignment with long curves is better from point of view of safety and aesthetics rather than a very long tangent section. So from safety point of view this is essential. Finally to avoid distortion in appearance the horizontal alignment should be coordinated carefully with the longitudinal profile and it should be kept in mind that road is a three dimensional entity. It is not only the horizontal alignment but also the vertical alignment and the coordination of horizontal and vertical alignment is also an important consideration. Some of the questions for you to answer;

Explain the need for providing extra widening at horizontal curves.
Explain the basis for design of extra widening as per Indian Roads Congress.

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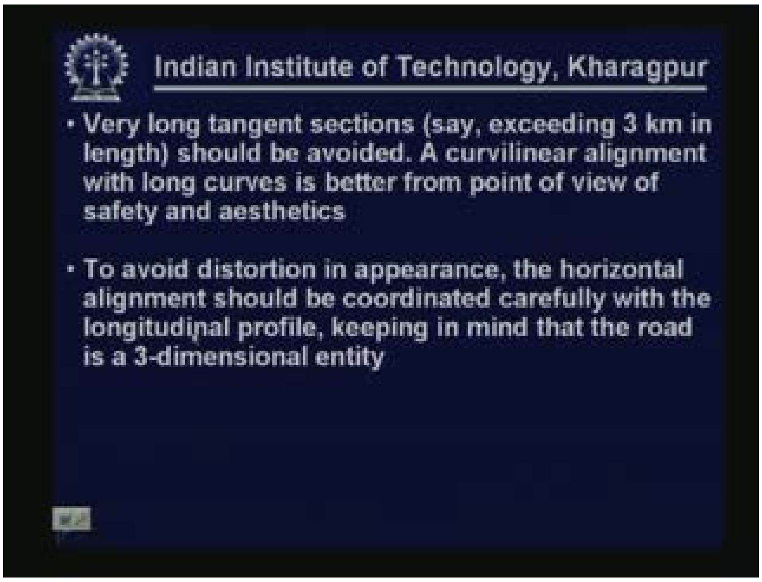

Explain the basic components considered in AASHTO for the design of extra widening and

Try to solve this problem or try to calculate the required extra widening as per Indian Roads Congress if the pavement width is 7m, radius of the horizontal curve is 200m and design speed is 70 km/h.

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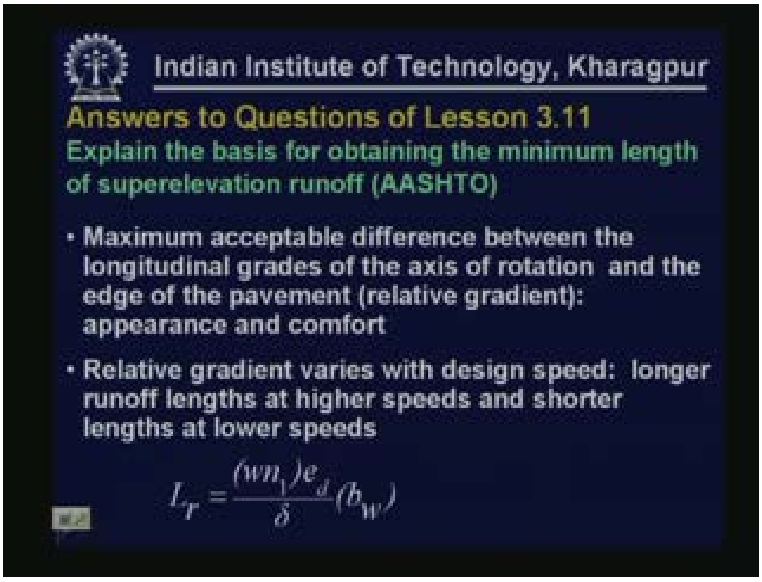

Now let me quickly try to give answers to questions of lesson 3.1. The first question was:
Explain the basis for obtaining minimum length of superelevation runoff. It is basically based on the relative gradient. Therefore there has to be maximum acceptable difference between the longitudinal grades of the axis of rotation and the edge of the pavement that is the relative gradient for better appearance and comfort. Relative gradient is also a function of design speed to have longer runoff lengths at higher speeds and shorter length at lower speed.

Now, explain the basis for calculation of minimum length of spiral transition curve. It is calculated based on driver's comfort that means maximum change of lateral acceleration normally value of one point two meter per cubic second is taken. Considering this maximum change of lateral acceleration what should be the length. This is the equation that can be used for calculation of the lanes. So, one aspect is the driver's comfort or maximum change of lateral acceleration. The other aspect is the based on the lateral shift because 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 the vehicle's natural path. So here p minimum value is used as 0.2m and this is consistent with the minimum lateral shift that occurs as a result of natural steering behaviour of most drivers. So considering that lateral shift what should be the minimum length of the curve and the higher of these two values should be accepted.

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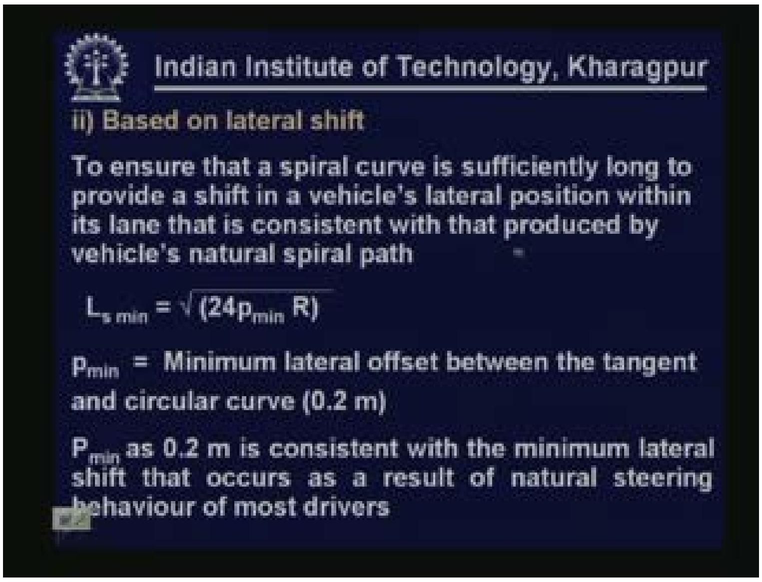

The last question was; explain the significance of considering an upper limit of the length of spiral. Why an upper limit is used? Basically safety problems may occur on spiral curves that are very long, very long means very long relative to the length of the circular curve. As compared to the length of the circular curve if the transition length is very high then safety problem may occur because that may mislead the driver about the sharpness of the approaching curve.

Therefore considering lateral shift when we calculated the minimum required length of spiral a similar formulation is suggested here but the maximum lateral shift is taken into consideration which is taken as one meter. And this pmax as 1m is consistent with the maximum lateral shift that occurs as a result of natural steering behaviour of most drivers. Also, this pmax as one meter provides a reasonable balance between the spiral length and transition curves that’s why the upper limit of length of spiral is also considered and is meaningful, thank you.