

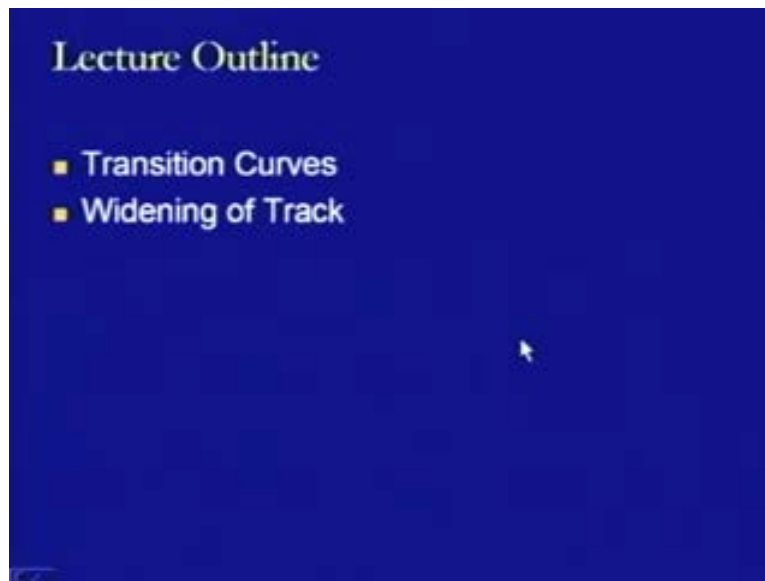
Transportation Engineering - II
Dr.Rajat Rastogi
Department of Civil Engineering
Indian Institute of Technology - Roorkee

Lecture – 17
Transition Curve and Widening of Track

Dear students, I welcome you back to the lectures in the lecture series of course material Transportation Engineering – II. In today's lecture, we will be giving emphasis on two aspects related to again the geometrics of the railway tracks. One is transition curve and another one is the widening of track. From the last two-three lectures, we have been discussing about the geometric design aspects. We have already discussed about some of the important aspects like the fixing of the alignment. We have then discussed about the horizontal curves, the design of the superelevations and then, we have also looked at the **design** speeds or the maximum permissible speeds or the safe speeds, which can be provided on any railway track.

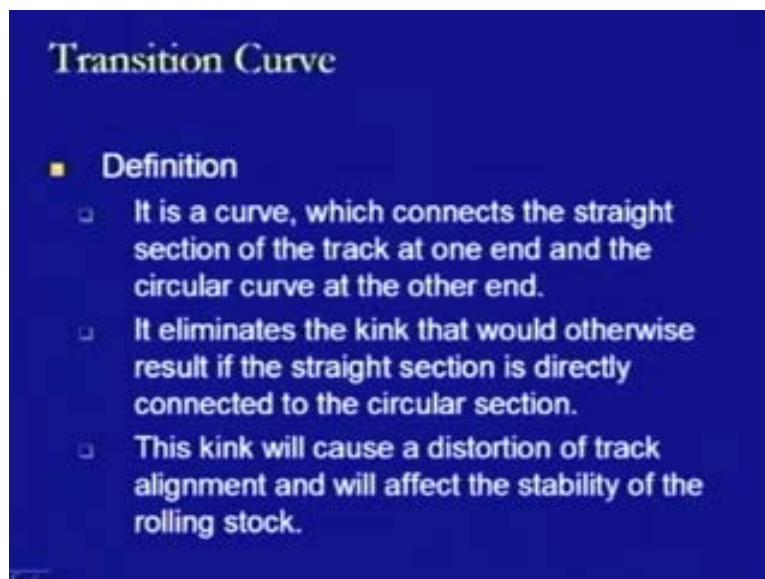
Now, this is in continuation of that one and we have seen that when we are computing the safe speed or the safe permissible or maximum speed on any of the track, then transition curve also plays its role and not only in that case, it also plays its role in the case of the alignment or in the case of the curves where the horizontal curve is being provided and it is to be connected with the straight section of the track.

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So, looking at these aspects, we will be discussing in this lecture the transition curves and the widening of the track. Now, we start with the first aspect that is transition curves.

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Transition curves as definition can be defined as it is a curve which connects the straight section of the track at one end and the circular curve at the other end. So, there are two things which are happening here. It is changing its radius from infinity where it is being

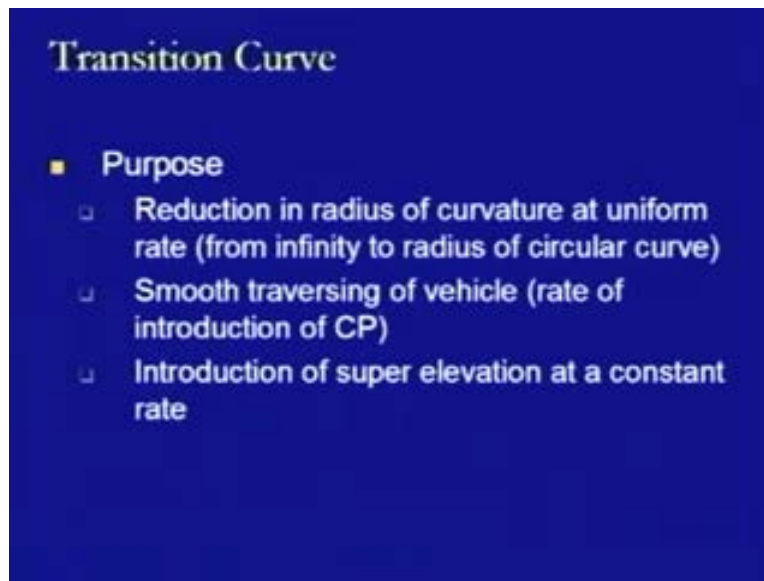
connected to the straight section of the track, where the straight line has infinite radius, whereas in the case of the circular curve it has a finite radius. So, the radius of the transition curve is changing from infinite value to a finite value. That is it is coming from a straight section to a curved section and that is how its definition is being created and it eliminates the kink that would otherwise result if the straight section is directly connected to the circular section. This is another important thing.

If we connect a circular section directly with the straight section, then there is no transition at all from the infinite radius to the finite radius that is R . In that case, this point of connectivity acts like a curve that is a kink and wherever this kink is being available, it is a point of discomfort. The person or the wagon where the rolling stock which is negotiating this kink, will experience a jerk as soon as it is crossed over and this jerk depending on the radius of the curve or depending on the speed at which the rolling stock is moving may be very, very high and it may be very uncomfortable for the passengers in that sense.

It may also be hazardous condition for the operation of the rolling stock. So, therefore it is an important thing to provide transition curve, so that these kinks can be eliminated and as just I discussed, this kink will cause a distortion of the track alignment. That is another condition, because there is a possibility that the jerks are being transmitted now to the track and then, with these transmission of the jerks of the impacts being created, the distortion may take place of the alignment. So, the alignment may go out of its location or its position and it will also affect the stability of the rolling stock.

That is another aspect, because the jerk is also transmitted to the rolling stock. So, it is a vice versa condition. So, both of that things are going to be affected; not only the physical features in terms of that rails being provided at the bottom or the other components of the tracks being provided at the bottom are going to be affected, where at the same time, in the form of the rebound the stability of the rolling stock is also getting suffered.

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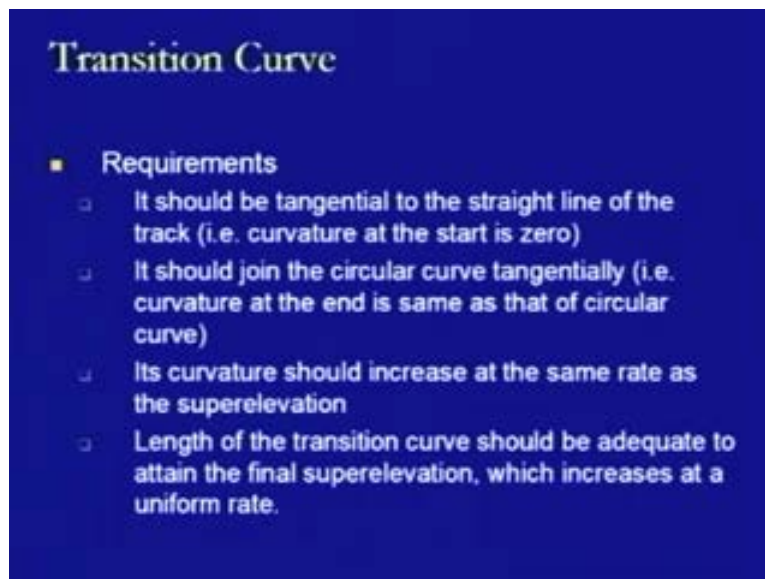
So, looking at this aspect, we have to look at what are the purposes for which the transition curves have to be provided between circular curve and the straight section of the track. The very first thing is that it is a reduction in the radius of curvature at a uniform rate. As I have told, in the case of a straight section the radius of curvature is infinity, whereas in the case of a circular curve it has a finite value, r . Therefore, it helps in reducing the radius from infinity to value r and this is to be done at a uniform rate. If it is not being done at a uniform rate, then again there will be the jerk conditions which will be experienced on the basis of differential change in the rate of change of this radius or the curvature while moving along the transition curve. So, this is one of the aspects.

Then, another aspect related to this is, because there is a uniform rate at which the things are changing or the curvature is changing, therefore it will be a smooth traversing of the vehicle. At the same time, it is also going to be related to the centrifugal force. Now, as soon as we are trying to move towards the circular section, the centrifugal force will also start getting introduced. Now, once it is being introduced, it will keep on increasing and will come to the maximum force as soon as we reach the circular section. So, it allows the introduction of the centrifugal force again in a uniform form from the straight section of the track to the circular section of the track. So, it means when it is being done at a

uniform rate, the rolling stock will not be observing any impact or any sort of a sway or any sort of a jerk in the outward direction.

Further, it also helps in the introduction or provision of superelevation at a constant rate. Again, as we have seen, the superelevation is a difference between the level of the inner rail and the outer rail. Now, if the circular curve is provided just at the end of the straight section, then it means just at the end of the straight section the level of the outer rail has to be increased by a value e above the level of the inner rail and it will be a drastic change and it will cause the derailment of the trains or the overturning of the trains, depending on the speed being provided or the speed on which the train or the rolling stock is moving. So, this is another important aspect that is so as to introduce the superelevation, the transition curves have to be provided.

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Transition Curve

- Requirements
 - It should be tangential to the straight line of the track (i.e. curvature at the start is zero)
 - It should join the circular curve tangentially (i.e. curvature at the end is same as that of circular curve)
 - Its curvature should increase at the same rate as the superelevation
 - Length of the transition curve should be adequate to attain the final superelevation, which increases at a uniform rate.

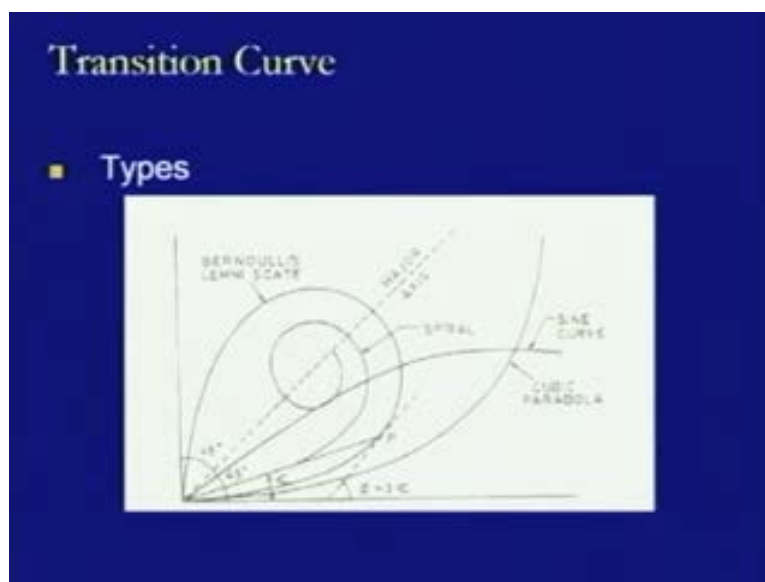
So, we have seen that there are three important things for which the transition curves have been provided - for the centrifugal force, for the smooth entry of the vehicles from the straight section to the circular section, for the uniform rate at which the curvature is being provided and as well as for the uniform rate at which the superelevation is to be

provided. Based on these things there are certain requirements of transition curves. Now, we will look at those requirements now.

The first requirement is that it should be tangential to the straight line of the track. So, whatever curve we are providing, that curve should remain tangential to the straight section that is the point from where it is starting, where the curvature is taken and we have the radius as infinity at that point. It should join the circular curve tangentially; again, when it is joining the circular curve that should also happen tangentially. They are here at this point we are having the same value as the circular curve.

Then, its curvature should increase at the same rate as the superelevation. This is another requirement. Whatever is the rate at which the superelevation is increasing, the curvature should also go by the same rate. So, they are same, proportional to each other and the length of the transition curve should be adequate to attain the full superelevation which increases at a uniform rate, means by the end of the transition curve the whole of the superelevation which is to be provided on the circular curve should be able to be achieved. If it is not so, then again there will be a jerk condition, which will remain at this location.

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Now, we look at some of the types of circular curves. Here in this diagram, the different types of circular curves have been shown and we will be discussing these types of circular, these types of, sorry, the transition curves not the circular curves, in detail in the coming slides. Here, we have shown a Bernoulli's lemniscate. This is Bernoulli's lemniscate being provided here. Then, we have a spiral. This is the spiral curve which is provided and then, we have a sin curve which moves like this, we have a cubic parabola which moves like this. So, there are different forms of the curves which can be used as transition curve. So, we will try to look at all these types of curves and then what is the suitability of those types of curves as for the transition curve.

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Transition Curve

- **Types**
 - **Euler's Spiral**

$$\phi = l^2 / 2RL$$

where, ϕ is angle between the straight line track and the tangent to the transition curve
 l is the distance of any point on the transition curve from the take-off point.
 - ideal but not preferred due to mathematical computations

Now, the first one we are looking at is the Euler's spiral. There are different types of spiral curves. One is the Euler's spiral curve, which is given by ϕ is equals to small l square divided by $2RL$, where ϕ is the angle between the straight line track and the tangent to the transition curve. So, whatever is the straight line track is being provided and the transition curve which is coming out of that straight section, if we make a tangent on that one, then the angle being made between the tangent and the straight is ϕ and this is computed using this equation, where we have the l is the distance of any point on the transition curve from the take-off point.

So, from where this transition curve is starting if we start from that one, then the distance being taken on the transition curve is defined as a small l , where R is the radius and L is the overall length to be provided of the transition curve and this is ideal but it is not preferred, because there is mathematical computations involved in this provision and it becomes little difficult, so as to provide it in the field. So, that is why generally it is not being preferred.

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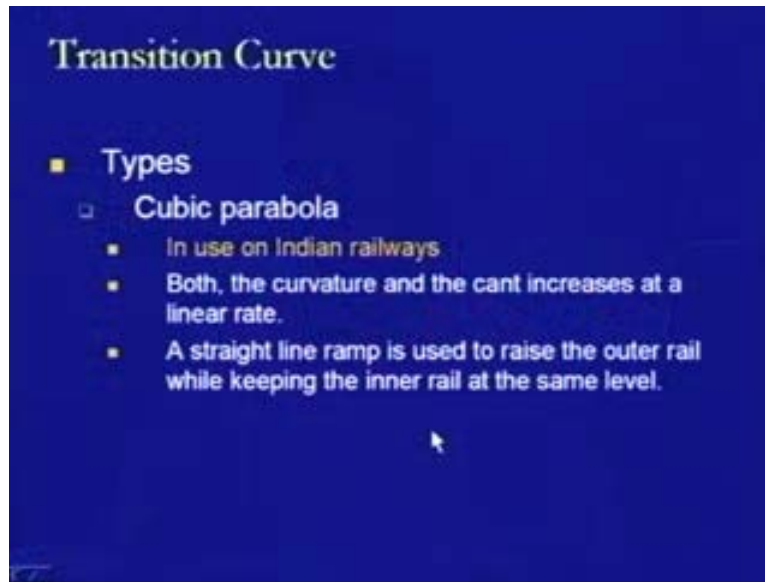
Transition Curve

- **Types**
 - **Cubic Spiral**
$$Y = l^3 / 6RL$$
 - Difficult to set in field
 - **Bernoulli's Lemniscate**
 - Radius decreases as the length increases and this causes the radial acceleration to keep on falling.
 - Uniformity is lost beyond 30° deflection angle

Then, another type of spiral transition curve is cubic spiral and this is given by Y is equals to l cube divided by $6RL$ and again this is also difficult to set in field. Then, we have Bernoulli's Lemniscate. This Bernoulli's Lemniscate, here the radius decreases as the length increases and this causes the radial acceleration to keep on falling, which is again not the desired thing in this case, where the transition curves has to be provided because their function is just opposite to this one and uniformity is lost beyond 30 degree deflection angle. So, within the 30 degrees deflection angles it may perform well, but as soon as this deflection angle increases, then this uniformity will not remain as such.

Further, we have the cubic parabola.

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This cubic parabola is mostly in use on Indian railways. Both the curvature and the cant increases at a linear rate and that is one of the requirements of the transition curve and the straight line ramp is used to raise the outer rail while keeping the inner rail at the same level. So, in this what we are doing is this, instead of providing a curved condition on the outer rail section a straight line ramp is provided, where the level of the outer rail is increased at a uniform rate because of the straight line condition and this is how this condition is achieved that is the cant is increased at a linear rate.

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The slide has a dark blue background with white text. At the top, the title 'Transition Curve' is displayed. Below it, under the heading 'Types', there is a bullet point for 'Cubic parabola'. To the right of this bullet point is the equation $Y = x^3 / 6RL$. Below the equation, the word 'where' is followed by four lines of text defining the variables: 'Y' is vertical coordinate, 'x' is horizontal coordinate, 'L' is length of transition curve, and 'R' is radius of circular curve.

Transition Curve

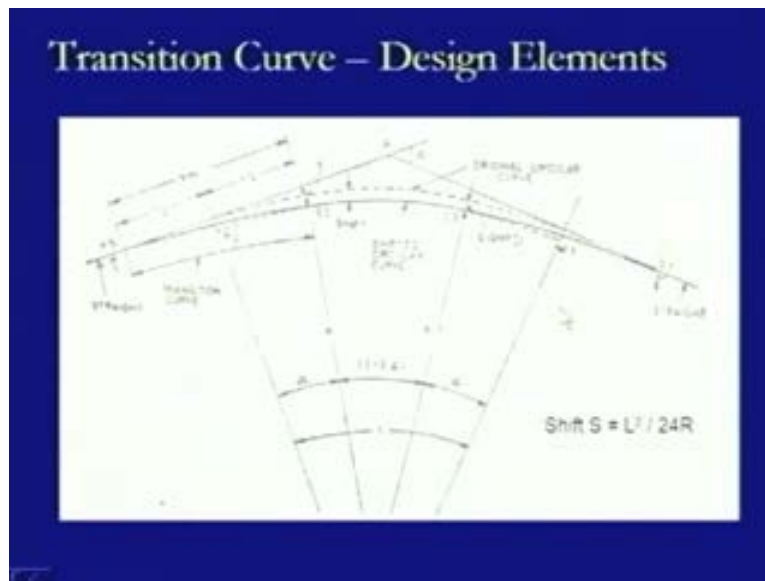
- Types
 - Cubic parabola
$$Y = x^3 / 6RL$$

where

 - 'Y' is vertical coordinate
 - 'x' is horizontal coordinate
 - 'L' is length of transition curve
 - 'R' is radius of circular curve

Then, in this case of a cubic parabola this is computed by the equation Y is equals to x cube divided by $6RL$, where Y is vertical coordinate, x is the horizontal coordinate, L is the length of the transition curve and R is the radius of the circular curve. So, if we know the radius of the circular curve and we have already computed the length of the transition curve, then we can take any ordinate, horizontal ordinate of x and using this coordinate of x , then we can compute the vertical coordinate as Y and once this vertical coordinate is being computed, then with respect to the tangent this value can be provided in perpendicular to the tangent and this is how number of points will be observed and once we connect all those number of points, then we will be getting the cubic parabola.

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Now, we come to the design element. The design element, here the different type elements have been shown. In this case we have a straight section here and we have a straight section on this side and then, in the center we are providing a circular curve. So, this is the circular curve being provided like this here. This is circular curve. So, this becomes the radius of the circular curve as R . Here, we see this radius of the circular curve. This is going up to this point.

What we are doing is, so as to adjust this transition curve, this is the transition curve which is starting from the straight portion here and it is getting connected to the circular curve portion at this point here, so as to make the, provide this connectivity. Otherwise, if we are providing simply the circular curve, then this is the circular curve which is being provided. So, it means it is starting from somewhere here and it is ending at this point. Now, because of the properties of this transition curve we have to displace this circular curve by some distance and this is the distance by which it is displaced downwards, so as to meet at this point and this is how the connectivity is provided and this amount by which it is to be displaced is known as shift and this shift is computed by this formula S is equals to L square divided by $24R$, where L is the length of the curve and R is the radius.

So, using this formula, then we can just shift the whole of the circular curve downwards and this is how it connects to the transition curve on this side as well as on this side here and this will be the length of the transition curve. This is total length and this is the tangent. So, we are getting the tangent from starting from the straight sections. So, if we draw it like this, then there will be angle α . From at this point if you draw another tangent and in this case this shift which we are taking here, if we take this shift here and if we continue this circular curve which is being displaced in this direction or in this direction, then it will be coming to this location.

So, this is the location at which the circular curve will come if it is extended. It means at this particular point where the length of the transition curve is half of the length L by 2 or L by 2 from this side, at this particular point the transition curve is placed in between the shifts. It means the distance by which it is coming away from the tangent line is half of the shift as that is S by 2. So, it is S by 2 from this side or is S by 2 from this side from the circular curve. This is another property which is used while laying the transition curves in the field and as we have discussed in the case of the circular curves in the previous lectures, this is the deflection angle by which we are deflecting, by the direction we have been coming in this direction and now we have changed our direction by angle δ and we are going in this direction.

So, this is another aspect of this one. This is the starting point or the tangent point 1, this is the starting or the tangent point 2. So, these are some of things and some of the features related to this transition curve.

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Transition Curve - Length

- Shift
 - This is the amount by which a circular is shifted inwards so as to meet a transition curve
 - Its function is
$$S = L^2 / 24R$$
where, S is shift in m
L is length of transition curve in m
R is radius in m

Now, we come to the length of the transition curve. The shift is already being defined and this shift is nothing but it is the amount by which a circular curve is shifted inwards, so as to meet a transition curve and its function is being given as S is equals to L square divided by 24R. This already we have seen, whereas S is shift in meters L is the length of the transition curve in meters and R is the radius in meter.

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Transition Curve - Length

Criterion	Desirable	Minimum
• Rate of change of cant	$C_s V_m / 125$ $0.008 C_s V_m$	$C_s V_m / 198$
• Rate of change of cant deficiency	$C_s V_m / 125$ $0.008 C_s V_m$	$C_s V_m / 198$
• Cant Gradient	Cant gradient not to exceed 1 in 720	Cant gradient not less than 1 in 360 for BG and 1 in 720 for MG and NG

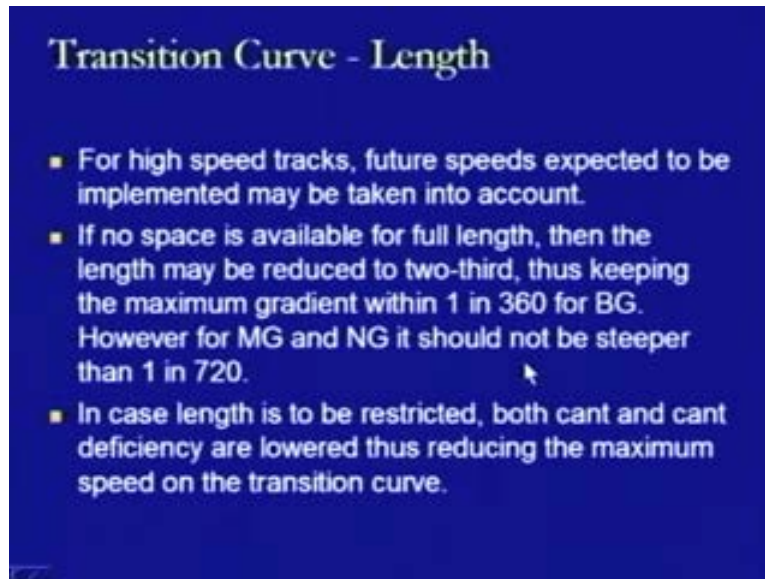
C_s and C_g are in mm; V is in km/hr

So, we look at the length. How we can compute the length of the transition curve? There are certain criteria, using that we can compute the length and there are two values of computing this length. One is the desirable value, another one is the minimum value. So, the first criterion is the rate of change of cant. In the case of rate of change of cant, this is computed as C_a multiplied with V_m divided by 125, where C_a is the actual cant being provided on the track and V_m is the maximum permissible speed which is allowed on any track and this is divided by a factor 125, whereas at a minimum level this is to be divided by a factor 198 and instead of taking as a division, in the multiplicative form the same formula transforms into $0.008 C_a$ into V_m .

Then, another is the rate of change of cant deficiency, where we are instead of taking C_a , now we are taking C_d . So, that is the only difference in the formula. The rest of the formula or the rest of the things remains the same. So, we are using cant deficiency value C_d here and it becomes $C_d V_m$ divided by 125 or $C_d V_m$ divided by 198 or in alternate form, 0.008 into $C_d V_m$.

Then, another one is the cant gradient. In this case of cant gradient, the cant gradient should not exceed 1 in 72 desirably and at the minimum level it can go up to a value of 1 in 360, but the cant gradient cannot be less than 1 in 360 for broad gauge. But, in the case of meter gauge and narrow gauge, the minimum value remains the same as the desirable value that is 1 in 720. This already we have seen in the previous lecture, where we have discussed about the change in the cant gradient and we were talking about the maximum permissible speed. Here, C_a and C_d are in mm and V is in kilometers per hour. So, this is with respect to the units being used here.

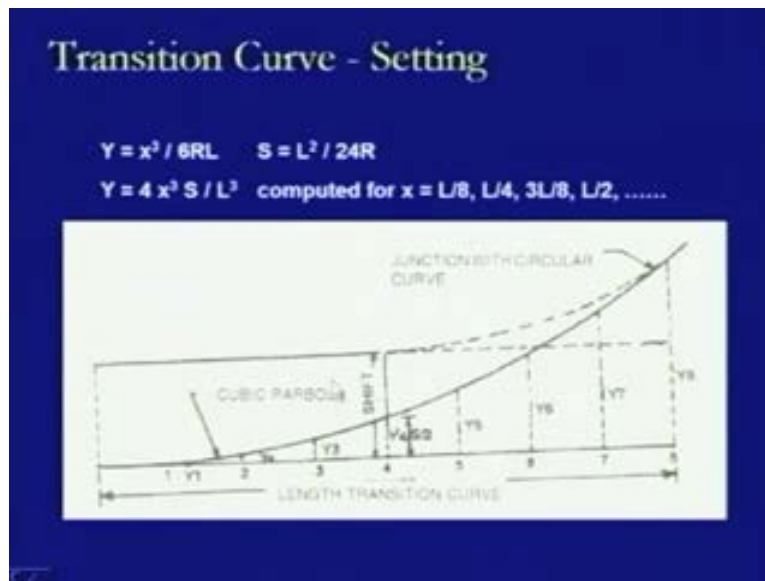
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Now, in the case of high speed tracks, one thing which is to be done is the future speeds expected to be implemented has to be taken into consideration. If we are not taking those higher speeds or the future speeds with which the tracks will be operated in future, then there will be certain deficiencies which will remain in the future and later stage it will become very difficult, so as to make any change in the overall layout or overall alignment of that track. So, it is always better to keep into consideration the future requirements, as far as the speeds are concerned and the result of that speed on the length of the transition curve.

If no space is available for full length, then what we can do is that the length may be reduced to two third thus keeping the maximum gradient within 1 in 360 for broad gauge. However, for meter gauge and narrow gauge, it should not be steeper than in 1 in 720 as we have seen previously. So, only thing what we can do is that we can reduce the length by two third in this case. In case length is to be restricted, both cant and cant deficiency are lowered and once we have lowered these, then we are reducing the maximum speed on the transition curve. So, this is another aspect which we can take into consideration while we discuss the transition curves.

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Now, setting the transition curve in the field what we have to do is that we have been using the formula for cubic parabola as x^3 divided by $6RL$, where the shift is being defined as L^2 divided by $24R$. So, here this is the tangent which is going up to the deviation angle δ . So, with respect to this one, this cubic parabola is to be set and here we are having the circular curve which is starting at this level. This is half of the length of the transition curve. This is another half of the length of the transition curve.

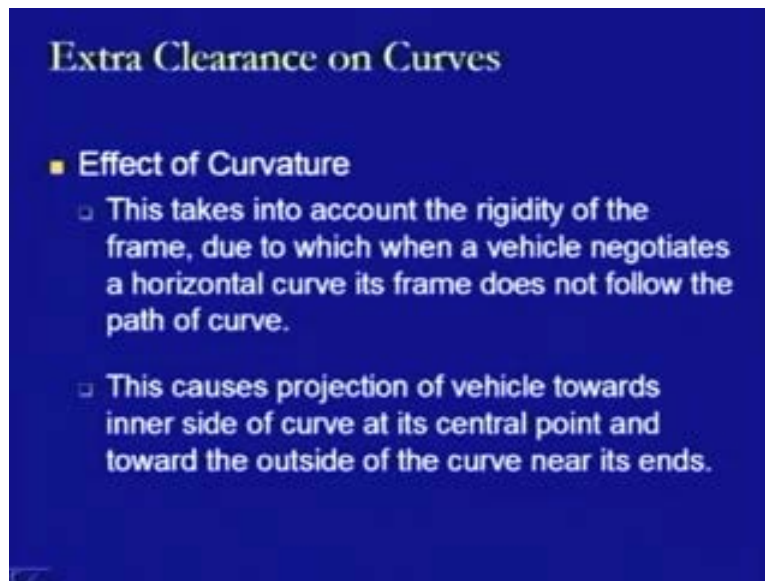
At this half of the length of the transition curve this is the shift value which is given by L^2 divided by $24R$ and from this point, the circular curve will be started. So, if we just make it further extended, we will be getting a point from where the radius R will be used and with that radius R minus S , we will be drawing the circular curve like this. So, this is how we can draw the circular curve first of all and then at this point, at the half of the distance of the shift, we will be having one point which will fall on the cubic parabola.

Now, the rest of the points need to be found out on the either side of this point and this can be done by using the value of x which is taken as any component, like here we are taking in the 8 parts the whole of the distance is being divided into 8 parts, because this is

half, then half of that one and likewise it is being done. So, we have L by 8, L by 4, 3L by 8, L by 2 and so on. So, for all these values of x we compute the value of Y and then, just we take it with respect to this tangent at perpendicular direction. So, we will be getting all these points like this, this point, this point and finally, we will be getting a point at which this transition curve will be touching the circular curve and before this one, there is a straight portion being provided. So, this is how we are getting here at this. This is the straight portion, so this shift remains as such. So, straight portion, transition curve and then, after this point there will be a circular curve in this direction. So, this is regarding the transition curves and the provision of transition curves.

Now, we start with another part of our today's discussion that is the clearances which needs to be provided on curves. Now, in the case of different curves which are provided, we have seen that on the curves number of forces are acting and due to the effect of all those forces, at times there is a leaning condition or at times there are chances of whole of the rolling stocks moving in one direction in the transverse way. So, looking at all these aspects we have to find out that whether there is a requirement of providing any clearance if the two tracks are laid simultaneously side by side or if there is a track which is being laid on the side of a platform. So, in such cases, number of clearances are there and we will look at all those clearances taking one after the other one.

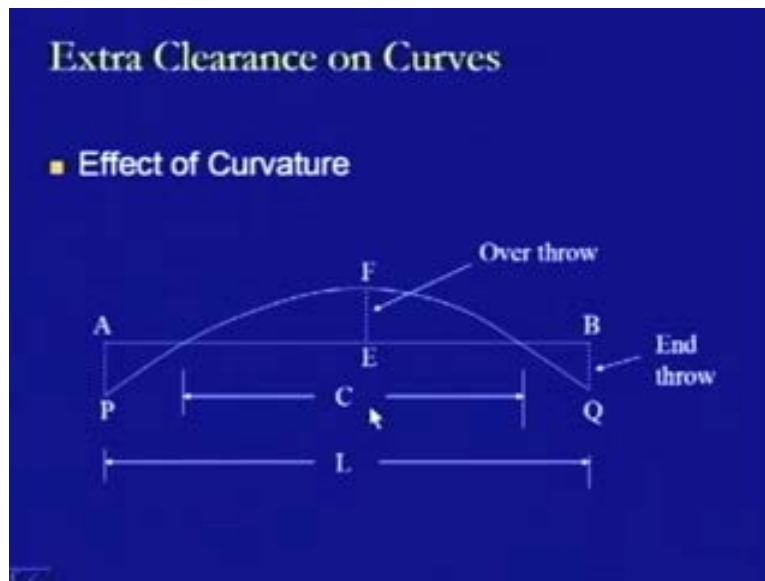
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So, we will be starting with the first type of the clearance which is caused due to the curvature. So, the effect of curvature is to be taken into account due to the rigidity of the frame. This we have already discussed, because the frame of the rolling stock is rigid. Therefore, the path which is taken by the forward wheel or the axial is not the same as being taken by the trailing wheel or the axial and the forward wheel or axial takes a path which is towards the outer side of the curve, whereas the trailing wheel or the axial, it takes a path which is towards the inner side. So, therefore there is a mismatch.

So, in this condition, because of this rigidity of the frame what happens is that when the vehicle negotiates a horizontal curve its frame does not follow the path of the curve and this causes projection of the vehicle towards the inner side of the curve at its central portion and towards the outside of the curve near its ends. So, this is one another thing which is happening in the case of curvature. It is a combined effect of curvature with the rigid wheel base. So, in this case, as it is trying to take a turn, what happens is that at the central point the vehicle remains on the inner side of the curve, whereas towards the outer side of the curve near its end it goes towards the outer side. So, this is type of the thing which is happening due to the effect of the circular curve in combination of rigidity of frame.

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Here in this diagram, the same type of thing is being depicted. Here, we have this normal condition and with respect to this normal condition as the vehicle negotiates, then at the central point it is going to the inner side, where at the end points it remains towards the outer side. This is how it is coming as A P on this side and B Q on this side, whereas at the central location it is going in the opposite direction and this is E F. Here, the total amount by which it is going in the other direction that this length is defined as C, whereas the total length of the whole of the wheel base, then this is being given as L.

Now, here what we can see is the two types of the things have been defined. One thing is that when this vehicle is going on the inner side of the normal condition, then there is a total amount by which it is getting displaced and this amount by which it is getting displaced is known as overthrow. Similarly at the ends, it is remaining on the outer side and again there is a certain distance by which it remains on the outer side and this value, because this is getting at the end condition, is known as end throw. It means when we are discussing about the extra clearance of the curve, then we have to compute its value on the basis of overthrow and end throw and this will be the computation, how we will be doing in the case of this effect of curvature.

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Extra Clearance on Curves

- **Effect of Curvature**
 - Extra clearance required is the distance by which the longitudinal axis of the body of vehicle moves out from the central line of the track.
 - Over throw is the extra clearance required at the center of the vehicle, towards the inside of the curve

Over throw = $C^2 / 8R$

So, the curvature effect is requiring that is this extra clearance is required. This is the distance by which the longitudinal axis of the body of vehicle moves out from the central line of the track. This is what we have shown in the previous diagram. There has been a central line as AB and then, there is overthrow or end throw at the central or the end locations and this is the distance by which it is getting displaced and this is what is the extra clearance which is required on two directions opposite to each other, means when we talk about, when we say it is opposite to each other, we can understand that it may be having the opposite effect, when we are computing the values in that sense and here the overthrow is being defined.

The overthrow is the extra clearance which is required at the center of the vehicle and this is towards the inside of the curve. This is already being shown in the previous slide that how we can show or we can compute this value of x, overthrow and this value of overthrow is computed by C square divided by 8R, where C is the total amount of the wheel base which is being affected in the overthrow condition and R, obviously remains the radius of the curve.

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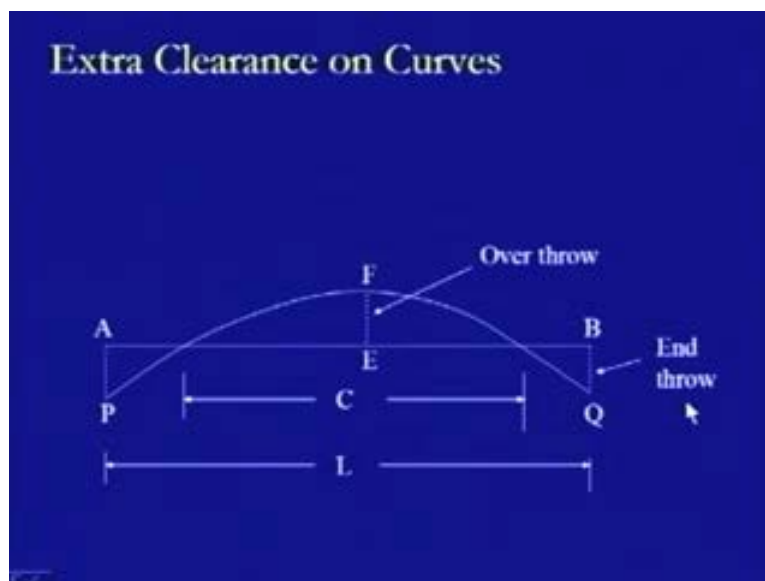
Extra Clearance on Curves

- Effect of Curvature
 - End throw is the extra clearance required at the ends where the vehicle projects towards outside of the curve.

$$\text{End throw} = (L^2 - C^2) / 8R$$

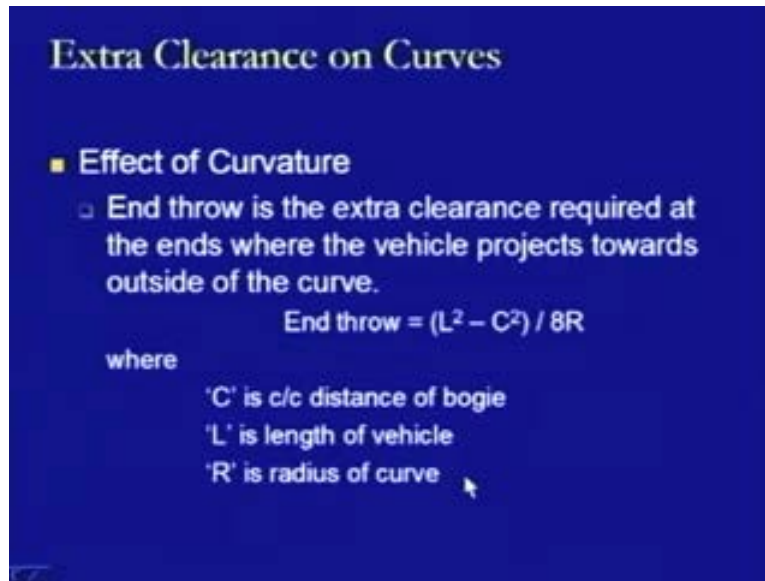
So, what we have seen here is that there is overthrow and which can be computed as C square divided by $8R$ and in the same condition of the effect of curvature, we can take up the another case that is the end throw and this end throw has already been defined in the diagram. It is the extra clearance which is required at the ends, where the vehicle projects towards outside of the curve and this is already been defined and this value is computed.

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As we have seen in the previous diagram, the overall length, if you go back to that diagram, we just see the diagram which we have seen it, this diagram, here we have this is the length of the affected portion and the overthrow that is C and that is why only C is being considered when we have computed the value of overthrow. When we are coming to the end throw, then this is the distance which is being affected. So, this is total L and this is C. So, L minus C means this value plus this value. So, this is the total section which is getting affected. So, we take this value as L minus C and then, we compute the value.

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Extra Clearance on Curves

- **Effect of Curvature**
 - End throw is the extra clearance required at the ends where the vehicle projects towards outside of the curve.

$$\text{End throw} = (L^2 - C^2) / 8R$$

where

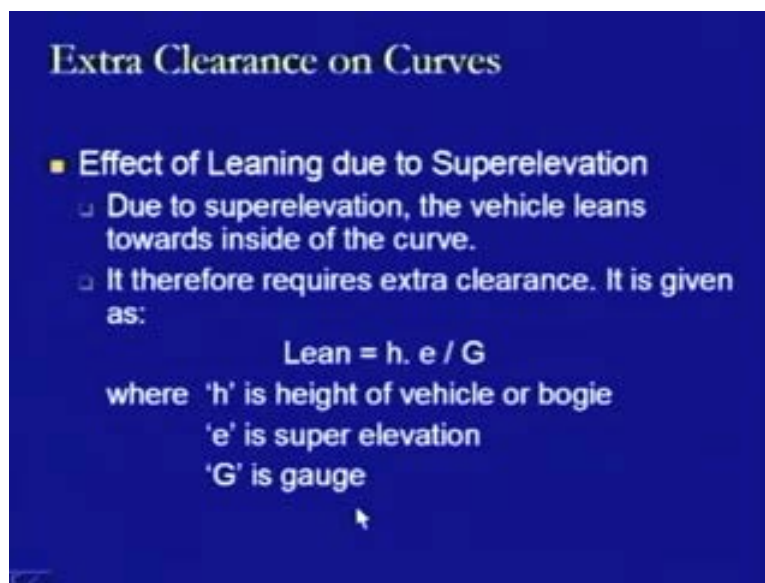
- 'C' is c/c distance of bogie
- 'L' is length of vehicle
- 'R' is radius of curve

So, therefore this is L square minus C square divided by 8R, instead of C square divided by 8R as we have taken in the previous case, we come to this value. Here, C is the center to center distance of the bogie. This is how in terms of the wagon or in terms of the rolling stock it is being defined. So, we have to find out the center to center distance of the bogies. This is one thing. Then, L is the length of the vehicle. So, whatever is the length of the vehicle is to be computed or of course all these values, they are standard values. Depending on the gauge and depending on the type of the vehicles which are using that gauge, these values are already being defined and therefore, we have to look at the standards given for the different bogies of the vehicles and we can borrow these

values from there and we can put the values in this equation or the previous equation, where we have computed the value of overthrow, so that we can compute overthrow as well as end throw and R remains as such. It is universally being taken as the radius of the curve.

So, once we have all these things, this is from the design charts or from the design specifications of Indian railways and this is the value from the actual condition of the curve. So, both are the things being taken together in this formula and that is how we are trying to find out the effect of the curvature or the distance by which this is to be taken into consideration. Now, in this case, what we can see is that with respect to the centerline profile, both the things are happening in two opposite directions. So, therefore if one is being taken as the positive effect, then another will become as the negative effect in that sense.

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Extra Clearance on Curves

- **Effect of Leaning due to Superelevation**
 - Due to superelevation, the vehicle leans towards inside of the curve.
 - It therefore requires extra clearance. It is given as:
$$\text{Lean} = h \cdot e / G$$
where 'h' is height of vehicle or bogie
'e' is super elevation
'G' is gauge

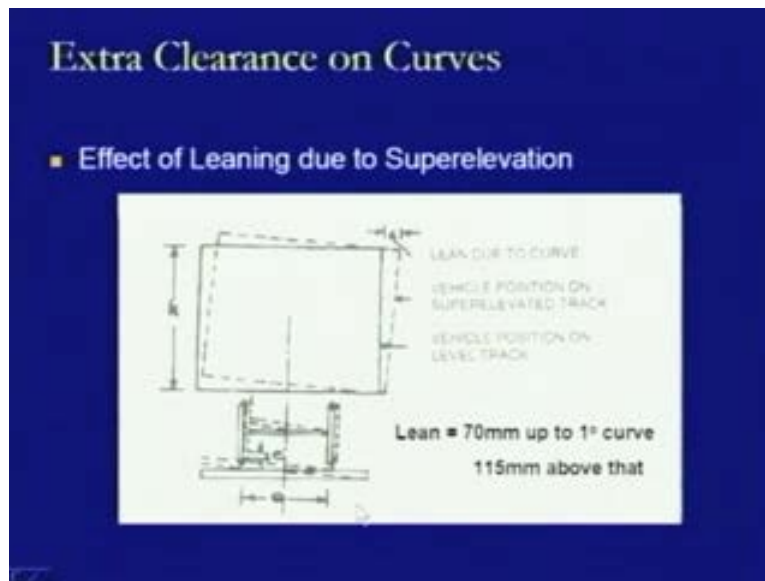
Now, another effect which is there in the case of extra clearances needs to be considered is the leaning due to superelevation. Now, what is happening in this case is, as we have provided the superelevation there is a tilting of the base of the track. The outer rail section or the level of the outer rail section is at a higher level as compared to the level of the

inner rail section by a value of superelevation equals to e . So, as soon as there is a tilting of this base, whatever vehicle will be negotiating this tilted surface will also remain in a tilted condition.

Now, when it is getting tilted, what happens is that it is tilting towards the inner side. So, the leaning is coming towards the inner side of the curve. So, this we will be looking at, when we look at the diagram where the leaning has been defined. Before that it is what is happening is that, it is due to the superelevation the vehicle leans towards the inside of the curve. This is important that it is leaning towards the inside of the curve, then probably there is no effect which is going towards the outside of the curve. So, it therefore requires extra clearance and this extra clearance is given as lean is equals to h into e divided by G .

So, this is how the value of the lean can be computed, where e is the superelevation which is provided, G is the gauge which is provided here and h is the height of the vehicle which is trying to negotiate the curve, where the superelevation e has been provided. So, h is the height of the vehicle or the bogie. Again, this value is a constant value for any vehicle or a bogie and this can be taken directly from the standards of the Indian railways. So, this is a sort of constant value, e is the value already provided in actual and G is again a constant value. So, there again in this formula we have two constant values with one actual value provided based on the equilibrium speed. So, e is superelevation, G is gauge.

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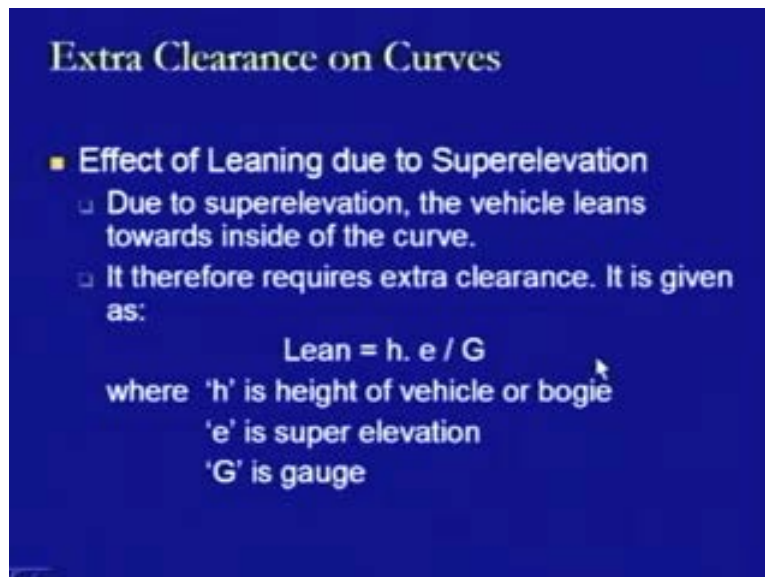
Now, we look at this diagram which is trying to define the leaning caused due to superelevation provided on the track. Now, as far as the straight section is concerned, when we look at both the conditions in this diagram, first of all let us look at the straight section, where this is the base here, this is one wheel, this is axial, this is another wheel, this is the inside of the track and this is outside of the track. So, in this case, when the balanced conditions are there, then this is the profile of the wagon or the vehicle, this one which is being shown by a solid line. Here, the height h is already shown here in this sense. This is the height h that is the height of the bogie or the wagon being provided.

Now, this is the case when we are moving on a straight section. As soon as we come to a curved section, the superelevation will be there and because as we have taken this as outer side and this as inner side, this outer side will be raised and see, it is being raised by a value e at this level and this is how the inclined surface is being formed. So, this is the inclined surface which defines the provision of superelevation. Now, on this provision of superelevation when this wagon is negotiating, then this will go up and this will remain in its normal natural condition. So, this is going up in the level.

Further, because this is rigid condition and the size of the wheels remains the same, therefore the distance maintained between the axial and the surface on which it is moving will also remain the same. So, this is also being tilted like this now. So, the axial has got tilted like this now by some angle here which is defined by the value of e and the gauge being provided in between. So, this is e divided by G is $\tan \theta$ and this is how this angle can be computed as θ .

So, once this is happening, then the new form of the bogie will be the one which is being shown by the dotted lines. So, this is the condition. This is the bogie, so this bogie has got tilted like this. So, now the whole of the bogie is instead of straight it is getting tilted towards the inner side. So, this is by this amount it has gone inner side. So, this is the actual previous condition. Now we are inside of the curve by this much amount and this is what is the lean due to curve. So, we have to compute this value of lean due to curve and this is computed with the help of the value of this angle which is to be computed using e and G . As we have seen that $\tan \theta$ is nothing but it equals to e divided by G , so if we use the same value of $\tan \theta$ here, then it is this lean divided by this value of height of the bogie.

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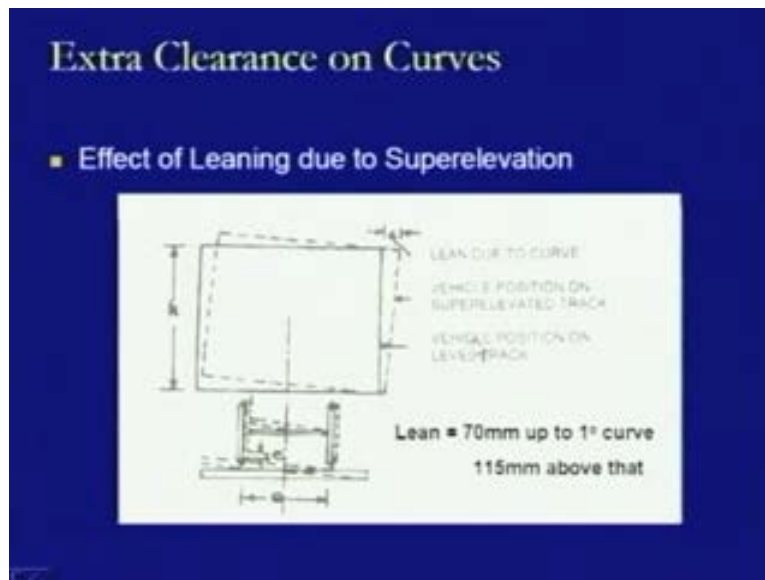


Extra Clearance on Curves

- **Effect of Leaning due to Superelevation**
 - Due to superelevation, the vehicle leans towards inside of the curve.
 - It therefore requires extra clearance. It is given as:
$$\text{Lean} = h \cdot e / G$$
where 'h' is height of vehicle or bogie
'e' is super elevation
'G' is gauge

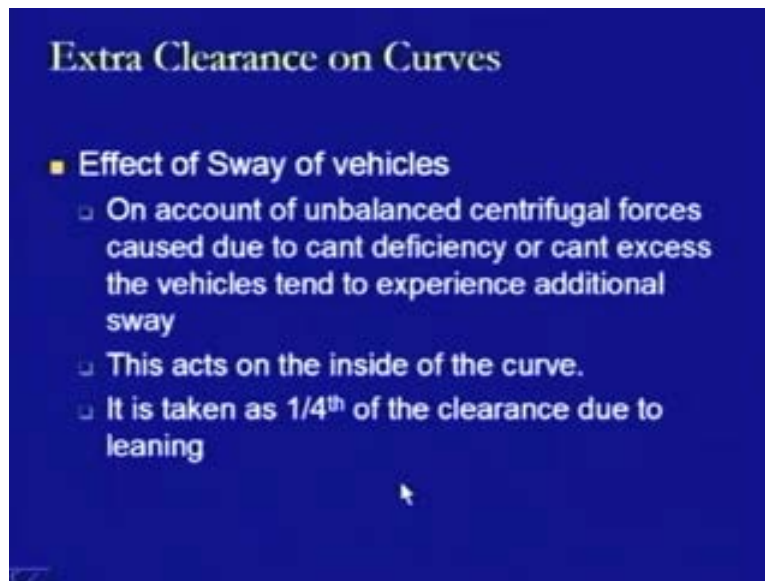
So, it means lean divided by height of the bogie is e divided by G and this is what you can see in the previous formula. So, the lean, this lean divided by h is $\tan \theta$. Similarly, e divided by G is also $\tan \theta$. So, when we **quit** the two we get lean is equals to h into e divided by G and this is how we have found out this value in this case.

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So, this is what is being shown or what is being defined, the effect of leaning due to superelevation. Now, in this diagram it is very much clear that in the case of this lean effect, the effect is going only on the inner side, whereas on the outer side even the vehicle bogie has gone inside by this much amount. This is the minimum amount by which it has gone inside. It means there is no such effect by which a clearance is to be provided on the outer side of this curve. Only clearance is to be provided on the inner side of the curve and this lean is being defined as 70 mm up to 1 degree curve and 115 mm above that, this value. So, this is how we compute this value.

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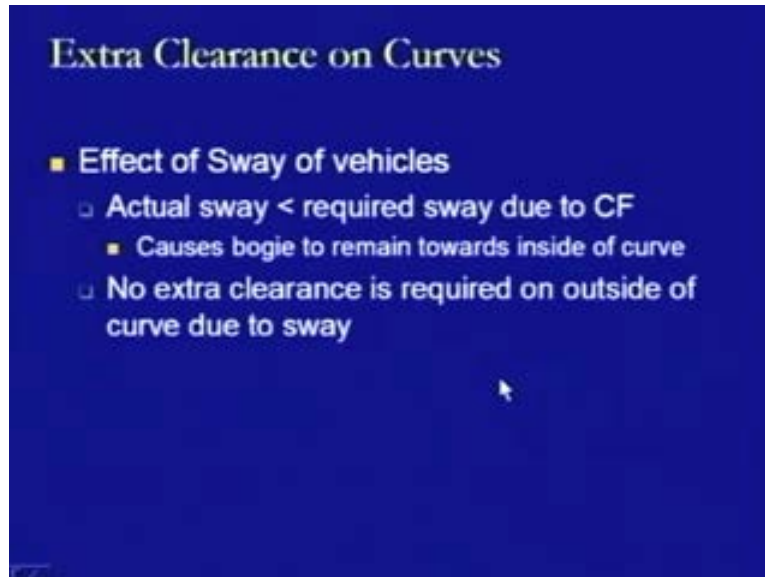


Another condition is the effect of sway of vehicles. Now, this already we have seen that in the normal condition when the diameter of the wheel on the two rail sections remains the same that is it is the average diameter, then in that condition the vehicle remains or the bogie remains in its most equilibrium central condition. Now, as soon as there is a sway, the sway will be in the lateral direction and if the sway is the outward direction, then it means the bogie is going to shift totally in the outward direction. So, whatever is the amount of shift in the outward direction that is the clearance which is to be provided on the outward side.

Similarly, the same bogie can also move in the inside of the curve. So, if that is happening, then again whatever is the amount by which it is shifting towards the inside of the curve then we have to provide that value on the inner side of the curve. So, on account of the unbalanced centrifugal force caused due to the cant deficiency or cant excess, as we have seen previously when we have discussed all these things, the vehicle tend to experience additional sway and this is what we have discussed as a lateral movement or lateral oscillation or lateral sway.

This acts on the inside of the curve. Mainly the effect is coming more on the inside of the curve in this one and this is taken as one fourth of the clearance due to leaning. This is the amount by which a clearance is to be provided in this case of the sway of the vehicle.

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So, this effect of the sway of the vehicle what we found is that the actual sway is less than the required sway due to the centrifugal force. This is because what happens is it causes the bogie to remain towards the inside of the curve in this case and there is no extra clearance required on the outside of the curve due to the sway, because as this is the condition where we are talking about if the actual sway is less than the required sway due to centrifugal force.

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Extra Clearance on Curves

- Total extra clearance required

- Inside the curve = over throw + lean + sway

$$EC_1 = C^2/8R + e.h/G + e.h/4G$$

- Outside the curve = end throw

$$EC_2 = (L^2 - C^2) / 8R$$

Now, once we have got all these clearances, then what is the total amount of clearance which is to be provided? Now, this total amount of clearance required is to be computed for both conditions that is for inside of the curve as well as for outside of the curve. In the case of the inside of the curve, as we have seen, the effect is in terms of overthrow plus there is an effect of lean of the vehicle due to superelevation and there is also effect of sway due to oscillation. So, all the three effects have to be summarized and taken as a summation, so as to find out the total extra clearance to be provided on inside. In that sense, it will be overthrow is C square divided by $8R$, lean was e into h divided by G and sway is one fourth of the lean that is e into h divided by $4G$, whereas in the case of outside of the curve only one factor is there that is end throw and this is being computed as L square minus C square divided by $8R$.

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Extra Clearance on Curves

- Values
 - C = c/c distance of bogie = 14785mm (BG)
13715mm (MG)
 - R = radius in mm
 - L = length of bogie = 21340mm (BG)
19510mm (MG)
 - h = height of vehicle = 3350mm (BG)
3200mm (MG)

Now, some of the values which are being used these are the standard values. The center to center distance of a bogie in the case of a broad gauge is 14785 mm. In the case of meter gauge it is 13715 mm, R is the radius in mm, this is already being defined and the minimum maximum radius is also been defined previously. L is the length of the bogie and this is 21340 mm in the case of a broad gauge vehicle and is 19510 mm in the case of meter gauge vehicle. Then, height of the vehicle, h it is 3350 mm in the case of broad gauge vehicle and it is 3200 mm in the case of meter gauge vehicle.

So, these are all standard values and if we put all these standard values in the formula which we have seen previously, so as to find out the total extra clearances to be provided on curve, then we can also reduce the size of the formula.

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Extra Clearance on Curves		
■ Empirical formulae normally adopted in the field for determining the extra clearance due to the curvature effect are as follows:		
Overthrow (mm)	$27330/R$	$23516/R$
End-throw (mm)	$29600/R$	$24063/R$

So, the Empirical formula normally adopted in the field for determining the extra clearance due to the curvature effects are, we are talking about the two things here, the overthrow in mm. Then, in that case this overthrow is computed by this formula directly where only one factor is there, which is the variant and if we know the radius, we can compute the value. So, this is 27330 divided by R for overthrow mm or this is 23516 divided by R for the broad gauge and meter gauge conditions. End throw similarly is 29600 by R and 24063 divided by R respectively.

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Extra Clearance on Curves

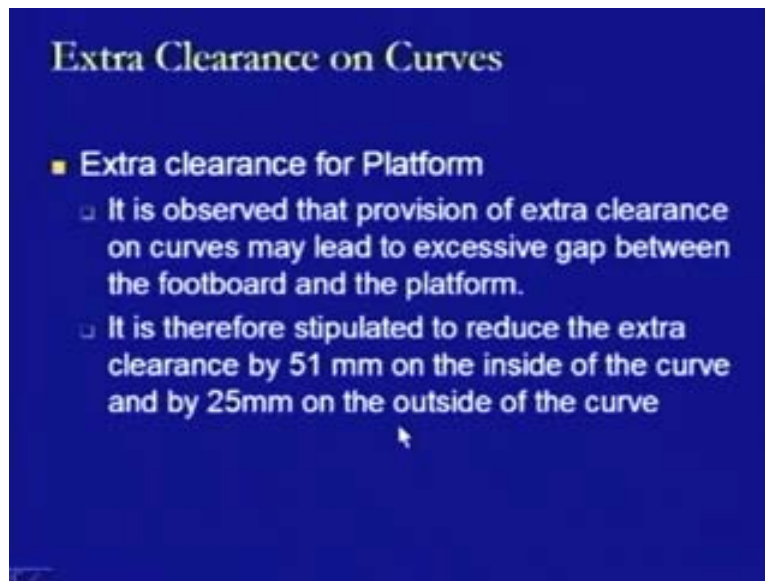
- Extra clearance between adjacent and curved tracks
= clearance on inside + clearance on outside – lean
- Lean is not considered as both the tracks have almost same super elevation

$$E_c = \text{overthrow} + \text{sway} + \text{end-throw}$$
$$= C^2/8R + e.h/4G + (L^2 - C^2) / 8R$$

Now, we come to the extra clearance between the adjacent and the curved tracks. Here, it is equals to the clearance on inside plus clearance on outside minus the lean, because lean is not to be considered, because both the tracks have been provided on the superelevation and because the rate of superelevation is same, therefore the lean effect will also remain the same and we have also seen then, when there is a lean effect on the inside, then at the outer side the weight of the bogie goes towards the inner side. So, there is some extra clearance which is coming at the outer side. This is the reason why this is to be subtracted from the other two conditions.

So, in that case it becomes overthrow plus sway plus end throw and this is C square divided by 8R plus e into h divided by 4G that is one fourth of lean plus L square minus C square divided by 8R. So, this is the amount of the extra clearance which is to be provided between two tracks on a curved section.

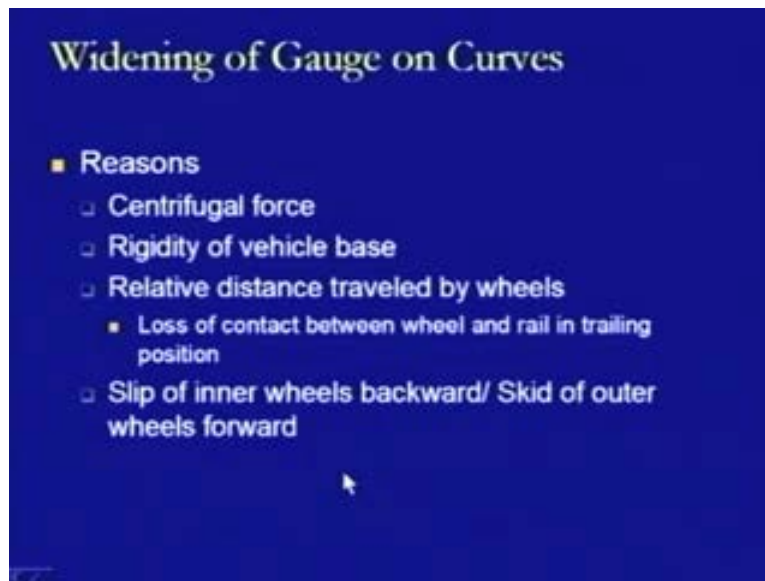
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So, another clearance which is to be checked is the extra clearance for platform now in this case of extra clearance for platform what happens is that, being observed that provision of extra clearance on curves may lead to excessive gap between the footboard and the platform. Now, as far as it is a straight section, then a normal distance can be provided between the platform and the track. But when there is a curved section, so the curved section is going say, something like this and with this curved section if a platform is to be provided which is straight in section, a rectangular shape, then in that case there will be an excessive gap, which will be coming between the footboard of the vehicle and the platform and this may be a very hazardous condition for those passengers who are boarding or alighting the vehicle. So, therefore it is to be somehow compensated in this case.

So, what is done is that it is stipulated to reduce the extra clearance by 51 mm on the inside of the curve and by 25 mm on the outside of the curve. So, whatever extra clearance is being computed, when once it is being computed then it is reduced by 51 mm on the inside of the curve and by 25 mm on outside of the curve.

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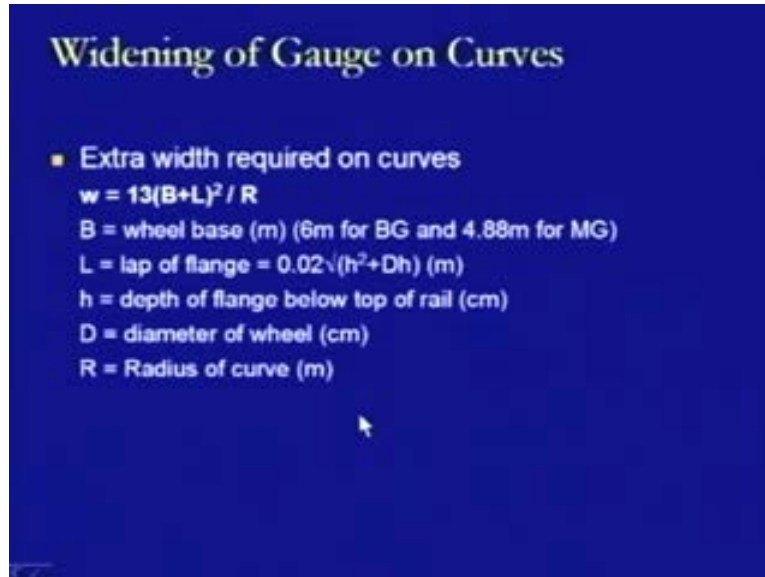


Now, we come to another aspect that is widening of gauge on curves. There are different reasons due to which the widening of gauge is to be done. These are already being discussed again and again. The one is the centrifugal force. The centrifugal force which is acting in the outward direction tries to take the vehicle in the outward direction and that is why some widening of the gauge is to be done in that direction. Another is the rigidity of the wheel base. As we have seen, due to the rigidity of the wheel base there are certain throws, the end throws or the end throws or the overthrows at the center or the end of the base. So, due to that reason again some widening is required on the gauge on the curves.

Then, there is a relative distance which is traveled by the wheels. Again, this is related to the rigidity of the wheel base as well as to the extra amount of distance because of the curvature. So, the loss of contact between wheel and rail in the trailing position will be coming because of the rigidity and because of the distance which is to be traveled and if this is the condition which is happening, then there are two things which will come across. One is that there can be a slip of the inner wheel in the backward direction and at the same time, there will be a skid of the outer wheel in the forward direction and by this slip of inner wheel in the backward direction and skid of the outer wheel in the forward direction, that extra amount of travel which is to be done on the outer rail section is

performed, otherwise it cannot be performed. So, due to this reason of slipping and skidding behavior further the widening of the gauge is to be done.

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Widening of Gauge on Curves

- Extra width required on curves
 $w = \frac{13(B+L)^2}{R}$
B = wheel base (m) (6m for BG and 4.88m for MG)
L = lap of flange = $0.02\sqrt{(h^2+Dh)}$ (m)
h = depth of flange below top of rail (cm)
D = diameter of wheel (cm)
R = Radius of curve (m)

Now, this extra widening which is required on the curves is given by w is equals to 13 multiplied with the square of B plus L and this whole is divided by R , where B is the wheel base in meters. This is 6 meters for broad gauge and 4.88 meters for meter gauge, L is the lap of flange which is defined by 0.02 and under root of h square plus Dh and this is computed in meters, where h is the depth of the flange below the top of the rail as taken in centimeters, D is the diameter of wheel in centimeters and this is, once we have got these two values, we can compute the lap of flange, L . So, we have B , we have L and the radius is known to us and with the help of that we can compute the value of this extra width which is required on the curves that is w . So, this is all about the transition curves and this is all about the clearances of different types which need to be provided on any curved section.

So, in the today's lecture, we have covered the two main things that is transition curves and clearances. So, we will be stopping at this point now and we will be continuing with another left aspect of the geometric design of the railway tracks in the coming lecture. Good bye and thank you to you.