

Transportation Engineering - II
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Lecture - 16
Speeds on Track

Dear students, today we are starting with another lecture on the lecture series related to the course material on Transportation Engineering – II. In today's lecture, we will be looking at the aspects of speeds on track. This is in continuation of the geometric standards which we have discussed in the previous lecture, where we discussed about the curves, the superelevation and the provision of superelevation and its design. Before that we have already discussed about the fixing of an alignment and the factors needs to be taken or considered while fixing any alignment of a railway track.

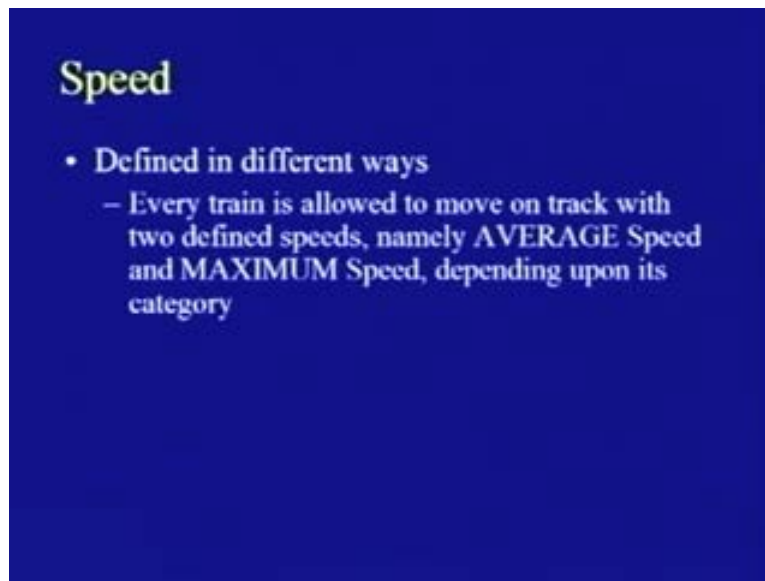
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Lecture Outline

- Speed and its effects
- Safe Speed
- Equilibrium Speed
- Maximum Permissible Speed
- Computation of Speed and Cant

In today's lecture, we are going to take the speed and its effects, the safe speed, the equilibrium speed and maximum permissible speed and finally, we will try to look at the computation of speed with respect to the given cant or the computed cant or the superelevation.

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Now, we start with the speed. A very first thing is that there are different ways in which the speed can be defined. As we understand, speed is the rate at which we are covering any distance. Now, in this case it may be defined in the way like it may be the average speed or the maximum speed. In the case of the tracks or may be in any of the cases of the transportation systems we take in general, we find that the speeds have been defined in different forms for the design purposes.

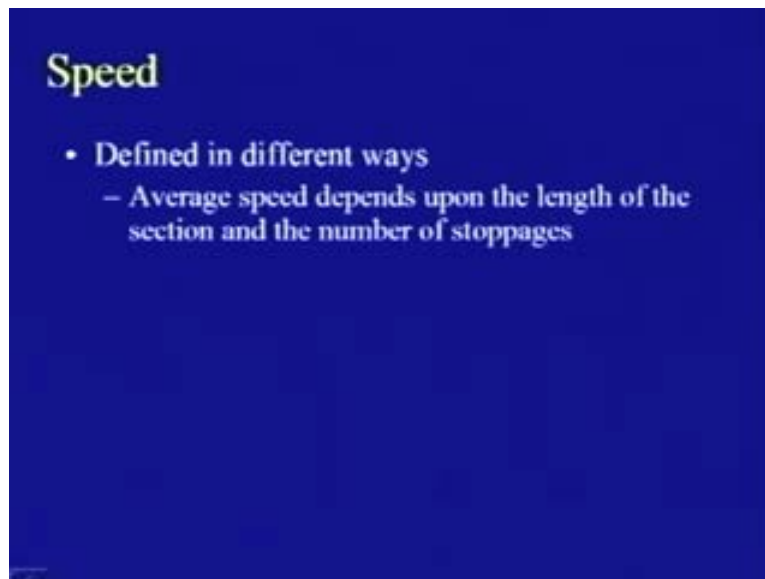
Here in this case, we are talking about that every train is allowed to move on track with two defined speeds, namely average speed and maximum speed depending upon its category. Now, as we know that there are different trains which are running on these tracks and all these trains have been defined or categorized on the basis of their speed characteristic mainly, that is they have been defined to move at certain maximum speeds and with respect to those maximum speeds the average speeds are also defined.

Average speed is the speed which is helpful in defining or in finding out the total time period a train is going to take, so as to cover a distance, whereas maximum speed is the value which a driver is allowed to attain subjective there is a requirement of attaining that value. At the same time, there are certain sections in which they are allowed to attain this

higher value, so as to economize on the travel time. So, we have to look at both the factors. That is how we compute average speed or how we are computing the maximum speed.

Now, when you talk about the maximum speed, we can go to as in one of the previous lectures I have told you that the maximum limits can go even up to a value of 500 to 550 kilometers per hour. Even in our Indian railways condition, now we are aiming at achieving the higher speed of some around 250 kilometers per hour and some corridors have been identified, which are going to be transformed into the high speed corridors, where the trains will be moving at a speed of 250 kilometers per hour. So, how we are going to fix up that speed and whether it is related to any safety measures to be taken up, so that there is no accident taking place or the hazardous conditions are not getting created. In that sense, we have to look at along with the maximum speed on the safer speed too. So, it means there will be different categories of speed which needs to be understood and which needs to be examined or computed.

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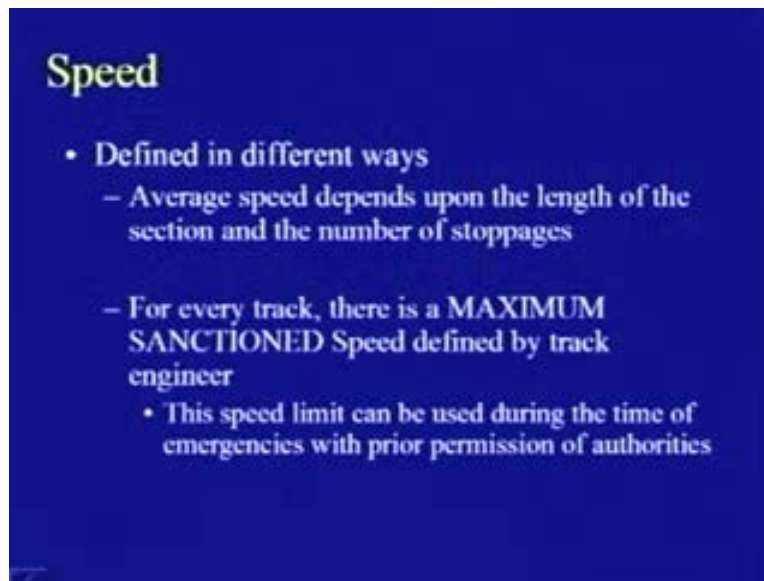
Now, we look at the different things. The average speed depends upon the length of the section and the number of stoppages. Like, even if we are providing the maximum speed

and the maximum speed can be attained by a train between two stations, then that is going to economize only the ... distance which is being provided between those two stations. But, in the case as we have seen while fixing an alignment, the alignment covers number of places, so that the revenue can be generated. In that sense, there will be two terminal stations, the station from where the train is starting and the station at which the train is finally ending and in between it will be passing through number of other stations.

Therefore, there will be, in all these stations the train has to stop down. So, it means it is losing some time while stopping. It is also losing some time while de-accelerating and it is also losing some time while accelerating. If the train is allowed to move on a constant speed from point a to point b, while it is passing through points c d and e, then there is not going to be any loss. But then in that case, there cannot be any stoppage. Therefore, whatever are the number of stoppages and whatever are the lengths of the sections, because this is another thing, if the length of the section is small between the two stations, then the maximum speed cannot be attained. As soon as the train starts attaining the speed, probably the time comes after which it has to be accelerated, so that it can stop at any other station. So, that is a condition which is generally found in the case of urban railways, where like in the cities the trains have been provided.

If we talk about those things, then we have metro in Delhi or we have suburban rail system in Mumbai or another metro in the Kolkata and likewise, we are having railways in Chennai. So many categories are there, where the length of the section also matters, because the train is not being allowed to attain the maximum speed at that section, as the length of the section is very less. So, this is one thing which is related to the average speed. So, therefore what we have to take is that we have to find out the total time period which it has taken from the station a to station b via station c, d and e and the total distance which is there between point a and b. So, the distance divided by the total time will give us the average speed and obviously, now it will be covering that amount which it has spent or in its stopping or in accelerating or while the train has been stopped at any of the station.

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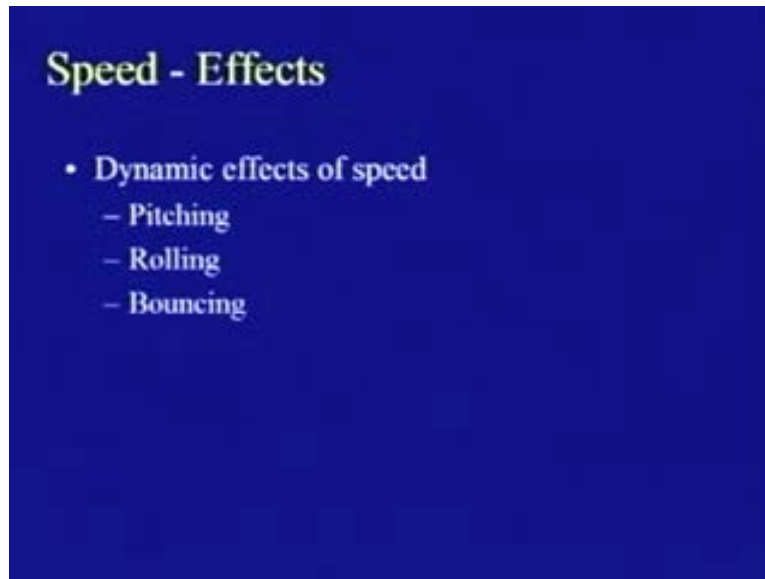
Speed

- Defined in different ways
 - Average speed depends upon the length of the section and the number of stoppages
 - For every track, there is a **MAXIMUM SANCTIONED** Speed defined by track engineer
 - This speed limit can be used during the time of emergencies with prior permission of authorities

So, for every track there is another thing that is maximum sanctioned speed and this maximum sanctioned speed is defined by the track engineer, who has designed that section. So, there are a number of factors on the basis of which this maximum sanctioned speed can be defined and they are, of course Indian railways as well as the other railways in the world have devised the formula, so as to find out this value of maximum sanctioned speed. So, this is another value. Any train which is moving on any of this section is not allowed to cross this value, because this is the most highest value which is being allowed by the track engineer and this value is the last value which is being taken into consideration while designing the track.

If we overcome or we come out of this particular value and it is being exceeded, then all chances that any accident may take place. So, to remove that hazardous conditions it is better to be far below this maximum sanctioned speed. But, in the case of emergencies, with the permission of the competent authorities, these maximum sanctioned speeds can be attained by the drivers of any train. So, this speed limit can be used during the time of emergencies with prior permission of authorities. That is what I have already enumerated.

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Now, in the case of speeds, we have already seen that the speed creates its effect in the augmentation of stresses as well as in the augmentation of the resistances. There are number of things in which the speed plays its role. They may be curvature, they may be gradient effect. In those cases, also at times the speed has its effect. So, we will be looking at some of the dynamic effects of speed, now in this lecture, at this point of time. So, different effects are like pitching. In the case of pitching, what happens is that there is a sort of throw in the forward direction or in the side direction. That sort of a throw which is coming because of the irregularities of the surfaces or may be because of the poor maintenance of the joints, whatever are the reasons, this is one of the effect which may be there and passengers who are sitting inside the wagons they may feel that there is a throw **to them** in the forward direction or they are felling a throw towards the side or hitting towards the side of the boggy. So, this is one type of effect and obviously, as the speed increases, this tendency of getting a pitching may also increase.

Another effect is rolling. Rolling is the effect where there is a movement with respect to the x-axis. In the case of x-axis, like that is the longitudinal movement which is taking place along the track. If it starts just moving in the clockwise or anticlockwise direction of that axis, then that is termed as rolling. But, in the case of the trains, it is not taking a

complete turn like this, but then there is a leaning effect towards the left side or towards the right side of the direction of movement and that can be termed as a rolling effect, which can be there and you will find that generally it is happening in the cases, where like the curves have been provided or the sections have been provided where there is a difference in the outer and inner rail levels. In such conditions, there are tendency of the material as well as of the passengers moving towards one side and that is the rolling effect which comes in.

Then, the next effect is bouncing. Bouncing is the condition where the train has a bumping effect at the same location where it is, whereas in the case of pitching it was the forward or the backward condition throw. In the case of the bouncing, this is in the vertical direction. So, the train has a vertical movement and with that vertical movement, like you feel a jerk in the upward direction or you feel a sort of a deflection in the downward direction. So, that is the effect of bouncing and bouncing effect may be coming, again because of the irregularities in the track and as the speed increases, this effect of irregularity increases tremendously or may be it is a condition which may be observed at a point where there is a joint and due to the impact of the difference in levels of the two rails, a bouncing effect may be coming.

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Speed - Effects

- Dynamic effects of speed
 - Pitching
 - Rolling
 - Bouncing
 - Lateral Oscillations
 - Resonance

Then, this is one aspect which we have been discussing from the very beginning is that there are all chances of lateral oscillations or sways taking place on any rail section and probably if I understand that you must have observed this whenever you have traveled by train that the train moves in either of the directions which is in lateral direction, when it is moving in any forward direction. So, that is lateral oscillation which keeps on coming and as soon as it hits on the one side, it rebounds back and moves towards the other side. So, you feel that your compartment is moving sideways and that is relative motion of the compartment in the side ways with respect to another wagon of the compartment. That is what is a lateral oscillation and this effect of lateral oscillation increases as the speed increases. This is another effect of the speed and we will find that if the speed is very heavy, then these oscillations may be so heavy that there are chances of overriding the rails. Now, that becomes obviously the hazardous condition.

Then, there is a resonance. Resonances you must have studied in physics that it is a condition, where the frequencies of the systems start matching. Now, when this is happening, here we are talking about the two metal surfaces. One metal surface is in the form of rail and another metal surface is in the form of the wheels. So, when these two things are interacting with each other, there is a continuous smooth movement on this one and at the same time there are chances, where there are impacts or bouncing effects or pitching effects, as we have discussed just above. Then, the frequency of the two may match and as soon as **there is** this frequency matching is there, a sort of vibrations will start moving in to the persons or to the freight which is being transported. So, this is another condition which at times people have observed that they feel a sort of a pinching effect which is coming from the bottom while they are sitting on any seat. So, that is coming, because of the resonance which has been achieved at the bottom at the track level.

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Speed - Effects

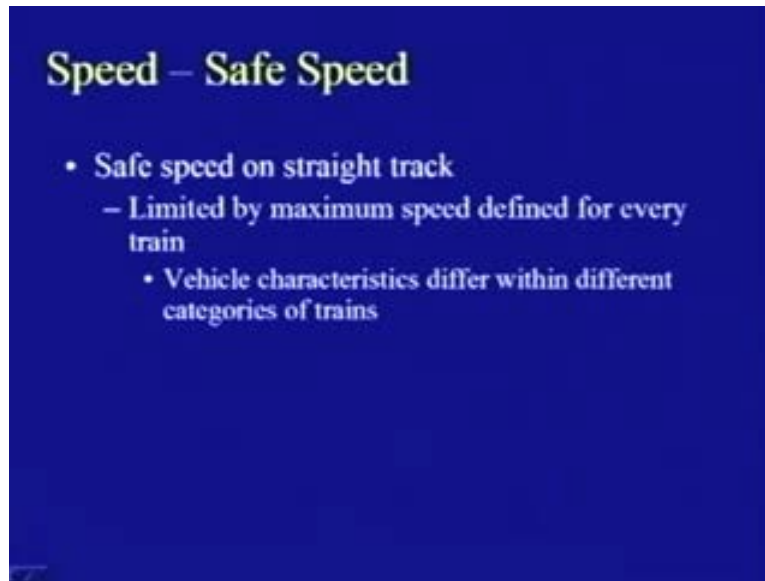
- Dynamic effects of speed
 - Pitching
 - Rolling
 - Bouncing
 - Lateral Oscillations
 - Resonance
 - Springing action
 - Suspension Characteristics

Then, springing action is coming out due the reasons of the springs being provided at the bottom of any wagon, so as to take care of the movements in the vertical direction. So, this springing action may be there, again unless and until it is a very smooth track, where the levels have been maintained, where the grease has been maintained or the alignment has been maintained properly, the joints are perfect, then you are not going to observe this springing action. But otherwise, if it is not there, any of the problems are there, you will observe that you are having oscillating condition in the vertical direction. So, you are going up and coming down and going up and coming down that is what is a springing action which will be there and this springing action is controlled by the devices which tries to dampen out these type of effects and you will find that if we move from the normal category of wagons to the higher category of wagons, then this springing action reduces by a large amount.

So, that is because better springing devices have been provided in those higher category of wagons as compared to those other lower category of wagons and then, the suspension characteristics are there. Suspension characteristics, again they are related back to the swinging action. We can say that it is trying to having a suspended condition along the wheel basis, along the axial basis, which have been provided because there the number of

bogies which are provided, so as to make a compartment as we have seen in the case of locomotives too, that when we define them by any nomenclature or we define them by the number of **axial** or the number of wheels, then it is not that the whole of those wheels have been provided on the same bogies. There are chances that there are two or three bogies which have been provided at the bottom. So, when that is being done, then there is a suspense effect which remains between those bogies. So, there are other characteristics which get enhanced because of the speed. So, these are some of the problems or some of the effects which are caused because of speed.

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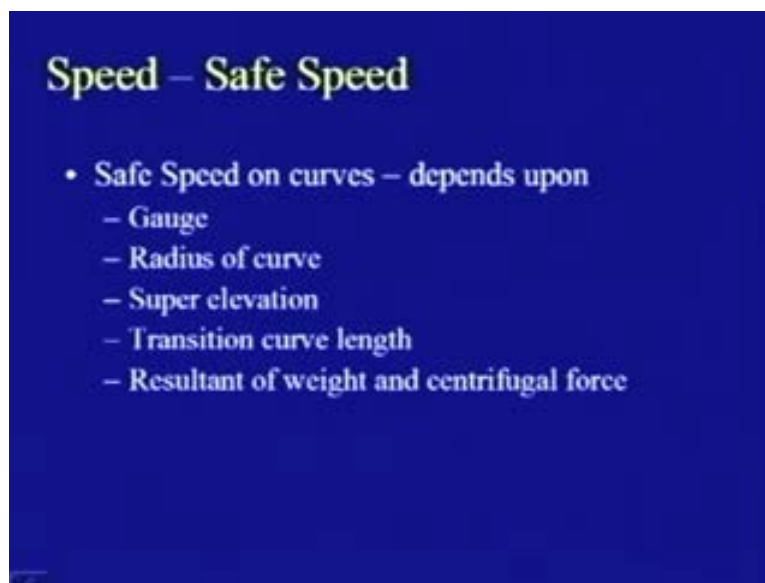
Now, we come to the important point that is how to compute the safe speed, because all the trains which are allowed to move on any of the track, they should move with a speed which is lesser than the safer speed or at the maximum they can attain this speed and after this one, then we have the maximum permissible speed or the maximum sanctioned speed of the track which of this can be taken up when there is an emergency. So, the safe speed on the straight track, in this case it is limited by the maximum speed defined for every train.

As we know that there are different categories of trains, we have passenger trains, we have express trains, we have superfast trains and then, we have other categories like

Rajdhani's and Shatabdi's, so all the categories of these trains, they are having their different values as maximum speeds, so they have been defined by the categories. So, the safe speed is also going to be governed by the same similar thing that is the maximum speed defined for every train. So, it has to be less than this or at the maximum it can attain this value of maximum speed.

Then, vehicle characteristics differ within different categories of trains. This is the reason why this value is going to change, because the different suspension systems or the safety features or the springing actions, everything they are all different, depending on the type or the category of the train and that is for what the railways charges you when you travel by that particular category of train. So, when these characteristics are changing, then obviously in that case, the speeds can also change or we can go for higher speeds if better characteristics have been provided.

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Speed – Safe Speed

- Safe Speed on curves – depends upon
 - Gauge
 - Radius of curve
 - Super elevation
 - Transition curve length
 - Resultant of weight and centrifugal force

In the case of the curves, it is going to depend on certain factors like it depends on the gauge that whether we are providing a broad gauge or a meter gauge or a narrow gauge, the radius of the curve. It is also you can see that it is degree of the curve or the radius of the curve, it is going to depend on that one. If the radius of the curve is bigger or large,

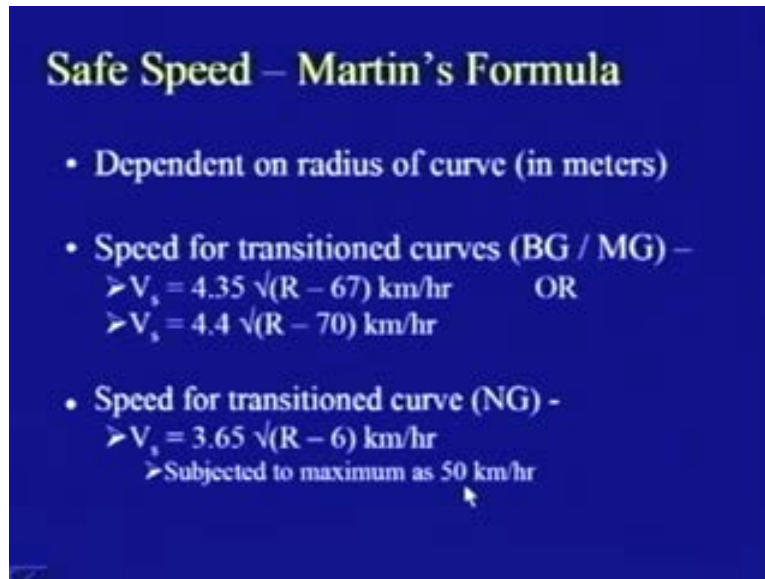
then obviously it is a flat curve and negotiating a flat curve with a higher speed is not a problem, but when the curve is quite sharper, then the higher speeds cannot be attained.

Then, the value of superelevation, this value of superelevation is another thing, because this superelevation as we have seen in the previous lecture is nothing but the GV^2 square divided by $127 R$. So, it means this superelevation and speed, they are co-related. Superelevation is co-related with the, is proportional to the square of the speed. So, that is how if we are providing certain value of superelevation, then we can find out the related speed or the restricted speed and this is what we have seen previously too, when we have computed the values in the case of negative superelevation being provided on a branch line with respect to a main line.

Then, transition curve length is another case. Here, it is governed by the length of the transition curve and this transition curve provides the smooth entry of the train from the straight section to the curved section and if we cannot provide the complete length of the transition curve, then the value of the safe speed needs to be restricted. But, in case if there is no problem in providing the overall length of the transition curve, then whatever value is being found out by the different other methods, then that can be provided on the basis of that one.

Then, resultant of weight and centrifugal force, this is another aspect which we have discussed when we devised the formula of superelevation that is e equals to GV^2 square divided by $127 R$, where in that diagram we have seen that the weight is acting vertically downwards and the centrifugal force acts in the horizontal direction and their resultant acts at an angle α with respect to weight **in the horizontal**, in the downward direction and this falls within the two wheels which have been provided on the axial. So, this is another thing, means we have to see that the resultant is not falling away or out of that wheel base, otherwise it will create the overturning movement condition.

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Safe Speed – Martin's Formula

- Dependent on radius of curve (in meters)
- Speed for transitioned curves (BG / MG) –
 - $V_s = 4.35 \sqrt{(R - 67)} \text{ km/hr}$ OR
 - $V_s = 4.4 \sqrt{(R - 70)} \text{ km/hr}$
- Speed for transitioned curve (NG) -
 - $V_s = 3.65 \sqrt{(R - 6)} \text{ km/hr}$
 - Subjected to maximum as 50 km/hr

So, now we look at how we can compute the safe speed. There is a Martin's formula, so as to compute the safe speed. This is quite old formula and it depends on the radius of the curve which is taken in meters, the speed for transition curves like the broad gauge curves and the meter gauge curves. In that category, the safe speed V_s is given by 4.35 and under root of the whole value of R minus 67 and this comes in kilometers per hour. So, this is one formula in the case the transition curves are provided on that track and this is what the broad gauge and meter gauge condition, whereas or it can also be simplified as 4.4 and under root of R minus 70, again as kilometers per hour.

Then, in the case of the narrow gauge and again the curve is being provided with the transition curve, then V_s of the safe speed is computed by 3.65 under root of a value of R minus 6, again in kilometers per hour and this is subjected to a maximum value of 50 kilometers per hour. So, whatever value we are getting using this formula with respect to the radius of the curve, if it is coming more than 50 kilometers per hour, then this is the maximum value which can be allowed as a safe speed on the track.

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Safe Speed – Martin's Formula

- Speed for non-transitioned curves
 - $V_s = 4/5$ of the above in all cases
 - Subjected to maximum as 40 km/hr for NG
- For High speeds
 - $V_s = 4.58 \sqrt{R}$
- Indian Railways no longer use the above formula of safe speed on curves

Then, in the case of non-transition curves, the speed can be computed as four fifth, 4 by 5 of the above all cases. Whatever value we have computed in the case of transition curves, if we take four fifth of that value, then that is taken for the non-transition curves and in this case for the narrow gauge, it is subjected to a maximum value as 40 kilometers per hour. Then, there is another formula which is given by Martin for high speed conditions or high speed tracks and here, the safe speed can be computed as 4.58 under root R. So, this is simpler formula, so as to find out the speed on the high speed tracks. But, in the case of Indian railways, no longer we are using the above formula of safe speed on curves.

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Safe Permissible Speed

- Martin formula is replaced by Railway Board Formula
- This formula considers the cant actually provided on the track and the standard deficiency allowed in it along with the radius of the circular curve.

What we are using is now being defined as safe permissible speed instead of simply the safe speed and this safe permissible speed is computed by the formula which is given by the railway board and this formula replaces the Martin's formula. This formula considers the cant actually provided on the track that is the superelevation which is being provided on the track and the standard deficiency allowed in it and the value by which any deficiency is being allowed in the value of the superelevation being provided that is whatever is the amount which can be provided as the maximum or whatever is the amount which can be provided as the minimum, considering those values then we can find out the speed and this is allowed in it along with the radius of the circular curves.

So, it means it is trying to consider three things. One is the superelevation, one is the deficiency in terms of the cant deficiency or cant axis or the radius of the curve. So, these three values will be there.

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Safe Permissible Speed	
Type of curve	Procedure for calculating V_m
• Fully transitioned curve	$V = 0.27\sqrt{R(C_a + C_d)}$ for BG $V = 0.347\sqrt{R(C_a + C_d)}$ for MG $V = 3.65\sqrt{R-6}$, for NG Max 50kmph
• Non transitional curve with cant	Cant to be gained over virtual transition, which is 14.6m on BG, 13.7m on MG and 10.3m on NG

Now, we will look at how we are computing this value, what are the formula being given by the railway board. In the case of fully transition curve, it says that it can be computed by V equals to 0.27 and under root of the whole value of R multiplied with C_a plus C_d , where C_a is the actual superelevation or cant being provided on that track and C_d is the cant deficiency which is allowed on that track and this is the case **for a meter**, for a broad gauge and in the case of meter gauge, the formula is 0.347 under root of the whole value of R multiplied with C_a plus C_d . So, the formula is more or less similar.

Here, now the only thing is the value of C_d will be changing with respect to the broad gauge or the meter gauge. C_a remains the actual superelevation which is being provided and this factor is changing here from 0.27 to 0.347. In the case of narrow gauge, the value remains the same formula, as been given by Martin that is 3.65 under root of the whole value R minus 6 and it is subjected to a maximum value of 50 kilometers per hour.

In the case of non-transition curve, the values needs to be found out based on the cant to be gained over virtual transition which is 14.6 meter on broad gauge, 13.7 meter on meter gauge and 10.3 meters on narrow gauge. So, this is the way how we compute in the case of non-transition curves, where the superelevation has been provided.

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Safe Permissible Speed	
Type of curve	Procedure for calculating V_m
• Non transitional curve with cant	Cant gradient not to exceed 1 in 360 on BG and 1 in 720 on MG, NG
• Non transitioned curve with no cant	Cal. Permissible cant deficiency to be gained or lost Use rate of change of cant deficiency as 35 mm/sec for BG and 55 mm/sec for MG

Now, we come to the non-transition curve conditions, where in this case again if the superelevation has been provided, the cant gradient that should not exceed 1 in 360 on broad gauge, whereas in the case of meter gauge and narrow gauge it should not increase above 1 in 720. So, on the basis of this value of 1 in 360 or 1 in 720 that is the rate at which the superelevation is being provided and that is one the criteria of finding out the length of the transition curve. So, we have to, because there is a restriction that the transition curve has not been provided, then using this value we can compute the distance by which the superelevation can be attained.

Further, when there is no superelevation being provided in the case of non-transition curve, that is no transition curve is available on this track, then we calculate the maximum cant deficiency to be gained or lost and in that case we use the rate of change of cant deficiency and the value is taken as 35 mm per second for broad gauge and 55 mm per second for meter gauge. These are the standards or the IRS standards related to the cant deficiency, change in cant deficiency.

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Safe Permissible Speed	
Type of curve	Procedure for calculating V_m
• Curves with inadequate transition	Actual cant or cant deficiency with consideration to its limiting value Considering rate of change of cant or cant deficiency within their limits

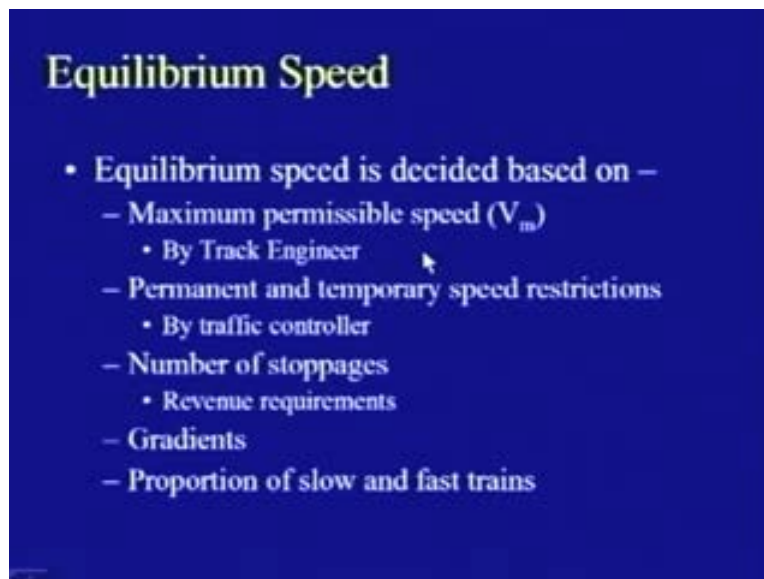
Further, when there are curves with inadequate transition, then in that case the actual cant or cant deficiency with consideration to its limiting value that becomes the criteria for finding out or for calculating the V_m . We take the actual cant which is being provided and we are considering the cant deficiency up to its limiting values. Then, considering rate of change of cant or cant deficiency within their limits, we try to find out the permissible limits of speed.

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Equilibrium Speed
• Defined as speed at which the effect of centrifugal force is exactly balanced by the cant provided

Now, once we have idea of this permissible safe speed or safe permissible speed, the next thing that comes into consideration is the equilibrium speed. This is the basis of design of the superelevation and this is defined as the speed at which the effect of centrifugal force is exactly balanced by the cant provided. So, that is what we have been talking when we discussed the cant. Then, we have founded that there are certain problems with respect to the centrifugal force and in that case what was happening was there was unbalanced condition of the load or the forces which are acting on the inner and outer rails. So, as soon as the superelevation is being provided it just counteracts the effect of the centrifugal force.

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Equilibrium Speed

- Equilibrium speed is decided based on –
 - Maximum permissible speed (V_m)
 - By Track Engineer
 - Permanent and temporary speed restrictions
 - By traffic controller
 - Number of stoppages
 - Revenue requirements
 - Gradients
 - Proportion of slow and fast trains

Now, when this counteracting is being achieved and now we have the same resistance on the two rail sections provided side by side, at that point of a time whatever speed can be obtained that speed is the equilibrium speed and this is decided based on number of factors. It is decided using the maximum permissible speed V_m on that track, which is generally decided by the track engineer who has designed this track. Then, there is a permanent and temporary speed restrictions, which are employed on the track for movement of different trains or the rolling stock and this restrictions may come by the

traffic controller who is controlling the traffic over all the track or on the track which comes under one division or a junction from where a big section has been controlled.

So, the person who is controlling the overall traffic, the trains which are moving on different tracks in different directions, the person is known as traffic controller that is the one person who controls all these things and that person can impose the speed restrictions depending on actual conditions. Sometimes these may be temporary, sometimes they have to be made permanent depending on the problems associated with the track. Then, another thing is the number of stoppages. As the number of stoppages increases, as we have seen or discussed previously, the speed is going to reduce. But then, it is to be done with respect to the revenue requirements or the generation of revenue for the railways.

Another aspect is gradients. The gradients we have discussed previously too, if there is great resistance, then it has its effect on the reduction in the speed and here when you are talking about the equilibrium speed, then the gradient should be such that there should be no reduction in the speed, then that particular gradient is to be taken into consideration. Now, the next point in the case of equilibrium of speeds is the proportion of slow and the fast trains. Not all the trains are moving with the same speed on any track. So, in that case, we have to look at what are the total number of trains moving in any of the speed category and based on that then, we can compute the value of the equilibrium speed. So, we will be looking at how we can find out these values in the further slides.

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Equilibrium Speed

- Calculating equilibrium speed (V_e)
 - For $V_m > 50$ km ph
 $V_e = \frac{3}{4} V_m$ or V_s or whichever is less
 - For $V_m < 50$ km ph

Now, this equilibrium speed or we can calculate here it is been designated as V_e in the case of the conditions where the maximum speed is greater than 50 kilometers per hour that is in most of the cases where we are talking about **above** narrow gauge, then in this case, V_e is taken as three fourth of V_m or V_s or whichever is less where V_s is the safe speed or safe permissible speed being defined for that track and V_m again is maximum permissible speed which is allowed. We take the three fourth of that or V_s and then, whatever is less is computed or taken as the equilibrium speed. In case the V_m is less than 50 kilometers per hour, then we will be taking V_e as either V_m or V_s or whichever is less. So, this is another way of finding out this value.

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Equilibrium Speed

- Calculating equilibrium speed (V_e)

Weighted average:

$$V_e = (n_1 V_1 + n_2 V_2 + \dots) / (n_1 + n_2 + \dots)$$

where V_1, V_2, \dots are speeds of different
number of trains n_1, n_2, \dots moving on the same
track

Further, we have the weighted average, where we are talking about a condition like it is computed as V_e equals to n_1 into V_1 plus n_2 into V_2 plus so on and this whole is divided by the value n_1 plus n_2 plus so on that is the summation of the numbers. So, here what is happening is that we categorize the trains by their speed bands and then for the midblock condition of that speed that is V_1 , we find out how many trains are moving in this speed band that is n_1 . So, if we have this categorization, as different speed ranges are there starting from 1 to m , then we have the midblock condition of that speed ranges V_1, V_2 up to V_m and for each of that category, we will be having n_1, n_2 to n_m .

So, now we have number of vehicles here and this is the multiplication of number of vehicles in that category of speed band with the speed. So, we get the weighted average and this is how the equilibrium speed can also be computed and this is the condition where we are taking into consideration the number of trains which are moving at a slower speed or the trains which are moving at a higher speed.

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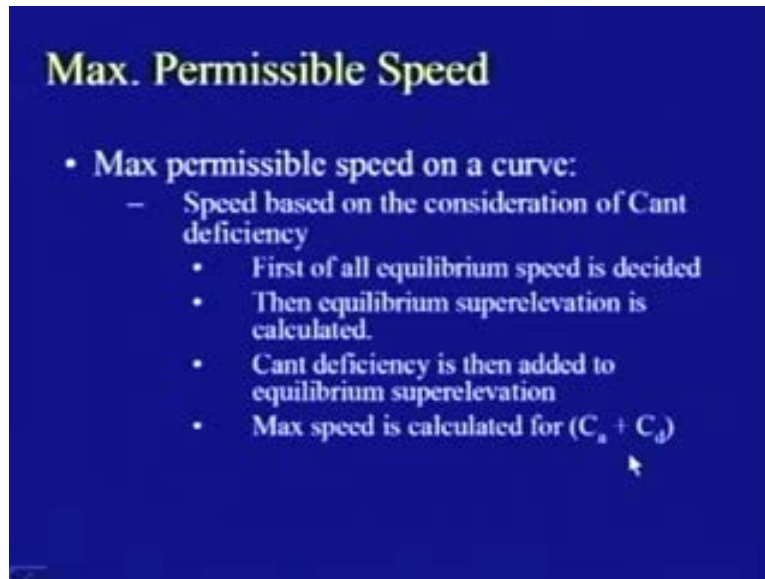
Max. Permissible Speed

- Max permissible speed on a curve is the minimum of the values calculated as (subjective length of transition curve can be increased)
 - Maximum sanctioned speed of the section
 - authorized by the commissioner of railway safety
 - Speed based on the consideration of Cant deficiency

Now, we come to another point that is maximum permissible speed. This maximum permissible speed on a curve is the minimum of the values calculated, as here we are talking about, we are assuming that the length of the transition curve whatever it is required can be provided and therefore, there is no problem as such in this case. So, in that condition, the maximum permissible speed is computed as the minimum value of certain conditions like the maximum sanctioned speed of the section. We have seen that the sanctioned speed of the section by the track engineer. So, once we have got this value, then this is one criteria of finding the maximum permissible speed and this is authorized by the commissioner of railway safety.

Then, the speed based on the consideration of cant deficiency, we have to compute this value based on the cant deficiency. As we have seen, there is a formula for finding out the speed as $.27 \sqrt{R} \sqrt{C_a + C_d}$, where C_d is the cant deficiency. So, if we use this formula, so as to find out this value, then we can find out one more criteria that is this one and compare it with respect to the maximum sanctioned speed. So, these are the mainly two values by using which we can find out the maximum permissible speed.

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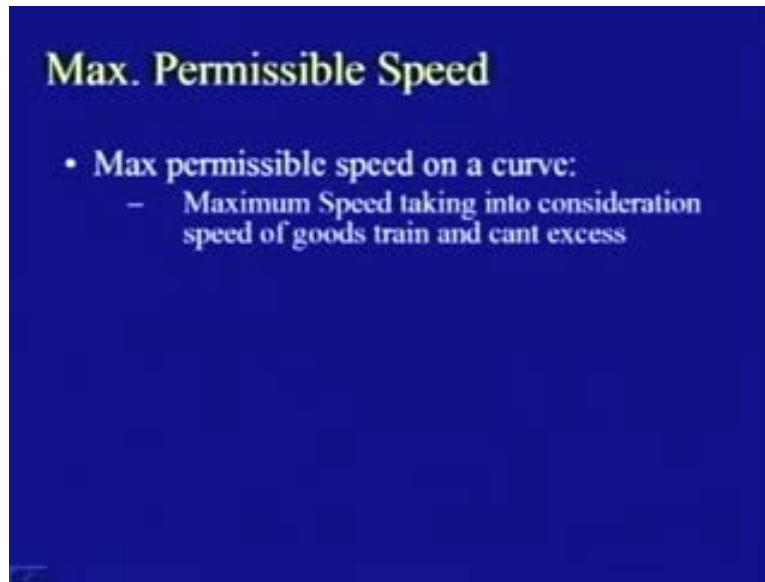
Max. Permissible Speed

- Max permissible speed on a curve:
 - Speed based on the consideration of Cant deficiency
 - First of all equilibrium speed is decided
 - Then equilibrium superelevation is calculated.
 - Cant deficiency is then added to equilibrium superelevation
 - Max speed is calculated for $(C_e + C_d)$

Now, further the speed based on the consideration of cant deficiency may be done in the form like first of all we have to find out the equilibrium speed, so what is the equilibrium speed is decided. Then, once it is being decided with respect to this equilibrium speed, the equilibrium superelevation is calculated. So, based on the raw data, based on the information collected from the track, that there are so many trains running with such type of a speed, we have already calculated the equilibrium speed and then we put it in the formula GV^2 square divided by $127 R$, we will get equilibrium superelevation e .

Now, once this equilibrium superelevation is calculated, then it is added to the cant deficiency and this cant deficiency as we have seen previously too, we were looking at certain permissible values of the cant deficiency for different tracks, then that value is to be added based on the type of the track to the value calculated in the previous step. So, we have the value now as $C_e + C_d$ and for this value of $C_e + C_d$, we compute the value of speed. So, that value is going to define the maximum permissible speed.

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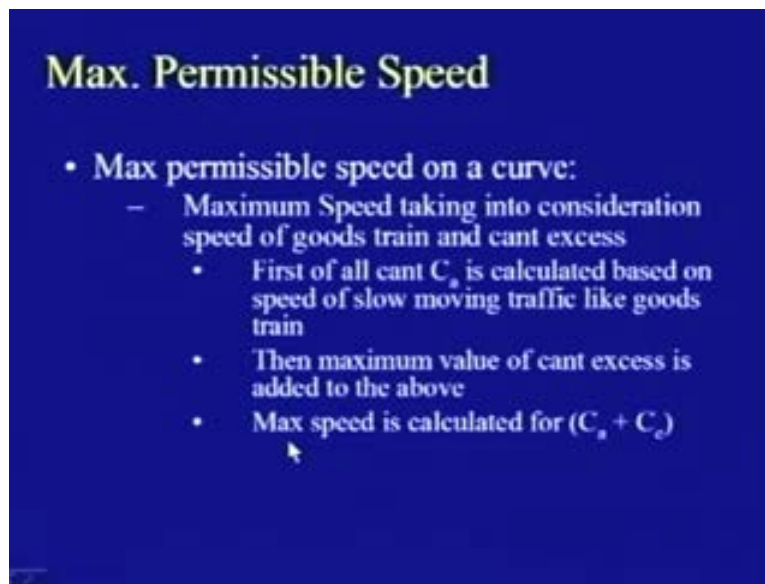


Now, this maximum speed taking into consideration the speed of goods train and cant excess this is another criteria, because in the previous case what we have taken is that there is an equilibrium cant. Now, when we talk about this equilibrium cant condition and cant excess and cant deficiency, we have two conditions. The cant deficiency is related with respect to the trains which are moving at a speed higher than the equilibrium speed. Now, suppose we are talking about the equilibrium speed as 80 kilometers per hour and there is another train which is moving at a speed of say, 120 kilometers per hour, now for the 80 kilometers per hour, we will be providing some superelevation and that superelevation be termed as equilibrium superelevation.

Now, if you take the effect of the centrifugal force which is governed by the speed, then for the value of 120 kilometers per hour, the superelevation to be provided is higher than what we have provided for 80 kilometers per hour. It means there is a difference between the value to be provided for 120 and which is being provided in actual for 80 kilometers per hour and this difference is what is termed as cant deficiency. Similarly, we take another case, where there is a train which is moving at a speed as at lower speed than 80 kilometers per hour, say 50 kilometers per hour is the speed.

Now, for this 50 kilometers per hour we require lesser amount of superelevation as compared to what we have provided with respect to 80 kilometers per hour. So therefore, in this case there is excess of the cant which is already being provided and the difference between the cant provided and the cant which could have been there for 50 kilometers per hour, this value is known as cant excess. So, these are the two conditions we have to consider while trying to find out the maximum permissible speed on a curve. So, in this case, what we are doing in this particular case, we are taking the lower speed that **it** is to be taken into consideration with cant excess.

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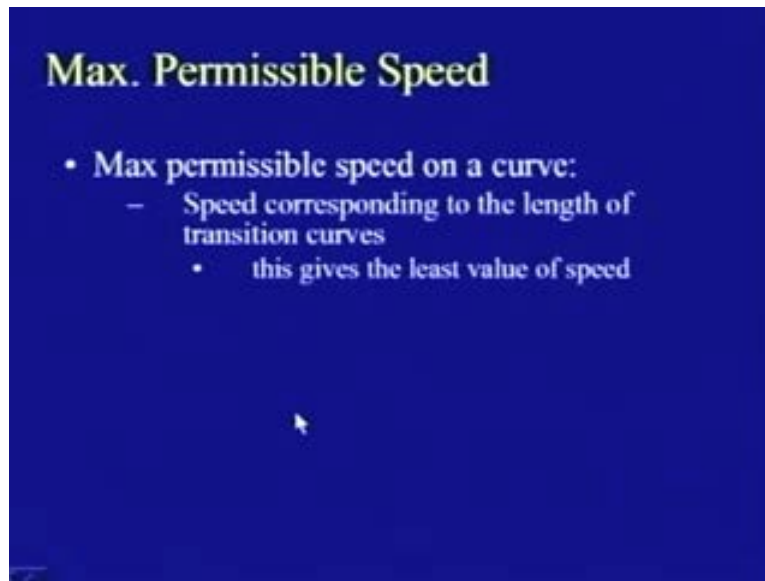
Max. Permissible Speed

- Max permissible speed on a curve:
 - Maximum Speed taking into consideration speed of goods train and cant excess
 - First of all cant C_a is calculated based on speed of slow moving traffic like goods train
 - Then maximum value of cant excess is added to the above
 - Max speed is calculated for $(C_a + C_e)$

First of all what we do is we calculate the value of the actual cant which is required based on the speed on which the goods train are moving. Generally, the speed of the goods train is lower than the high speed trains in the passenger category. So, for that value of the goods train, the C_a value is to be computed. So, this is going to be the lowest condition which is available. Now, from this one, then we add the cant excess and as soon as we add the cant excess value which is allowed for that gauge of the track, we will be reaching the equilibrium condition. So, we are coming from the down towards the center point in this case, whereas in the previous case where we have talked about the higher speed, there we were coming down from the top to the middle condition or we are going

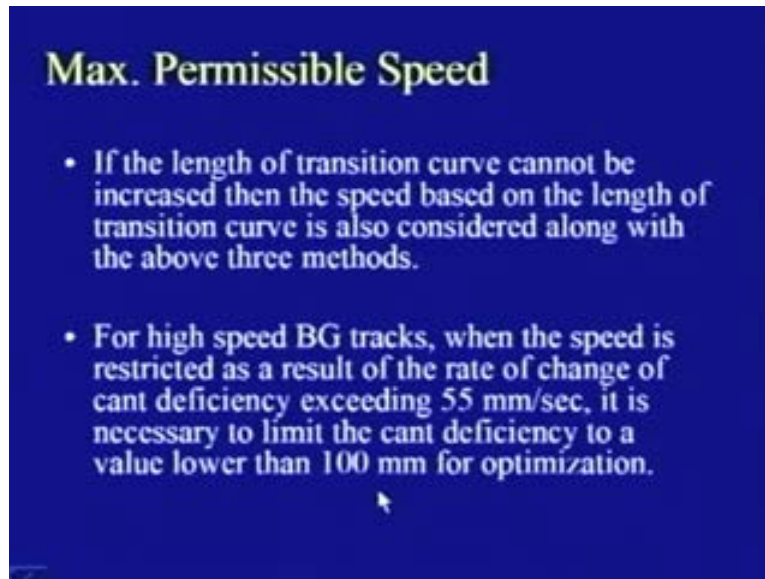
from middle to the top condition, if we add the cant deficiency in the value of cant actually provided. So, now we are coming to the above condition that is to the central equilibrium condition and for this value of C_a plus C_e , where C_e is the cant excess, we find out the maximum speed. So, we have this value of speed, we have the previous value of speed and we have the maximum sanctioned speed already available.

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So, the speed corresponding to the length of the transition curve is another consideration and based on the criteria how we provide the transition curve and how we design the transition curve, we have to look at that if there is any restriction imposed in the provision of the length of the transition curve, then the speed is to be computed. Otherwise, if there is no such restriction being imposed, whatever lengths come, can be provided in the field. Then, there is no requirement of using these criteria. So, this criteria generally gives the least value of the speed.

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Max. Permissible Speed

- If the length of transition curve cannot be increased then the speed based on the length of transition curve is also considered along with the above three methods.
- For high speed BG tracks, when the speed is restricted as a result of the rate of change of cant deficiency exceeding 55 mm/sec, it is necessary to limit the cant deficiency to a value lower than 100 mm for optimization.

If the length of the transition curve cannot be increased, then the speed based on the length of transition curve is also considered along with the above three methods. Now, for high speed broad gauge tracks, when the speed is restricted as a result of a rate of change of cant deficiency which is exceeding 55 mm per second that is what is happening it means to say this is the highest value of cant deficiency in the rate of change of cant deficiency which is being allowed and if the value exceeds this one that means we are going to a speed which is above the maximum safer permissible speed which could have been prescribed using this value. So, in that case, we have to limit the cant deficiency to a lower value.

In the terms of the mm, this value transforms into 100 mm. So, we have to go for a value lesser than 100 mm and then optimize and try to find out the restricted speed on that high speed track. Now, these are some considerations which have to be made while computing the maximum permissible speed, because it has its safety implications.

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Definitions

- Cant
 - Difference in height between the outer and inner rail on a curve. Inner rail is maintained at its original level and is called Gradient Rail.
- Cant Deficiency
 - Occurs when train runs at a speed higher than the equilibrium speed; overturning may be caused.

Now, we come to some of the technical words which have been used in the previous computations. One is cant. Cant is nothing but the same thing as superelevation and that is how it is defined here. It is the difference in the height between the outer and inner rail on a curve and this we have already seen that how this difference can be computed. Inner rail is maintained at its original level and is called the gradient rail, whereas cant deficiency is it occurs when the train runs at a speed higher than the equilibrium speed.

So, as I have discussed previously too that once that speed train is running at a speed higher than the equilibrium speed, then it means it requires a cant which is higher than the cant provided for the equilibrium speed, because e is directly proportional to the square of the speed. That is e is GV^2 divided by $127R$, that is what we know. So, in this case, as it is going to be proportional to the square of speed it means higher value of cant is to be provided, if the higher speed is available. So, in this case if we are not doing this, then there is a deficiency in the cant being provided and in this case it may result in overturning. So, that is the problem associated with the higher speeds being attained with respect to the equilibrium speed and with respect to this criteria, this higher speed is to be restricted or is to be fixed.

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Definitions

- Cant Excess
 - Occurs when train runs at a speed lower than the equilibrium speed; Derailment may be caused

Similarly, there is another term which we have used and that is cant excess and cant excess can be defined as it occurs when the trains are running at a speed lower than the equilibrium speed and this is again we have discussed that if the speed is lower, then we require a lower amount of superelevation, again from the same concept that the superelevation is proportional to the square of the speed and whereas what we have provided is higher than that one. Therefore, there is extra amount superelevation already being provided.

Now, when extra amount of superelevation is being provided, then it has a tendency to move the overall train or the rolling stock towards the inner side of the curve, whereas in the previous case, when we talked about the cant deficiency, then because of the extra force which is being left, which is not being counteracted by superelevation, when the train is moving at a higher speed than the equilibrium speed, it will try to overturn it on the outer side of the curve. So, in this case, when it is coming in the cant excess towards the inner side of the curve, there are all possibilities that derailment may take place. So, we have to control this derailment or we have to control the overturning of the train in the two cases that is cant excess and cant deficiency respectively.

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Limiting Values ($V < 100$ km/hr)		
Item	BG	MG
• Max Degree	10	16 for MG and 40 for NG
• Min Radius	175m	109m for MG, 44m for NG
• Max cant	165mm (A,B,C) 140mm (D, E)	90mm (100mm with special permission)
• Max cant deficiency	75mm (100mm in special case for A and B)	50mm
• Cant excess	75mm	65mm
• Max cant gradient	1 in 720 (1 in 360-exceptional case)	1 in 720
• Rate of change of cant	35mm/sec (D) 55mm/sec (M)	35mm/sec (Desirable) 35mm/sec (Maximum)

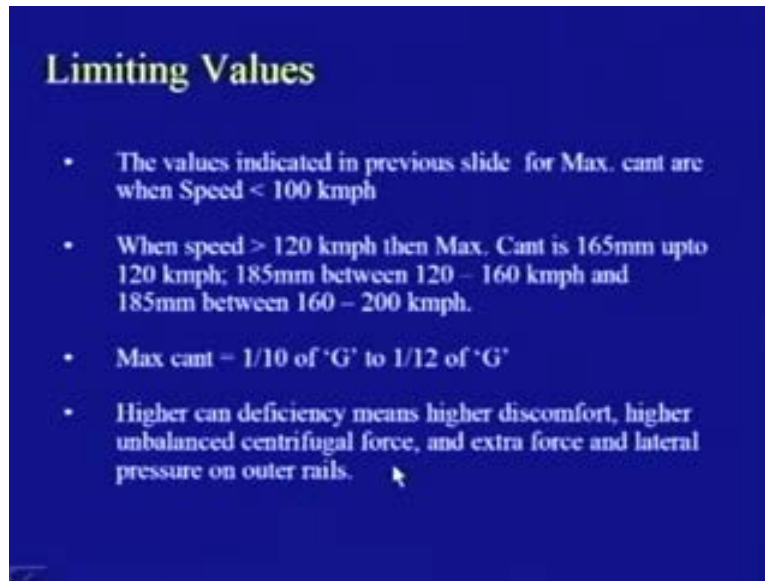
Now, we come to the limiting values. In this case the limiting values are with respect to the speed which is lower than 100 kilometers per hour. So, we are taking the values for the broad gauge and the meter gauge. Here, the maximum degree is 10 for broad gauge, it is 16 for meter gauge and 40 for narrow gauge. Then, the minimum radius is 175 meters, again this already we have seen previously as broad gauge, 109 meters for meter gauge and 44 meters for narrow gauge. In the case of narrow gauge, we can have a sharper curve, whereas in the case of broad gauge sharper curve cannot be there. Maximum cant is defined as 165 mm in the case of A, B and C category of routes in broad gauge and 140 mm as D and E category of routes in broad gauge, where in the case of meter gauge it is 90 mm and with a special permission, we can go for 100 mm.

Then, for cant deficiency, this maximum value of cant deficiency is being restricted to 75 mm in the case of broad gauge and 50 mm in the case of meter gauge and in special cases only for route A and B in the broad gauge category, this value of 75 mm can be upgraded to 100 mm. That is we are interested in higher speed movement in the case of route A and B only. Then, in the case of cant excess the value is 75 mm for broad gauge and it is 65 mm for meter gauge. The maximum cant gradient it is 1 in 720 in broad gauge and 1 in 720 in meter gauge. In exceptional cases in the case of broad gauge only, not in the case

of meter gauge and narrow gauge, it can be reduced to a value of 1 in 360 means it is made further steeper as compared to 1 in 720.

Then, rate of change of cant. This rate of change of cant in the case of, here it is 35 mm per second. This is desirable value, whereas at the maximum it can attain a value of 55 mm per second. M is for maximum and D if for desirable as mentioned on this side, whereas in the case of the meter gauge, the desirable and the maximum value remains the same that is 35 mm per second.

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Limiting Values

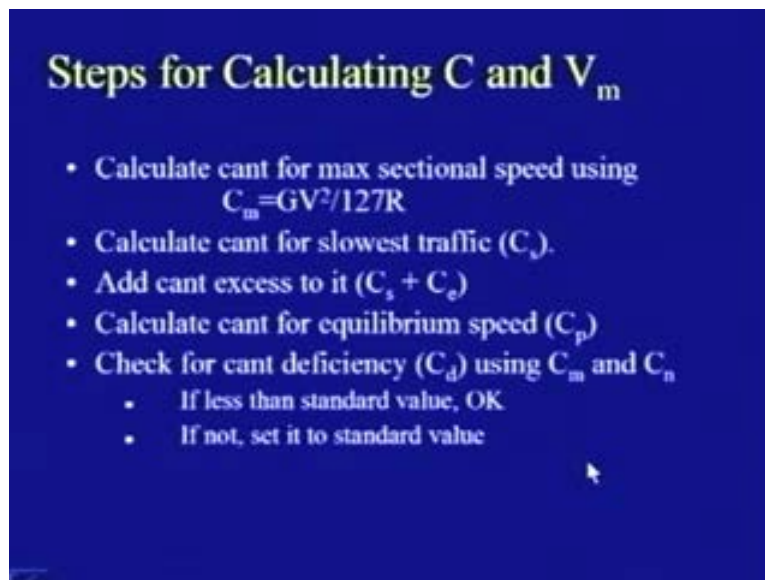
- The values indicated in previous slide for Max. cant are when Speed < 100 kmph
- When speed > 120 kmph then Max. Cant is 165mm upto 120 kmph; 185mm between 120 – 160 kmph and 185mm between 160 – 200 kmph.
- Max cant = 1/10 of 'G' to 1/12 of 'G'
- Higher cant deficiency means higher discomfort, higher unbalanced centrifugal force, and extra force and lateral pressure on outer rails.

Then further, the values are indicated in the previous slide for maximum cant when speed is less than 100 kilometers per hour, whereas when the speeds are greater than this one, **that is if you** that is exceeding 120 kilometers per hour, then the maximum cant is 165 mm up to 120 kilometers per hour. But, when the speed is increased from 120 to 160, then it can be reached to 185 mm and when it goes from 160 to 200 kilometers per hour, then it can be reached, again it remains the same value as 185 mm. These are the different speed bands which have been defined and considered by the Indian railways and another way is that the maximum cant at approximate condition can be computed as one tenth to one twelfth of the gauge. So, whatever is the gauge value if you take one tenth or one

twelfth of that one, then that is going to be the maximum cant value. This is the rough way of computing or calculating the cant.

Then, higher cant deficiency means, this is not can, this is cant, higher cant deficiency means higher discomfort, higher unbalanced centrifugal force and some extra force and lateral pressure on the outer rails. This I have already discussed as that if the speed is more than the equilibrium speed, so we are left with the force which is not being eliminated and the effect of this force is to take the vehicle towards the outer side and that is when the lateral pressure on the outer rails are increasing and due to this unbalanced condition of the centrifugal force, the discomfort will be there and there are chances of overturning.

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Steps for Calculating C and V_m

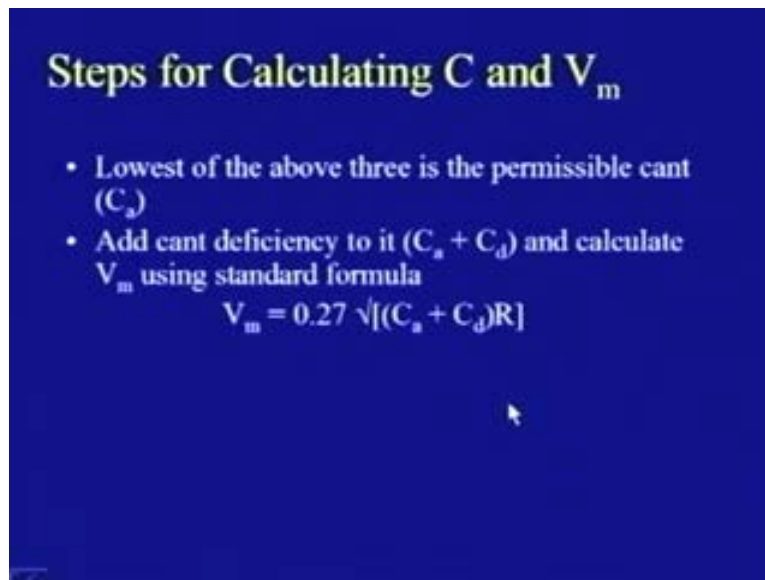
- Calculate cant for max sectional speed using $C_m = GV^2/127R$
- Calculate cant for slowest traffic (C_s).
- Add cant excess to it ($C_s + C_e$)
- Calculate cant for equilibrium speed (C_p)
- Check for cant deficiency (C_d) using C_m and C_n
 - If less than standard value, OK
 - If not, set it to standard value

So, now we come to the last condition, where we have to calculate the value of cant and we have to calculate the value of the maximum speed permissible on any of the track. There are different steps which need to be considered here. First of all, we have to calculate the cant for the maximum sectional speed using the value GV square divided by $127 R$ and this designated here as C_m . Then, calculate the cant for the slowest traffic as we have seen in the case of the goods train, so we have to calculate the cant for that

category also. That is what is C has been defined here again the same formula is to be used.

Then, we add the cant excess to it that is C_s plus C_e . Then, C_e value as we have seen in the previous slide, where we discussed about the permissible values of deficiency or excess, so that value we can take and add to it. Then, we calculate the cant for the equilibrium speed and that is designated as C_p . So, we have got three values here now as C_m , C_s plus C_e and C_p and then, these three values has to be just considered. Check for cant deficiency C_d using C_m and C_n and here, we have this value of maximum value of the cant which is provided for the maximum sectional speed and we have the cant deficiency. If we just subtract cant deficiency from this C_m value, we should achieve the equilibrium speed condition of cant that is C_p or your C_n is being defined in this way. If it is less than the standard value, then it is okay. But, if it is not that, then the standard value is to be set.

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Steps for Calculating C and V_m

- Lowest of the above three is the permissible cant (C_a)
- Add cant deficiency to it ($C_a + C_d$) and calculate V_m using standard formula

$$V_m = 0.27 \sqrt{(C_a + C_d)R}$$

Further, the lowest of the above three is the permissible cant, C_a and once we have got the permissible cant C_a , then we add the cant deficiency to this value and we calculate the value of V_m that is the maximum permissible speed using the standard formula. The

standard formula we have already seen previously, it is 0.27 multiplied with under root of the whole value as $C + C_d$ and this is multiplied with R and this value remains within the square root.

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Example

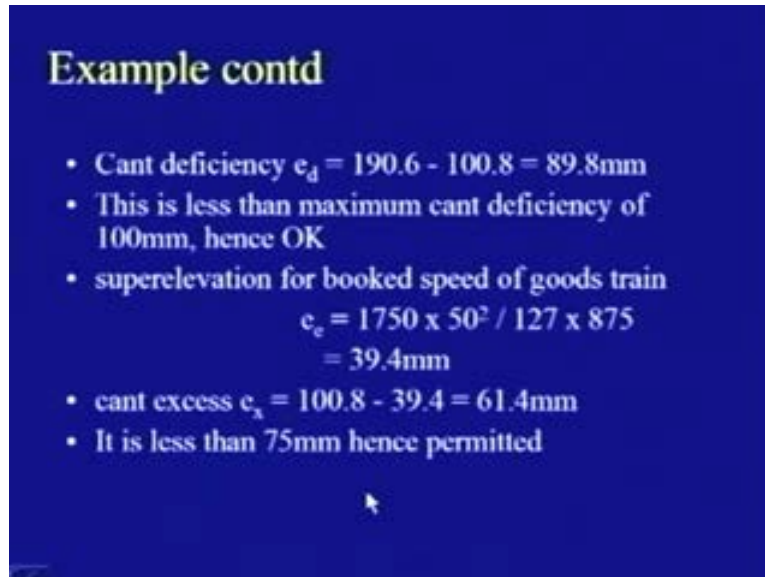
- 2° BG track, maximum sanctioned speed 110 km/h, equilibrium superelevation speed 80 km/h and booked speed of goods train 50 km/h
- $R = 1750/D = 1750 / 2 = 875\text{m}$
- superelevation for equilibrium speed
$$e_e = 1750 \times 80^2 / 127 \times 875$$
$$= 100.8\text{mm}$$
- superelevation for maximum permissible speed
$$e_m = 1750 \times 110^2 / 127 \times 875$$
$$= 190.6\text{mm}$$

So, now we come to one of the example. We have been given a two degree broad gauge track with the maximum sanctioned speed as 110 kilometer hour, the equilibrium superelevation speed is 80 kilometers per hour and the booked speed of goods train is 50 kilometers per hour. So, we have been given three values of the speeds and the broad gauge is being designated by degrees. So, you have to compute the value of allowable maximum value of speed as well as the cant. So, what we are doing here is that first of all we are computing the radius using this value of degrees. So, we are getting 875 meters. Then, the superelevation for the equilibrium speed is computed and this is with respect to the equilibrium superelevation speed of 80 kilometers per hour. So, this is being computed here and **this form** by GV^2 divided by $127R$ formula and we are getting 100.8 mm.

Now, once we have got this value, then the superelevation for the maximum permissible speed is computed which is given as 110 kilometers per hour and for this value we are

getting the value as 190.6 mm. So, what we are providing as superelevation is 100.8 mm, whereas if we go to the maximum speed, then it is 190.6 mm. This is what is the difference between these two deficiency.

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Example contd

- Cant deficiency $e_d = 190.6 - 100.8 = 89.8\text{mm}$
- This is less than maximum cant deficiency of 100mm, hence OK
- superelevation for booked speed of goods train
$$e_e = 1750 \times 50^2 / 127 \times 875$$
$$= 39.4\text{mm}$$
- cant excess $e_x = 100.8 - 39.4 = 61.4\text{mm}$
- It is less than 75mm hence permitted

So, the cant deficiency is 190.6 minus 100.8 is 89.8 mm that is the amount of cant deficiency in this track and this is less than the maximum cant deficiency of 100 mm. Hence, the design is okay here. If it is going above 100 mm, then this is to be restricted to 100 mm. Then, superelevation for the booked speed of the goods train is given and for this value of 50 kilometers per hour, we have to compute the value of superelevation. That comes out to be 39.4 mm. So, this is less than the actual condition. So, there is excess of superelevation provided and we can check that also. So, this is, 100.8 is the equilibrium cant and this is minimum cant. So, the difference is 61.4 mm and this 61.4 mm is less than 75. So, hence it is allowed.

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Example contd

- Maximum speed potential

$$\begin{aligned}V_m &= 0.27 ((e_c + e_d) \times R)^{1/2} \\&= 0.27 ((100.8 + 89.8) \times 875)^{1/2} \\&= 110.1 \text{ km/h}\end{aligned}$$

- Therefore, maximum permissible speed is least of the following:

- maximum sanctioned speed = 110 km/h
- speed computed = 110.1 km/h
- Assuming there is no restriction of transition curve length, $V_{\text{max}} = 110 \text{ km/h}$

So, the maximum speed potential will be 0.27 multiplied by this formula, which we have seen. So, we get the value of 110.1 kilometers per hour. So, therefore the maximum permissible speed will be the least of these following: the maximum sanctioned speed 110 kilometers per hour, the speed computed 110.1 kilometer per hour and assuming that there is no restriction of the transition curve length, what we get is as 110 kilometers per hour. So, this is how we can compute the cant as well as the maximum permissible speed on any track.

So, students, today in this lecture we have looked at another aspect of geometric design, which is very, very important aspect that is speeds and we have seen that the speed can be defined in different form. It may be the maximum permissible speed, the safe speed, the equilibrium speed, the average speed and likewise. At the same time, when we are computing these values, we have to take care of the cant deficiencies and cant excess. Now, we will be continuing with some more things in the coming lectures related to the geometric design. We stop here at this point and I convey to you my thanks and goodbye.