Introduction to Transportation Engineering
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Lecture - 20
Vertical Alignment Part - I

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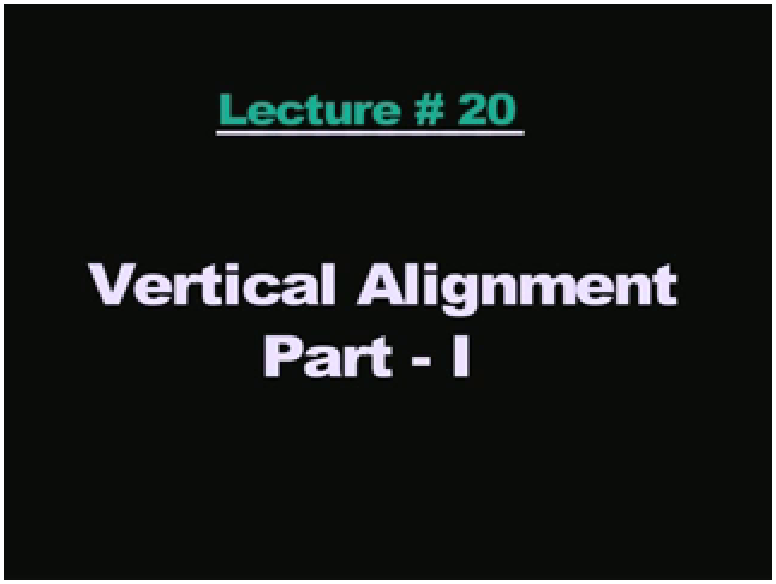

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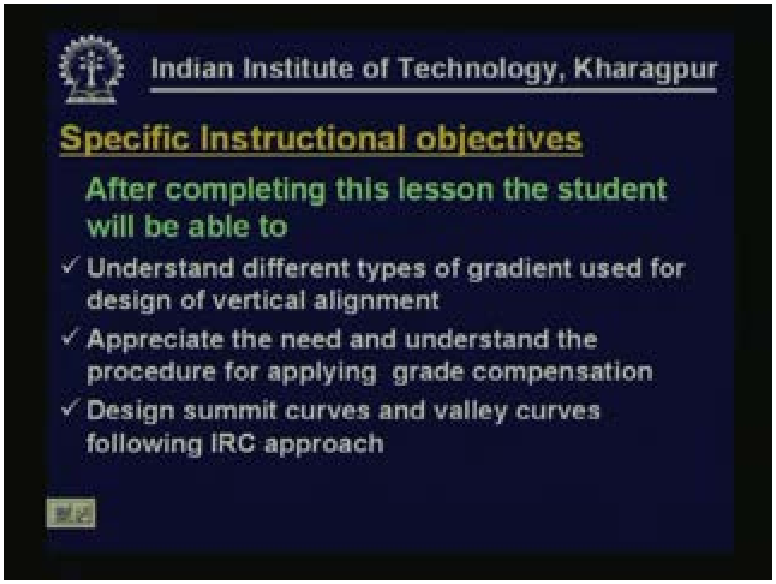

Vertical alignment part I, we have already discussed about horizontal alignment. Today we shall start our discussion about vertical alignment. After completing this lesson the student will be able to understand different types of gradient used for design of vertical alignment, appreciate the need and understand the basis or the procedure for applying great compensation and also the student will be able to design summit curves and valley curves following Indian Roads Congress approach or guidelines.

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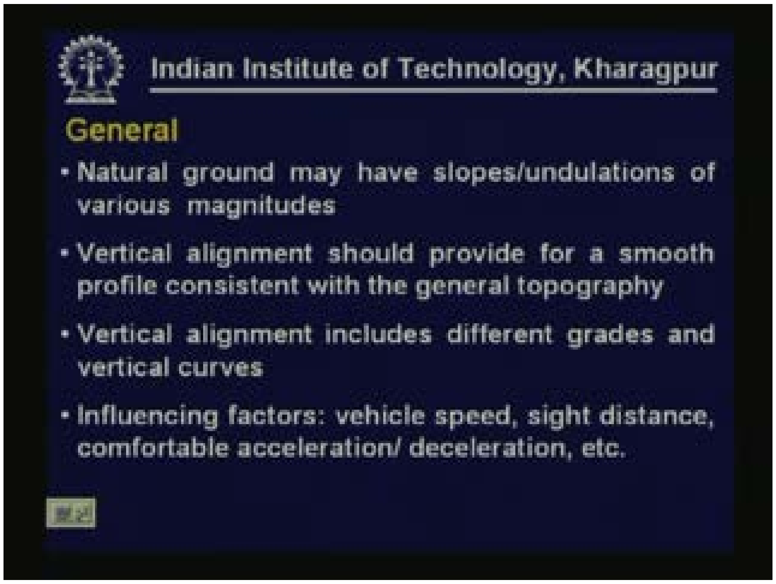

Natural ground may have slopes or undulations of various magnitudes. We do not expect the ground to be perfectly flat so it is expected that there will be undulations. Vertical alignment basically should provide for a smooth profile consistent with the general topography. It cannot be in absolute terms like it depends on the terrain for flat or say for a plane terrain whatever alignment is possible it is difficult or may be economically not viable to attempt to provide that kind of vertical profile for hilly religion so it has to be a function of the terrain.

Vertical alignment includes tangent and curves but in this case tangents are essentially grades and curves are vertical curves. There are several influencing factors which control the overall vertical profile design. There are a large number of factors and to mention a few it is the vehicle's speed, sight distance consideration, comfortable acceleration deceleration characteristics and other features.

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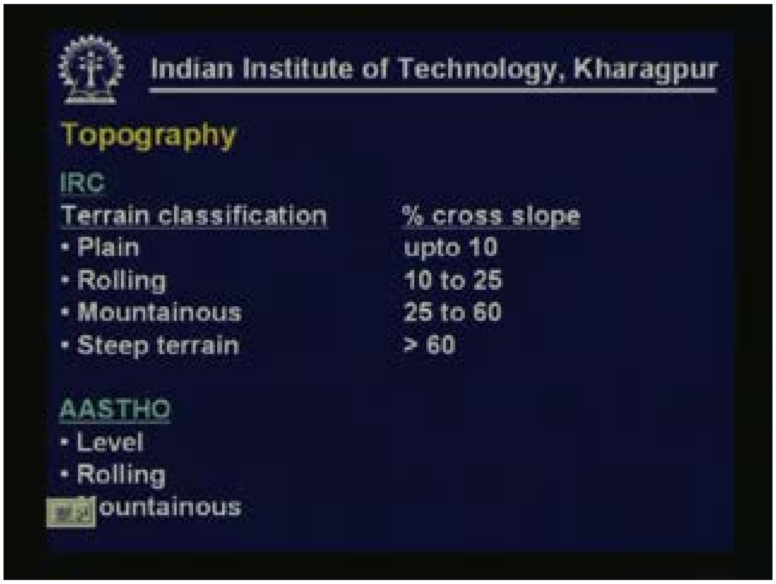

Now we have already discussed earlier about the topography classification. Indian Roads Congress use four types of terrain classification namely plain terrain, rolling terrain, mountainous and steep terrain and the terrain is classified based on the percentage of cross slope that is slope approximately in the perpendicular direction of the road that's what is normally indicated as cross slope. So, depending on the cross slope four different terrains are defined. Similarly AASTHO defines three types of terrain; level terrain, rolling terrain and mountainous terrain.

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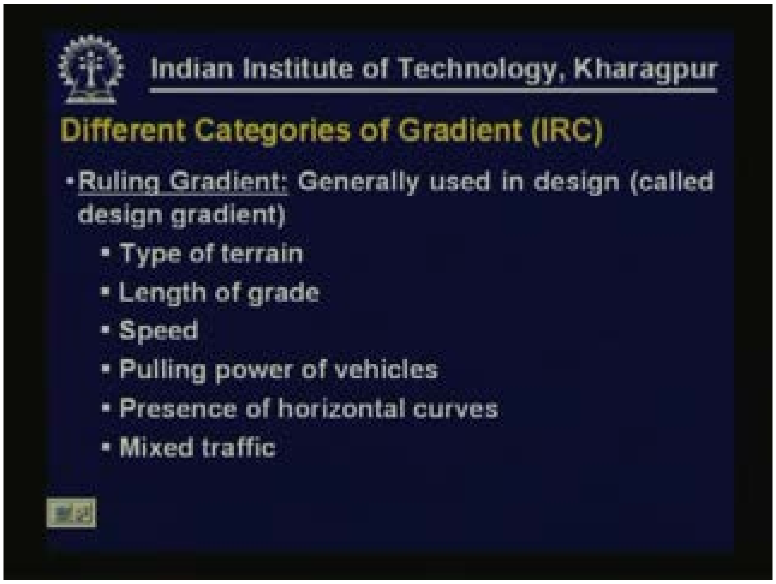

This terrain classification is relevant because we know that the vertical profile also will depend on the terrain condition. it is not possible to achieve the same standard at all terrain conditions there has to be a compromise in terms of when the terrain conditions is difficult.

Now let us see different categories of gradient used in Indian context. IRC defines mainly three types of gradient. of course there is one ((00:05:01 min)) limit also so if you consider them that way there are four types of terrain. First is the rolling terrain; rolling terrain is generally what we should try to use for normal design practice. That means this is the limit what we should try to use as far as possible under normal condition when we are adopting the design. So it is basically generally used in design so they are generally called as also design gradient. It is not an easy task to fix the limit for ruling gradient because the gradient whatever is acceptable in a plain region may be the same type of gradient may not be acceptable for a hilly region so it has to be a function of the terrain classification or depending on the terrain condition it will vary.

Similarly length of the grade and speed; when vehicle negotiates grade depending on what the grade is there will be actual loss in speed, longer the length of tangent and higher the grade there will be higher reduction in speed which is again likely to influence the overall traffic operation. Therefore length of the grade also is another factor. We cannot simply say this is the limit or this is the value of the ruling gradient but also what is the length is also important, what is the speed of vehicle that is important and then this reduction or the loss of speed depends on the pulling power of vehicles. So pulling power of vehicle will also control that for a given grade up to what level the speed reduction is possible.

Then the vehicle operation is also affected by the presence of horizontal curves. That means in addition to gradient whenever horizontal curves are there are additional losses or additional resistance. All these things make it a complicated task to fix up the limiting value. Also, for Indian condition the traffic environment is heterogeneous or the mix traffic environment therefore different vehicles have different speed capability, different pulling power so altogether it becomes a very, very complex task to suggest or to decide a single value for ruling gradient.

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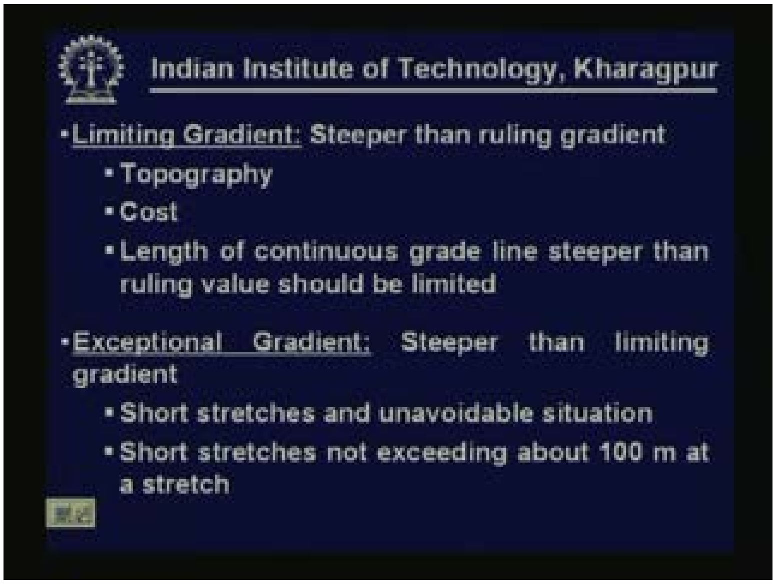

Next is limiting gradient. This gives you another limit and obviously this is steeper than the ruling gradient. Depending on the topography it may not be possible to limit the gradient up to ruling gradient. Let me revise this statement. it might be possible to achieve that gradient or to keep it or to limit it up to the ruling gradient but may be with increase in cost which is substantial and it may not be economical also to try to achieve that. Therefore depending on the topography and also considering the cost there is another upper limit where acceptable gradients are bit steeper than the ruling gradient and that's what we call as limiting gradient.

Now obviously since limiting gradient is steeper than ruling gradient length of continuous grade line steeper than ruling value should be limited. Then the third type of gradient that is used is exceptional gradient. It is further steeper than the limiting gradient and by name itself it is exceptional so it will be used or applied or accepted only under exceptional condition. complex situation and terrain condition does not permit if we try to provide a flatter gradient cost is going to be enormously higher so under truly exceptional situation one can adopt exceptional gradient so that's another limit which is also given in IRC. But since exceptional gradients are much steeper we should not use exceptional gradient for a continuous length of the stretch it can be used only for short stretch normally not exceeding about hundred meter at a stretch. Therefore only for a short length it is permissible.

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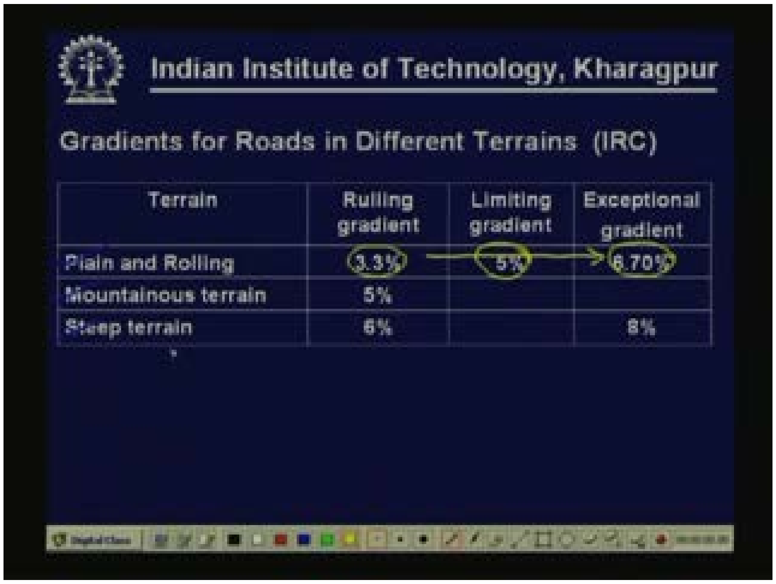

Now gradient depends on terrain condition and there are three types of gradient; ruling gradient, limiting gradient and exceptional gradient. So this table shows the values for plain terrain, for mountainous terrain and for steeper terrain. Now obviously rulling to limiting to exceptional values will gradually become higher. Say for example for plain and ruling terrain, rulling gradient is 3.3%, limiting gradient is 5%, exceptional gradient is 6.7% so you can say 5% is higher than 3.3 again 6.7 is higher than 5%. Similarly as the terrain becomes difficult this way vertically also the values will increase. So, for rulling gradient in plain terrain the limit is 3.3% mountainous 5% and for steep terrain it is 6% like that for different terrain conditions the limiting values of rulling gradient, limiting gradient and exceptional gradients are given.

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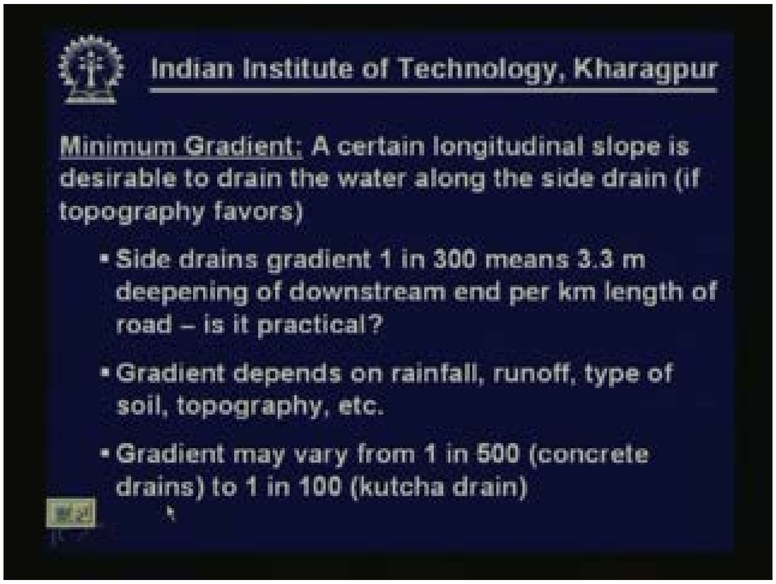

Now there is also another type of gradient which is called minimum gradient. Now let us first try to appreciate the need for minimum gradient. Camber will normally help the water to disperse and go to the side drains; then again water has to flow in the side drains so actually a mild longitudinal slope is required along the length of the side drench. So if we consider even a mild slope say 1 in 300 which is generally mild slope then that means for a length of 1 km we need the downstream to be deepening by 3.3m as compared to the upstream. That means in 1 km length you need basically 3.3m deepening of downstream, is it practical? Probably the answer is no. It’s extremely difficult to maintain that kind of gradient by earthwork. So the idea is if we can provide a natural slope obviously where the terrain condition permits if we can provide a mild longitudinal slope that itself will solve this kind of problem. That means obviously in the side drains also the water can flow without any problem.

So a certain longitudinal slope is desirable to drain the water along the side drain and obviously this is possible or should be attempted if topography favors. Therefore matching it to the natural topography if we can provide a mild longitudinal slope then it may be beneficiary. Obviously how much gradient is required will also depend on the rainfall, runoff, type of soil and the topography. So gradient may vary in general say 1 in 500 for concrete drains to 1 in 100 for Kutcha drain. Obviously for concrete drain a milder slope is acceptable but for the Kutcha drains you need a much steeper slope.

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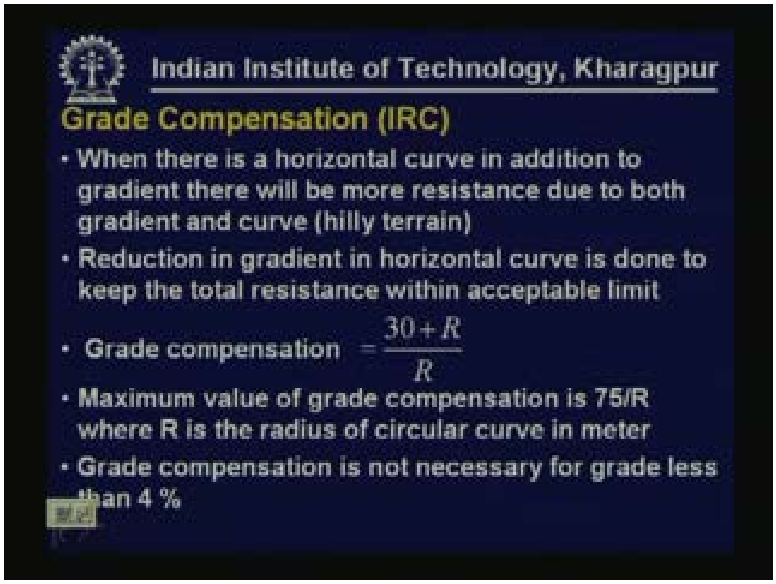

Grade Compensation: this is another topic itself. What is great compensation? When there is a horizontal curve in addition to gradient there will be more resistance due to both gradient and the curve. This is often a situation what we encounter in hilly terrain. We have gradient and we also have horizontal curves. Now why there will be additional resistance. We also discussed earlier about the curve resistance but let us again try to refresh our memory. Suppose if this is the tractive force which is available in the direction of movement and if the vehicle is negotiating a horizontal curve then this T cos alpha component if this angle is alpha is only available in the direction of movement because in rear axel this tractive force is there t, in the direction of movement front wheels are rotated in this direction making an angle alpha therefore in the direction of movement T cos alpha is available but not the complete T is available.

Now, if there is a gradient also let us call another angle beta then again T cos alpha cos beta that component will be available in the direction of the movement so there will be additional loss. In the curve resistance the loss is T into 1 – cos alpha similarly due to the gradient also there will be additional loss depending on this angle and now this angle will obviously be more when the grade is more or when a steeper grade is used. Therefore to avoid this excessive loss which will affect the vehicle movement as well as the overall traffic operation on roads it is necessary to go for grade compensation. That means compensate in terms of grade that is provide a lesser grade than what is normally used when there is no horizontal curve. That means if we provide or if horizontal curve is encountered then compensate in terms of the gradient so that the overall operation remands acceptable. It is reduction in gradient in horizontal curves to keep the total resistance within acceptable limit.

IRC suggests this basis for grade compensation so grade compensation is basically 30R by 30 + R/R where R is the radius of the curve so that amount of grade compensation may be applied. Now, when we are applying this there is also maximum limit which is suggested in the quote. Maximum value of grade compensation is 75/R so when we are doing grade compensation using this basis we have to also check whether the value exceeds 75/R then the maximum value will be provided as 75 by R.

Also grade compensation is not necessary for grades less than 4%s. So if the initial grade is less than 4% there is no need of providing grade compensation. Also, if initial grade is steeper than 4% and we are going for grade compensation then we need not ease the grade below 4% when we are compensating the grade because anyhow if it is less than 4% we need not go for grade compensation. So when we are calculating the compensated grade if the theoretical calculation shows the grade as less than 4% we can only go up to 4% so it need not be eased below 4%. That’s the grade compensation part.

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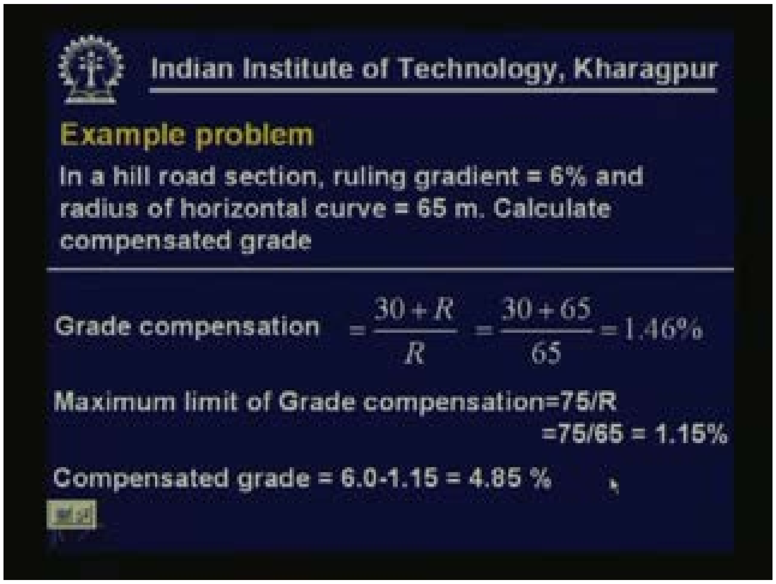

Let us take an example problem; in a hill road section say the ruling gradient is 6%, radius of horizontal curve is 65m then we have to calculate the compensated grade. Now, grade compensation as per the earlier discussion is 30 + R/R so R is the radius of curve in meter, here the radius of curve is 65 so put this value as 65, we calculate the grade compensation as 1.46. But we also need to check the maximum limit so maximum limit of grade compensation is 75/R so 75/65 which is 1.15 percentage. Now this grade compensation whatever you have calculated is 1.46 which is higher than 1.15 which is the upper limit that is 75/R therefore we provide grade compensation only up to 1.15% not up to 1.46. So accordingly we calculate the compensated grade, 6% was the initial grade here, it was indicated minus this 1.15% so 4.85% and 4.85% again is more than 4% therefore it is acceptable and it is okay for design purpose so the compensated grade is actually 4.85%.

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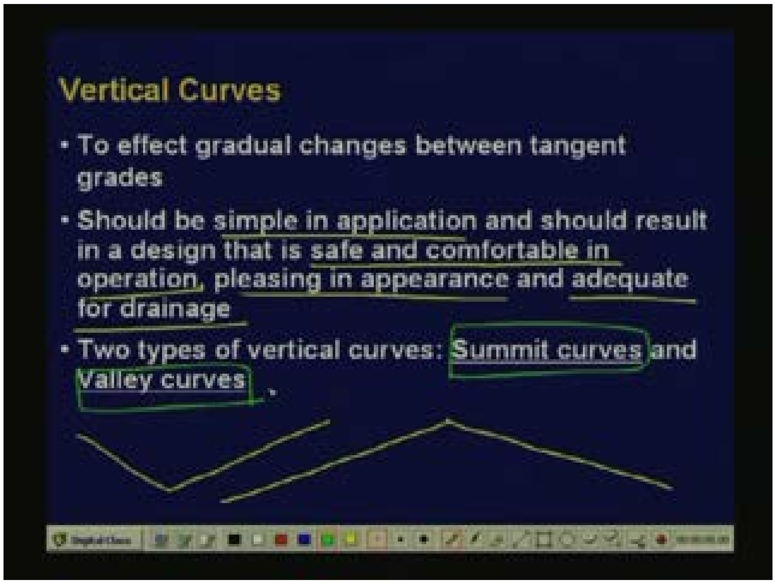

Now coming to vertical curves it is necessary to effect gradual changes between tangent grades. You have two tangent grades. It may be of various types but let us consider this is a one tangent, this is another tangent so there is a change in grade it may be other way also like this. So whenever there is change in grade to effect gradual changes between tangent grades we need to provide vertical curves. Vertical curves should be simple in application number one, should result in design that is safe and comfortable in operation, pleasing in appearance and adequate for drainage. So we have to keep in mind all these considerations when we are going for the design of vertical curves.

There are predominantly two types of vertical curves; one is called summit curve, the other is called valley curve. One is summit the other one is called valley curve. Now we shall discuss about the design of summit curve and also then what is valley curve and what should be the basis suggested in Indian Road Congress guideline for the design of valley curve.

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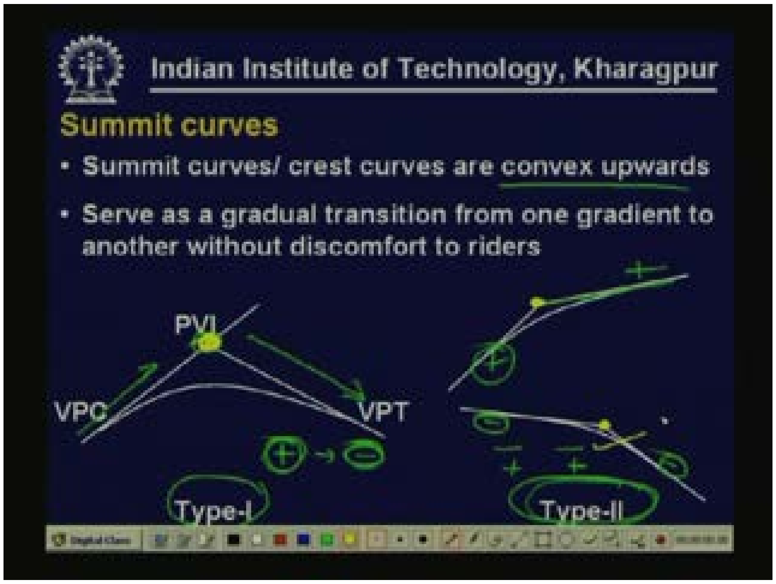

Let us first talk about the summit curve. Summit curves generally have convexity upwards. They are also called crest curve because it gives the shape like that. So summit curve or crest curves are convex upwards. Now summit curves also serve as a gradual transition from one gradient to another gradient without discomfort to riders. We shall comeback and we shall discuss again about this particular aspect. I have shown here two types of summit curve type I and type II. Now type I summit curve is basically positive gradient to negative gradient. You can see this is the positive gradient this part and then this is a negative gradient. That means one is positive, another is negative so that kind of summit curve we call it as type one curve.

Now type II curve is where both grades are negative or both grades are positive but still it is forming a summit curve. Say for example in this case this is a positive gradient then this part is also a positive gradient obviously this is less steeper as compared to the first one but still this is a situation which will give rise to a summit curve. Similarly it is possible, this is negative gradient, this one is also negative gradient but still a summit curve is formed which we are calling as type two curve. So type I is when grade changes from positive to negative and type II is when positive to positive or negative to negative but still forming a summit curve.

Another interesting or easy way to identify summit curve is if we are considering these two grades then this is the Point of Vertical Intersection, this is the Point of Vertical Intersection here, this is the point of vertical intersection, and in this case this is the Point of Vertical Intersection and so on. Now, if the road surface is below the Point of Vertical Intersection PVI then it is a summit curve. If the road surface is below the PVI it is summit curve but if it is the other way then it is valley curve. So in all the three diagrams you can check that here also the road surface is below the Point of Vertical Intersection, here also road surface is below the Point of Vertical Intersection and the same thing is valid in this case also, so that’s what is summit curve.

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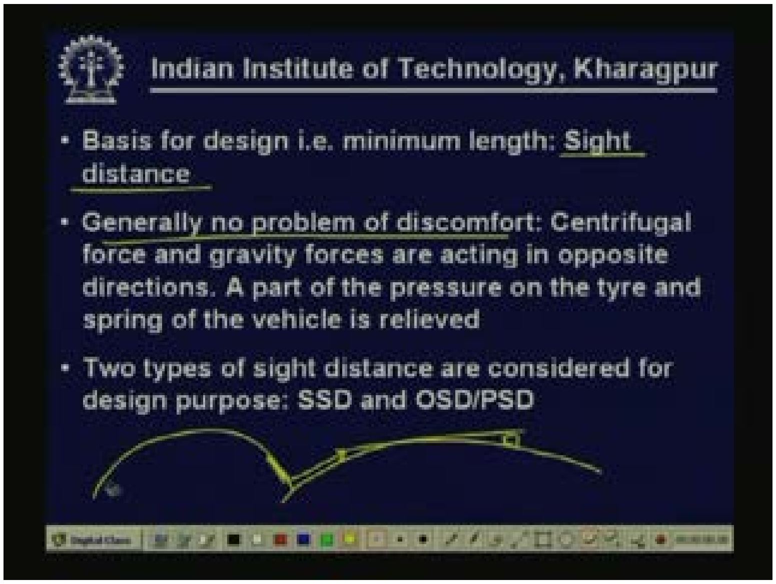

Basis for design of summit curve: in summit curve the problem is actually the sight distance. If we see that a vehicle which is approaching from this direction then sufficient side distance should be available to see the vehicle which is coming from opposite direction or see even a stationery object which is on the road. So basically sight distance is the measure consideration for the design of summit vertical curves. Generally there is no problem of discomfort because the centrifugal force and gravity force are acting in opposite direction.

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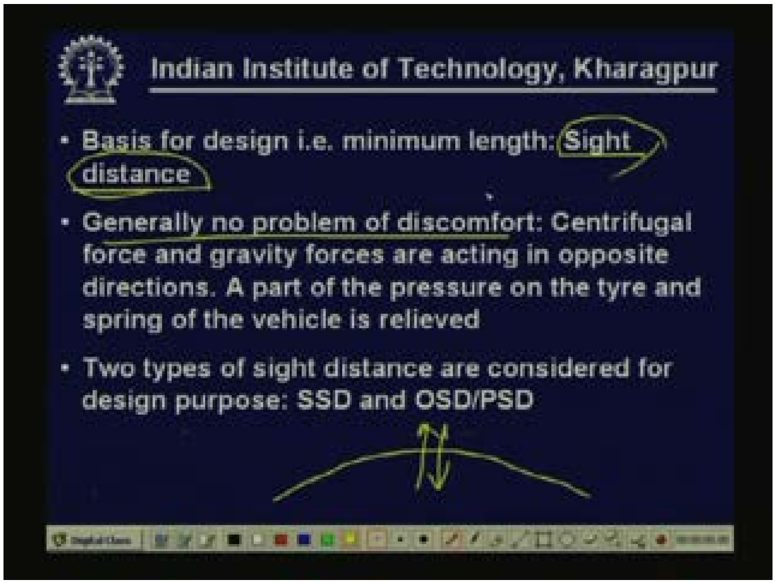

Let us take this one, so this is the curve. So when vehicle is negotiating this curve the centrifugal force is acting in the upward direction and the gravity force is acting in the downward direction therefore what is happening is a part of the pressure on the tyre and spring of the vehicle is actually relieved so there is as such no problem of discomfort to passengers. Therefore the only consideration for the design of summit curve is sight distance, that's what is important. Obviously two types of sight distances are considered. We know that one is the Stopping Sight Distance, the other one overtaking or passing sight distance. So both the sight distances are considered and accordingly the required length is estimated or calculated.

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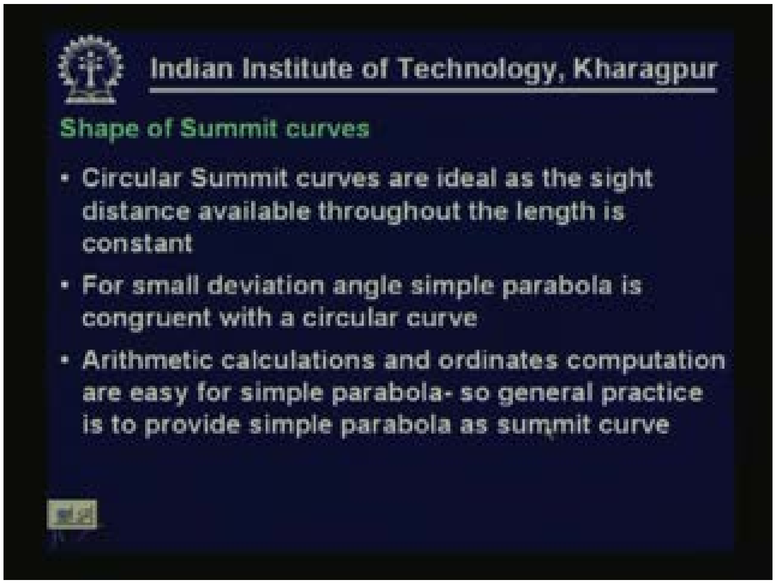

Let us talk about the shape of summit curve now because for summit curve the only major consideration is sight distance. so if we see that it is only the requirement that is sight distance then ideal shape is circular because on circular curve at every point the available sight distance is equal therefore the circular curve is most preferable or that kind of summit curve but for small deviation angle simple parabola and circular curves are nearly similar. Also, arithmetic calculations and coordinate computations are easy for simple parabola. Hence altogether general practice is to use a simple parabola as summit curve. But one must keep in mind that the requirement is only the sight distance therefore a circular curve theoretically is also acceptable. But because for small deviation angles the circular curves and simple parabola are not much different therefore there are certain advantages if we use parabola in terms of arithmetic calculation, coordinate computation, field layout and all these things.

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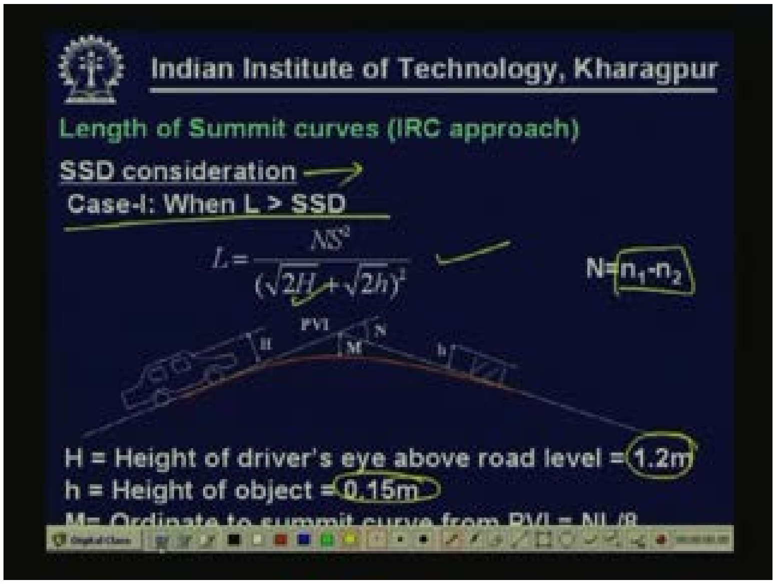

Now let us try to see the basis for calculation of the length of summit curve. Summit curve length may be designed for providing the required SSD Stopping Sight Distance. It may be also designed to provide the requirement of Overtaking Sight Distance or passing sight distance. First let us consider the SSD Stopping Sight Distance criteria. When we are considering the Stopping Sight Distance then again there are two possibilities. The length of the curve may be greater than the Stopping Sight Distance and the other case could be that the length of the curve is lesser than the Stopping Sight Distance.

Now, if the length is greater than Stopping Sight Distance this formula shown here can be used for the calculation of the length of the summit curve. Basically here S is the required sight distance which is the Stopping Sight Distance; N is the deviation angle algebraic difference between the two grades so it is $n_1 - n_2$. Remember that in the sketch n_2 is actually negative so n_1 is positive n_2 is negative so if it is h then it is $n_1 - n_2$. Basically it is the algebraic difference we have to take. Capital H is the indicated as the height of driver's eye above road level which is taken as 1.2m as per IRC standard, height of the object is taken as 0.15m so if we put all these values then we can easily calculate L in a simpler form that is NS square by 4.4.

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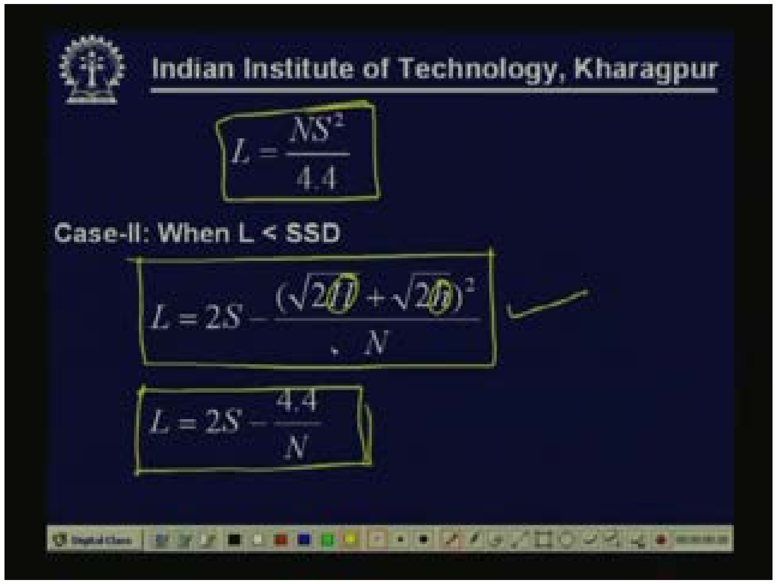

This is a simplified version of the original formula what we have discussed just now that is this; L = NS square by root 2H + root to small h whole square. So it is the same, just by putting the value of capital H and a small h we get a simpler derivation that is NS square by 4.4.

Now case II is when length of the curve is less than the required Stopping Sight Distance. In this case this formula may be used for the calculation of the length. Again, if we put the value of capital H and small h as to whatever is recommended by Indian Roads Congress as 1.2m and 0.15m then this equation can be simplified like this; L = 2S – 4.4/N.

Now, if we consider the sight distance as Overtaking Sight Distance, that means instead of considering the Stopping Sight Distance if we try to provide length of summit vertical curve which will be adequate for the requirement of the Overtaking Sight Distance then the basic formula is just the same but the only thing in this case is that the object height is also 1.2m. So capital H and small h in the formula have equal value. In this case it is the same basic formulation there is no difference but the only thing is that the height of driver's eye above road surface is 1.2m like in the earlier case which is 60 and height of object here is also 1.2m because for Overtaking Sight Distance this object is nothing but another vehicle which is coming from opposite direction. If we do that then this formula can be written in a simplified form that is L = NS square by 9.6.

Similarly, if we consider case two that is when L greater than OSD again this basic formula is same. We put the value of capital H as 1.2m, small h also as 1.2m we get this expression L = 2S – 9.6 by N. That means basically when the curve length is greater than sight distance and the curve length is lesser than sight distance the equations are different. But basic equations are not different for Stopping Sight Distance and Overtaking Sight Distance the only different is the value of h. We have used the height of driver's eye above road surface which in both the cases is 1.2m but for Stopping Sight Distance the object height is 0.15m but for Overtaking Sight Distance it is 1.2m again but the basic formulation is the same.

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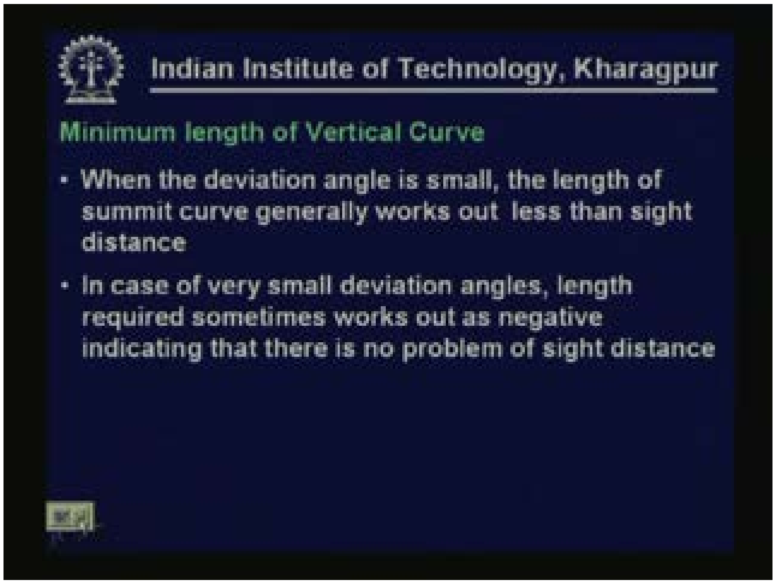

Minimum length of Vertical Curve:
We have already discussed or understood the formula which may be used for the calculation of summit vertical curve length. There we have seen for small deviation angle the length of summit curve generally works out less than the sight distance. And in case of very small deviation angles length required sometimes work out as negative basically indicating that there is no problem of sight distance and as such there is no requirement in terms of the length of summit vertical curves to satisfy the requirement of sight distance.

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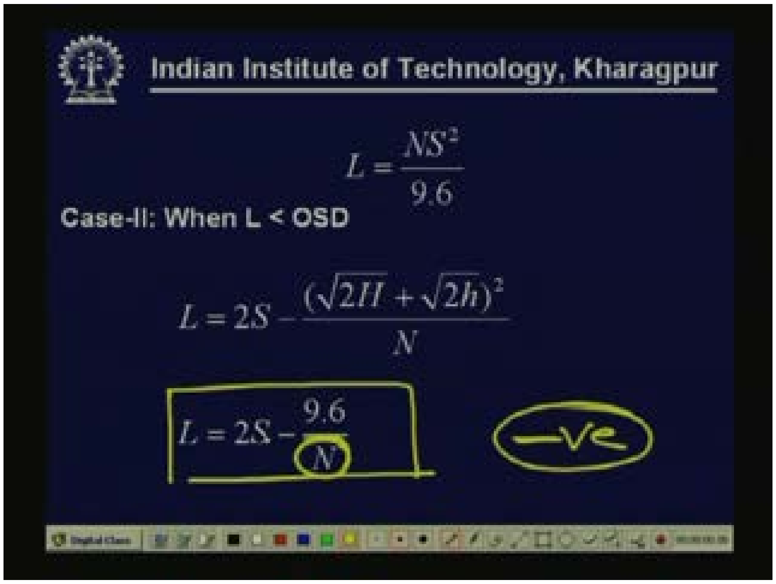

Let us consider this equation itself. Here if the deviation angle is small, N is small then it is possible that we may get a value of L which is negative theoretically at least. If we get that for small deviation angle this kind of situation is possible that theoretically we get a negative value. What does it indicate? It indicates that actually from the consideration of sight distance there is no requirement in terms of the length of the summit curve. It is quite logical because as such the deviation angle is very small you can get a negative value of L only when the value of N is very small. So obviously for small deviation angle there is no sight distance problem as such and that's why one may get a negative value. But while this is a possibility it is recommended by IRC considering other aspects aesthetics and all other considerations that a certain minimum length should be provided. Although from theoretical consideration it is not necessary to provide certain minimum length.

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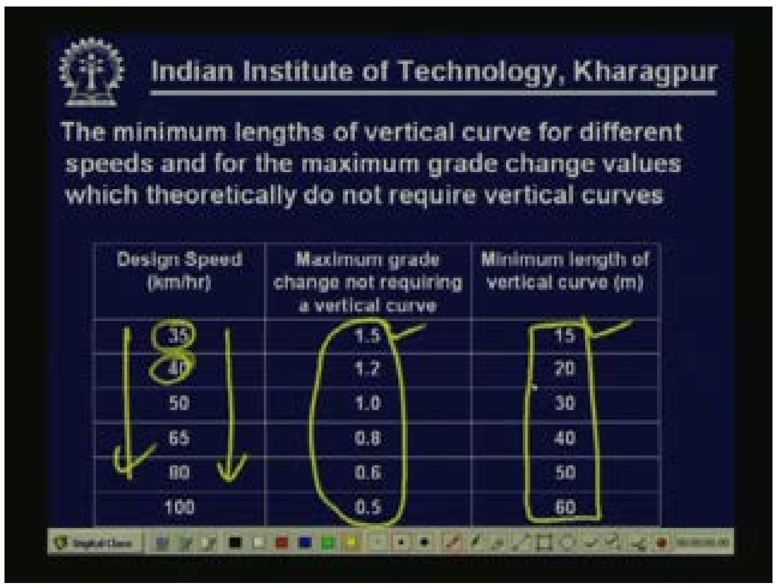

Design Speed (km/hr)	Maximum grade change not requiring a vertical curve	Minimum length of vertical curve (m)
35	1.5	15
40	1.2	20
50	1.0	30
65	0.8	40
80	0.6	50
100	0.5	60

So IRC gives these values which may be applied for Indian conditions. It says; the minimum length of vertical curve for different speeds and for the maximum grade change values which theoretically do not require vertical curves. This means it may be interpreted like this; these are the corresponding designs speeds. Now this is the maximum grade change one can work out from the division angle. This is the maximum grade change and up to this grade change theoretically we do not require any vertical curve. Obviously as this speed is more this value is reduced. So, in the first column the values are increasing and in the second column the values are decreasing. It is obviously logical. At lower speed may be up to more change in grade vertical curves may not be required. As the speed is more the requirements will change and it is quite logical that these values are coming down. Up to this values say for 100 km 0.5 and 50 km it is 1 and we as such do not need any length of vertical curves at least from theoretical consideration.

Here as you see in this column IRC suggests that for 35 km/h it is 15m and up to 1.5 maximum grade change we should provide a minimum length of 15m and like that for different design speed and different maximum grade change up to where it is theoretically not required to provide a vertical curve but from practical consideration mainly the aesthetics IRC provides the guideline as to what should be the minimum expectable length. So we can follow that and accordingly design the minimum required length of vertical curve. So there is a minimum requirement in this perspective also.

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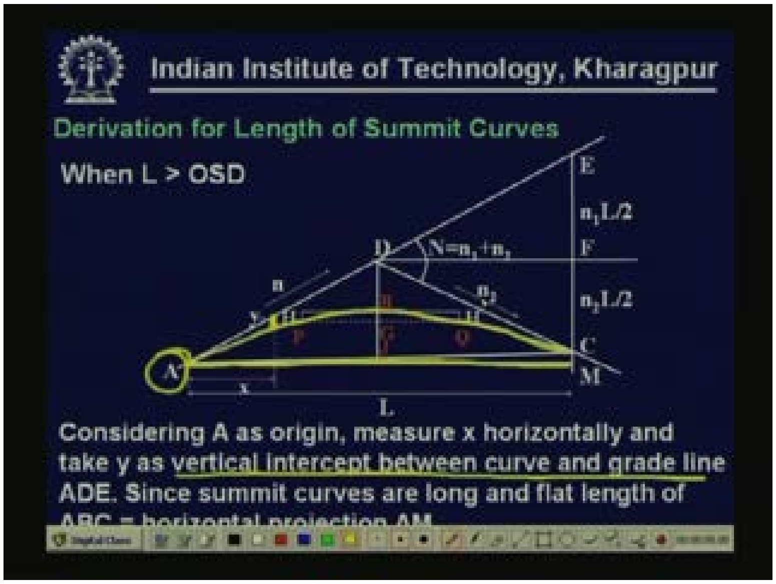

Now we have talked about the basis, we have given the formula that when you know length is more than sight distance, length is less than sight distance what is happening or which formula may be used but let us try to see the basis at least for one. Let us consider a case where length is greater than Overtaking Sight Distance. In this case I have shown the summit curve. If we consider A as the origin and measure x horizontally and y is measured as the vertical intercept between the curve and the grade line. So, if we consider x here up to this point then y is actually this yellow portion the difference vertical intercept between curve and the grade line. So this is the grade line Ae, curve is this one so vertical intercept between curve and grade line is what is y.

Now, since summit curve are long and flat the length of ABC that is this curve the length of ABC can be assumed almost equal to the horizontal projection AM because summit curves are long and flat. Therefore actual curve length and the horizontal projection of that is not much different.

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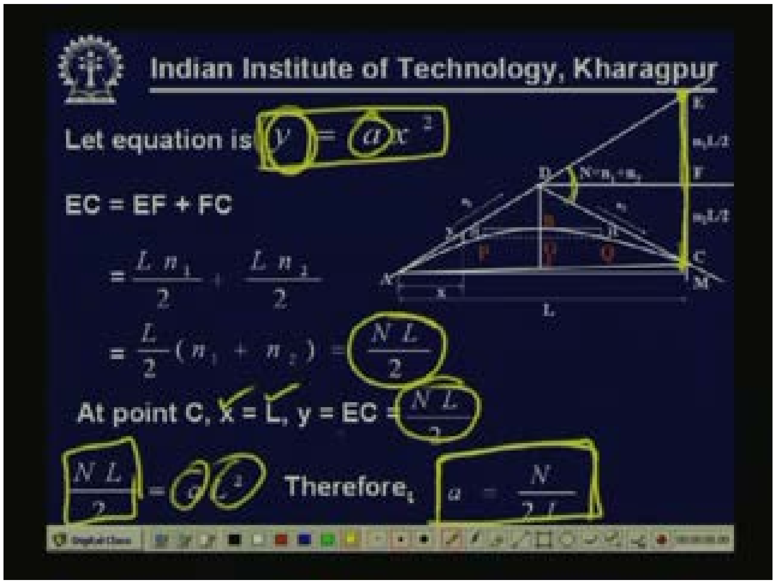

Now let us see the basic equation as we have told. The equation is assumed as parabola. So, if we assumed y = ax square as the basic equation then this EC from this point to that point EC =EF + FC. EF is nothing but L/2, this length is L/2 into N_1 this part + L/2 into N_2 so that is nothing but NL/2.

Now at point C at this point what is the X? X is nothing but AC that is L length of the curve and what is Y? Y is nothing but EC. Remember that it is the difference between this tangent line and the point on the curve as we have defined y, I mentioned it earlier also. So y in this case is EC and EC is nothing but NL by 2. Then NL by 2 in the basic equation is Y = ax square keep it 'a' and what is x is x is nothing but the length of curve L square therefore we find a = N/2L that's all, that's what gives us the equation of the parabola for summit curve; a = N/2L.

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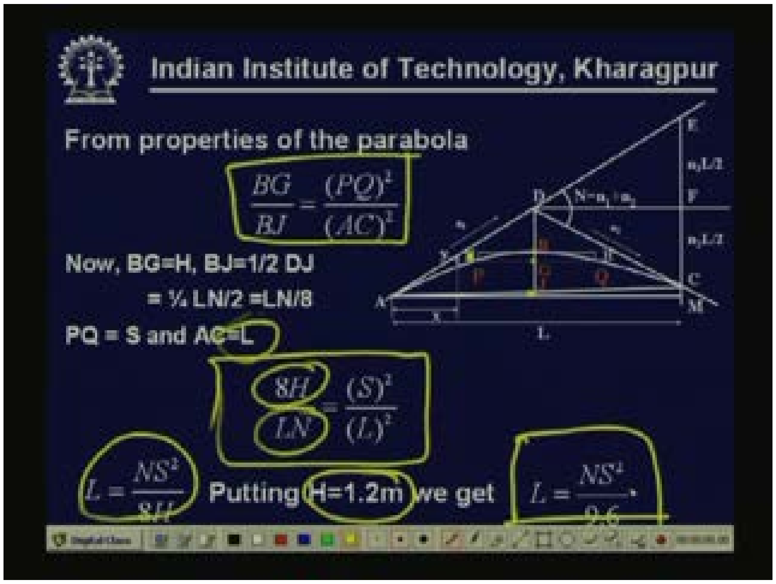

Now again from the properties of the parabola if we consider again the same sketch DG this distance by BJ where J is the point here, G is the point here and B is the point here on the sketch. So BG/BJ it varies square of the distance that means BG/BJ = PQ square by AC square. Now BG equal to H this much height, height of object, height of driver's eye because in this case both are same and BJ is half of DJ that is equivalent to LN/8. Now PQ is actually the required sight distance, AC is actually the length of the curve therefore from this basic equation what we find is BG/BJ = PQ square by AC square that is nothing but 8H by LN = S square by L square.

Now from this basis we can find out and we can see that L = NS square by 8H. Again you put the value H as 1.2m because height of object is also 1.2m here because we are discussing the basis for Overtaking Sight Distance so that gives you L = NS square by 9.6. This is how we can logically derive the expressions. It is also possible to derive the other expression with suitable modification. I have shown just once.

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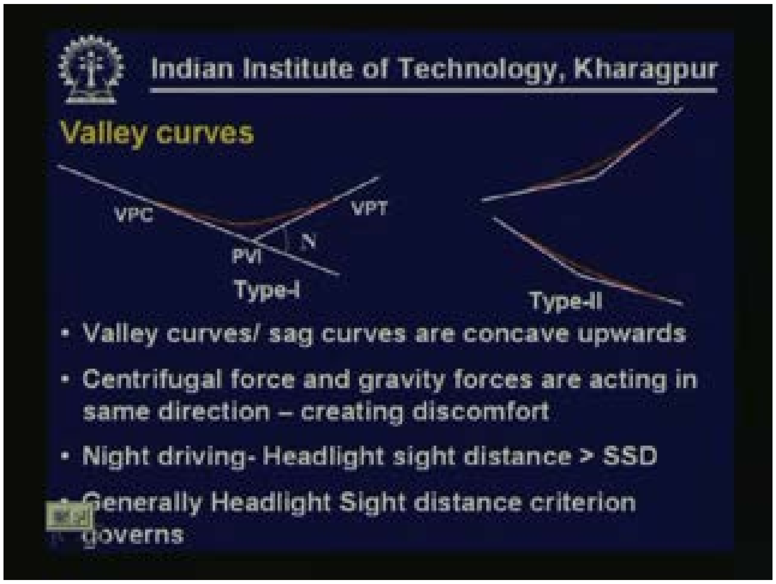

Valley curves: valley curves are concave upward and centrifugal force and gravitation force are again acting in the same direction like for the reason comfort condition is not a major consideration for the summit curve and for the same reason it is a major consideration for valley curve because it is acting in the same direction. Now obviously when vehicles are traveling in the night time night time driving is another major consideration and only the portion of the light which is illuminated by headlight that is only visible so that illuminated portion length of the road must be adequate for vehicle for emergency stopping. Therefore headlight sight distance is a major consideration and criteria in the design of the valley curve. There are comfort conditions that are also present. Also, the headlight conditions are dominating both are to be considered but normally it is found that the head light sight condition dominates.

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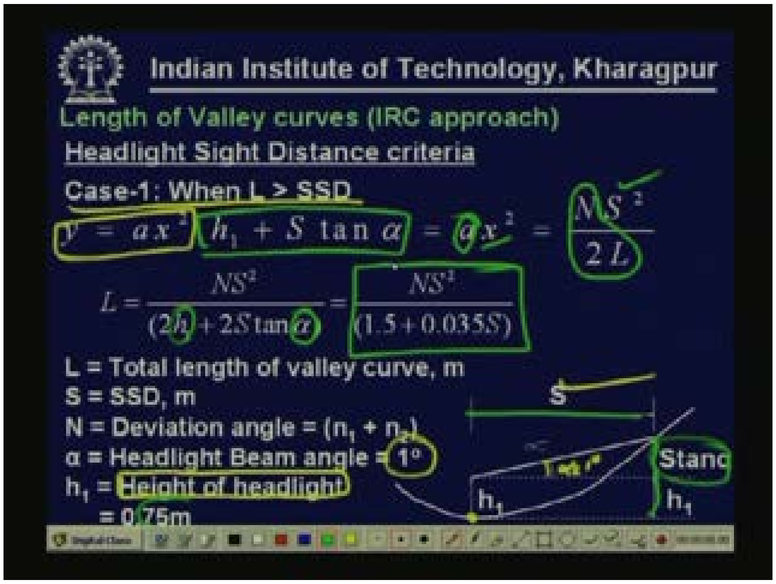

Let us see the length of valley curve considering the Headlight Sight Distance criteria. In this case critical position of vehicle is at the bottom of the curve at the lowest point on the curve. Say this is the point the lowest point on the curve let us again consider case one where L is greater than SSD. In this case it is lowest position on the curve that is the critical position and again the equation we can consider as Y equal to ax square.

Now let us consider this is the required sight distance S, h_1 is the height of headlight it is different it is the height of headlight in this case which is normally taken as 0.75m, N is the deviation angle and alpha is the headlight beam angle which is taken as 1 degree. It is not really perfectly horizontal but for high beam a small inclination is there for the headlight so that angle is considered as alpha and the value is taken as 1 degree. Therefore let us consider this sketch and we can find out what is this distance, this distance is h_1 + S tan alpha so y is h_1 + S tan alpha. And what is the value of a? Equation is y = x square, and 'a' we already know it is N by 12 and what is x? x is nothing but the required sight distance S. So, from this basic equation we can find out L = N S square by $2h_1$ and 2S tan alpha. Again put the value of h as 0.75m, put the value of alpha as 1 degree you get this expression. So this equation can be used to calculate the length of valley curve considering the headlight sight distance and when length is greater than the Stopping Sight Distance.

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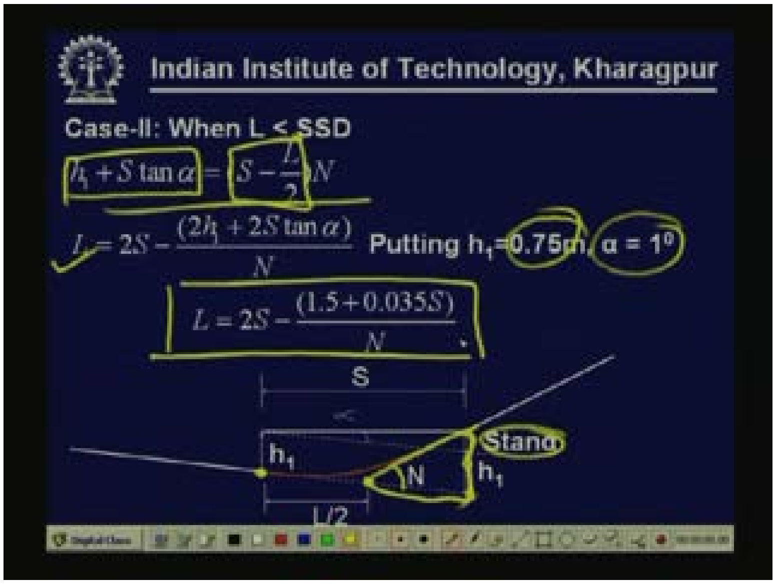

If length is less than the Stopping Sight Distance let us consider this as the tangent point. So when the vehicle is on the tangent point the red line shows the valley curve, the white line shows the tangent therefore the critical portion is when vehicle is on the tangent. Again in this case it is the same thing, the same equation y = ax square. In this case what is this y? This is nothing but if you draw a parallel line like this, this is h_1 + S tan alpha it is not really that equation but we can get it the other way that is h_1 + S tan alpha this distance is nothing but this distance. What is this distance shown by the yellow line? The total is S and up to this point it is L/2 so it is S – L/2 multiplied by the division angle N and that again gives us the same distance. So these are the two similar things so we can express this height either in terms of h_1 + S tan alpha or it is in terms of S – L/2 the whole thing multiply by L. so from this basic equation also one can calculate the length of the valley curve and here again we put the value of h_1 as 0.75m and alpha as 1 degree we get this simplified formula which can be used for the calculation of the length of valley curve.

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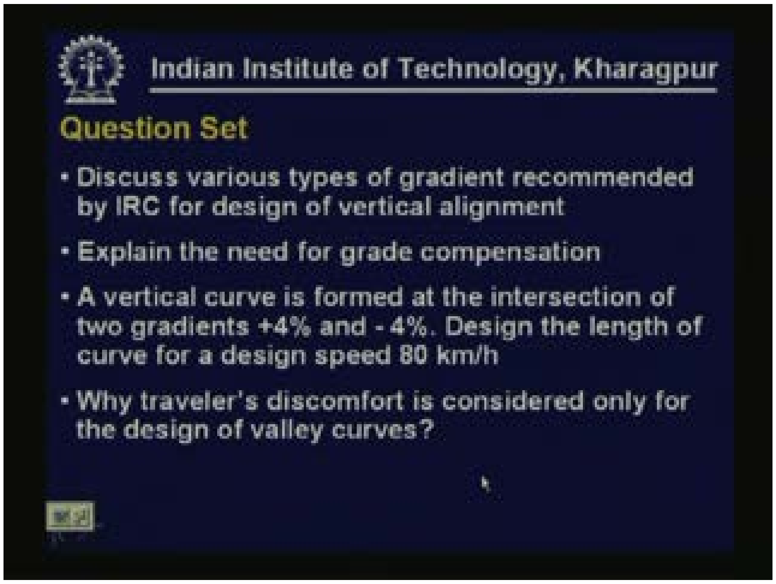

Now let me put some question set:
I indicated that the length of the valley curve should be calculated based on headlight sight distance criteria and also based on the comfort condition. But most of the cases it is the head lights sight distance criteria that will govern. In fact Indian Roads Congress guideline also recommends that the value should be checked against it, the design should be done on the basis of the available headlight sight distance criteria. Although it mentions that yes comfort condition is also another criteria but normally that is not the dominating one.

In the next class we shall talk about the basis. we can calculate the require length even though that is not dominating even though IRC does not really recommend any sort of calculation for comfort conditions but we can do that we can calculate that and there are so many takes books were it is also given we shall take up that part in the next class.

This is the question set. Try to answer to these questions.
Discuss various types of gradient recommended by IRC for design of vertical alignment. Explain the need for grade compensation why grade compensation is necessary. Try to solve this problem also; a vertical curve is formed at the intersection of two gradients + 4% and then the gradient is – 4% these are that two tangents so intersection of two gradients + 4% and then – 4% design the length of the curve for the design speed of 80 km/h. and also try to answer to this question why traveler's discomfort is considered only for the design of valley curves it is not considered in the design of summit curve, try to answer to that.

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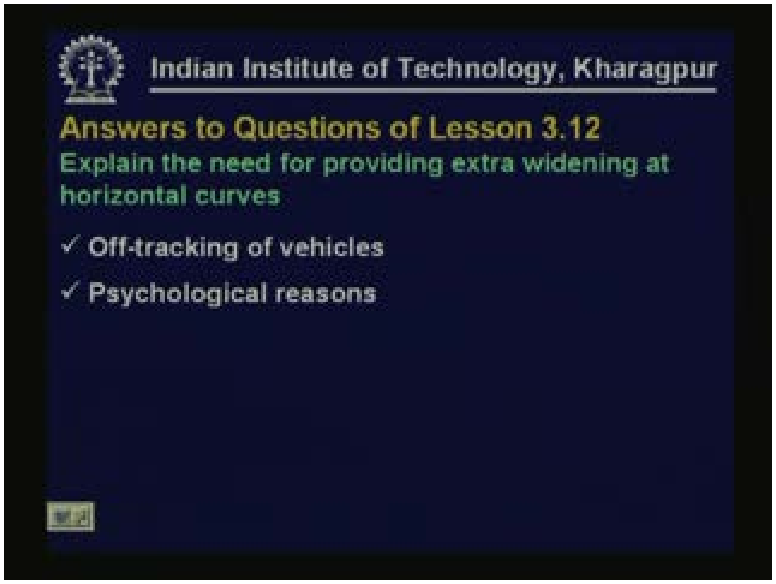

Now let me quickly try to answer to the questions of lesson 3.12. Explain the need for providing extra widening at horizontal curves basically for two reasons; off-tracking of vehicles and also for psychological reasons we need to provide extra widening.

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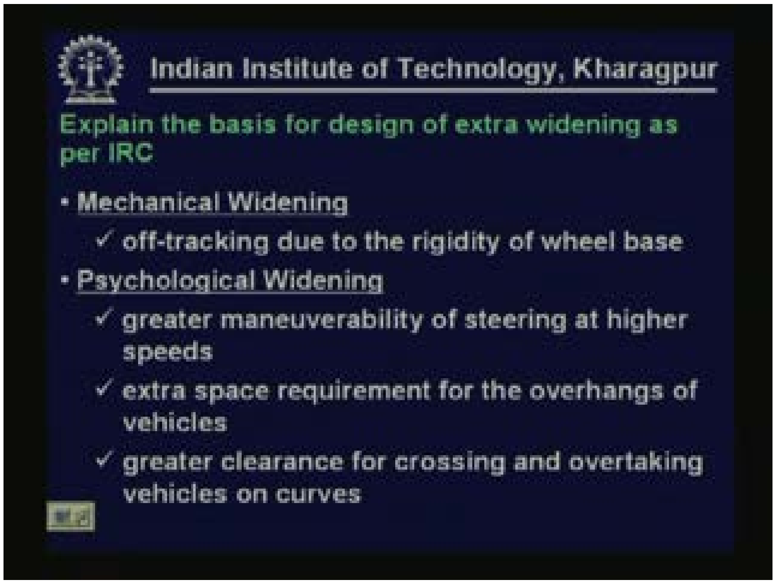

Explain the basis for design of extra widening as per IRC. IRC considers two aspect; mechanical widening and psychological widening. in mechanical widening predominantly it is the off-tracking of vehicle due to rigidity of the wheel base is considered. Psychological widening considers other factor like greater maneuverability of steering at higher speeds, extra space requirement for the overhang of the vehicles and greater clearance for crossing and overtaking of vehicles on curves. These are all predominantly psychological reasons. So, the two components are considered and then they are added together to get the total requirement.

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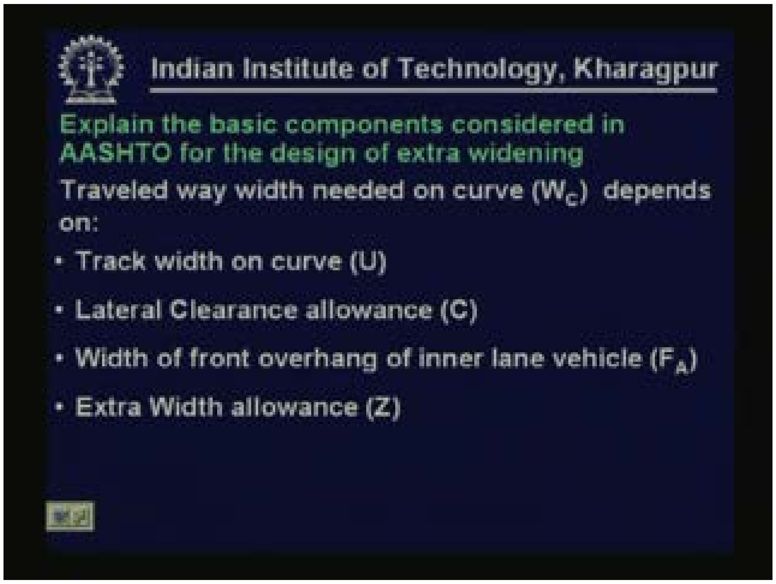

Explain the basic components considered in AASHTO for the design of extra widening. Four major components are to be considered to design or to decide the total traveled way width needed on curve. They are basically track width on curve what is the track width on curve, lateral clearance allowance, width of the front overhang of inner vehicle and then the extra width allowance. These are the four major components.

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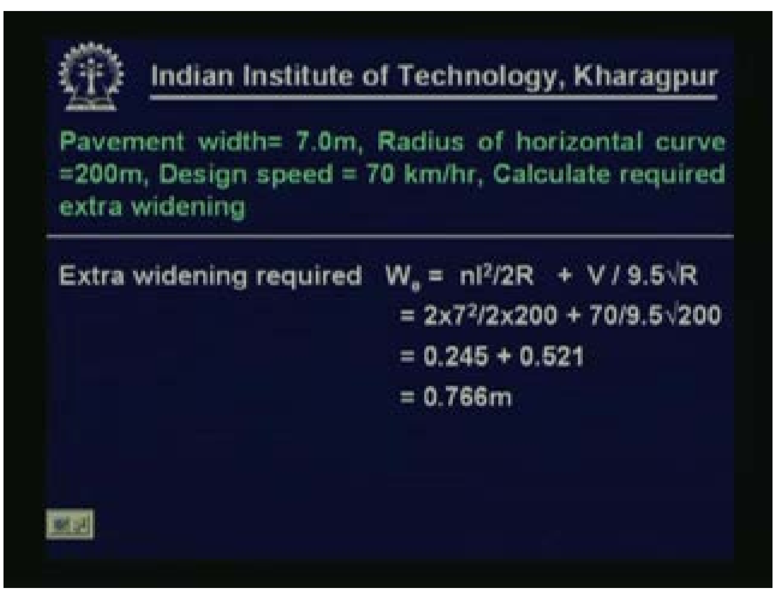

Now pavement width is 7m, radius is 200m, design speed is 7m so calculate the required extra widening. Basically again two components mechanical widening nl square by 2R and psychological widening V by 9.5 root R. Put the values and we get the required widening as 0.766m. That completes our discussion for today’s session, thank you.