Introduction to Transportation Engineering
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Lecture - 21
Vertical Alignment Part - II

In lesson 13, we discussed about design of vertical alignment, particularly the design of summit and valley curves following IRC approach or Indian roads congress guidelines.

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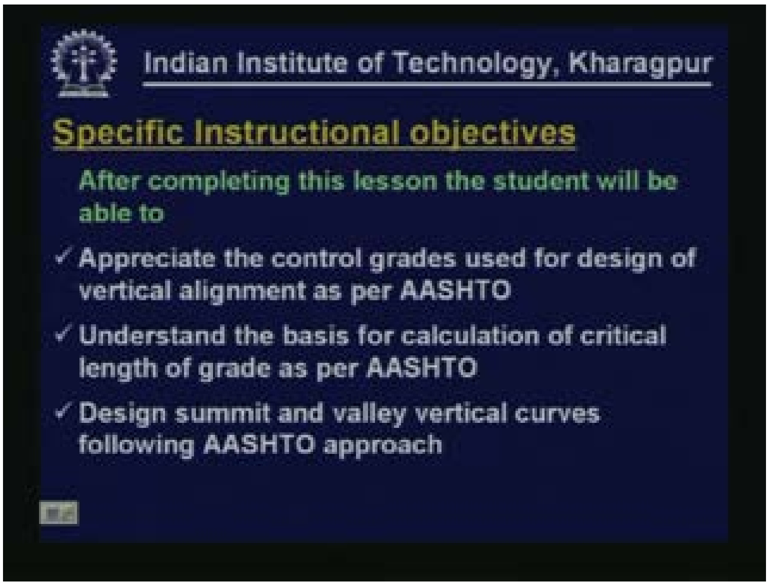

After completing today's lesson, the student will be able to appreciate the control grades used for design of vertical alignment as per AASHTO - American Association of State Highway and Transport Officials. Student will be able to understand the basis for calculation of critical length of grade again as per AASHTO approach and students will be able to design summit and valley vertical curves following AASHTO approach.

We have already covered the IRC approach in lesson 13. So after today's lesson student will be able to design vertical summit and valley curves following AASHTO approach. The AASHTO recommendation about grade what should be the maximum or minimum grade that is basically based on vehicle operating characteristics on grades.

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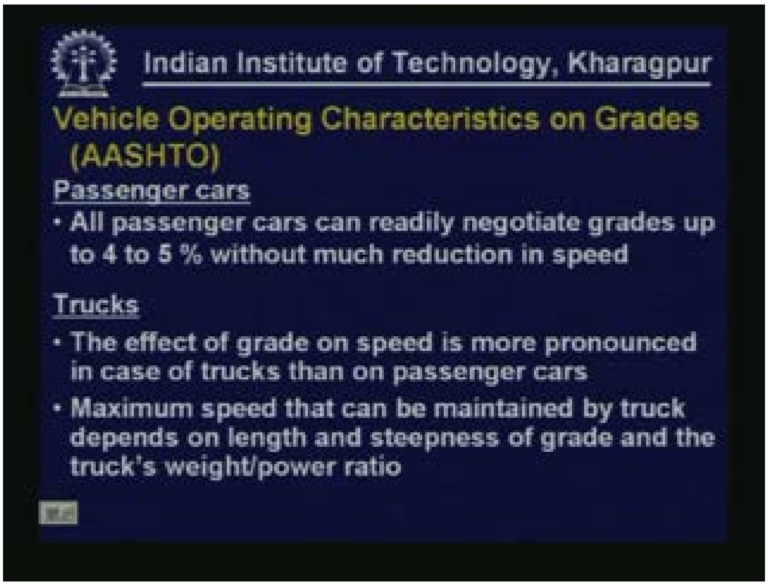

It is observed that almost all passenger cars can readily negotiate grades up to 4 to 5 % without much reduction in speed. That means if the grade is up to 4 or 5 %, then it is generally acceptable to cars, they do not face many problems. Now, what happens if the design vehicle is a commercial vehicle or a truck instead of a car?
The effect of grade on speed is more pronounced in case of trucks than on passenger cars. Obviously maximum speed that can be maintained by truck depends on length as well as steepness of grade and the truck's weight power ratio. So generally the effect is more pronounced on truck. Now, let us see the graph how the truck speed is reduced.

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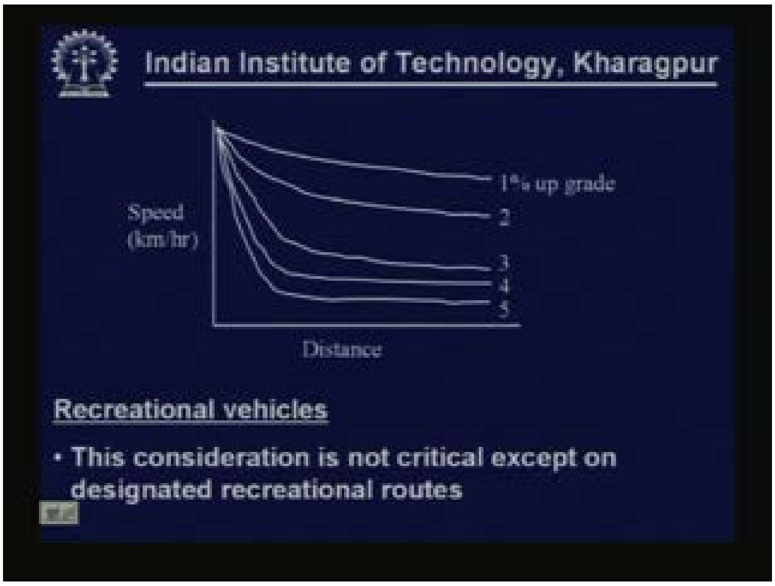

Here it is shown that, at various longitudinal grades, how the speed is reduced over distance. It is clearly observed that more the grade, more is the reduction in speed and also the speed generally reduces more as the distance is more.

Now, keeping this in mind that means commercial vehicles particularly when they negotiate grades as the distance is more, there is a reduction in speed. Keeping that phenomenon in mind the grade upper limits are decided. Sometimes the design vehicle is a recreational vehicle, but this consideration is not critical except on certain designated recreational routes where special type of recreational vehicles are taken as design vehicles.

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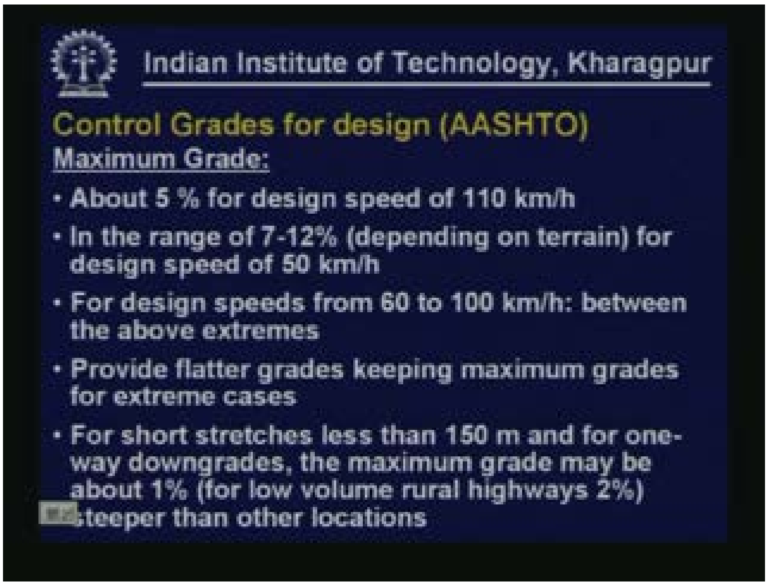

So, based on the vehicle operating characteristics, the control grades for design are recommended. There are two types of limit, one is the maximum value and the other one is the minimum value.

Now, let us have a look at certain salient features or the points of the maximum grades. About 5% grade is recommended for design speed of 110 km/hour. So if the design speed is up to 110 km/h, then 5% grade is acceptable. As the speed is less, obviously steeper gradient can be used, so the gradient may be in the range of 7 to 12% if the design speed is around 50km/h.

Obviously for design speed in between that is 60 to 100km/h, the grade will also vary between the above two extremes. We should try to provide flatter grades as far as possible. The maximum allowable grade should not be used all the times for design. We should try to provide flatter grades keeping the maximum grades for extreme situations where terrain condition is difficult, site specific problems are there. So we should try to keep the extreme values for those cases.

There are certain relaxation say for short stretch, less than 150m and for one way down grades, the maximum grade may be about 1% steeper than other locations and if it is low volume rural highways it may be more by about 2% steeper than other location. So for short stretch, if the length is less than 150m and for one way down grades the maximum grade may be 1% higher in general. For low volume rural highways it may be even 2% steeper. That is the relaxation which is available or allowed / permissible in the design standard.

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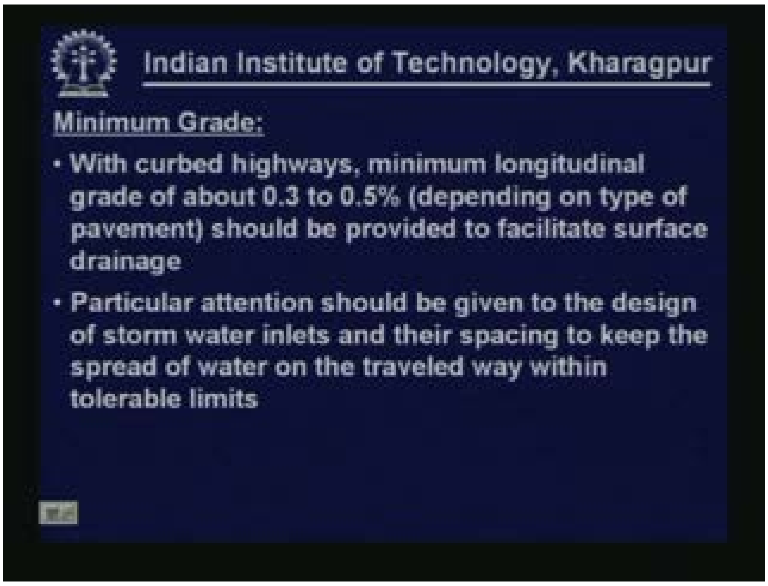

Let us look at the other extreme that is the minimum grade. With curbed highways minimum longitudinal grade of about 0.3 to 0.5% should be provided to facilitate surface drainage. Obviously what should be the exact grade between 0.3 to 0.5%? That will depend on the type of pavement.

Why this minimum grade provision and why it is for curbed highways?
For curbed highways, the water cannot go directly to shoulders because the road side curbs are there. So the water cannot go directly on shoulders, that is why there is a slight longitudinal grade that should be provided, so that the you know the water can flow in a desirable manner or in an acceptable manner to the water inlets.

In that type of situation, particular attention should be given to the design of storm water inlets and their spacing to keep the spread of water on the travelled way within tolerable limits, because not that at every point water cannot directly go to the shoulder. It has to go on certain designated water inlets so appropriate slope should be provided, so that water can go easily to those inlets and the spread of water is done in a controlled manner that is what justify the need for the minimum grade.

It may be recalled that when we discussed about the Indian roads congress guidelines, there also we talked about the minimum longitudinal grade. But the reason why IRC recommends minimum grade wherever topography permits and the reason why a minimum grade is recommended for curbed highways as per AASHTO they are not really identical, the basis is different. This should be understood and kept in mind.

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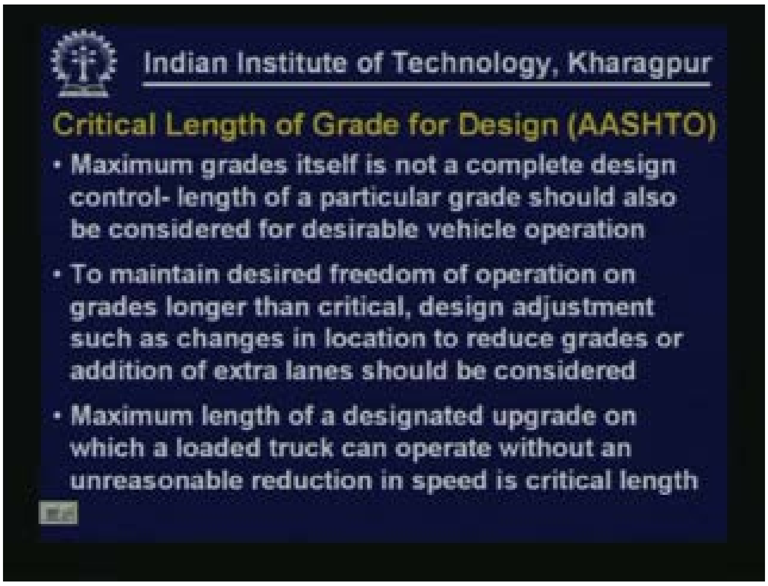

Coming to the critical length of grade for design, we have talked about the maximum grade but maximum grade itself is not a complete design control. Length of a particular grade should also be considered for desirable vehicle operation. This is purely based on the fact that, if the length is more and as the grade is also more, then there is a reduction in speed. We have already seen this trend earlier.

If it is heavy commercial vehicle or the commercial vehicle proportionally significant, or if the design vehicle is commercial vehicle, then there may be significant loss in speed or significant reduction in speed. So therefore to have the overall operation within desirable limit, it is also necessary to specify the maximum length of grade. For different grade what should be the maximum length at a stretch to keep the overall vehicle operation within desirable limit.

Now, it is difficult to the freedom of operation on grades longer than critical. So obviously there will be loss in freedom of movement. Therefore suitable design adjustment such as, changes in location to reduce grade or addition of extra lengths should be considered. That means wherever the length is becoming more than the critical length then in those locations suitable adjustments are to be made. Extra efforts are required to bring the operation within desirable limits.

Let us try to formally define what is critical length of grade? We have already discussed, but let us try to define it now. Maximum length of a designated grade on which a loaded truck can operate without an unreasonable reduction in speed is critical length. That means it is that maximum length for a given upgrade, where a loaded truck can operate without unreasonable delay or without unreasonable reduction in the speed. So we will try to limit the length and that is what the critical length of grade is.

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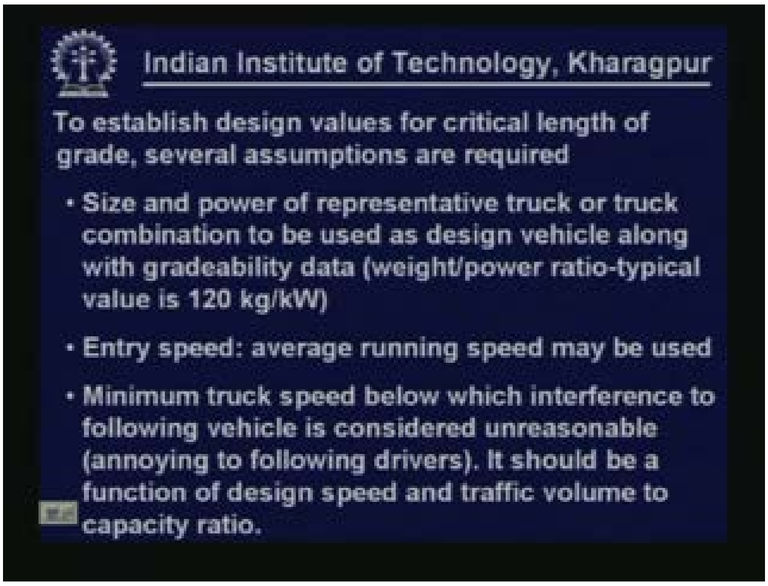

Now to establish design values for critical length of grade, several assumptions are required. Number 1: size and power of representative truck or truck combination to be used as design vehicles along with gradeability data that is weight power ratio a typical value is may be 120 kg/KW. So, we have to specify the size and power of the representative truck or the truck combination which is what we are trying to use as design vehicle and the gradeability data particularly weight power ratio becomes critical. Then it is also necessary to mention or to define the entry speed which may be taken as the average running speed on plains. Then the minimum truck speed below which interference to following vehicle is considered unreasonable or annoying to the following driver.

Now, obviously if on a grade a commercial vehicle is moving and there is a continuous reduction in speed particularly for two lane roads, sometimes other vehicles which are may be cars or other light type of vehicles, they are forced to follow this slow moving vehicle which is moving at a much lesser speed. So it becomes annoying to the following driver to follow a slow moving vehicle for a much longer time.

Obviously, what is annoying that will depend on the design speed for which the road is designed or the road is designed to accommodate certain design speed. So, the minimum truck speed that will depend on the design speed and also logically the volume to capacity ratio. Because, at low volume to capacity ratio, there may not be many vehicles which have to follow the slow moving vehicles, but as the volume to capacity ratio approaches unity that means as the vehicle volume generally increases on road, it becomes more annoying and more critical consideration. Therefore the speed value has to be considered keeping this in mind that, generally it is more annoying when the volume to capacity ratio is higher.

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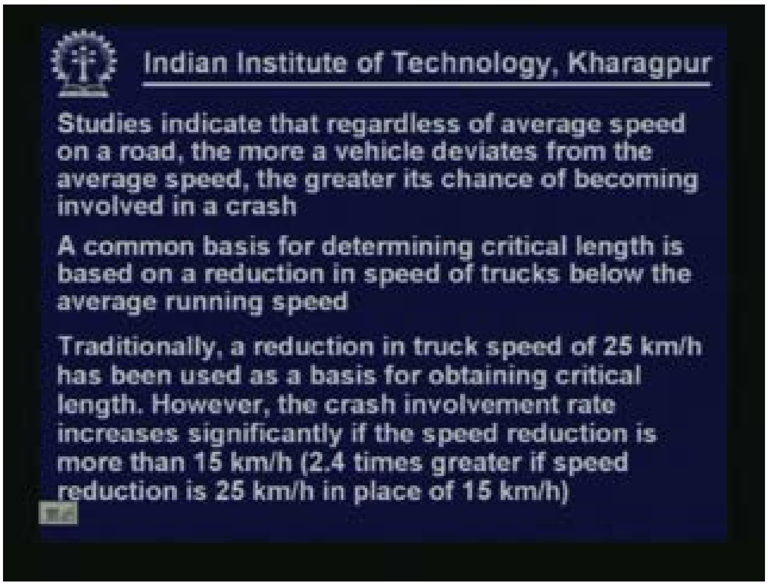

Now, studies indicate that it is observed from several studies that regardless of average speed on a road the more a vehicle deviates from the average speed, the greater its chance of becoming involved in a crash. That is a very interesting and a very vital observation. The more a vehicle deviates from average running speed, the more is the possibility of that vehicle to get involved in crash or accident.

So a common basis for determining critical length is based on reduction in speed of truck below the average running speed, because the basis is following. Once it is mentioned that the more a vehicle deviates from the average running speed, more is the possibility of getting it involved in crash. So therefore the critical value we are trying to define or understanding the critical length of grade, then a common basis is recommended that on the basis of reduction in speed of truck below the average running speed, control that deviation from the average running speed.

Let us see, traditionally a reduction of truck speed 25 km/h has been used as a basis for obtaining critical length. However, the crash involvement rate is found to increase significantly if the speed reduction is more than 15 km/h.

It is observed that if we take a speed deviation of 25 km/h and another speed deviation of 15 km/h, in the first case the possibility of vehicle getting involved in a crash is almost 2.4 times higher. That means as the speed deviation is more, instead of 15 it becomes 25, then the possibility of involvement of vehicles in crash becomes 2.4 times higher, which is a very vital observation. Although earlier 25 km/h speed reduction was used as a basis for design, based on these findings it is now revised and recommended as 15 km/h.

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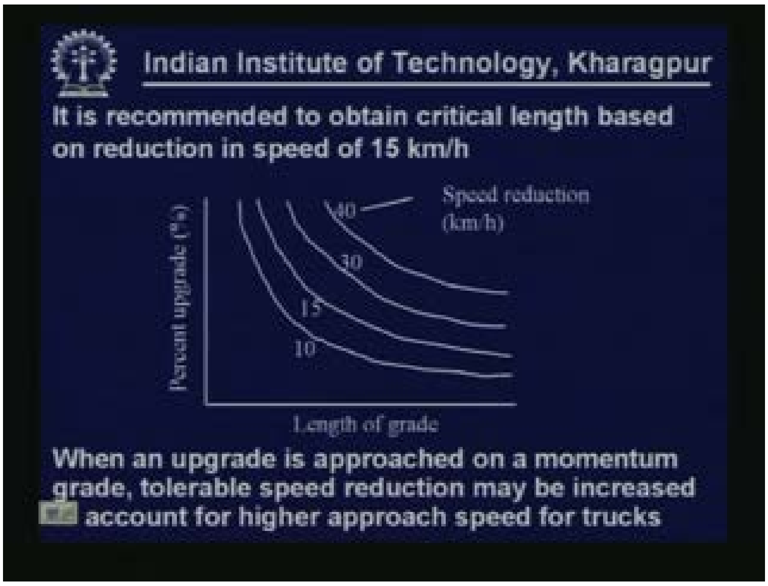

Therefore, it is recommended to obtain critical length based on reduction in speed of 15 km/h and not 25 km/h. Here the above graph shows as the length of grade increases and as the percentage of upgrade increases for various speed reductions, how the curves will look like. It is obvious that, if for a particular percentage upgrade say if we take this one, (Marking a point in the y axis – Percent upgrade : Refer Slide Time 21:04) and if we consider allowable speed limit as 15 km/h, then obviously the length requirement is something, speed reduction.

If we consider a higher speed reduction say 25 or 30 say just for example, obviously a longer length of grade is acceptable. But normally taking 15 km/h as the speed reduction limit the critical length of the grade is decided. Now, this value of critical length of grade will be lesser as compared to what was used earlier. That means if we use 25 km/h as acceptable deviation, then obviously critical length of grade would have been higher. So if we consider 15 km/h, then it is lesser.

When an upgrade is approached on a momentum grade, that means there is a down grade and then an upgrade, obviously even the heavy vehicles also probably can have a better speed profile. In this case, tolerable speed limit may be increased to account for higher approach speed for trucks. That means earlier what we were using as the basis say 15 km/h, now if there is a momentum grade then the tolerable speed limit may be adjusted. May be instead of 15, one may take this limit as 20 or the reduction is 20 km/h. This of course is the designers' judgement. So looking at the condition, the tolerable speed limit or speed reduction may be increased by certain amount for higher approach speed for trucks. That kind of adjustment is possible and can be done.

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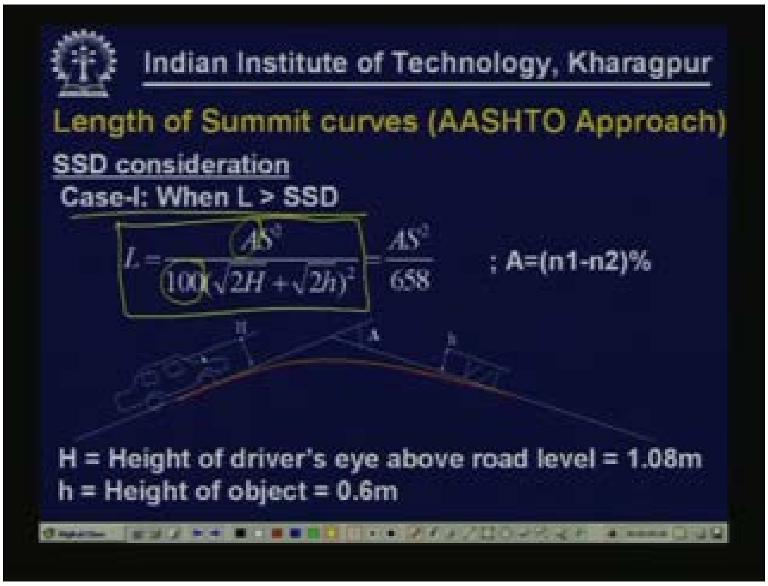

Now, let us come to the curve design parts. We have discussed the upper limits of grades, the lower limits of grades and also the basis for deciding the critical length of grade as per AASHTO. With this background, let us try to understand what should be the basis for design of summit and valley curves. We have already defined and discussed in lesson 13 about summit curve and the valley curve and the rationality of design of those two types of vertical curves as per IRC approach. Now we shall discuss about the AASHTO approach for design of summit and valley curves.

First let us talk about the summit curves. Summit curve design; again it is basically the sight distance is the major consideration. And the sight distance may be stopping sight distance or it may be overtaking sight distance. Also for each of these two cases, that means stopping sight distance and overtaking sight distance, the length of the curve may be more than the sight distance available or the length of the curve may be less than the sight distance available. So that means, the sight distance is the major consideration. Sight distance may be in terms of stopping sight distance which is the absolute minimum requirement or it may be overtaking sight distance. Then in each case the length of the curve may be more than the available sight distance or it may be less than the available sight distance. All these cases were covered when we discussed about the IRC approach.

Now, basic formulations or basic equations whatever were used or mentioned during the earlier discussion when we discussed about the IRC approach, here also the basic equations are generally same.

Let us see, look at this equation SSD consideration and Case-I: When length is greater than stopping sight distance. In this case, this is the basic equation that may be used for calculation of the length of summit vertical curve. This is similar to what we have discussed or what we have indicated when we talked about the IRC approach. Basic equation is same, only thing here A the deviation angle is expressed in percentage, so it is A by 100. There it was N where N is essentially A by 100.

Now, the final form ‘A S square by 658’, this looks apparently different from what we indicated in terms of IRC approach. But in this case, the value of H that is height of driver's eye above the road surface as per AASHTO is 1.08, in IRC it was 1.2 and height of object ‘h’ is 0.6 m and as per IRC it was taken as 0.15m. So, if we substitute the AASHTO recommendation for the height of driver's eye above road level and also height of the object, then it is a simplified expression like ‘A S square by 658’.

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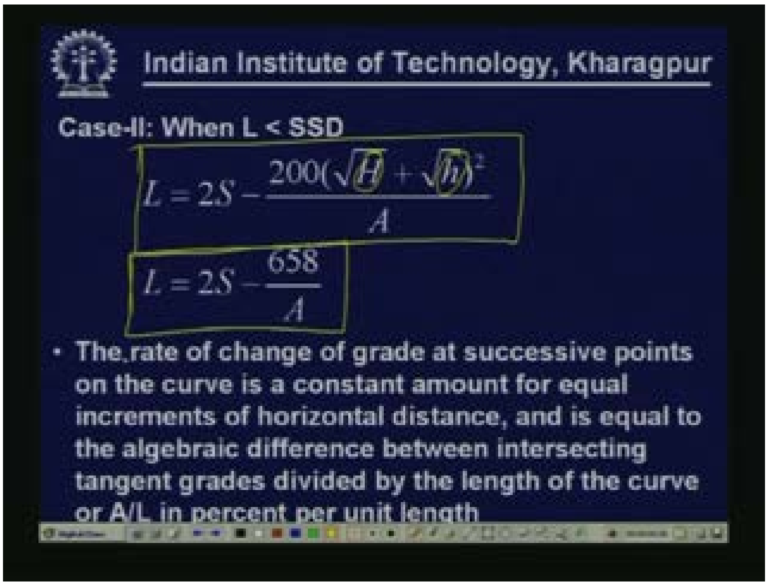

Similarly for Case-II also the basic equation is as indicated here. It is same as what we have indicated in IRC approach, it is basically same and basic equations are not different. Again if we put appropriate value of ‘H’ and ‘h’, then it becomes a simplified expression like this: ‘L = 2S minus 658 by A’. So basic equations are same, the only difference is the height of driver's eye above road level and height of object that is different as per AASHTO.

Appropriate values are to be given and also here the deviation angle is expressed in percentage. Basically it is A by 100 and in IRC we have indicated it as N the deviation angle. Now if we come back to this equation, the rate of change of grade at successive points on the curve is a constant amount for equal increments of horizontal distance and it is equal to the algebraic difference between intersecting tangent grades divided by the length of the curve. Simply, A is the algebraic difference between intersecting grades or the deviation angle that much deviation angle is negotiated over a length A. So what is the change of grade? It is nothing but A by L in percentage per unit length.

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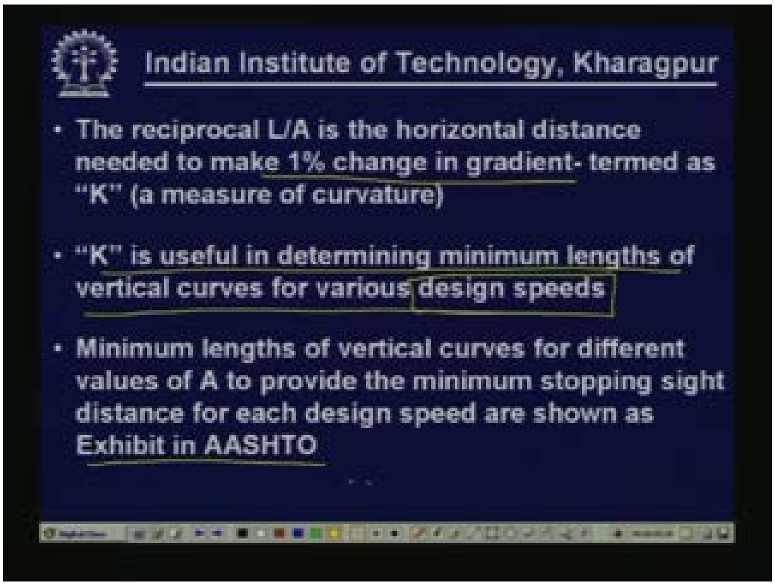

Now the reciprocal of this is L by A, which is nothing but the horizontal distance needed to make 1% change in gradient. That means what is the horizontal distance required to make a 1% change in grade. That means per percent change in grade what is the length of the curve that is required? This is termed as K factor and we call it as K. It is nothing but a measure of curvature. K is useful in determining minimum length of vertical curves for various design speed.

We call K as L by A and it is useful in determining minimum lengths of vertical curves for different design speeds. Why for different design speed, because for different design speed the sight distance requirement or the stopping sight distance requirement is different. So the length also will be different.

Now, minimum length of vertical curves for different values of A to provide the minimum stopping sight distance for each design speed are shown as exhibit in AASHTO. AASHTO gives exhibit showing the minimum required length of vertical curves for different values of A, it will vary depending on A as the length is K(A). Then again it will vary depending on the design speed because the sight distance requirements or the stopping sight distance requirements will also vary depending on the design speed. So AASHTO gives the length of the curve as exhibit. Let us have a look at that.

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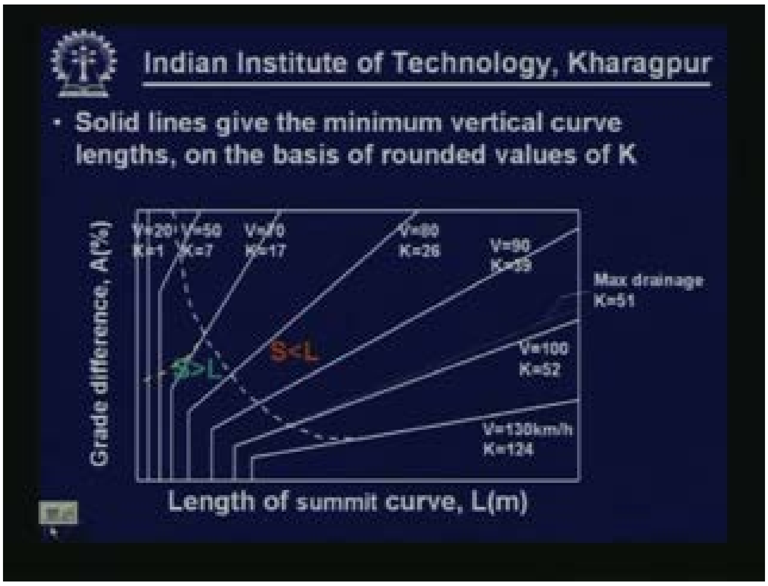

Look at this graphs or exhibit. The solid lines shown in white colour in the graph are the minimum vertical curve lengths on the basis of rounded values of K. Note that it is based on the 'rounded values of K'.

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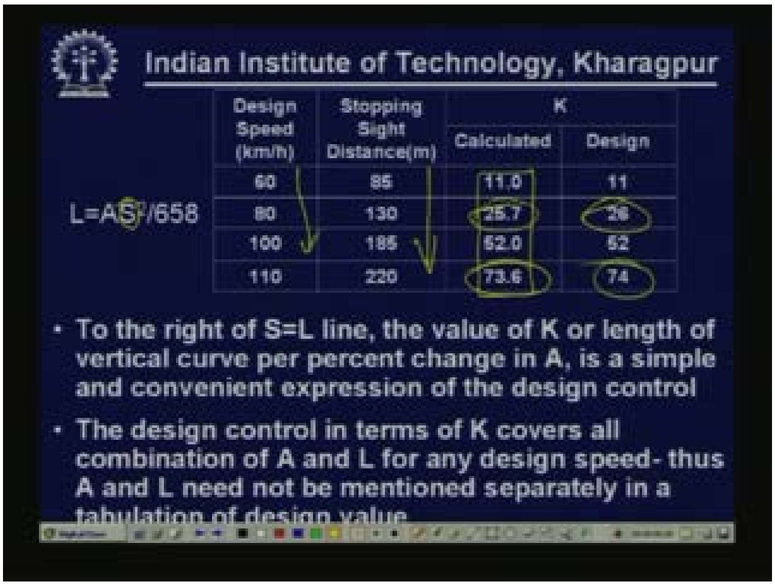

What is rounded values of K?
Actually, we know this expression L equal to 'A S square by 658'. We have already discussed that say it is for SSD consideration and when L is greater than stopping sight distance, the length of the curve can be calculated by this simplified formula 'A S square by 658'. If we take this formula then for different design speed, we can anyhow calculate the stopping sight distance. We have covered and discussed earlier about how the stopping sight distance can be calculated.
If the design speed is known, we can easily calculate what the required stopping sight distance is. Considering the reaction time and the design deceleration rate and all these

things, we can calculate the required stopping sight distance. Now, once the stopping sight distance is known that means this S value is known. So if we know the first column of the table shown in the above slide, then we can also calculate this stopping sight distance values.

Once we know S, then L by A is K. So we can calculate the actual K value which is nothing but 'S square', the 'sight distance-square' divided by 658. If we do that, the values shown in the 3rd column are the calculated values for different design speed. Now these values are rounded off. Say for example it is 25.7, then it is rounded off to 26 and 73.6 is taken as 74. So using these rounded values of K, these solid lines are drawn (Refer Slide time 35:01). So you can see here it is for speed 50 the K is 7, for speed 70 the K is 17, for speed 80 the K is 26 and so on. These are the rounded values of K. The solid line gives the minimum vertical curve length on the basis of rounded values of K.

Now, to the right of S equal to L line, there are two different formulas to calculate the length of the curve when L is greater than S and another case when L is less than S. This dotted line indicates when S = L and in the right side it is S < L and in the left side it is S > L. Now what is being said that is, to the right side of S = L line, the value of K or the length of vertical curve per percent change in A is a simple and convenient expression of the design control. You can obviously see these are basically just straight line equation. So for every percentage change in grade, the length of the curve or K value that can be obtained very easily. It is a simplified expression because if you take this dotted line which represent S = L, then the right side, it is the convenient expression of design control because these are essentially straight lines (Refer Slide Time: 36:38).

The design control in terms of K covers all combinations of A and L for any design speed. Therefore it is not necessary to define or to mention A and L separately. If we consider K, that covers all combination of A and L. And therefore it is not necessary to define or to address A and L separately in design tables.

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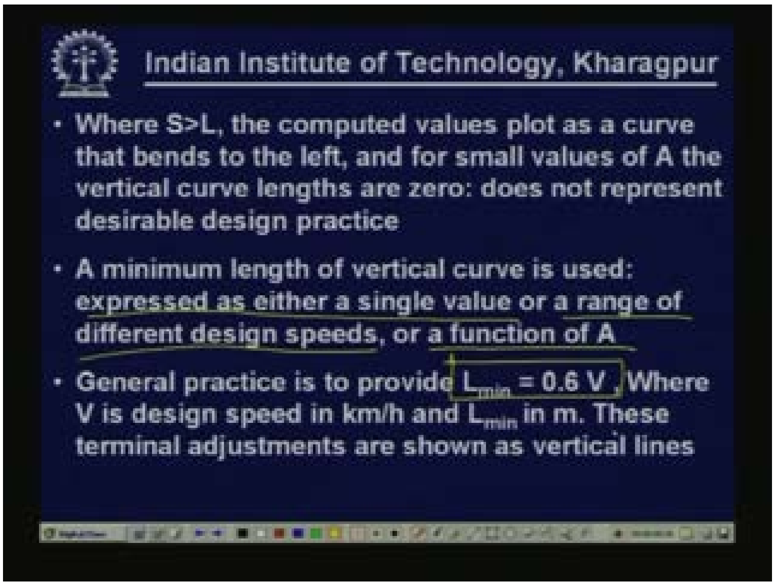

Now, again where S > L that is left side of this dotted lines which represent S=L, the computed values plot as a curve that bends to the left and for small values of A the vertical curve lengths are 0.

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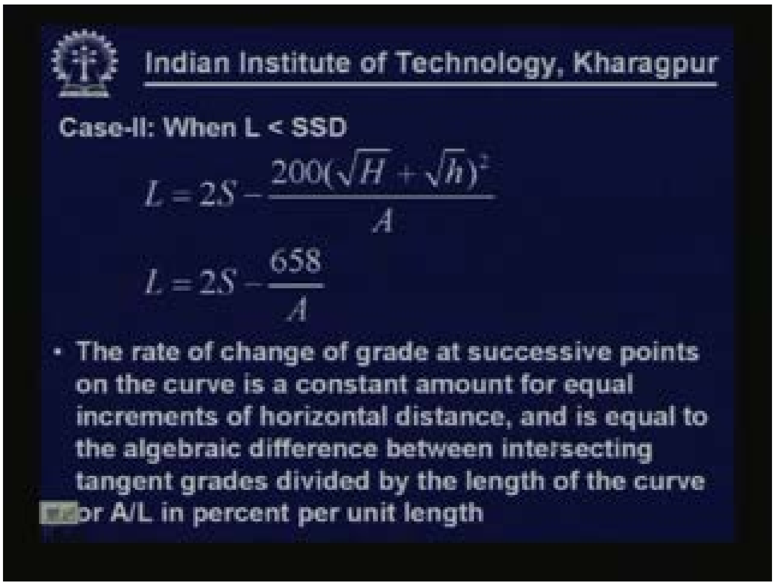

To the right side it is this expression ‘A S square by 658’ and to the left side it is this expression ‘2 S minus 658 by A’. So for small deviation angle or if we try to use that equation ‘2 S minus 658 by A’, then the theoretical curves to the left of this one it actually takes a turn or it bends like this as indicated by this yellow line.

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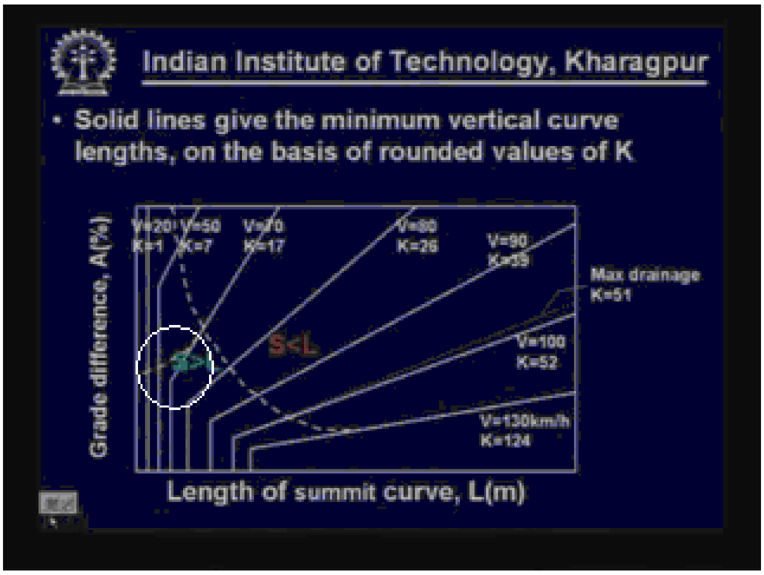

So for V =7 up to this point it is a straight line, then beyond that it is a dotted line as shown in this case. So may be for K = 80 also it may be something like this, it takes bend to the left side as per the formula. So if we use the formula then try to calculate the length and the lines will take a shape like this and obviously for small length of A the curve length may be 0. That means indicating that as such for small deviation angle there is no need to provide the length of curve, but this is not a good design practice. So that is why, where S > L computed values plot as a curve that bends to the left, and for small values of A the vertical curve lengths are 0, it does not represent desirable design practice. You can again see that it is taking a turn to the left (Refer Slide Time: 40:22), so it will be shape of that kind.

Because it does not represent desirable design practice, a minimum length of vertical curve is used. Now the moment we say a minimum length of vertical curve is used, there are many approaches; sometimes this is expressed as either a single value, sometimes a range of different design speed, sometimes as a function of A, but the general practice is to provide L minimum as 0.6V. It is the general practice to provide minimum length of summit curve as 0.6V where V is the design speed in km/h and L minimum (L_{min}) is the minimum length of curve in meter. Now these terminal adjustments are shown as vertical line. Let us again go back to this to that curve.

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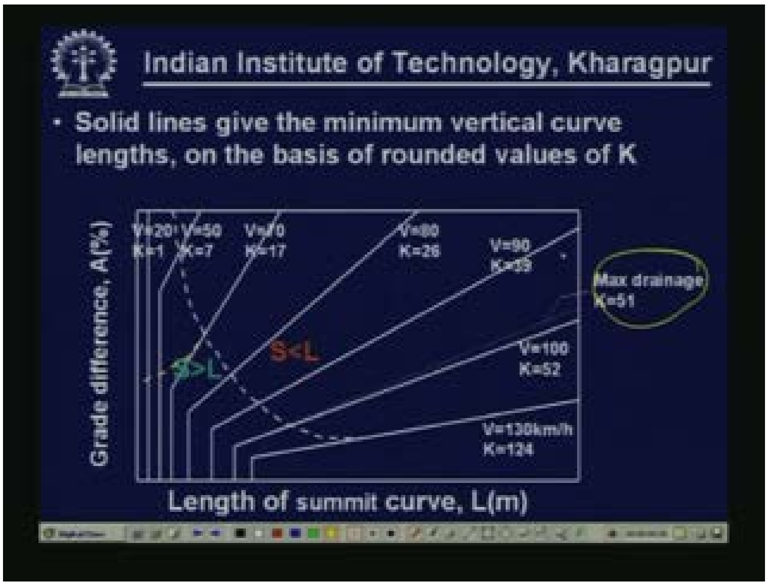

So, theoretically it goes like this it takes a bend. But from practical consideration we use some minimum limit which is again a function of the design speed. So these vertical lines are essentially showing those terminal adjustments. That is what should be the minimum one. Now then this exhibit actually extends the line for S < L and it extends it up to that vertical line that means these are the limits, draw a vertical line here, extend this horizontal line wherever it meets. This total curve represents the required length of curve for that particular design speed. So these terminal adjustments are made and then this S < L portion is extended to meet the extended vertical lines. That way this whole exhibit is developed.

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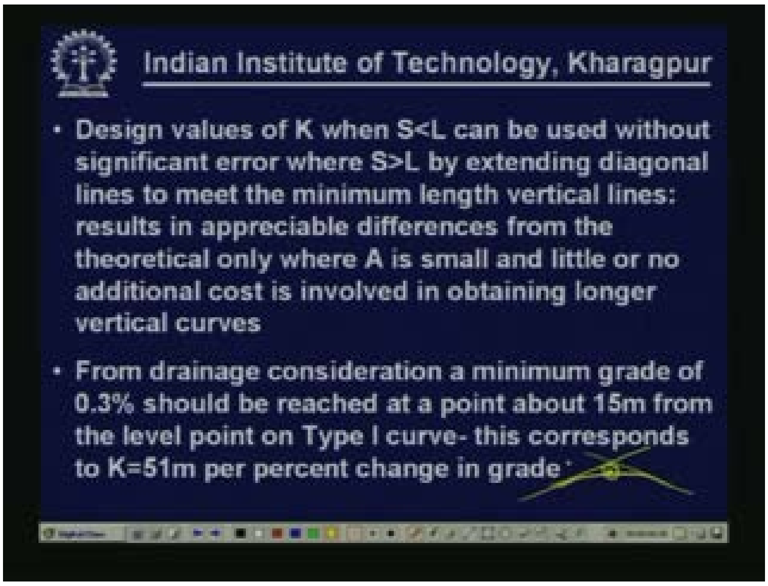

I have mentioned it once again, design values of K when S < L can be used without significant error where S > L by extending diagonal lines to meet the minimum length vertical lines; and this results in appreciable difference from the theoretical calculation only when A is small. If we draw the theoretical curve that takes a turn towards a left and that gives value even 0. So these vertical terminal adjustments are made.

Now, appreciable difference is obtained from theoretical calculation, only when the deviation angle is very small. And obviously for deviation angle where deviation angle is very small, although theoretically we do not need probably any length of vertical curves, but it is not a good design practice and we want to use some minimum length of vertical curves. So that way these overall things become acceptable. So the difference from theoretical only when A is small and little or no additional cost is involved in obtaining longer vertical curves. Now that is from one side. Let us look at that other component that is from drainage consideration, which is again a very vital part.

From drainage consideration, a minimum grade of 0.3% should be reached at a point about 15m from the level point on 'Type I' curve. What is 'Type I' curve? 'Type I' curve was like this (The curve is shown in the above screen shot – Refer Slide Time: 45:00). This is the point where it is a level point. So what it is saying for 'Type I' vertical curve from drainage consideration a minimum grade of 0.3% should be reached, at a point 15 meter from the level point on 'Type I' curve just to facilitate drainage. If we consider this corresponds to a K value of 51. Let us go back to that exhibit.

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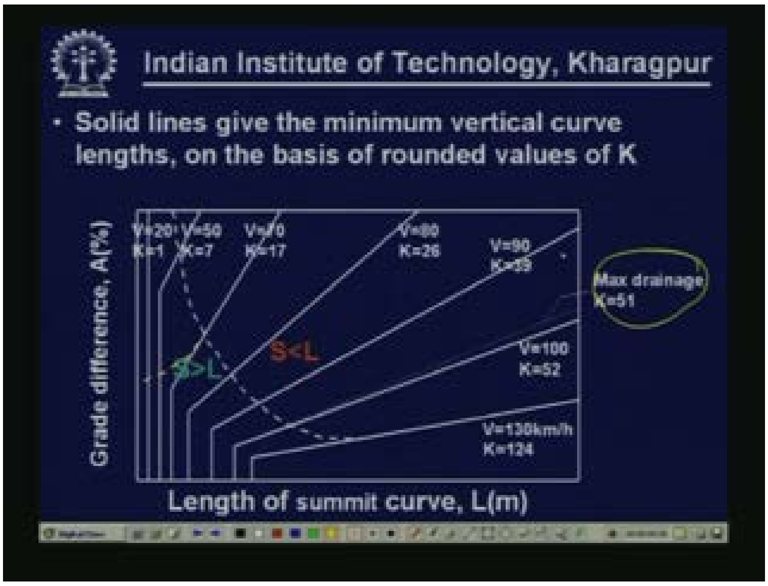

You can see here this K = 51 is also shown as a dotted line, this is from drainage consideration. That means up to that point for 'Type I' curve, we should have K = 51 as the limit; Not as a design limit, but I will come back for that discussion later. So, maximum value of K for drainage is 51. If it is more than 51 it means, it is much flatter, the grade is much flatter or grade in general is flatter than what is required for drainage point of view. Look at this exhibit again to the right side of this dotted line: This whole area V = 100, 130 etc, all represent the K value as more than 51. That means this is a range where the length of the curve or the grade is not appropriate for drainage consideration.

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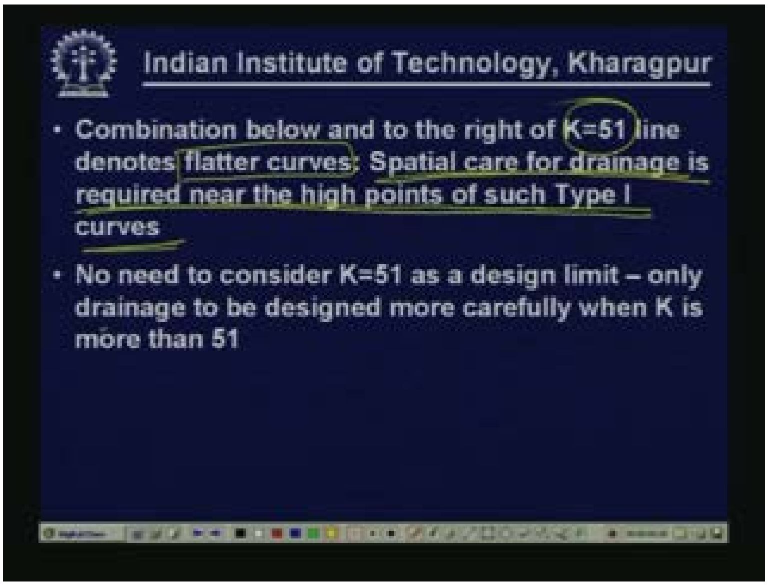

Of course, if it is more than 51, then special care should be taken for drainage near the high points of such 'Type I' curves. If K is more than 51 that means they are essentially flatter curves. Therefore special care is necessary for drainage near the high point of such 'Type I' curve. However this K equal to 51 should not be used as a design limit.

What we are trying to indicate is, if it is more than 51 for the K value, special attention is required for drainage, but it is not that K more than 51 is not acceptable. Certainly it may be acceptable, but we have to keep it in mind that if K is more than 51 then special care or attention is required for drainage purpose. So no need to consider K = 51 as a design limit. It only says that drainage to be designed more carefully when K is more than 51.

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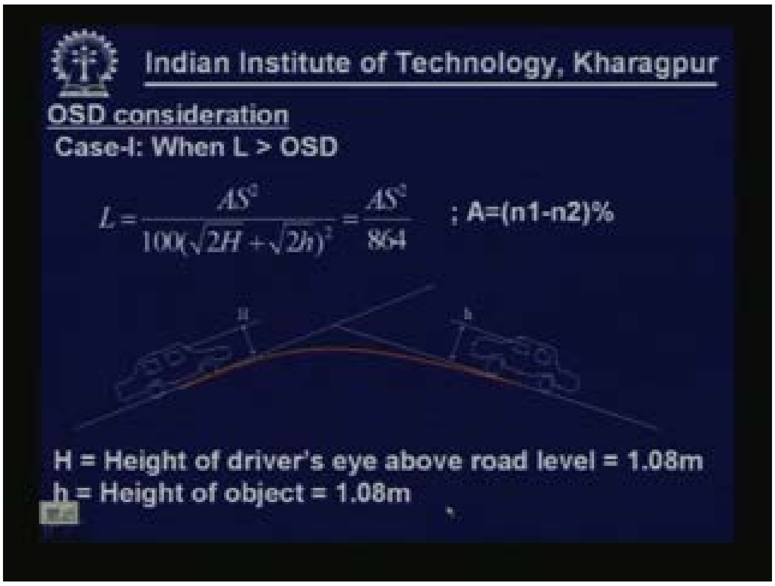

Now, coming to OSD consideration, again the basic formulation is same. Only thing in this case both the capital H and small h should be taken as 1.08. So appropriately one can get the required length.

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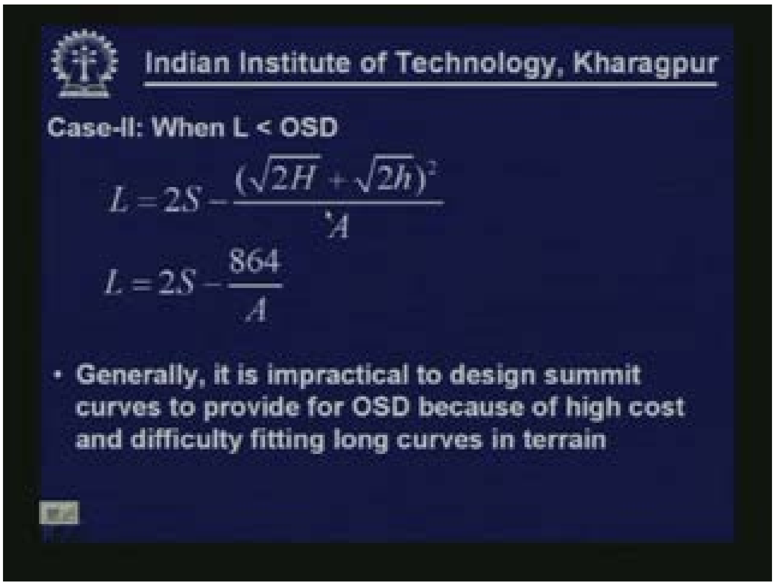

For L < OSD, again the same basic equation, only thing capital H or small h are same here. So accordingly values are to be provided. But generally it is found that if the length is to be designed to provide adequate overtaking sight distance the length requirement is much higher. So it is not practical to design summit vertical curves to provide required overtaking sight distance. Most of the cases this is not designed for providing overtaking sight distance, so only satisfying the requirement of SSD may be adequate.

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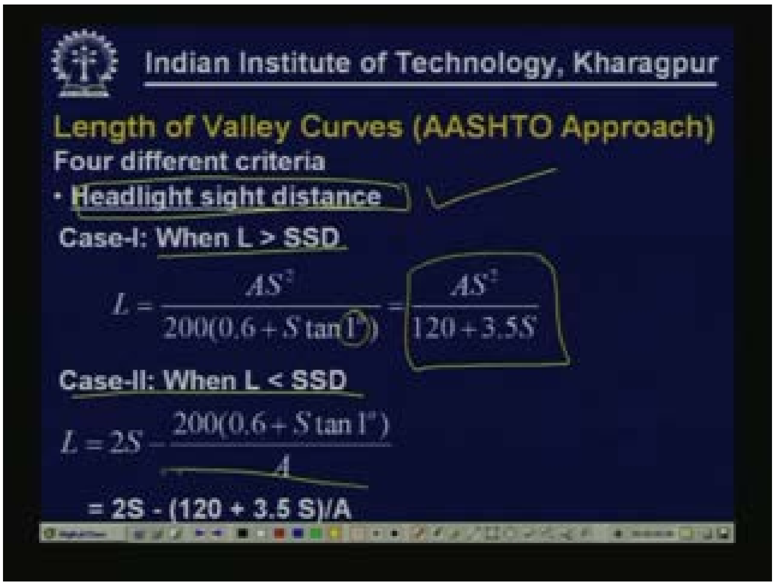

Now length of valley curves: There are four different criteria that are considered. First one is the 'Head light sight distance'. We have already discussed about this head light sight distance requirement during our discussion about IRC approach. Here also it is the same. Two cases are considered when length is more than stopping sight distance and the other one is length is less than stopping sight distance.

We have again discussed these two cases during our discussion about IRC approach. It is exactly same except the tail light height is different here and A is expressed in percentage which is the deviation angle. So substituting the appropriate values here, this light beam angle is taken as one degree, accordingly you can get these expressions: 'A S square by 120 + 3.5S' and '2S – (120+3.5S)/A'. So, basic formulation is same, but only AASHTO specific design values are given.

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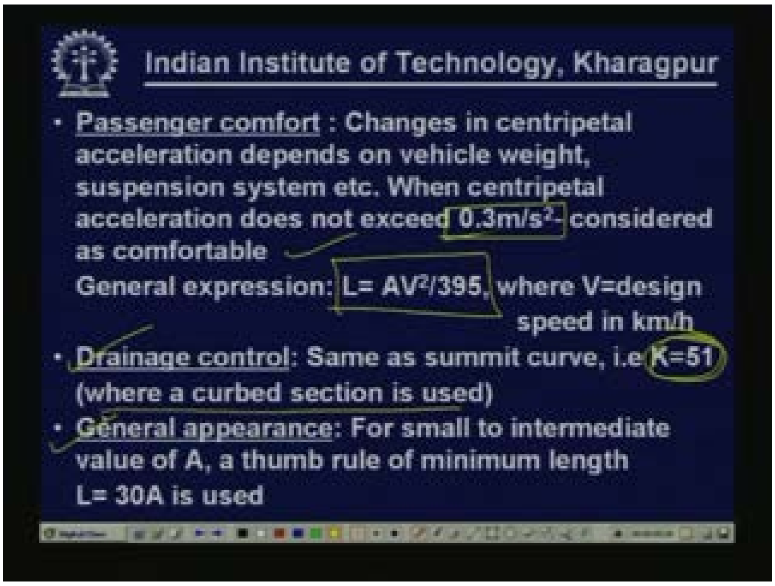

Now the second criterion is passenger comfort. We have already discussed this, but for IRC normally this headlight sight distance criteria dominate. Therefore design is done only based on the headlight sight distance, because if it is safe for that consideration it will generally satisfy the requirement of other things. So passenger comfort is another criterion which is considered.

Changes in centripetal acceleration depend on vehicle weight, suspension system, etc and when centripetal as acceleration does not exceed 0.3 meter per second square, it is generally considered as comfortable. So, according to that if we take the general expression, then the length of the curve may be obtained like this (L=A V square/395).

Similarly for drainage control, we have already discussed. For summit curve K equal to 51 presents a kind of limit, although we can go beyond that. And this is particularly for curbed section. Because in curbed section the water cannot go directly on to the shoulders. So especially for curbed section this is important and here also K = 51 is used as a limit.

Now, for general appearance is also considered. Another criterion considered for design, for small to intermediate value of A, a rule of thumb is used and length is calculated like this: L =30 A. So these are the four different criteria those are used. One is head light sight distance criteria, then passenger comfort, then drainage control and the general appearance.

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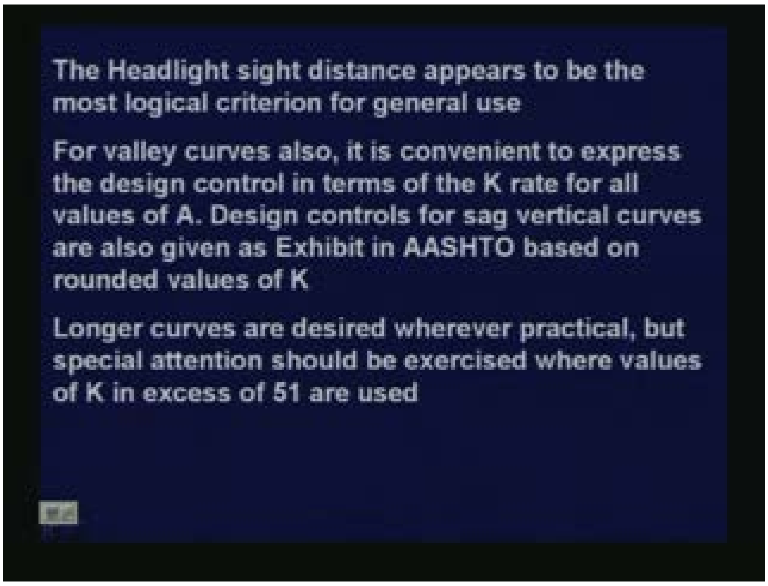

It is normally found that the head light sight distance appears to be the most logical criteria for general use and of course for valley curve also it is convenient to express the design controls in terms of K as we have discussed in details about the summit curve. So, for valley curve also it is convenient to express the design control in terms of the K for all values of deviation angle A. Design control for sag vertical curves are also given as exhibit in AASHTO based on rounded values of K as it is given for the summit curve. Similar type of exhibit is also available expressing it in terms of the rounded values of K.

Longer curves are desired wherever practical, but special attention should be exercised where values of K exceeds 51. That means special care is needed when value of K is more than 51 particularly considering the drainage part.

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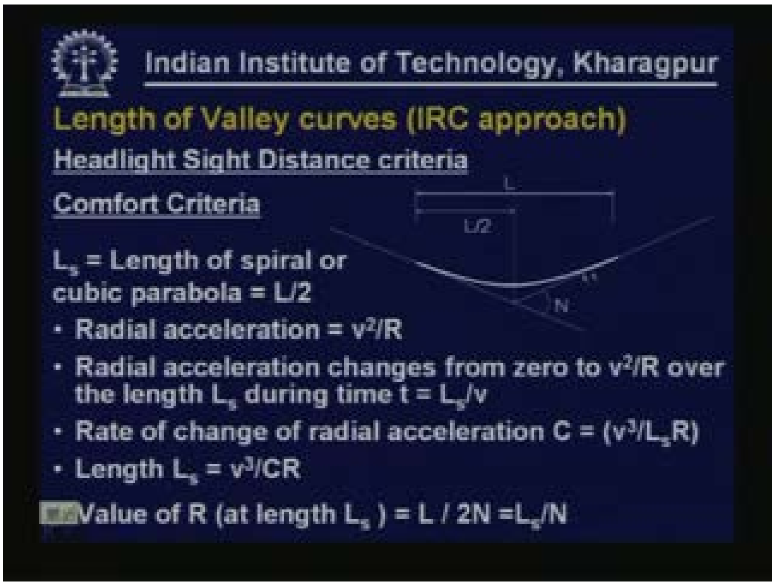

In the last class, lesson 13 we talked about the valley curve. We told that comfort criteria could be a basis. Now in this case, let us quickly try to see that how we can calculate even the required length. In many text books in India, the same approach is given and you can also calculate the length. Here the valley curve is considered as two transition curve without a circular curve in between. So if L_s is the length of spiral, it is actually L by 2 where L is the total length of the valley curve. So, radial acceleration is V square by R.

You can get this radial acceleration changes from 0 to V square by R over a time t. How we can calculate the time? The time is nothing but to cover this L_s distance which is the length of the spiral. If L_s is the length, V is the speed the time taken t is L_s by V. So rate of change of radial acceleration is nothing but V square by R by t, where t is L_s by V. So the length becomes V cube by LR. Now value of R at length L_s is nothing but L by 2N or L_s by N.

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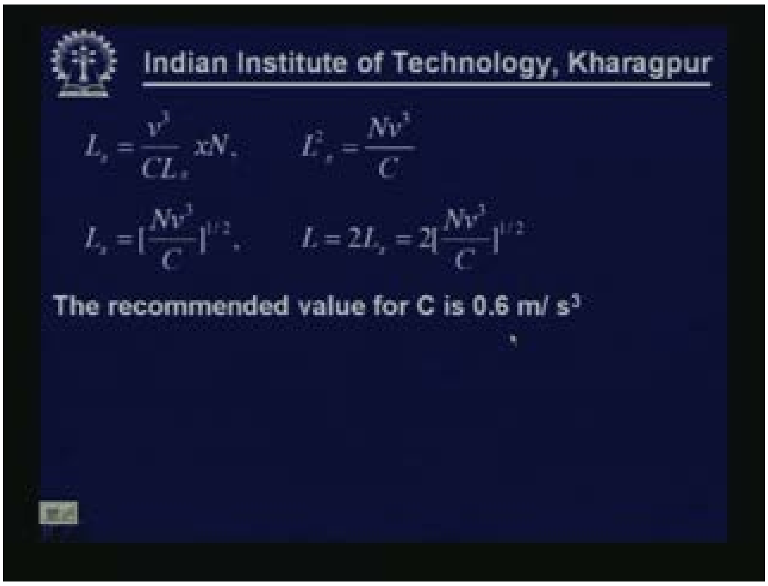

So if we put these values, then accordingly you can calculate the length L_s equal to NV cube by C to the power half and the total length L is $2L_s$. It is recommended that the value of C may be taken as 0.6 meter per second cube. So if we take that value of C, accordingly we can calculate what should be the required length considering the comfort condition, although IRC says and it is also found the dominating criteria will be the head light sight distance criteria. Now try to answer some of these questions.

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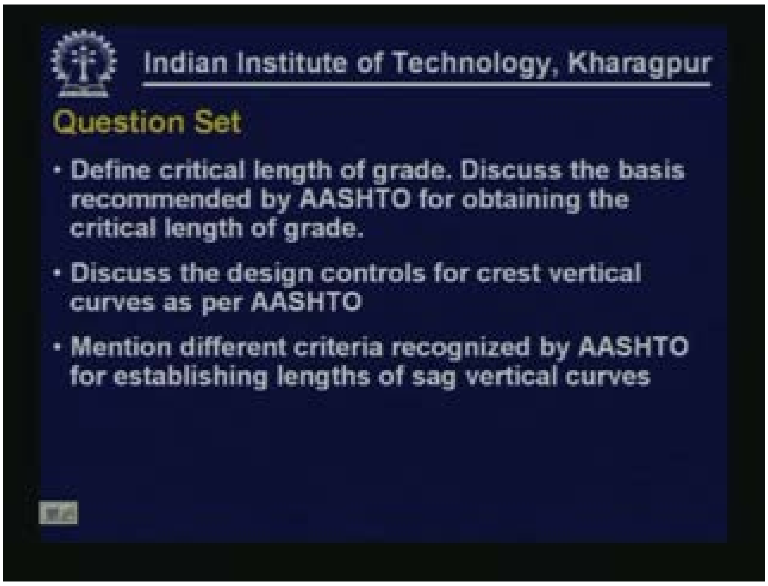

1. Define critical length of grade. Discuss the basis recommended by AASHTO for obtaining the critical length of grade.
2. Discuss the design controls for crest vertical curves as per AASHTO.
3. Mention different criteria recognized by AASHTO for establishing lengths of sag vertical curves.

Try to think about the answers and we shall discuss the answers in the next lesson. Now, let me quickly try to answer to the questions of lesson 13.

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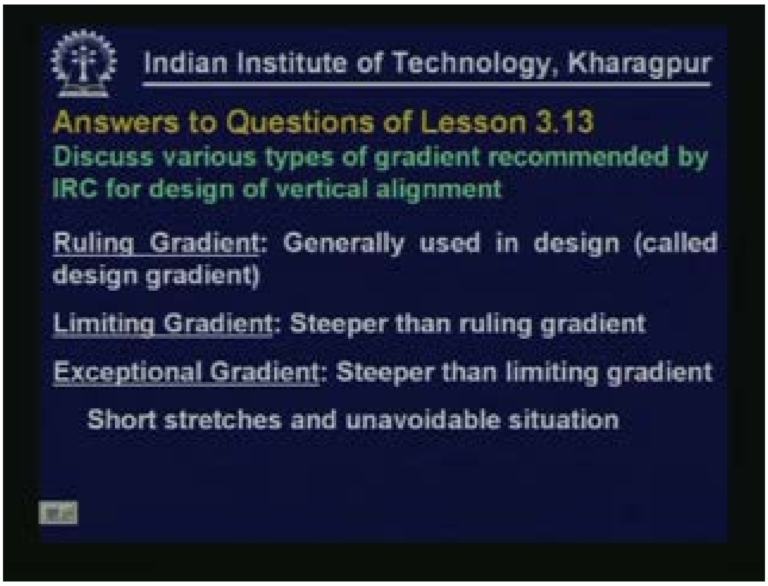

What are the various types of gradient recommended by IRC?

Ruling gradient: We should try to design it for ruling gradient if the terrain does not permit, we can go up to limiting gradient. For a specific situation we can go up to limiting gradient where it is higher or steeper than ruling gradient. Under exceptional situation we can go up to exceptional gradient.

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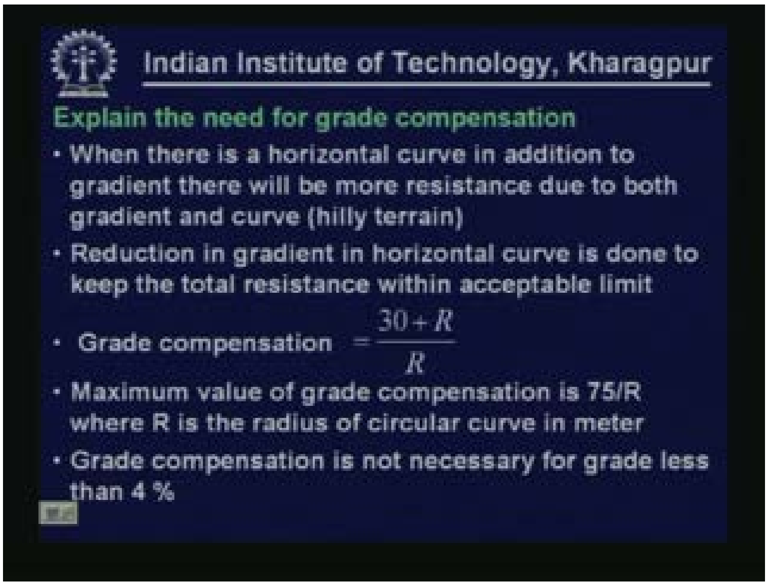

Why the grade compensation is required? If horizontal curve is there and vertical curve is there, the component of tractive effort available in the direction of movement becomes lesser. If it is 't', the tractive effort and if it is a horizontal curve only the 't cos alpha' component is available. So even if the grade is there, it is further a component. Therefore a kind of grade compensation is required for smooth operation of vehicles.

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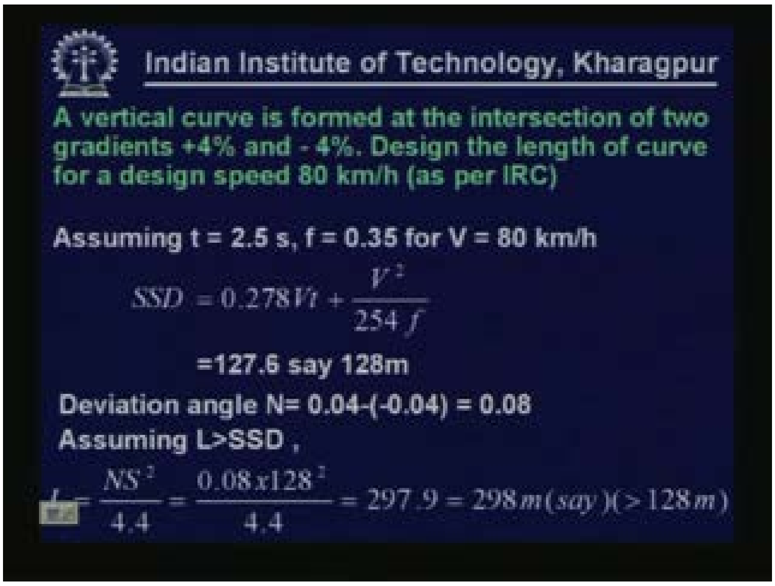

Now a vertical curve is formed at the intersection of two grades 4% and -4%. So this is clearly a case of a summit curve. One can calculate what the required stopping sight distance is, and then the deviation is the algebraic difference which is 0.08. Let us assume L is greater than SSD accordingly NS square by 4.4, we calculate the length it is 298 which is greater than 128. So our assumption is correct. Hence in that way we can calculate also the length of curve.

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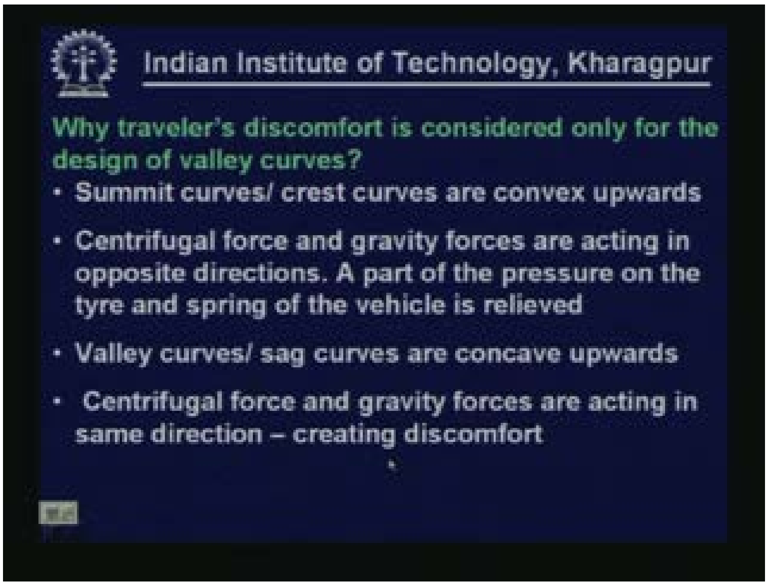

Now why traveller's discomfort is considered only for the design of valley curves?
The answer is simple. The centrifugal force and gravity force are acting in the same direction. That is why for this kind of valley curve, it is considered. In summit curve they are acting in opposite direction. So there is no problem of discomfort. Thank you.