Introduction to Transportation Engineering
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Lecture - 22
Vertical Alignment Part - 3

We have already discussed about various types of grade, the critical length of grade. We have also discussed about vertical curves, design of sag vertical curve or may be two types of vertical curve we can say, the summit curve and valley curve. The design considerations as approach suggested in Indian roads congress guideline and also the approach suggested in AASHTO.

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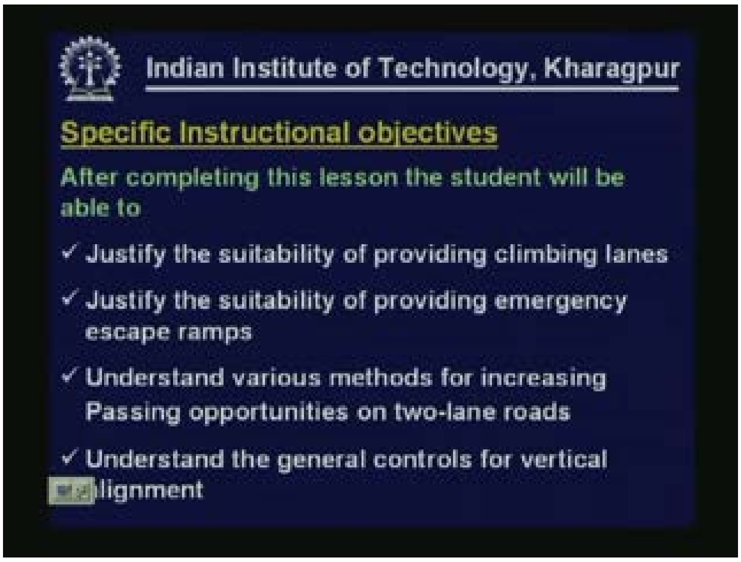

Today after completing this lesson the student will be able to justify the suitability of providing climbing lanes, justify the suitability of providing emergency escape ramps, understand various methods for increasing passing opportunities on two lane roads and also understand the general controls for vertical alignment as well as some of the general guidelines for coordination of horizontal and vertical alignment. First let us start with climbing lanes. Climbing lanes are used or necessary for two lane highways as well as may be required for multi lane highways.

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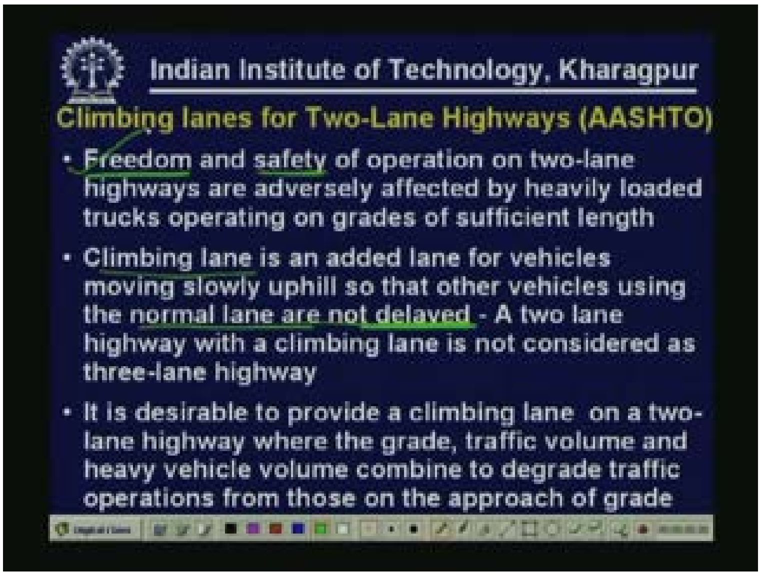

But requirements are generally predominant for two lane highways with two way traffic movements. Almost in all the cases the movements are two way traffic movements. So we restrict our discussion about climbing lanes for two lane highways. You know that the traffic movements are very special on two lane highways, because multiple lanes are not available for movement and if the overtaking or passing opportunities can be accomplished only by encroaching the lane which is otherwise or normally supposed to be used by traffic from opposite direction. So when there are upgrades, longitudinal grades, long upgrades, that time the slow moving vehicles particularly the commercial vehicles create substantial disturbance to other or to the normal traffic movements. So often the fast moving vehicles are forced to follow the slow moving vehicles and we find a long queue length.

In fact the reduction in speed of commercial vehicles or commercial traffic and because of the resulting disturbance on the moving traffic stream or overall traffic stream, we considered the critical length of grade. So keeping all these things in mind, the provision for climbing lanes is worked out. So let us see the slide now.

Freedom and safety of operation on two lane highways are adversely affected by heavily loaded trucks operating on grades of sufficient length. Remember that we are talking about the freedom of movement that we are referring and also the safety. Why the freedom of movement? Because, often a slow moving vehicle is there, other vehicles are generally forced to follow that vehicle. This is because normally two lane roads passing opportunities are limited. So on long grades freedom of movement is affected due to the presence of commercial vehicle as well as the grade.

Why safety?
We have already discussed when we talked about the critical length of grade. The more the vehicle deviates from the average running speed of the traffic stream, more is the possibility of that vehicle getting involved in a crash. So there are more possibilities when slow moving vehicles are there and long grades are there, safety problem becomes more acute. So, to improve the freedom of movement and also the safety of operation, climbing lanes are added for vehicles moving slowly uphill, so that the other vehicles using the normal lane are not delayed. It is basically to avoid the delay. So once the other vehicles are not delayed, it is a

better freedom of movement. But remember that a two lane highway with a climbing lane should not be considered as a three lane highway. If you consider a three lane highway, the operation is very different. All the three lanes are available for all traffic movement.

But when you add a climbing lane, the purpose is very different that the climbing lane is supposed to be used by the slow moving vehicles to give adequate passing opportunity and improve the overall freedom of movement for traffic operation and also enhance the safety. So a two lane road with an added lane, particularly climbing lane should not be considered just as a normal three lane road.

It is desirable to provide a climbing lane on a two lane highway where number one the grade, number two the traffic volume, and number three heavy vehicle volume. Altogether cause sufficient degradation of traffic operation from those on the approach grade. It is not a single factor, combined effect of grade traffic volume and heavy vehicle volume. So altogether, it is the length of the grade, overall traffic volume and commercial traffic volume, wherever we have got substantial degradation to the operational characteristics of the overall traffic stream on upgrade, there we should provide climbing lane.

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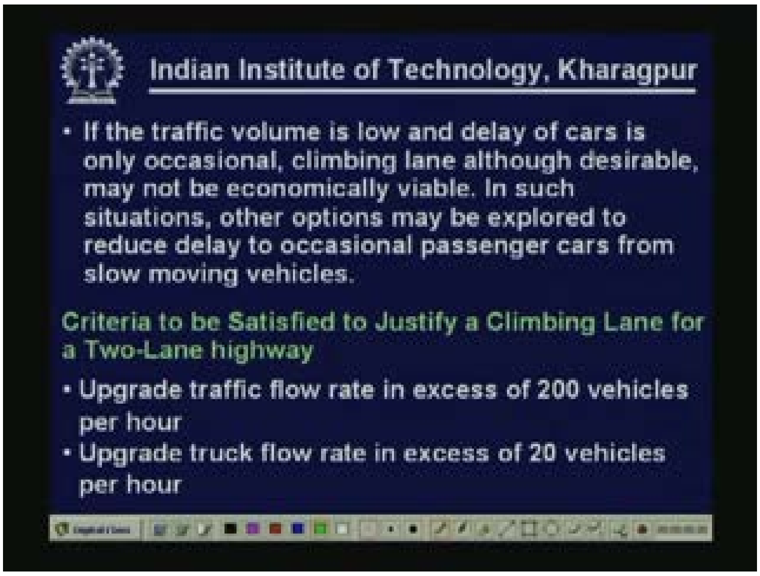

Of course a climbing lane may also be desirable even if the traffic volume is low and delay of car is only occasional. Carefully observe this part; 'delay of curve is only occasional'. That means overall traffic volume is low and not that all the time a fast moving vehicle is forced to follow a slow moving vehicle and not that all the time there is a long queue. Under those circumstances a climbing lane although desirable but it may not be economically viable or economically acceptable. In such situations one should explore the other options for improving the passing opportunities. We shall also come back to that part and discuss about various methods.

Now let us see the criteria to be satisfied to justify a climbing lane on a two lane highway. As I have indicated a climbing lane may be necessary even for multi lane facilities. But we are restricting our discussion about the climbing lanes for a two lane highway. So what are the criteria that should be satisfied, should justify the climbing lane or a climbing lane on a two lane highway? As I have already mentioned it has to be on the basis of total traffic volume and also the volume of commercial vehicles and overall operational service characteristics.

Let us see that first one: Upgrade traffic flow in excess of 200 vehicles per hour. So upgrade traffic flow has to be more than 200 vehicles per hour and truck flow rate or commercial vehicle movement should be in excess of 20 vehicles per hour. Both these requirements are to be satisfied.

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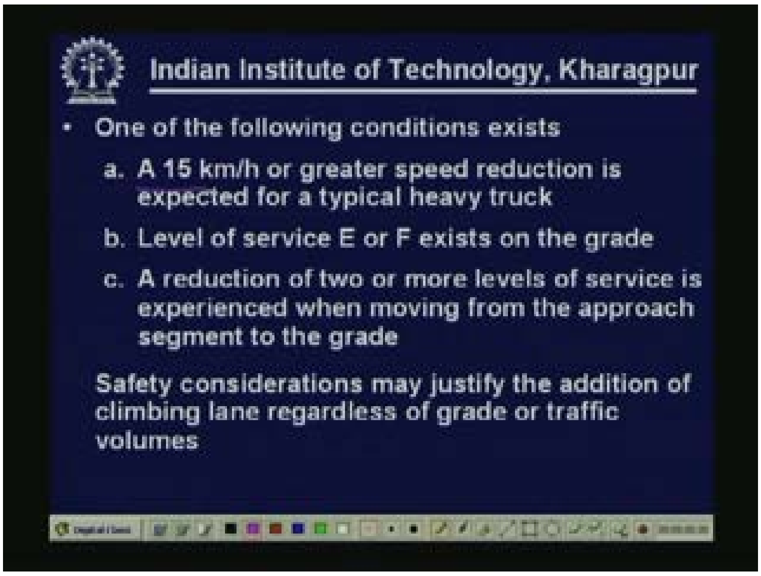

Moreover one of the following three conditions should also get satisfied.

1. A 15km/h or greater speed reduction is expected for a typical heavy truck.

Recall our discussion about critical length of grade where we use this 15km/h speed deviation as a basis. That means if it is more than 15km/h reduction in speed from the average traffic stream speed then we have restricted or we have considered that one as a basis for critical length of grade. In the same way we say that do we expect a 15km/h or greater speed reduction for heavy trucks.

2. Level of service E or F exists on the grade.

You know that there are 6 level of service that we normally use, starting from A B C D and E F. A is the best possible operation whereas F is the worst and E represent the operation at or near the capacity. So E and F practically indicate poorer level of service, F is the worst and E is just one level of service better than the worst. So the condition is, whether E or F level of service exists on grade.

3. A reduction of two or more levels of service is experienced when moving from the approach segment to the grade. That means when traffic is on the approach, it is enjoying a certain level of service. When it is negotiating the grade whether the change in level of service is by two or more levels that means not that every time on grade the level of service has to be E or F, it may be D say for example. But if it is level of service A on the approach, then there is degradation in level of service by two or more levels. So under those conditions also a climbing lane is justified.

So one of these three conditions should get satisfied 15km/h or greater speed reduction, level of service E or F on the grade or a difference or a reduction of two or more levels of service is experienced on grade.

Also, the other two conditions what I have already mentioned; the total traffic volume and the total commercial vehicle volume also should satisfy. Then a climbing lane should be justified. But let me mention that even if some of those conditions are not getting satisfied, still a climbing lane may be justified solely from the safety point of view. If lot of safety problems are reported, accidents are occurring and fatal accidents are occurring, then on the basis of safety, one can also go ahead with a climbing lane.

I have mentioned this part; safety consideration may justify the addition of climbing lane regardless of the grade or traffic volume. One should keep in mind this as well because, safety is a major aspect and we cannot compromise in terms of the road safety.

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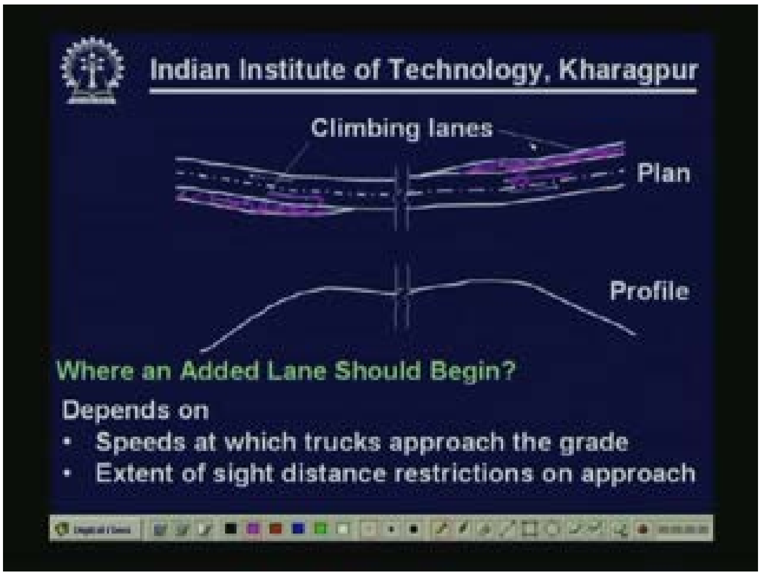

Here I have shown the climbing lane, following the US convention of driving. This is the climbing lane, traffic is moving in this direction (pointing towards right) and here the traffic is moving in this direction (pointing towards left), so we have added one extra lane (indicated in a different colour). In this case, we have provided climbing lanes for both the sides. Now the question comes where an added lane should begin? We are trying to explore that part. It basically depends on what is the speed at which truck approach the grade, is it more or is it less? What type of approach grade is there?
Because if the speed is more, the approach speed is more, you do not expect 15km/h or more speed reduction very quickly or right at the entry of the grade. But if the speed is less and then the truck is trying to negotiate the grade, you expect the reduction of speed much early. And then secondly, extents of sight distance restrictions on approach. This is very crucial because sight distance availability seriously controls or has serious impacts on safety as well as the passing opportunities, so whether there is any restriction sight distance. These two conditions will decide where an added length should begin.

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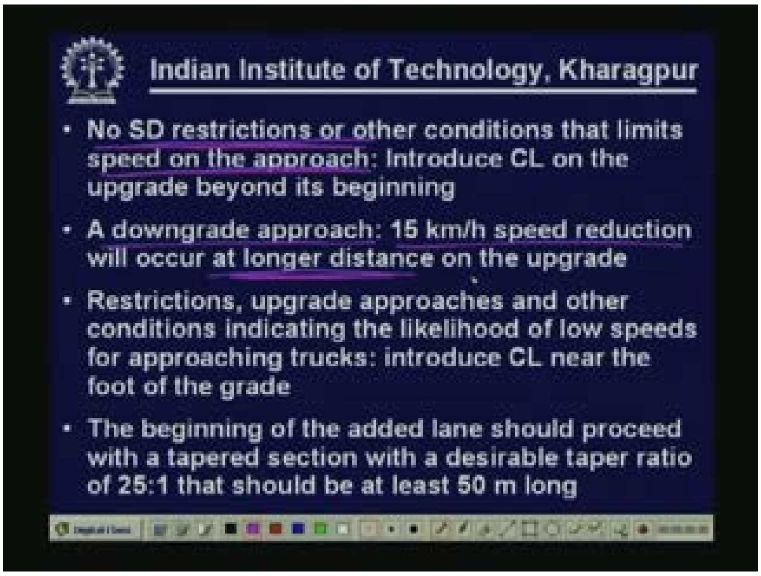

Some of the other points are:
No sight distance restriction on grade or other conditions that limits the speed of the approach, one can introduce the climbing lane on upgrade beyond its beginning. That means climbing length need not be introduced right at the beginning of the grade. Why because, the approach speed is sufficient. So you do not expect immediate reduction in speed more than 15km/h. So there is no necessity to provide climbing lane immediately.

If the approach is a down grade approach then obviously when the commercial vehicle is trying to negotiate the grade, the approach speed will be higher. In that case 15km/h speed reduction will occur at a longer distance under normal situation. If there is a down grade approach, one can expect a better approach speed at the beginning of negotiating that grade. So 15km/h speed reduction will occur at a longer distance.

Wherever there are restrictions, upgrade approach obviously will reduce the approach speed and other conditions indicating the likelihood of low speed for approaching trucks. In that case you may introduce climbing lane just near the foot of the grade meaning start it early. If not you can start it after sometime or after some length. Remember that, the beginning of the added lane should proceed with a tapered section and with a desirable taper ratio of 25:1 subject to a minimum of 50 meter length. This tapering is necessary to make the road system or the design compatible with driver behaviour, basically the way the driver normally change the lane or shift the vehicle. To make it compatible with driver behaviour, this tapering or proper tapering must be done.

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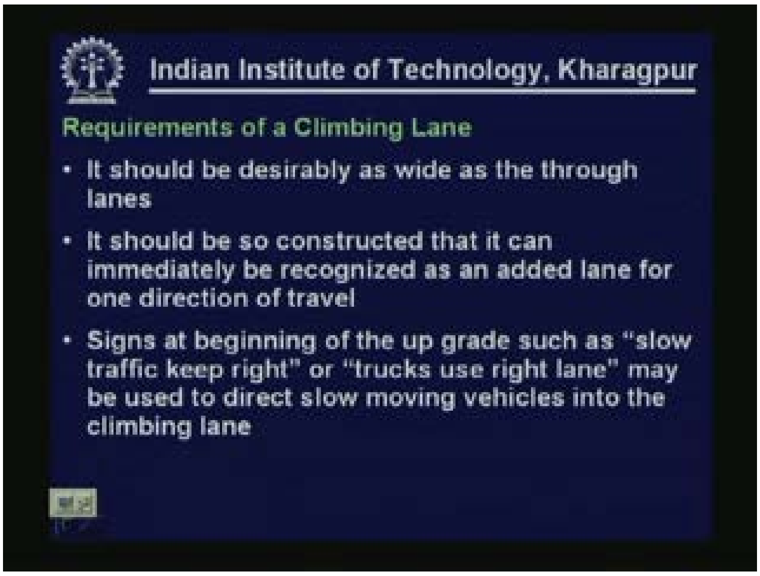

Then what are the requirements of climbing lanes? We should say the ideal characteristics or some of the characteristics that you should keep in mind for climbing lanes.

It should be desirably as wide as through lanes, it should be so constructed that it can immediately be recognised as an added lane for one direction of travel. Wherever we are providing it for one direction, the driver should be easily able to recognise it as an added lane and not just think that it is a three lane. They should understand that it is basically a climbing lane/added lane for specific purpose.

Also, signs at the beginning of upgrade such as 'slow traffic keep right'- again following the US convention. If we are putting this kind of sign in India, we should put it as 'slow traffic keep left'. For 'trucks use right lane' in Indian conditions it is – 'truck use left lane', may be used to direct slow moving vehicle in to the climbing lane for a better, efficient and safe operation of traffic and better use of the climbing lane.

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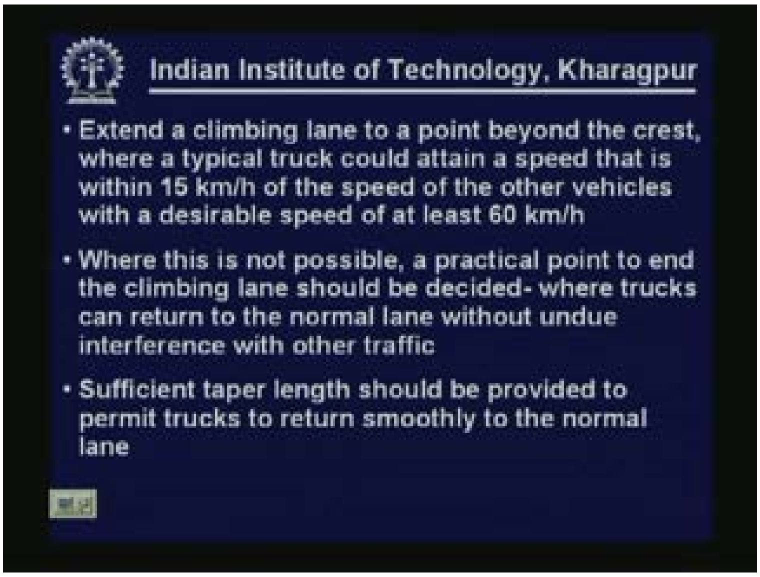

Now, where this climbing lane should terminate? We have discussed where it should start. The climbing lane should be extended to a point beyond the crest where a typical truck could attain a speed that is, within 15km/h of the speed of the other vehicles. Why this is said? Because on long grades, where we are providing a climbing lane it is expected that the speed deviation will be substantial. Once it has reached to the crest, immediately the speed gain may not be sufficient to limit the speed deviation within 15km/h. You should extend it a little bit so that the commercial vehicle can improve the speed or have more speed and the deviation becomes within acceptable limit that is 15km/h.

In some cases it may not be possible. In those conditions, you decide a suitable location where you find that there will be least interference to the moving traffic stream. Because that is the major consideration when a truck or commercial vehicle after using the climbing lane it is joining back to the main traffic stream, it should not cause much disturbance to the traffic stream. So judiciously decide the location where it should cause least disturbance to the moving traffic stream.

Needless to mention that, sufficient taper length should be provided to permit trucks to return smoothly to the normal lane. Here also keeping it or matching it with the driver's behaviour, the way the vehicle moves, the way the driver behaves, and the way the vehicle operates provide smooth tapering, so that the vehicle can smoothly come back to original lane.

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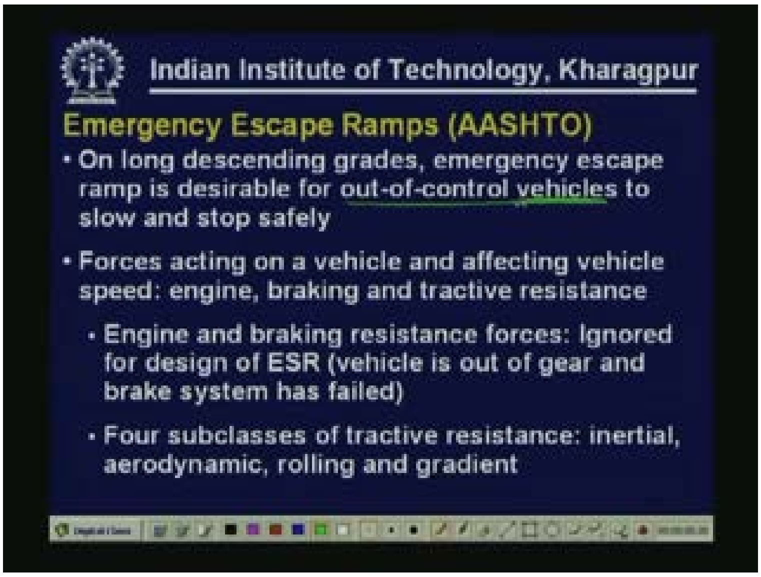

That completes our discussion about climbing lanes. Now let us try to understand about emergency escape ramps. Till now we talked about the problems on upgrade, particularly the long upgrades where commercial vehicle movements are significant, the total traffic volume is significant and how to provide the relief. The emergency escape ramps actually relates to traffic operation on down grades. It is not that the problem occurs only on upgrades. Upgrade problem occurs with the speed reduction, deviation in speed and therefore the safety problem. But on down grade it is a different type of problem altogether. A vehicle may lose control because of application of brakes there could be brake failure and high temperature. Therefore eventually it may affect the overall safety of traffic operations on down grades. Therefore emergency escape ramps essentially are provided to improve the traffic safety. Remember, once again to improve the overall traffic safety on down grade and obviously at situations or locations where safety is a major problem. Not that wherever there is a down grade there will be a safety problem, it may occur or it may not occur. But wherever there are safety problems emergency escape ramps helps in improving the safety of the traffic operation.

On long descending grades, emergency escape ramps are desirable for out of control vehicles. We are talking about how to tackle out of control traffic vehicles. While this is negotiating the grade, the down grade there could be brake failure, so how to handle out of control vehicle without causing serious damage to other traffic and also to averting properties and human being.

Let us see what are the forces acting on a vehicle and affecting vehicle speed. Primarily three sources; number one is engine, number two is braking and number three is tractive resistance. Now engine and braking resistance force are ignored for the design of emergency escape ramp. Because we should design emergency escape ramps for the most critical condition.

When the critical condition will occur?
Critical condition will occur when the vehicle is out of gear and the brake has failed. That is the most critical condition. If a design is safe for the critical condition, it will automatically be safe when there are engine force and also the braking force. So for the design of emergency escape ramps, we neglect the engine and braking resistance. Now what remains is tractive resistance. There are four subclasses of tractive resistance. They are inertial, aerodynamic, rolling and gradient.

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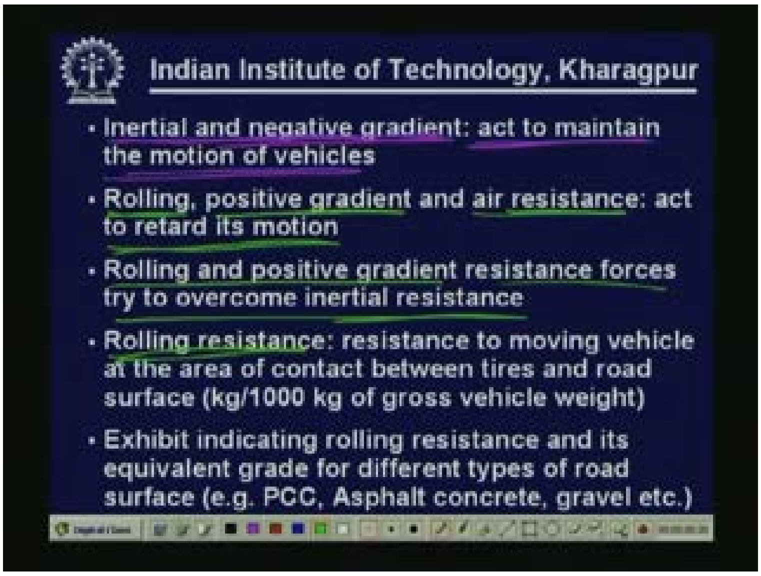

Let us talk about these four subclasses of tractive resistance.
Inertial or negative gradient: What is inertial resistance? Inertia means, it will help the vehicle body or the vehicle to maintain its original condition. That means if the vehicle is on movement this inertial resistance will help the vehicle to keep the movement or to maintain that movement.

Similarly, if there is a negative gradient or negative slope, that will also help the vehicle to keep the movements. Therefore we can say that inertial and negative gradient basically act to maintain the motion of vehicle. They help the vehicles to maintain the motion.

On the other hand, if you consider this rolling resistance and positive gradient; positive gradient means upward gradients, the upward gradients and in all the cases the rolling gradients and also the air resistance basically act to retard the vehicle motion. Essentially we can say that rolling and positive gradient, resist forces and try to overcome inertial resistance. In one way the inertial resistance is trying or helping the vehicle to keep motion. On the other hand, rolling and positive gradients are trying to put a restriction or try to overcome that. They are really resisting or trying to act against the inertial resistance.

Now, what we mean by rolling resistance?
Let us try to develop or keep our understanding clear. It is a resistance to moving vehicles at the area of contact between tyres and road surface. Normally AASHTO refers the calculation in terms of kg/1000 kg of gvw or gross vehicle weight. AASHTO also gives exhibit showing what should be the value of rolling resistance. You can appreciate that rolling resistance will definitely be a function of the type of pavement surface.

If we consider say Portland cement concrete surface, bituminous concrete surface, may be gravel surface; again gravel compacted and loose gravel surface, in all the cases the rolling resistance will be different. In fact the way I have mentioned the rolling resistance will increase in that manner. That means, least for PCC, more for may be gravel compacted and then further more for gravel under loose condition.

So for different types of surface what is the rolling resistance?
And as the rolling resistance is trying to act against the inertial resistance, we can also express rolling resistance in terms of equivalent positive grades. What is the equivalent positive grade? Rolling resistance can be converted in to equivalent positive grade. So, AASHTO gives exhibit showing for different types of surface, what is the rolling resistance and what is the equivalent positive grade for that. If we want the gradient resistance to be effective then vehicle must move upward against gravity. It is very clear because grade resistance will not be effective if it is a down grade.

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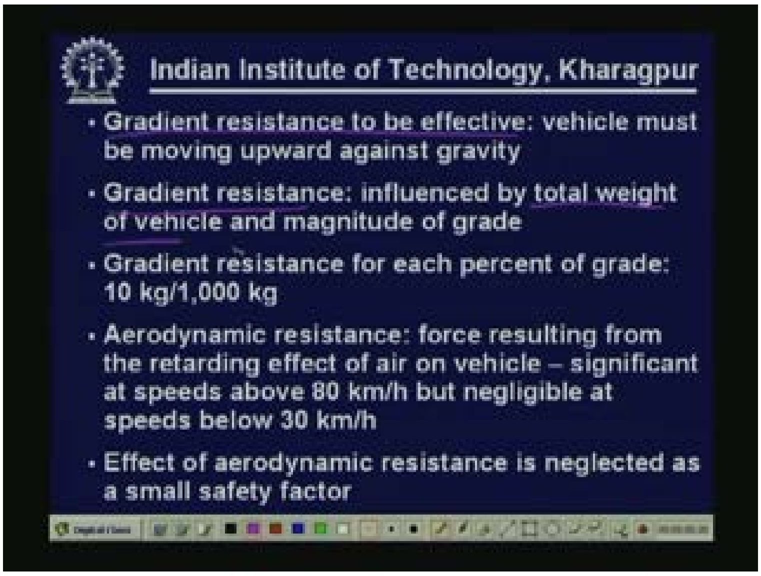

It will rather help the vehicle to keep motion. So for grade resistance to be effective, vehicle must be moving on upgrade against gravity. And grade resistance is also influenced by total vehicle weight and magnitude of the grade. Grade resistance for each percent of grade is considered as may be 10 kg/1000 kg. Now what is remaining is aero dynamic resistance. Aero dynamic resistance is basically the force resulting from retarding effect of air on vehicle. It is found from experience and experiments that this aero dynamic resistance is significant if the vehicle speed is above 80 km/h, but it is negligible if the speed is below 30km/h. So it will only become effective if the vehicle is moving at a high speed.

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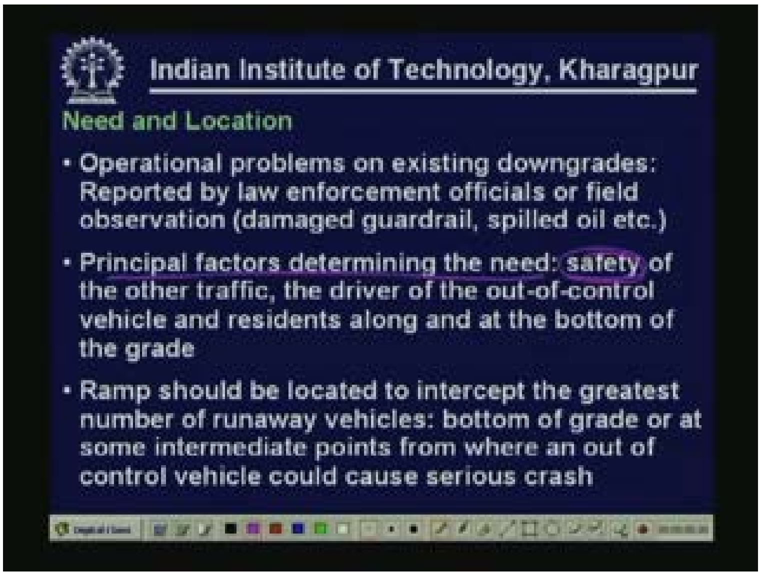

Now, for the design of emergency escape ramps, this factor or this aerodynamic resistance is neglected. It just gives a cushion or factor of safety for the overall design. Let us see the need and location for emergency escape ramps.

Operational problems on existing downgrades if it is observed or there it may be justified: On existing grades normally the law enforcement authorities, may be the traffic police or corporation they will often report. Their record itself will show that there are lot of accidents taking place. Also from field observations, one can get a trace of that kind of problem say you may find the broken guardrails or spilled oil which is the indication of potential safety problem on that segment. So if such problems are reported and found, an emergency escape ramps may be justified.

Remember that principal factors determining the need for emergency ramp is safety. That is the principal factor; safety of other traffic, safety of the driver of the out of control vehicle and also safety of residents along and at the bottom of the grade. Again, it is safety of the other traffic, safety of the driver of the out of control vehicle and safety to other residents who are located or who are residing or who are using the abutting road length. That safety is the major factor in justifying emergency escape ramps. Ramps should be located to intercept the greatest number of runaway vehicles. So obviously the bottom of grade is a very crucial location and also at some strategic intermediate points from where an out of control vehicle could cause serious crash. That is the location where we should put emergency escape ramps.

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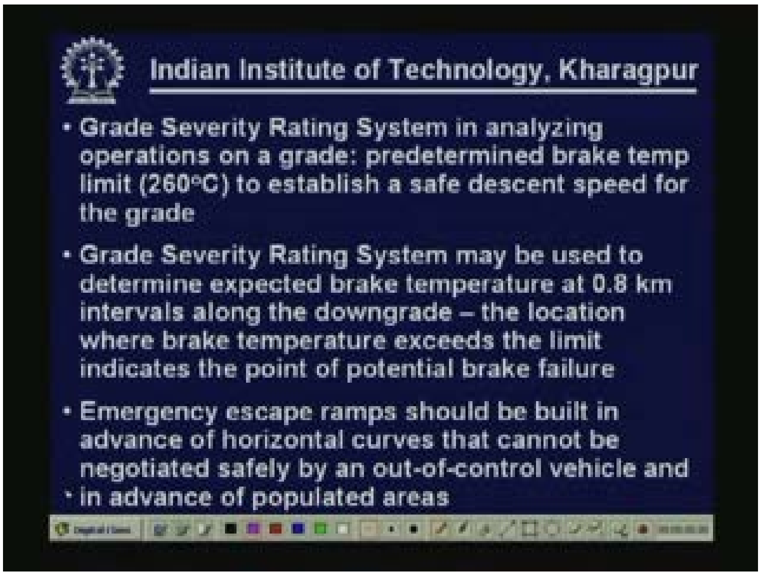

These days a 'Grade severity rating system' is also used to analyse for analysing operations on grade where a predetermined brake temperature limit is used. That is say 260 degree centigrade is used to justify or to establish safe design speed for grade.

Remember that using grade severity rating system, it is possible to calculate the expected brake temperature at 0.8km interval along the grade. Therefore the locations where the brake temperature exceeds the limit, that is say 260 degree centigrade indicates the point of potential brake failure. Obviously if we calculate the temperature at every 0.8km interval and wherever it exceeds the permissible or limiting temperature, we know that, it is the point of potential brake failure. So accordingly one can start introducing an emergency escape ramps at that location.

Again trying to put that point of safety or the safety consideration once again, emergency escape ramps should be built in advance of horizontal curves, because an out of control vehicle will be in utter danger if it has to negotiate a horizontal curve. So it says that emergency escape ramps should be built in advance of horizontal curves. That cannot be negotiated safely by an out of control vehicle and in advance of populated areas. There are three types of emergency escape ramps that are used; gravity type, arrester bed type, and sand pile type.

In gravity type ramps, paved or densely compacted aggregate surfaces are used and we predominantly rely on gravitational forces to stop the runaway vehicles whereas in 'arrester bed type emergency escape ramp', rolling resistance is the main consideration.

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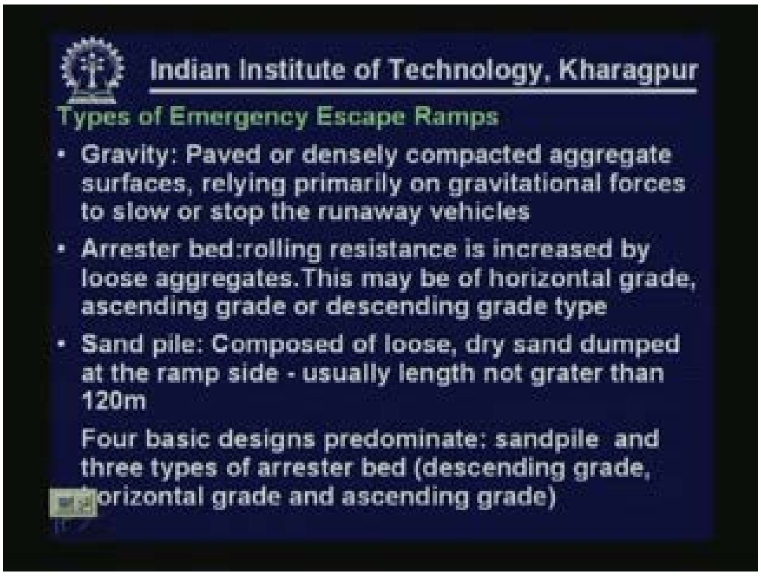

So rolling resistance is increased by providing loose aggregates and obviously in arrester bed it may be horizontal grade, ascending grade or descending grade.

Sand pile: In this type of emergency escape ramp, composed of loose, dry sands are dumped. And normally for sand pile the emergency escape ramps length is not greater than 120 meter. Although there are types of emergency escape ramps like gravity type, arrester bed type, and sand pile type, four basic designs predominate. One is the sand pile and then three types of arrester bed. Three types of arrester bed means arrester bed with descending grade, arrester bed with horizontal grade and ascending grade.

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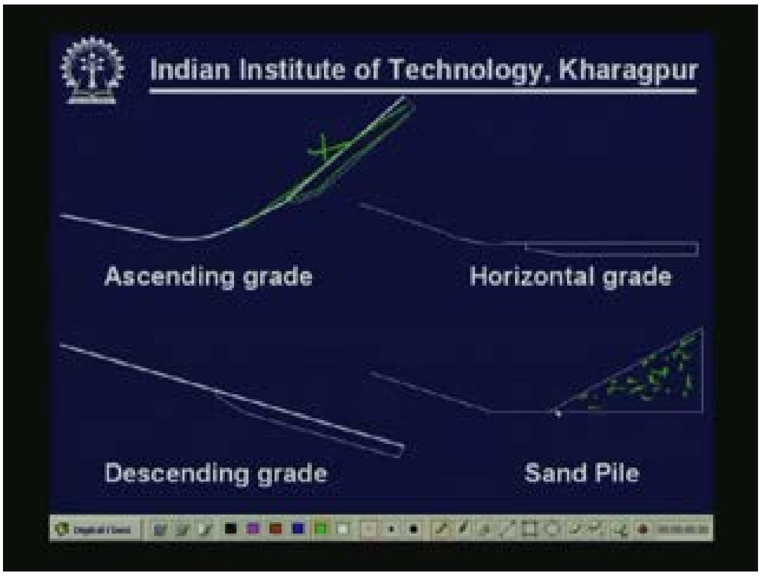

Let us have a look at different types of emergency escape ramp or the four types of designs which are generally predominant. This is ascending arrester bed emergency escape ramps with ascending grade, positive grade. And the next one is the arrester bed emergency escape ramp with horizontal grade and the third one is with a descending grade and the last figure shows emergency escape ramps with the sand pile, which is all filled up with loose sand.

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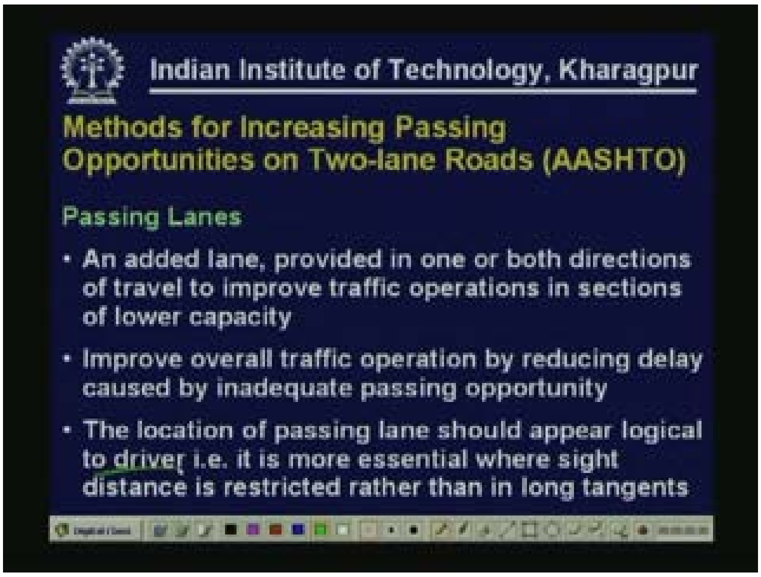

We shall discuss about various methods for increasing passing opportunities on two lane roads. There are three four types of measures taken.

First is the passing lane. Passing lane is an added lane provided on one or both directions of travel to improve traffic operations in sections of lower capacity. It improves overall traffic operation by reducing delay caused by inadequate passing opportunity. It is basically essential if you say this is an added lane of some predetermined design length and not a continuous length. So the slow moving vehicle can shift to that lane and then the through traffic lane is free for the other moving vehicles which were till that time following the slow moving vehicle, or rather they were forced to follow the slow moving vehicle. You provide a passing lane so that the slow moving vehicle start using the passing lane and the through traffic lane is free for the vehicles to complete passing maneuver easily.

The location of passing lane should appear logical to driver. Suppose there is a long tangent, obviously sooner or later passing opportunities may be available on long tangents. Whereas in addition restrictions to sight distance there the passing opportunity may be even more restricted. So the location of passing lane should appear logical to the drivers. That is why it is said that it is more essential where sight distance is restricted rather than on long tangents. So provide it where there are problems or inadequacy in terms of sight distance.

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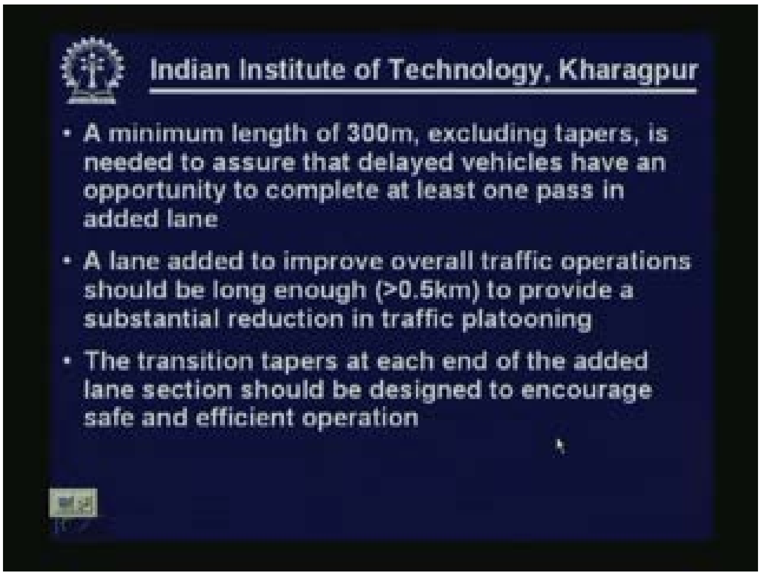

A minimum length of 3 meter is recommended excluding the length of tapers to ensure that delayed vehicles have an opportunity to complete at least one pass in added lane. Delayed vehicle should be able to get an opportunity to complete at least one pass in that lane segment or in that portion of the road. However, often it may happen that there is long queue that has formed behind a slow moving vehicle. So under that condition, when we are providing passing lane, the length should be adequate so that most of the vehicles can complete the maneuver or the passing and the queue length is decreased substantially. In that case one need to provide a slightly longer length of the passing lane and that is why it is mentioned here in this slide as 'A lane added to improve traffic operation when there are long queues should be long enough to provide a substantial reduction in traffic platooning'. Basically, the queue length should decrease. The transition taper at each end of the added lane should be designed to encourage safe and efficient operation. This is absolutely a requirement for traffic safety point of view. Proper tapering is required and also one must ensure that adequate sight distance is available at the entry and also at the exit point of such developments.

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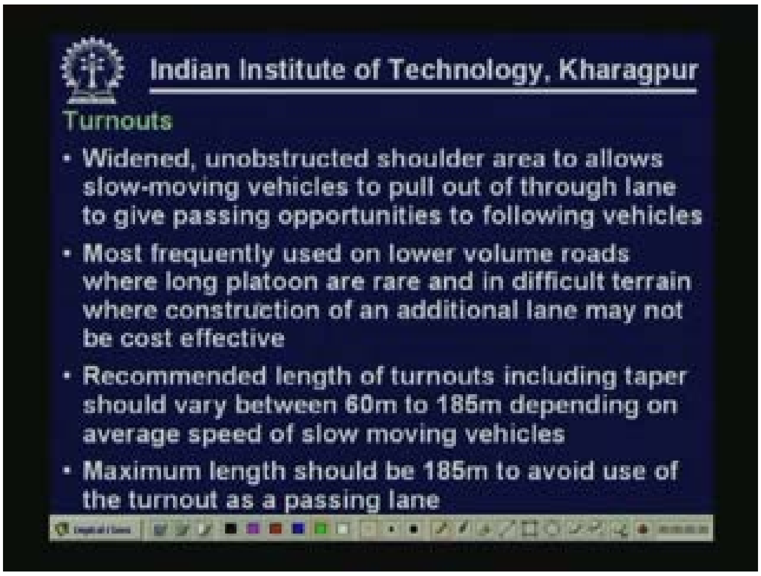

We have discussed about the passing lane. The next is 'Turnouts'. Turnout is basically widened unobstructed shoulder area to allow slow moving vehicles to pull out of through lane to give passing opportunities to following vehicles. Only up to that time it will pull out just to give an opportunity for other fast moving vehicle to complete passing opportunities. All these measures are basically to improve the passing opportunity; obviously the basic objective is to give an opportunity for passing. So, it is basically unobstructed shoulder area, the slow moving vehicle will move to that unobstructed shoulder area and give an opportunity for vehicles to pass. But this is suitable where the traffic volume is generally low and rarely there is a long queue.

That means, most of the times may be only one or two vehicles are following a slow moving vehicle. So provide turn out so that the slow moving vehicle can go to the turn out and give one or two vehicles to have that passing opportunity. It is more frequently used on lower volume roads where long platoons are rare and in difficult terrain where construction of an additional lane may not be cost effective.

Recommended length of the turnout including taper should vary between 60 meter and 185 meter depending on the average speed of slow moving vehicle.

Why there is a lower limit?
Lower limit is justifiable because one should have at least a minimum length to serve the objective that is, to give an opportunity for passing. So a certain minimum length is required.

Why there is an upper limit?
Because it is not a turn out and it is not intended for places where you know you have long queue and there is heavy traffic volume. So it is not a turnout. This maximum length is basically to avoid the use of turnout as a passing lane. It is a turnout and not a passing lane. So just to make sure that a turnout does not work as a passing lane, it is necessary to restrict its length. That is why an upper limit is there which is 185 meter.

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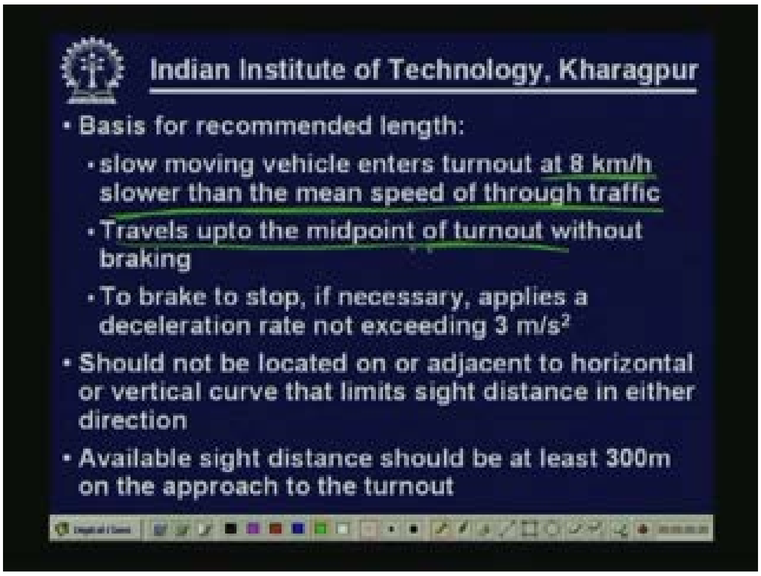

Have a look at the basis for recommended lengths. How the length is calculated?
It is assumed that the slow moving vehicle enters turn out at 8 km/h slower than the mean speed of the through traffic. That is when it is entering in to the turnout. And the slow moving vehicle travels up to the mid point of the turn out without applying any brake. Then brake to stop of course if necessary, because not that all the time the brake application is necessary. Suppose there are just one or two vehicles then there is no need of brake application. The slow moving vehicle can normally come back to the original lane. But if say more than one or two vehicles are there, then it is necessary to apply brake, so that time the deceleration rate should not exceed 3 meter per second square.

On this basis one can calculate the length. This type of facility should not be located on or adjacent to horizontal or vertical curves that limit the sight distance. Basically, why to invite again the safety problem? And available sight distance should be at least 300 m on the approach of the turn out. Obviously we do not allow it where the sight distance restriction is there and a minimum of 300 sight distance is required on the approach of the turn out.

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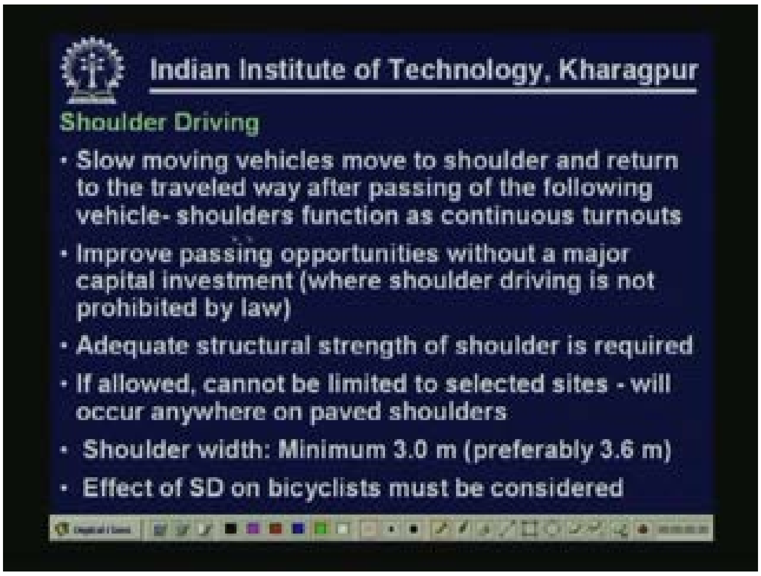

Shoulder driving is another way of improving passing opportunities where slow moving vehicles move to shoulder. It is a normal shoulder, nothing extra, no extra widening essentially and returns to travel way after passing of the following vehicles. So shoulder function as a continuous turnout. This improves the passing opportunities without a major capital investment cause. But please remember that in many states shoulder driving is not permitted, that means not permitted by law. So, if you are allowing shoulder driving or this kind of opportunities can be taken to improve passing opportunities only where shoulder driving is not prohibited by law.

Some of the other points, logical derivation: If we are allowing shoulder driving, then adequate structural strength must be there for the shoulder to support vehicle weight and also remember that once shoulder driving is allowed it cannot be limited to selected site. It is very difficult to enforce that. So what will essentially happen? It will occur anywhere on paved shoulder. So keeping these things in mind one should decide whether to go ahead with the shoulder driving. If shoulder driving is allowed, a minimum of 3 meter width is necessary for the shoulder or preferably 3.6 meter.

And last but not the least, effect of shoulder driving on bicyclists must be considered. Once shoulder driving is permitted, this should not cause a potential safety problem to bicyclist. So impact of shoulder driving on bicyclist should also be explored. These are all the points: Adequate shoulder strength, minimum width and effect of shoulder driving on bicyclist and also remember that once it is allowed it will occur everywhere on paved shoulder. So, by keeping these things in to consideration, one has to decide whether the shoulder can be allowed.

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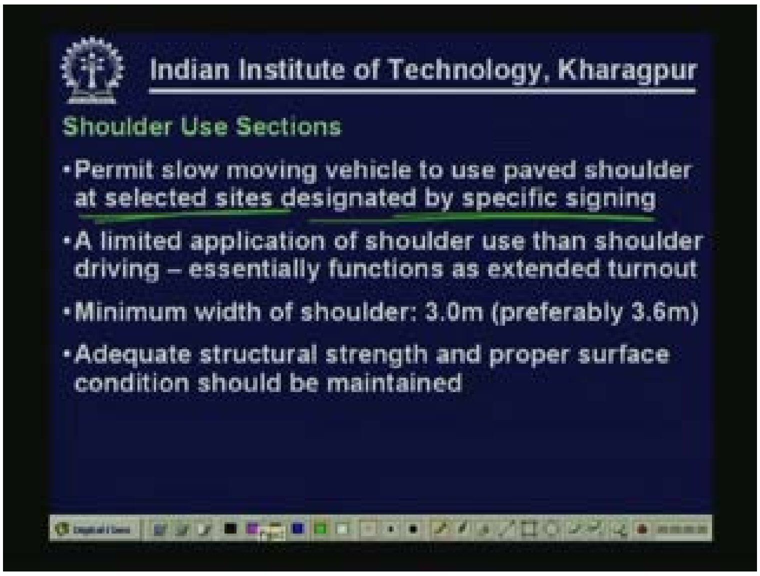

The last one is 'shoulder use sections'. The shoulder driving will occur anywhere and everywhere. For 'shoulder use section', overtaking or passing is permitted only at selected sites designed by specific signing. So only at selected sites designed by specific signing saying that 'yes, overtaking is allowed here', then overtaking can take place and that is what we understand by 'shoulder use sections'.

It is a limited application of shoulder use because we are not allowing it everywhere. We are allowing that only at selected points where adequate shoulder strength is available and it is permissible. Or it can be allowed without other disturbances or safety problem. But it essentially functions as extended turnout, because in turnout also we do like that. It is a very similar thing, so it functions like an extended turnout.

Here also minimum width of 3 meter is required for 'shoulder use sections' like we did for shoulder driving or preferably 3.6 meter. And also adequate structural strength of shoulder where 'shoulder use section' is provided. So shoulder must have adequate strength. These are the four different methods that may be applied to improve the passing opportunities.

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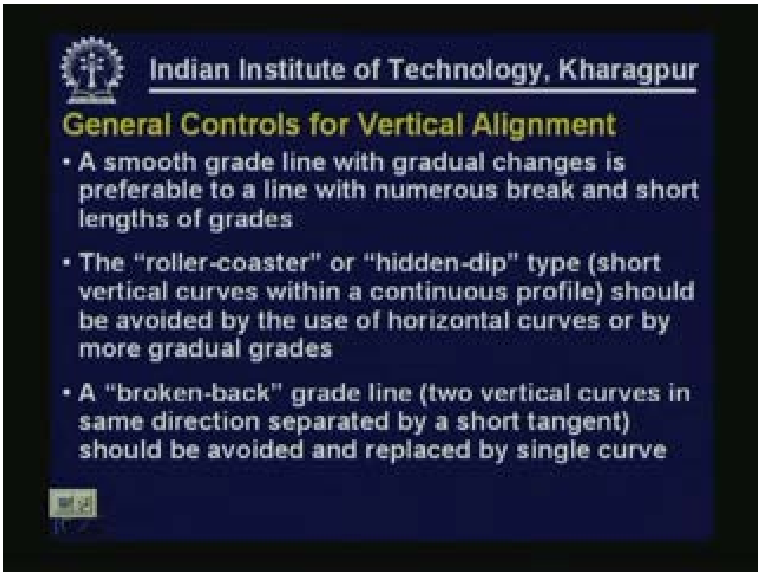

Let us see some of the general controls for vertical alignment. A smooth grade line with gradual changes is preferable rather than with numerous break and short tangents often they give the better profile.

The "roller-coaster" or "hidden-dip" type, that is short vertical curves within a continuous profile should be avoided by the use of horizontal curves or by more gradual change because if there is a hidden dip. Obviously a vehicle when it is approaching it might not recognise that inside that valley curve, inside the dip there is another vehicle and suddenly the driver finds a vehicle. That type of design should be avoided, if we provide a horizontal curve as the horizontal curve again provides restriction to sight distance or drivers become cautious, or by providing a smooth or gradual change in grade.

A 'broken back' grade line should be avoided and replaced by a single curve. This point also we have mentioned when we talked about the horizontal alignment.

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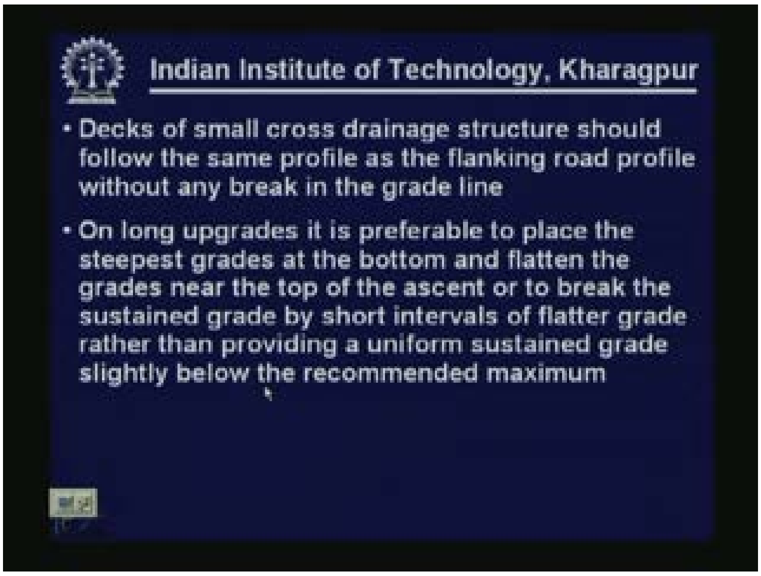

Deck of small cross drainage structure should follow the same profile as of the flanking road profile without any brake in the grade line, it should match. Suppose we are providing a road profile, if there is a cross drainage structure, then that cross drainage structure also should match with the overall profile of the road.

On long upgrades it is preferable to place the steepest grade on the bottom and flatten the grades near the top of the ascent or to break the sustained grade by short interval of flatter grade rather than providing uniform sustained grades slightly below the recommended maximum. This is just to provide a relief to the traffic continuously negotiating a steep grade. So, instead of that, provide a steep grade give a relief, and then again provide a bit steep grade provide a relief. So the operation becomes easier and more comfortable for that commercial vehicles or heavily loaded vehicles.

Where at-grade intersection occur on roadway sections with moderate to steep grades, it is desirable to reduce the grade throughout the intersections. When we are approaching or meeting an intersection, intersections approach grade must be designed very carefully and it should be controlled.

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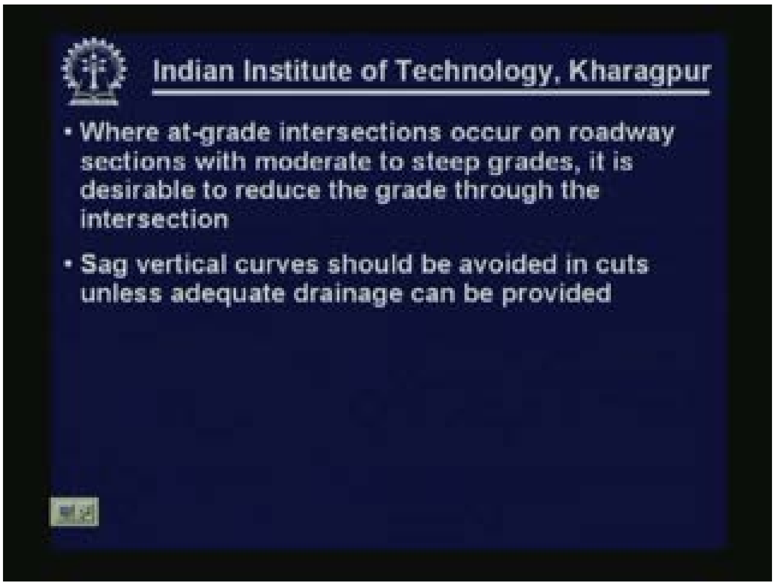

Sag vertical curve should be avoided in cuts. Needless to mention that because, obviously if we are using sag vertical curves in cuts it will invite drainage problems. So, very special attention is required for drainage consideration.

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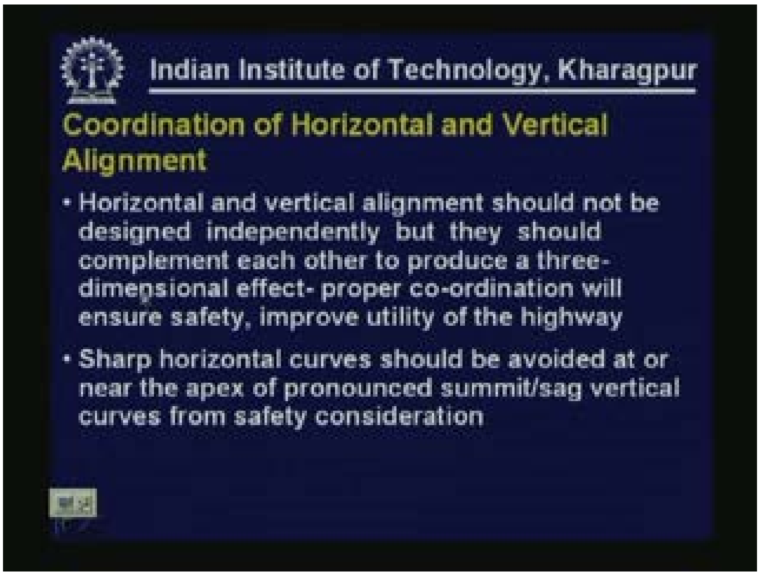

Let us see some of the general points about the coordination of horizontal vertical alignment. Ultimately road is a three dimensional profile, it has got a xyz dimension. So we have talked about the horizontal alignment, talked about the vertical alignment, but the overall three dimensional profile is very important. So the horizontal, vertical profile should complement each other with proper coordination. Sharp horizontal curves should be avoided at or near the apex of pronounced summit or sag vertical curves for safety consideration.

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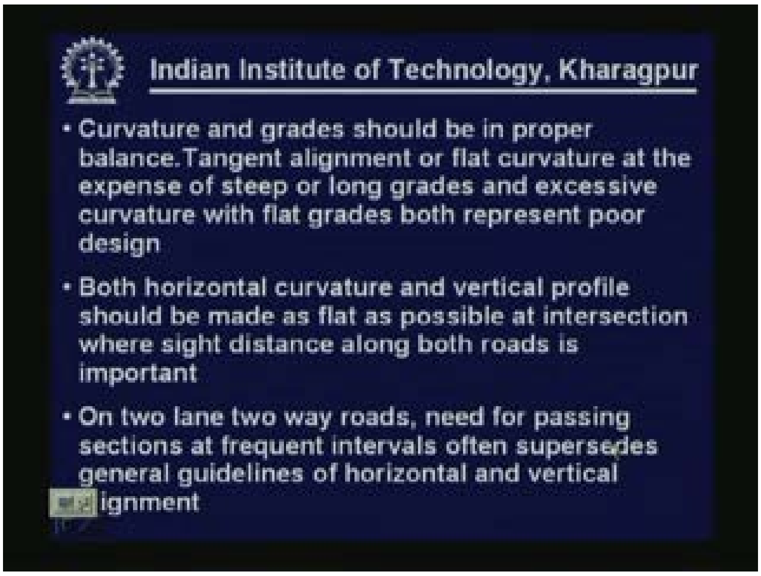

Curvature also should be designed properly. Both horizontal and vertical curve should be made as flat as possible and to give an overall better three dimensional set.

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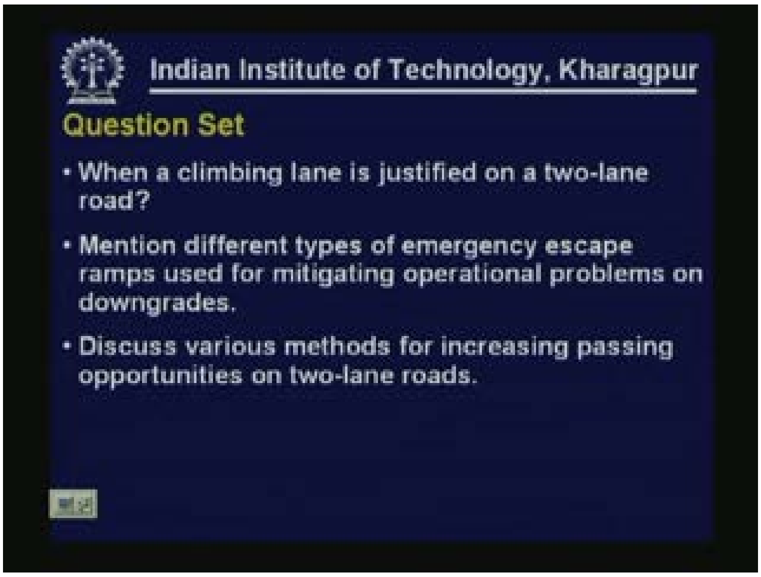

Now some questions for you to answer.

- When a climbing lane is justified on two lane road?
- Mention different types of emergency escape ramps used for mitigating operational problems on down grades.
- Discuss various methods for increasing passing opportunities on two lane roads.

Try to answer to these questions and we will discuss the answers during the next lesson. Before I close let me quickly try to answer some of the questions that I raised in the last lesson.

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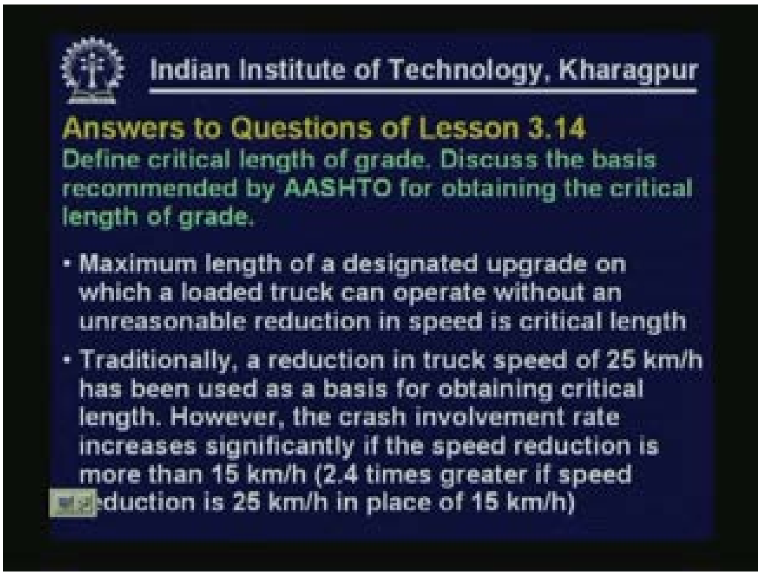

1. Define critical length of the grade. Discuss the basis by AASHTO.
It is basically the maximum length designated on upgrade where a loaded truck can operate without an unreasonable reduction in speed and as per AASHTO a 15 km/h speed deviation is taken.

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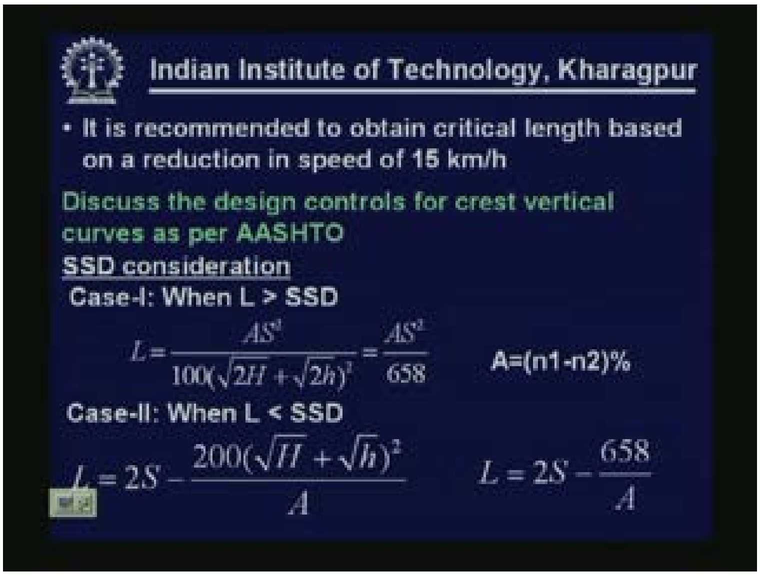

2. Discuss the design control for crest vertical curves.
It is basically sight distance is the problem. For sight distance consideration, two cases are there; the length of the curve greater than SSD and less than SSD. In both cases we can calculate the required length.

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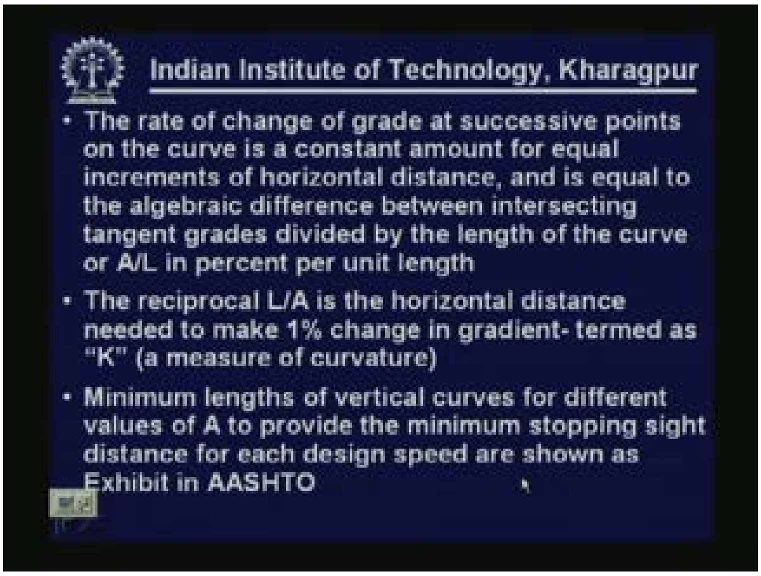

And here the reciprocal that is a K factor is defined which is basically the distance needed to make one percent change in gradient and accordingly AASHTO provides the exhibit to help us to calculate the length of the curve under various conditions for different K value. K for drainage is also another requirement which does not restrict the design, but ask you to be little bit more careful.

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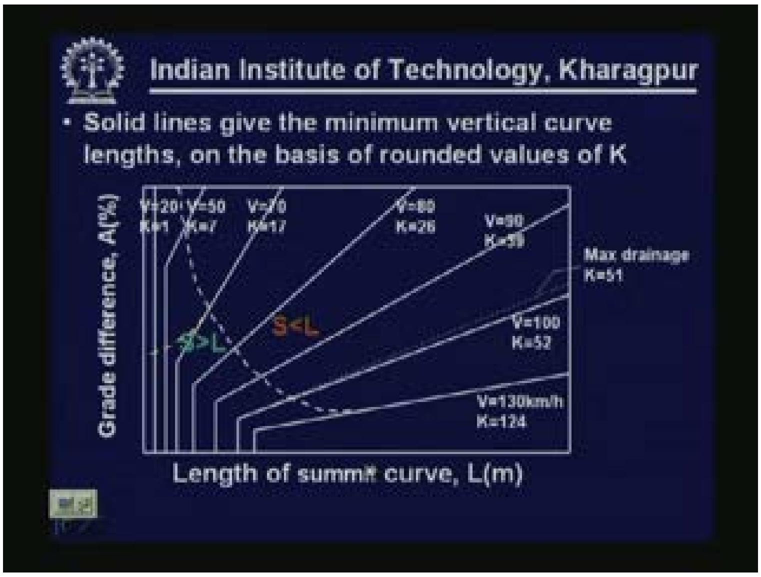

Then the criteria considered by AASHTO for establishing the length of the vertical curves we consider the head light sight distance. Again calculate the length depending on whether L is greater than stopping sight distance or less than stopping sight distance.

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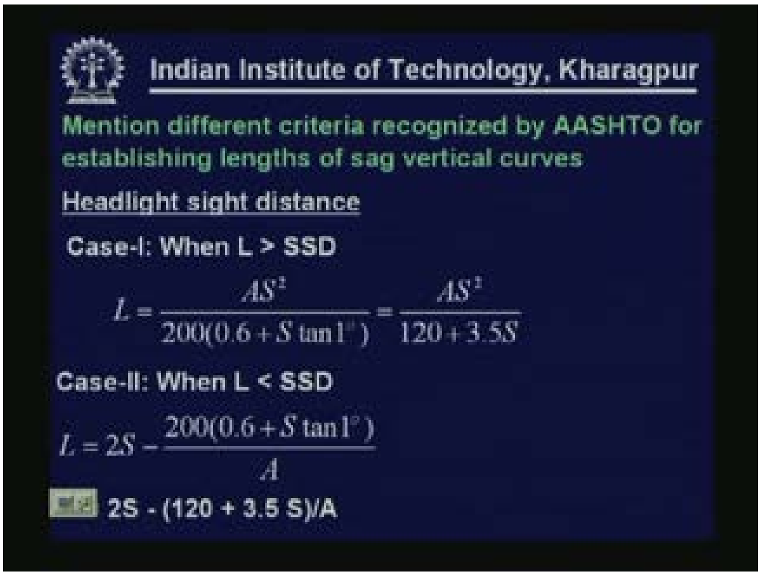

Also, second one is the passenger comfort and third one is the drainage control and fourth one is the general appearance. But generally it is the head light sight distance consideration that governs the design or designed length of the valley curve.

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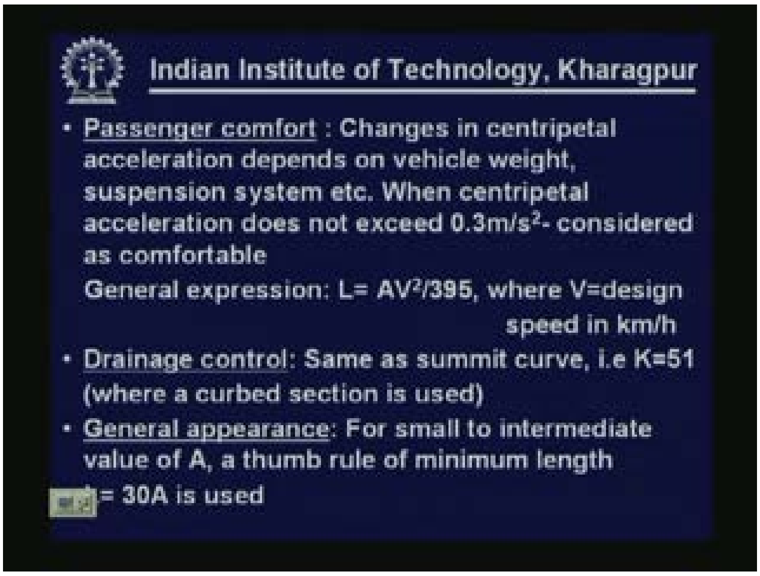

That completes our discussion, thank you.