Introduction to Transportation Engineering
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Lecture - 10
Stopping Sight Distance and Decision Sight Distance

Lesson 3.3, stopping sight distance and decision sight distance.

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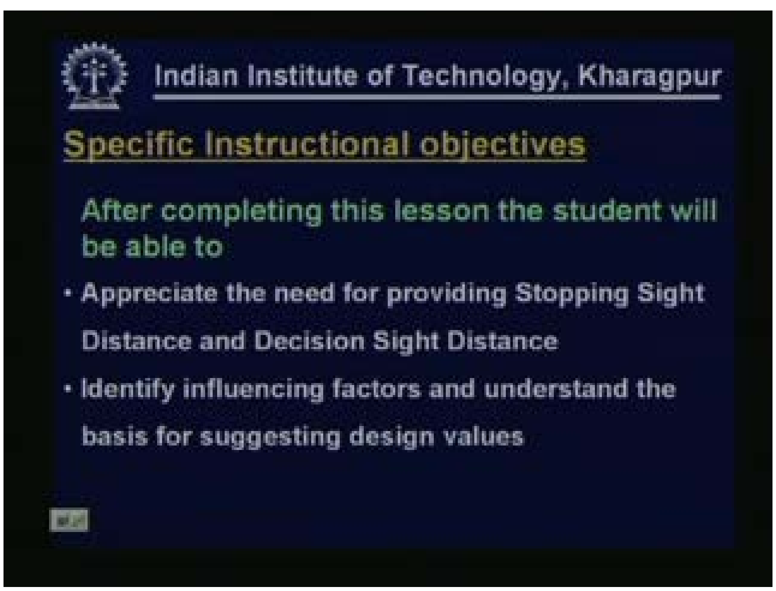

After completing this lesson the student will be able to appreciate the need for providing stopping sight distance and decision sight distance. Also, will be able to identify influencing factors and understand the basis for suggesting design values.

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What is sight distance?
The length of the road visible to a driver is the available sight distance. It is the actual length of the road and not the straight line distance. It is basically the actual length of the road visible to a driver. There are possibilities that for the available sight distance there could be some sort of obstructions. Obviously for a straight road on level ground there is no problem in terms of the sight distance. However, it is impossible or impractical to think of a road which will be absolutely straight and on level ground. There will be horizontal curves, vertical curves and also intersections which are integral part of road system. So these are the potential places where there could be restriction in terms of available sight distance. Intersection; there could be some establishments some buildings near the corner which may obstruct the line of sight. Similarly the vertical curves where there is convincity upwards which is called as the summit vertical curve due to the road itself there could be obstruction to sight distance. Wherever there is horizontal curve again due to some development, some buildings, shops in the inner side of the curve the line of sight may be obstructive. So there are three potential places: intersection, horizontal curves and vertical curves where there could be possible obstruction in sight distance.

Next is one of our topics for today is stopping sight distance. Stopping sight distance is the length of the road required for safe stopping of a moving vehicle. For various reasons drivers they are required to stop their vehicles. At least sufficient length of the road should be visible to a driver so that the vehicle can be stopped under emergency condition.

We will see later in the subsequent lesson that there are other types of sight distance but the minimum required sight distance is SSD or the Stopping Sight Distance because stopping is the elementary or the most essential maneuver that is required. Vehicles must be able to stop so this is required for safety. So this is the minimum required criteria that the available sight distance should be at least equal to the stopping sight distance. So, stopping sight distance is also called the absolute minimum sight distance because that is the absolute minimum requirement.

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Criteria for measurement:
Now, when we are talking about the sight distance it depends on what is the height that means the level for driver’s side and what is the height of the object that we are talking about. You can appreciate the available length of the road or the length of the road visible to a driver will depend on the height of the seat particularly the eye level height of driver's eye above road surface and also the height of the object. If we consider more height of the object obviously available sight distance will be more. Similarly if we consider higher height of eye level above road surface again the available sight distance will be more.

You can see, one can understand easily that the length of the road visible in front of a car is generally lesser as compared to the length of the road visible in front of a truck. So it is necessary to specify the height of driver's eye above road surface and also the height of the object when we are talking about the stopping sight distance. So here as per Indian Roads Congress the height of the driver's eye above road surface is taken as 1.2 m and the object height is taken as 0.15 m. As per AASHTO American Association of State Highway and Transport Official as per AASHTO requirement height of driver's eye above road surface is considered as 1.08 m and the height of object above road surface is taken as 0.6 m. these are design values.

Now the height of the object as taken by AASHTO is much higher 0.6 m as compared to the object height considered in Indian condition as per Indian Roads Congress recommendations that is 0.15 m. now, the value of object height is based on certain consideration.

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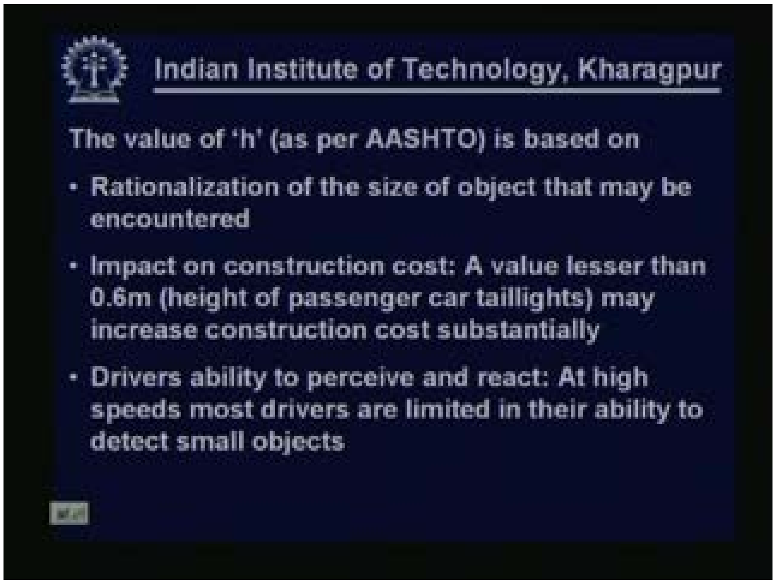

Number 1: rationalization of the size of object that may be encountered. What are the types of objects that drivers normally encounter while driving the vehicles?
Number 2: impact on construction cost. As I indicated earlier, if we consider lesser object height the required length or the requirement of sight distance will be more so obviously to provide better standard may be a flatter curve will be required so the construction cost will go up. So there is a possibility that a value lesser than 0.6 m may increase construction cost substantially. 0.6 m height is actually the height of passenger car tail lights that is the basis for taking 0.6 m as recommended by AASHTO.

Third: driver's ability to perceive and react. It is found that at high speeds most drivers are limited in their ability to detect small objects. So when the object height is decided which is recommended as 0.6 m as per AASHTO all these points are considered.

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Let us try to see what are the factors affecting stopping sight distance. Number 1:

- Perception, reaction time of driver
- Speed of vehicle
- Efficiency of brakes
- Frictional resistance between road and tires or deceleration rate

As per IRC the frictional resistance of the coefficient of friction is considered while calculating the stopping sight distance while AASHTO calculates or AASHTO recommends values which are based on the deceleration rate and five

- Longitudinal gradient of road

All these five factors they actually influence the stopping sight distance, how let us discuss.

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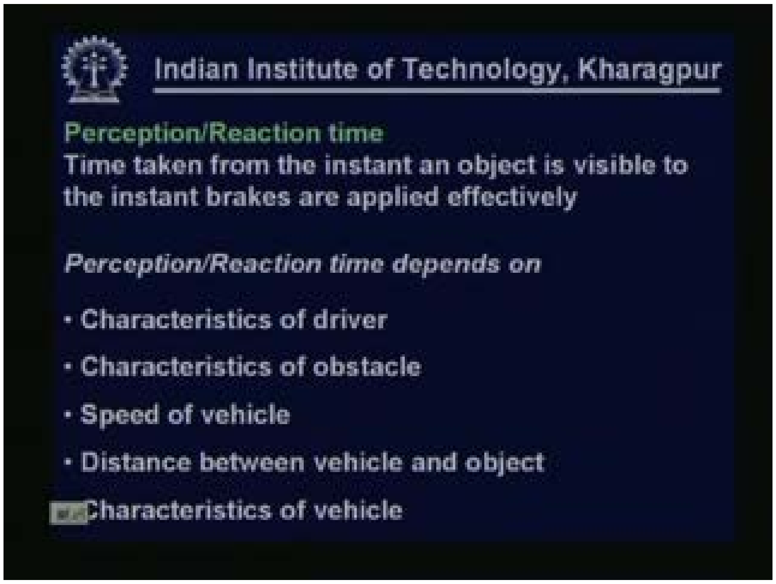

First, the perception reaction time. Whenever there is a necessity to stop the vehicle how it happens? First of all may be an object is visible to driver, it goes inside the mind that information, it is analyzed or processed and the driver makes decision that yes he needs to stop the vehicle so accordingly he puts pressure on the brake pedal and at that point only the effective application of brakes that starts. So there is a time gap, by the time the object is visible to a driver and by the time the brakes are applied effectively. This time is considered as perception time. Sometimes this time is split into perception time as well as the brake reaction time.

Perception time is the time lag between the object once the object is visible and by the time the decision is made that yes brakes should be applied and brake reaction time is the actual time which is then required for effective application of brake. But often these are considered together so we are calling this time as perception reaction time which includes perception as well as the reaction. So this is the time taken from the instant an object is visible to the instant brakes are applied effectively.

From your logical mind you can understand that this time depends on several factors. For example, characteristics of driver, what is his age, what is the mental alertness? Similarly the characteristics of obstacle, whether it is a moving object or whether it is a stationary object, third; speed of vehicle, driver's alertness also depends on the speed of the vehicle and otherwise also in general the required distance for stopping will be more as the speed is more. It also depends on the distance between vehicle and object and also the characteristics of vehicle, not that every vehicle type namely a car, a bus or a heavy commercial vehicle. It depends on the type of vehicle, the type of mechanism or mechanical system which is there in the vehicle. So it depends on the characteristics of vehicle also.

So, perception reaction time is not really a fixed value, it varies on drivers, vehicle type, type of object and so many other factors. But for design we need a single value because the road system is to be designed for a single value. So what should be the basis or what should be the major considerations when a single design value is selected, let us have a look.

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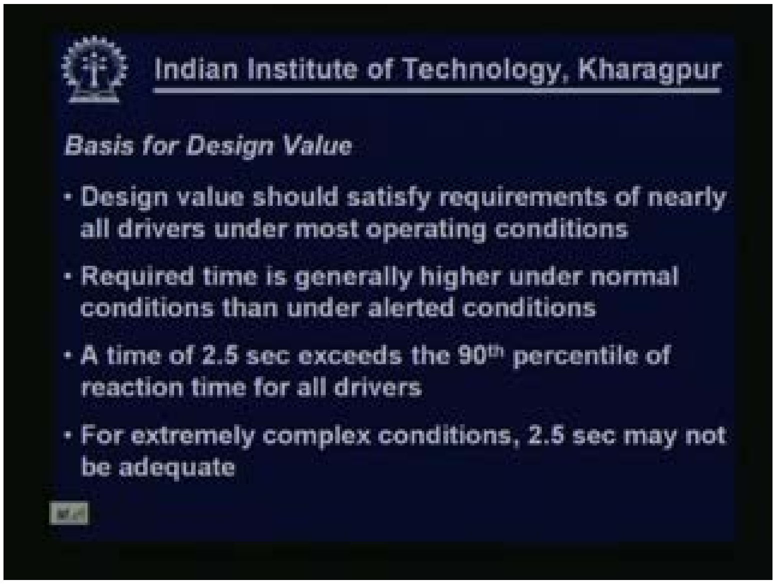

Basis for design value:
Design value should satisfy requirements of nearly all drivers under most operating conditions.
So, nearly all drivers, may not be 100 percent and under most operating conditions not under all operating conditions. If we try to select a value which will satisfy the requirement of all drivers and under all operating conditions then the value will be substantially large. Obviously there will be an impact on the construction cost and the overall economy. So design value is selected in such a way that it satisfies requirements of nearly all drivers under most operating conditions. It is also worthwhile to mention that required time is generally higher under normal conditions than under alerted conditions. When drivers are alerted, yes, there could be a possible object or maybe there is a school ahead they know it then under alerted condition the reaction time is lesser. It is also found that a 2.5 second reaction time, a time of 2.5 seconds exceeds the 90th percentile of reaction time of all drivers.

One can justify that if 2.5 seconds value is taken that exceeds the 90th percentile of reaction time for all drivers. So, 2.5 seconds reaction time is generally acceptable and accepted for design purpose. However, for extremely complex operating conditions 2.5 seconds reaction time may not be adequate. We shall come back to this discussion and that will lead us to the decision sight distance, we shall come back to that part later.

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Now it also depends on the speed of the vehicle. Obviously higher the speed higher will be the required SSD because it will take more or longer time for the vehicle to stop once the speed is higher. Third: it depends on the efficiency of brakes. What we understand by 100 percent brake efficiency? 100 percent brake efficiency means the wheels are fully locked so there is no rotation. This is not desired from safety point of view because there will be skidding and once the vehicle skids the driver will not have the required or desired control on the movement of vehicles so therefore it is not desired to have 100 percent braking efficiency while applying brakes, it depends on frictional resistance between road and tyres.

The coefficient of friction depends on speed of vehicle; higher the speed lesser will be the value for coefficient of friction type and condition of pavement both. Type means whether it is bituminous pavement or waterbound macadam or a harden road or a concrete road so what is the type of pavement or the type of surface for this. So obviously coefficient of friction will depend on that and it will also depend on the condition of pavement whether it is dry or wet. The coefficient of friction value is normally much lesser on wet pavement as compared to the pavement which is in dry condition.

Type and condition of tyre also affects the coefficient of friction. Old tyres, worn out tyres which are practically flat and new tyre with very good treads they behave in different way and also the brake efficiency, as I told if it is 100 percent brake efficiency wheels are completely locked against rotation so obviously higher coefficient of friction will be applicable within the braking distance. Yes, coefficient of friction varies depending on all these factors but for design purpose Indian Roads Congress has recommended a value in the range of 0.35 to 4 depending on the speed of vehicle. For higher speed the values are lesser.

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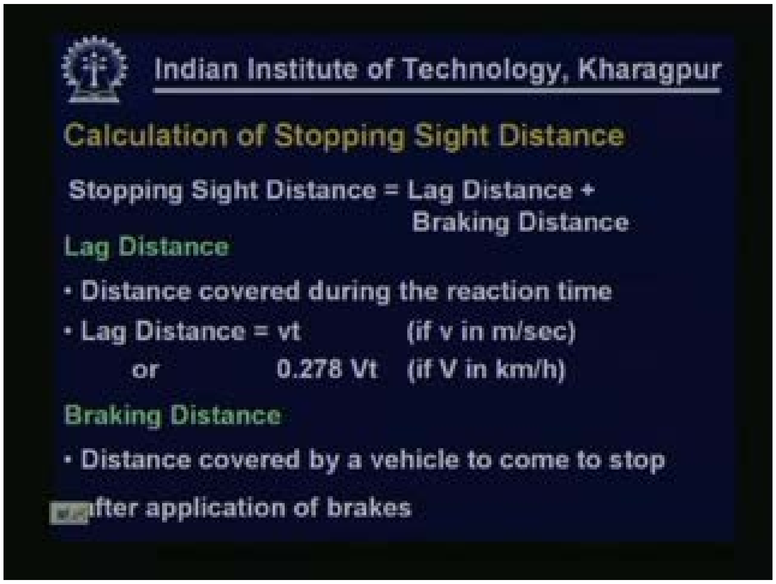

How the stopping sight is calculated?

As I mentioned earlier it is the distance vehicle travels during the thinking time, in a more refined form it is now the time during the reaction or the perception reaction time, we have understood what is perception reaction time, so the vehicle travels in its original speed during the perception reaction time what is known as lag distance and then once the brakes are applied effectively the vehicle will again travel some distance before it stops so that distance is known as braking distance. Thus, stopping sight distance is equal to lag distance plus braking distance.

Lag distance we can calculate easily. It is the reaction time multiplied by the speed. So, if v is the speed in meter per second then it is simply v multiplied by t where design value of t is 2.5 seconds or if v is expressed in kilometer per hour then it is 0.278 v into t, t is in seconds and v is in kilometer per hour. Now, the braking distance is actually the distance covered by a vehicle to come to stop after application of brakes. Now how this distance can be calculated?

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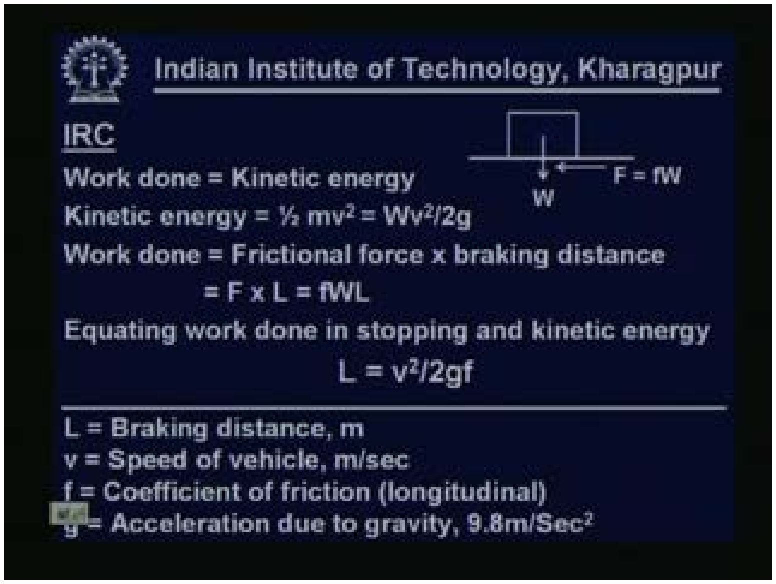

The basic equilibrium or the basic equation is: work done in stopping equal to the kinetic energy. This is the basic equation used by Indian Roads Congress and also by AASHTO. However, AASHTO rather IRC Indian Roads Congress they use coefficient of friction for calculation of stopping sight distance. So here the diagram is shown where a vehicle's weight is W, show the frictional force what is generated is F equal to is indicated as f which is equal to coefficient of friction multiplied by the weight of vehicle. So capital F is equal to small f multiplied by w. So work done is frictional force multiplied by braking distance. So, if the braking distance is nil then the work done is force multiplied by braking distance so coefficient of friction multiplied by weight multiplied by length. The kinetic energy equal to half into mass into velocity square so half mv square where m is the mass equal to half w by g into v square. So if we equate these two work done equal to kinetic energy L is v square by 2gf where L is the braking distance in meter, v is the speed of vehicle in meter per second, f is the coefficient of friction longitudinal, we are talking about the coefficient of friction which is longitudinal coefficient of friction and g is the acceleration due to gravity 9.8 m per second square.

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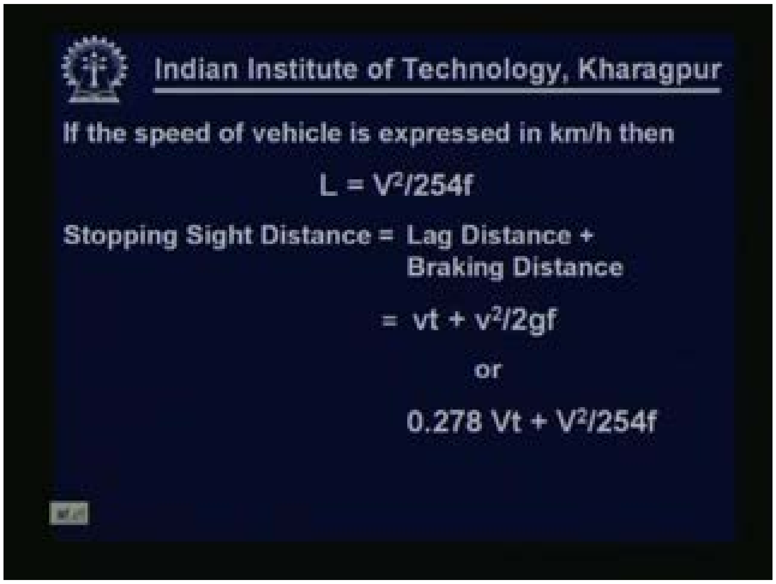

Now, if the speed of vehicle is expressed in kilometer per hour then with multiplier it will become v square by 254f. In this case v is in kilometer per hour. Therefore the stopping sight distance is lag distance plus braking distance so either it is v into t plus v square by 2gf if v is in meter per second or it is 0.278 Vt plus V square by 254f in this case V is in kilometer per hour and in both cases t is the perception reaction time in seconds where the design value is 2.5.

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Coming to the AASHTO it is found that approximately 90 percent drivers they decelerate at rates greater than 3.4 m per second square. Also, it is found that such decelerations are within drivers' capability to maintain steering control during braking on wet surfaces because wet surface is critical as compared to dry surface. So even on wet sight surface drivers can very well keep control on the movement of vehicle with deceleration 3.4 m per second square. At the same time most vehicle braking systems and tyre-pavement friction levels are capable of providing a deceleration rate of at least 3.4 m per second square. Considering these three aspects AASHTO recommends a fixed value of 3.4 m per second square, a fixed value for deceleration of 3.4 m per seconds square for the calculation of stopping sight distance. It does not calculate SSD based on coefficient of friction. Instead of using coefficient of friction a constant deceleration rate of 3.4 m per seconds square is used.

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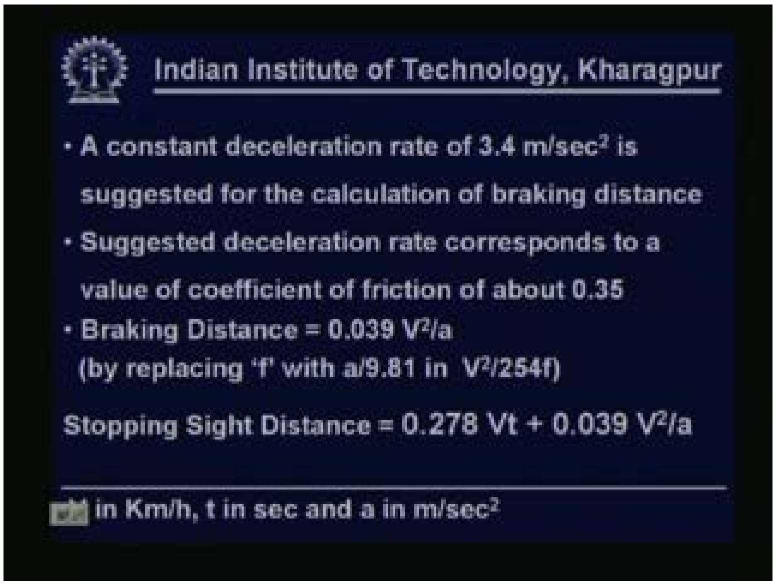

The suggested deceleration rate corresponds to a value of coefficient of friction of about 0.35. So whatever braking distance value will be obtained by considering a deceleration rate of 3.4 m per second square nearly same value will be obtained if the coefficient of friction is assumed as about 0.35. Using deceleration rate the braking distance can be expressed as 0.039 V square by a where a is the deceleration rate and V is in kilometer per hour. It is basically the earlier equation V square by 254f so if we replace f by a by 9.8 9.8 which is the value of g then this equation we will get that is the braking distance equal to 0.039 V square by a where V is in kilometer per hour and a is in meter per second square.

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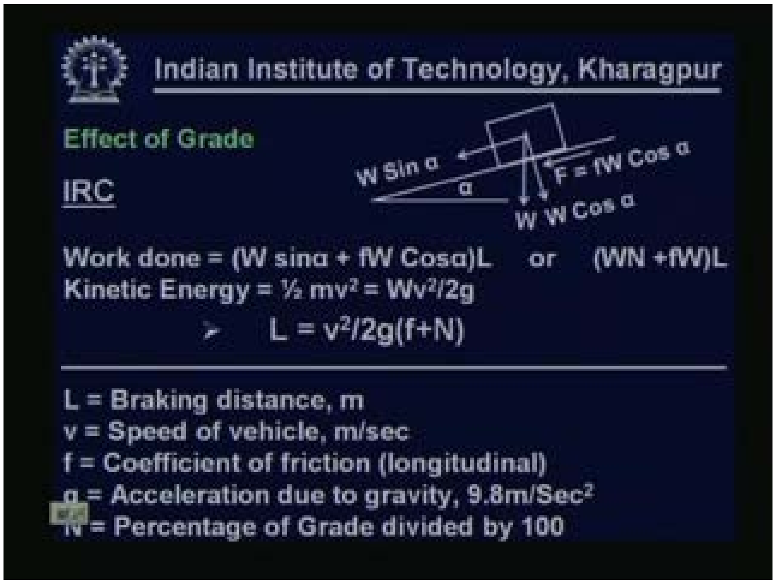

What is the effect of grade on stopping sight distance?

No doubt the stopping sight distance on grades will be different from what we got on level road. We can also estimate or calculate the effect of grade on stopping sight distance. Look at this sketch where W is the weight of the vehicle and alpha is the slope, share if we consider an upward slope then this weight we can split it into two components two parts: W cos alpha in the perpendicular direction and W sin alpha in the parallel direction. So therefore the frictional force is coefficient of friction multiplied by this component of width in the parallel direction that is W sin alpha. So, force equal to coefficient of friction into weight into cos alpha. Therefore, work done is total is W sin alpha plus this frictional force which is f W weight of vehicle cos alpha multiplied by the length.

Here if normally that slope is small so for small alpha cos alpha is approximately equal to unity and sin alpha is approximately equal to tan alpha which is nothing but taken as N here, N is the percentage of grade divided by 100. So if we say 3 percent grade it actually means 3 by 100 that is the value of N. So kinetic energy is as we calculated earlier is half L V square. So if we make work done equal to kinetic energy then we get: length is V square by 2g(f plus N). In this case L is the breaking distance in meter, v is the speed of vehicle in meter per second, f is the coefficient of friction longitudinal, g is the acceleration due to gravity 9.8 m per second square and n is the percentage of grade divided by 100. Therefore, if there is an upward slope from the equation you can understand that the required stopping sight distance will be lesser as compared to the SSD on plain or leveled road.

Similarly, if there is a downward slope then n will be minus n the sign will change so you can understand that the required stopping sight distance value will be more when it is a downward grade. For upward grade the required SSD will be lesser as compared to the required SSD on plain and downward grade will be reverse that means for downward grade the required SSD will be more.

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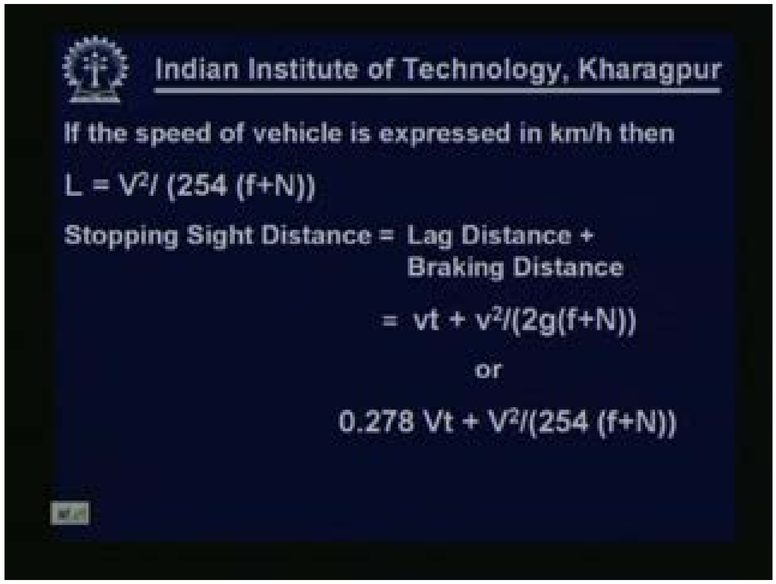

Now, if again V is expressed in kilo meter per hour then L will be V square by (254(f plus N)). Therefore whenever there is a grade that equates stopping sight distance equal to lag distance plus braking distance so it is vt plus v square by (2g(f plus N)). Here v is in meter per second, t is in second or 0.278 Vt plus V square by (254(f plus N)), here if V is expressed in kilometer per hour.

Now in AASHTO the basis is again the same, the basic understanding is the same but the only difference is AASHTO does not calculate it on the basis of coefficient of friction it rather uses the deceleration rate. So look at this sketch (Refer Slide Time: 37:37) here f is taken as mass into acceleration, the component parallel, parallel component is taken as W by g (a). When we tried to derive it based on IRC we used small f(W cos alpha), here we are using F equal to mass force equal to mass into acceleration so W by g(a) and the remaining is the same. So work done is W sin alpha plus W by g(a) this is the force multiplied by L the length and kinetic energy is as usual W by g v square half of W by g v square. So, if we equate these two we can find out L as L equal to v square by 2g(a by g plus N) as shown here. Here L is the braking distance, v is the speed of vehicle in meter per second, a is the acceleration rate in meter per second, g is the acceleration due to gravity 9.8 m per second square and N is the percentage of grade divided by 100.

Now, again if the speed is expressed in kilometer per hour then the equation will be L equal to v square by (254(a by 9.8) which is the value of g plus N. So the stopping sight distance is vt plus v square by (2g(a by 9.8 plus N)) if v is expressed in meter per second or it will be 0.278 vt plus v square by (254(a by 9.8 plus N) as shown here. Here V is in kilometer per hour.

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Variation for trucks:

The recommended design values for SSDs particularly the AASHTO recommendations are based on considering or based on the car traffic movement. It does not explicitly consider design of or design for truck operations. Now trucks especially the larger and heavier units need longer stopping sight distance due to the vehicle characteristics. However, there is a balancing factor that is height of drivers' eye above road level in case of a truck is much higher as compared to the height of drivers' eye for cars that is a balancing factor. Therefore, because of the higher height drivers can see longer distances of road so the available sight distance are generally higher for trucks therefore separate stopping sight distance values are not recommended for design purpose.

However, one must remember that there is a special situation where this more height of truck drivers will not be meaningful or useful that is when horizontal sight restrictions occur at the hint of long down grades, at those conditions the speed of trucks will be almost equal to speed of cars it may be even more if the grade is long enough so speed-wise it is comparable but drivers' eye their level its level or height of drivers' eye above road surface is not at all advantageous under these special conditions. So wherever horizontal sight restrictions occur at the end of long downgrades one must try to provide more sight distance than what is recommended as SSD under normal conditions.

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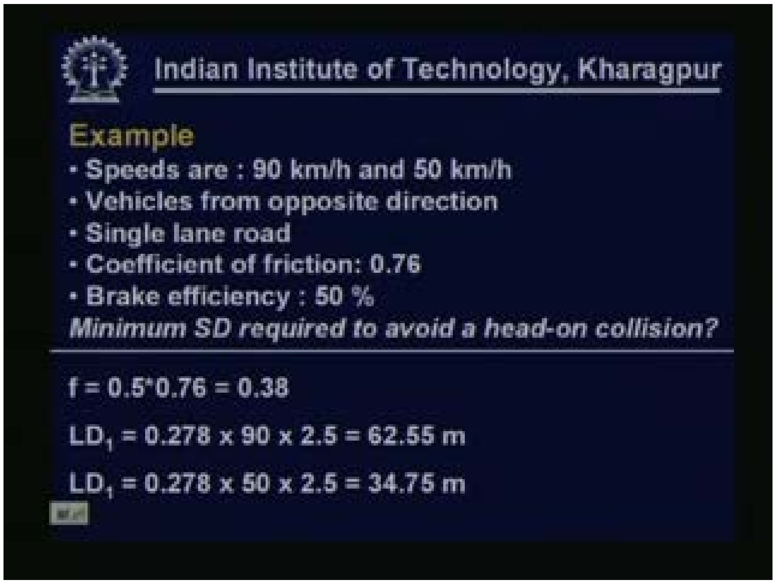

Let us take an example. Let us consider two vehicles which are approaching each other: one is traveling at 90 kilometer per hour speed, the other is traveling at 50 kilometer per hour speed and it is a single lane road that means it is a narrow road. The coefficient of friction is 0.75but break efficiency is only 50 percent. Now what will be the minimum sight distance required to avoid a head-on collision? Obviously we have to calculate the SSD.

Now, effective coefficient of friction is only 0.5 of 0.76 because the brake efficiency is 50 percent so that is 0.38 that will be the design value for the coefficient of friction. Now we can calculate the lag distance for the vehicle traveling with 90 kilometers speed it is 0.278 into 90 into 2.5 second reaction time so, that is 62.5 m and for the second vehicle which is traveling at 50 kilometer per hour speed the lag distance is again 0.278 into 50 into 2.5 that is 34.7 m.

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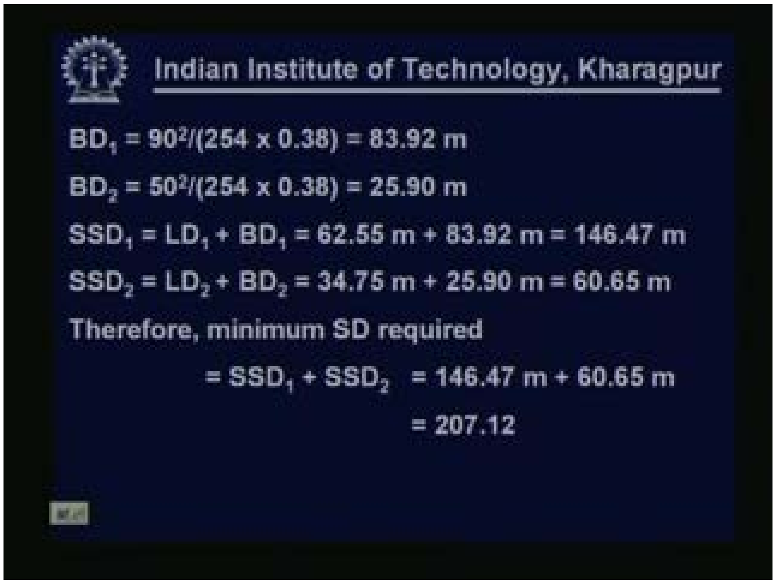

Now we shall calculate the braking distance v square by 254f so, for the fast vehicle it is 90 square divided by 254 into design f is 0.38 that is 83.92 m. For the second vehicle it is 50 square because 50 is the speed divided by 254f the designed value of f is 0.38 so 25.90. Therefore the required stopping sight distance for the first vehicle is lag distance for the first vehicle plus breaking distance for the first vehicle so the total is 146.47 m, for the second vehicle the required SSD can be calculated in the similar manner: lag distance plus breaking distance and total is 60.65.

Now, since it is the single lane road which is a narrow road that means to avoid head-on collision the vehicles should be able to see each other and the distance in between should be equal to SSD required for the first vehicle plus SSD required for the second vehicle because then both the vehicles require that much gap or length of the road in between so that both of them can really come to a stop condition without any head-on collision so the total distance is calculated here as 207.12 m.

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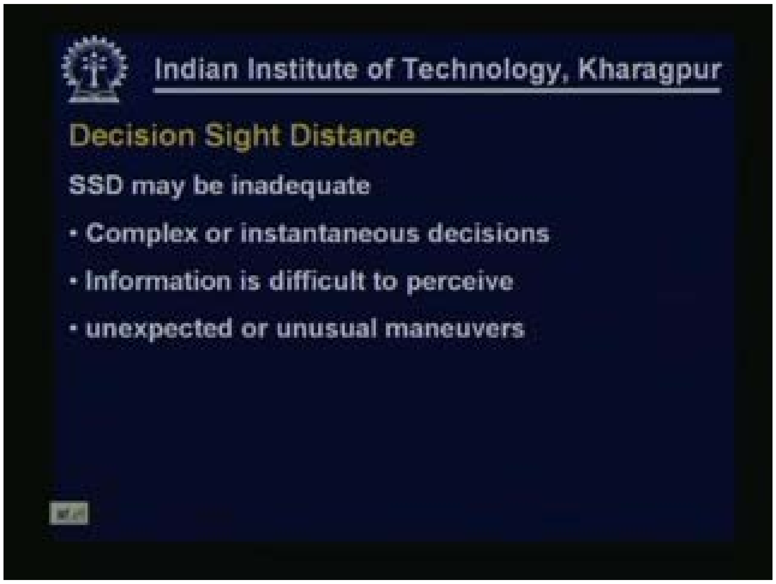

Now, stopping sight distance what is provided is normally adequate for normal conditions or general operation. It may be inadequate under complex or instantaneous…… complex situations or where drivers have to make complex or instantaneous decisions. Number 2: where information is difficult to perceive, number 3: where again drivers have to make unexpected or unusual maneuvers. Under these conditions the available stopping sight distance will not be adequate. So, in complex or critical locations there could be error in either information reception, decision making or control actions, for example, interchange and intersection locations.

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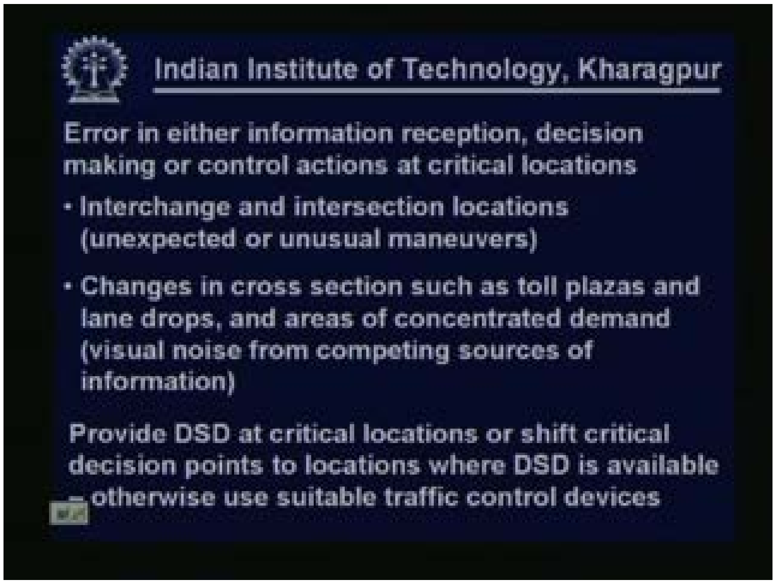

You know there is a possibility that unexpected or unusual maneuvers are required; vehicles may come suddenly. Similarly, wherever there are changes in cross section such as toll plaza and land drops and areas of concentrated demand particularly areas of concentrated demand in urban environment there could be visual noise from competing sources of information: from advertisement. From other lights traffic lights so competing sources of information it may be difficult. So in those conditions decision sight distance is provided which will give sight distance value higher than the stopping sight distance. So idea is, at all complex or critical locations provide Decision Sight Distance in short DSD or shift critical locations to places where decision sight distance is available. If none of these options are acceptable means they are not practically possible because of the sight condition and other constants then suitable traffic control devices should be installed to warn drivers about possible condition.

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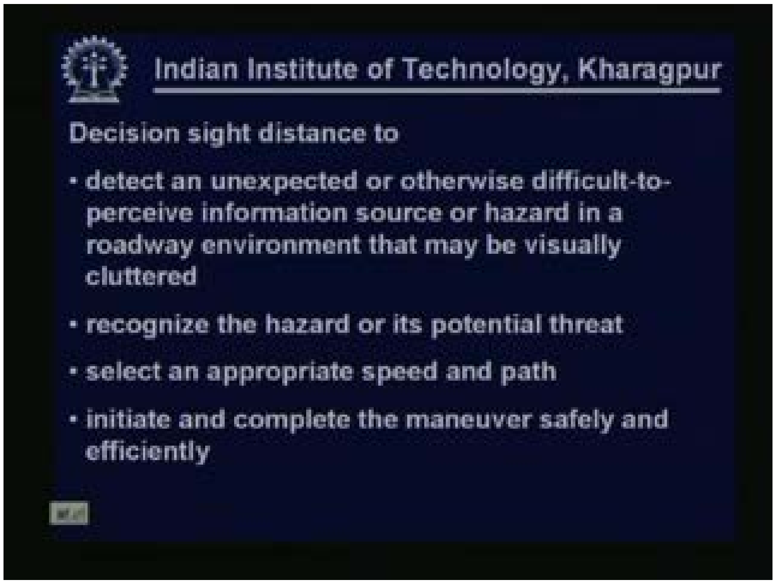

Decision sight distance should be adequate to:

- detect an unexpected or otherwise difficult-to-perceive information source or hazard that may be visually cluttered
- to recognize the hazard and its potential threat
- to select an appropriate speed and path and
- to initiate and complete the maneuver safely and efficiently

Considering all these AASHTO suggests DSD values for different avoidance maneuver.

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For A to E

- A is stop on rural road
- B is stop on urban road
- C is stop speed, path, direction change on rural road
- Avoidance maneuver D is for speed, path, direction change on suburban road
- Avoidance maneuver E: speed, path, direction change on urban road

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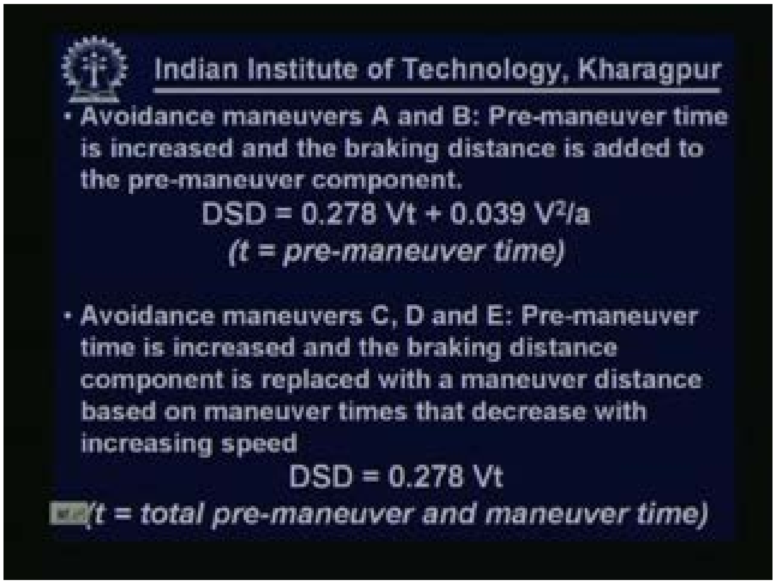

For avoidance maneuver A and B pre-maneuver time is increased. Whatever we considered as perception reaction time that is the pre-maneuver time that t value is increased and the braking distance is added to the pre-maneuver component because ultimately it is a stopping maneuver. So equation is just like SSD 0.278 Vt plus 0.039 V square by a. But here the t is pre-maneuver time and not the reaction time of 2.5 seconds as what we considered in case of SSD. In case of DSD this t value is higher.

For avoidance maneuver C D and E it is not the stop of the vehicle so the stopping component, the breaking distance component will not be applicable. So pre-maneuver time remains as it is as it was for avoidance maneuver A and V higher values are used higher value than the reaction time and the breaking distance component is replaced with a maneuver distance based on maneuver times that decrease with increasing speed. So essentially in this case DSD is 0.278 Vt but do remember that this t is total pre-maneuver plus maneuver time as discussed.

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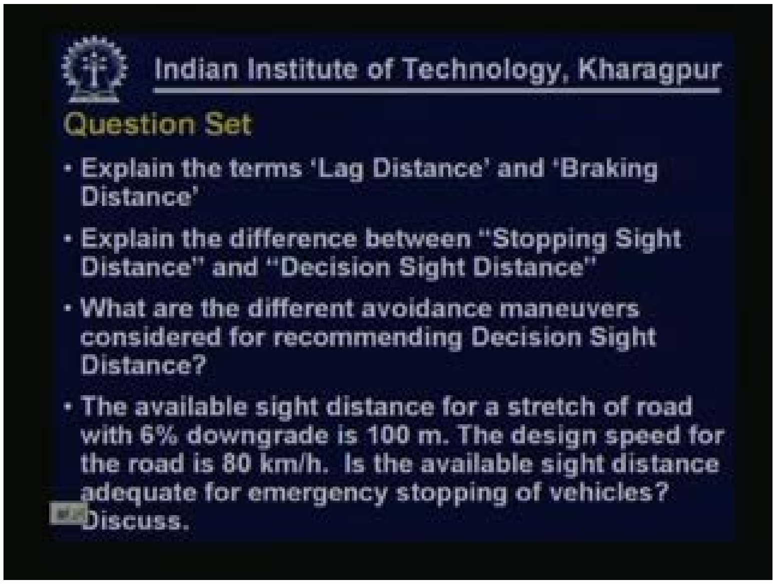

Now I have a few questions for you.
1) Explain the terms lag distance and braking distance:
2) Explain the difference between stopping sight distance and decision sight distance:
3) What are the different avoidance maneuvers considered for recommending decision sight distance?

Try to answer these questions and also try to solve a problem.
The available sight distance for a stretch of road with 6 percent downgrade is 100 meter. The design speed for the road is 80 kilometer per hour. Is the available sight distance adequate for emergency stopping of vehicles? If not what will be your recommendations?
You may follow AASHTO approach for solving this problem. Now I will try to answer the questions which were raised during the last lesson.

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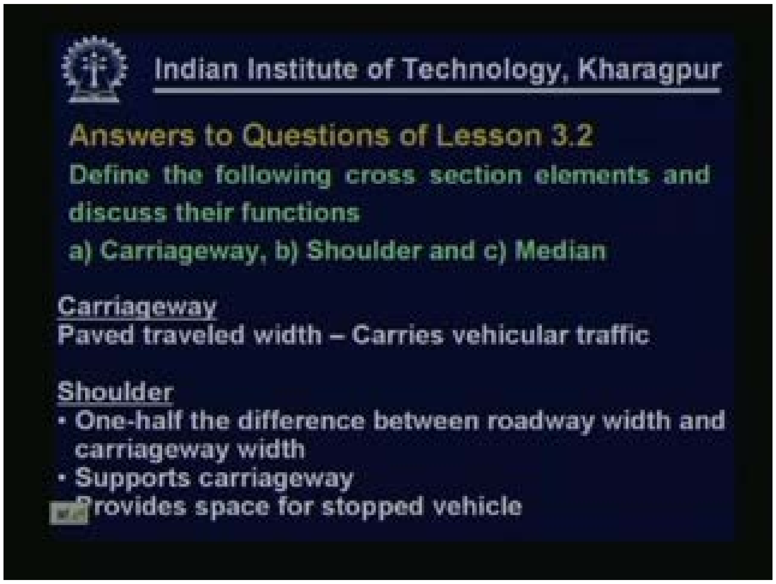

Define the following cross section elements and discuss their functions: carriageway, shoulder and median.

Carriageway is the paved traveled width. It carries the vehicular traffic, all the loading is taken by the carriageway. Shoulder is that extra portion on each side of the carriageway. It basically provides support to carriageway and provides space for emergency stopping of vehicles without disturbance to the through traffic stream or the moving traffic stream. Median is basically the longitudinal space separating dual carriageway. It separates directional traffic stream so it enhances the safety and it works as a traffic control device.

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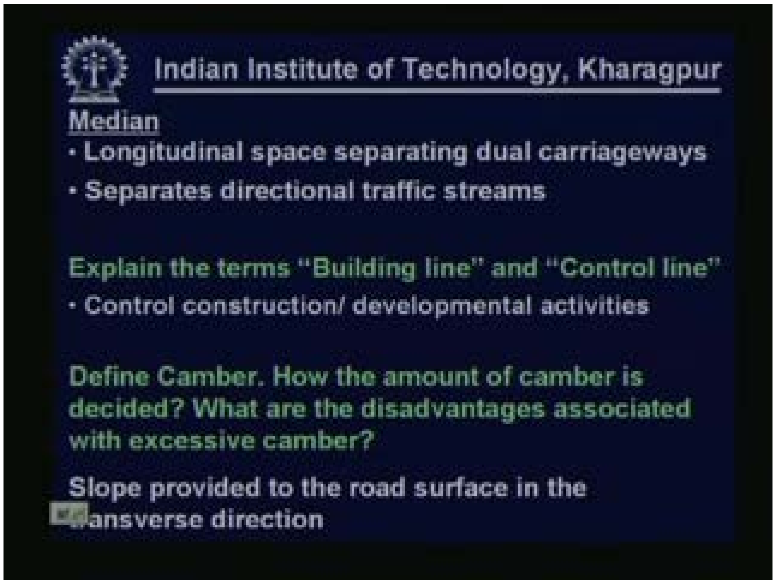

Explain the terms building line and control line:
You know, road is acquired up to the right of the way or the land width. Beyond that this building line and control lines these things are considered considering the future need for expansion. So it is basically an attempt to control construction or developmental activities in a way which will be or which will be beneficial or which will be advantageous for the acquisition of additional land in the future.

Define camber:
It is a slope cross slope provided to the road surface in the transverse direction. So it is a slope provided to the road surface the carriageway in the transverse direction for the drainage of water.

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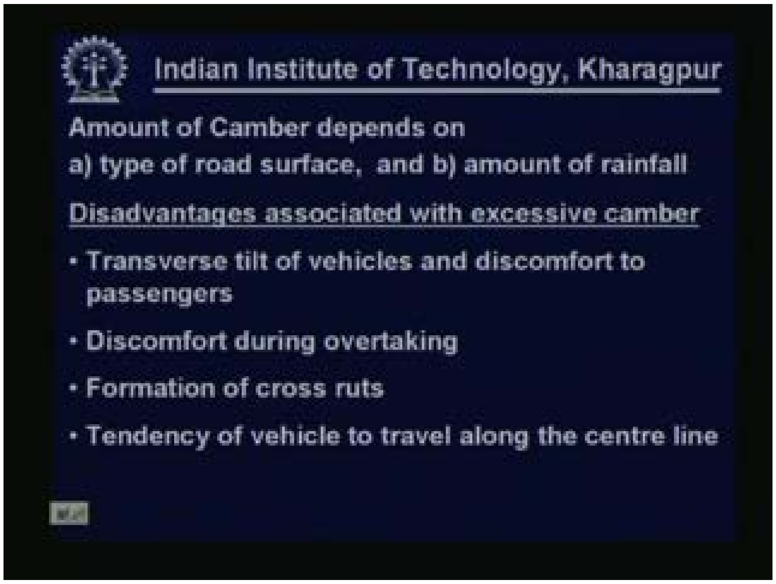

Amount of camber depends on the type of road surface: pervious or impervious; for more impervious surface lesser camber is required and also it depends on the amount of rainfall. For heavy rainfall more the camber or more cross slope will be required and for less rainfall lesser camber or cross slope will be required.

What are the disadvantages associated with excessive camber?
Transverse tilt of vehicle because of the camber and this causes discomfort to passengers. It will also cause discomfort during overtaking because vehicle has to go to the other lane in most of the cases particularly for two lane road with two way traffic. Formation of cross ruts where there is heavy rain and also the tendency of vehicle to travel along the central line which is called the central seeking tendency of vehicle which is not good or acceptable from safety point of view.

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Discuss the functions of kerbs and guard rails:
Kerbs basically facilitates and controls drainage strengthens and protects pavement edge, delineates pavement edge present the more finished appearance and encourages orderly roadside development and guard rail basically prevents vehicle from running off. So wherever at the approach of bridge or high embankment or at the outer edge of horizontal curve wherever vehicles are prone to run off from the carriageway we provide guard rail for safety or to enhance the safety, thank you.