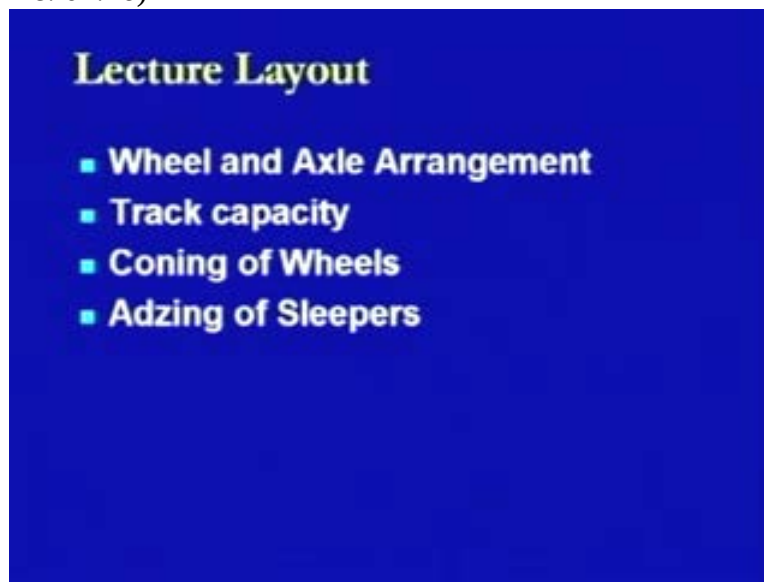


Transportation Engineering -II
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Lecture - 3
Wheels and Axles, Coning of Wheels

Dear students, we are starting with another lecture on transportation engineering two course. This lecture pertains to the wheels and the axles and their configuration and the associated feature of wheels, that is, coning of wheels. In the previous lectures we have discussed about the gauges; the various types of gauges being used in globally or in India, the problems associated with the gauges and the uniform gauge policy of Indian railways. In today's lecture we will be taking up the wheels and axle arrangements, the track capacity, coning of wheels. These are the three major important points which we will be covering today.

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There is an associated feature of coning of wheels, that is, adding of sleepers will also be taken up in short. Starting with the wheels and axles; in the case of wheels and axles we have the different types of the locomotives under wagons which are used for the hauling of the passengers and freight. All these wagons and locomotives have different specifications depending on the gauges for which they have been used. If you look at the various locomotives from the very starting of our history, we have been using steam locomotives and then they have been replaced by diesel locomotives and finally by the electric locomotives. When I am talking about the most innovative design features of the locomotives which are come into play in the recent past where we are in position to attain the speeds of as high as 250 to 300 to 500 kilometers per hour.

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Wheels and Axles

■ Steam Locomotives:

- Traditionally, steam locomotives have been classified by their wheel arrangements. The system most widely used was the **Whyte system**.
- Under this, the loco's leading non-powered wheels, the (usually coupled) driving wheels, and the trailing non-powered wheels are indicated separately.

Now, here we are talking about the initial three versions of the locomotives, that is, the steam locomotives, diesel locomotives and electric locomotives. In the case of the steam locomotives, the wheels and axles are classified by on the basis of Whyte system. Traditionally, steam locomotives have been classified using either their wheel arrangements or sometimes they are also been classified on the basis of axle arrangements.

In the case of the wheel arrangements classification, they are being classified on the basis of Whyte system and other system locomotives have three different types of wheel basis. They have the wheel basis which are either coupled or which are having the driving conditions or detective power attached to them or the wheel basis on which no attractive power is attached. In such cases where the detective power is not being attached on the basis of the locations where they have been placed, they can be termed as the leading fields or the failing fields. Taking this type of classification based on the leading wheels or the tailing wheels or the coupling or the conditions of the wheels where the power has been attached to the wheels or not, we can have the classification is, that the locomotives leading no power wheels. The driving wheels which are usually coupled but in some cases they may not be coupled also and the trailing non powered wheels. All these three categories of wheels have to be separately indicated in the weight system.

Now, when we take the Indian practice, the Indian practice has been taken from the United Kingdom because British were the persons who introduced the Indian railways in our country and in this system we count wheels and we do not count the axles as far as the steam locomotives are concerned. In the case of steam locomotives, one examples is been taken here where it is been shown as 2-4-2. Now this 2-4-2 has the significance in terms of the wheel basis as been defined earlier. The first 2 is the front wheels or the 2 number of wheels have been placed or what we can say is that there is one axle which is being placed in the front condition. Then the 4 part is to the 4 number of wheels which have been placed in the central condition where they are the powered wheels or the

driving wheels and therefore they transform into the 2 axles condition and then there are trailing wheels where we have 2 wheels at the back and again, if it transform them into the actual condition, it will be working to one axle.

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Wheels and Axles

- **Indian practice (following the UK) was to count wheels and not just the axles.**
- **E.g. 2-4-2**
 - **Front wheels (2 Nos. i.e. 1 axle)**
 - **Central wheels (4 Nos. i.e. 2 axles) – Driving or powered wheels**
 - **Trailing wheels (2 Nos. i.e. 1 axle)**

So, if we are interested in transforming this from the wheel condition or wheel count to the actual count then it will be nothing but 1-2-1 instead of 2-4-2. Now when we are talking about the steam locomotives; the steam locomotives require a certain storage area or the tank where the coal can be stored because this is the flying condition which is required for the movement of the steam locomotives. In such cases, a suffix is also used to indicate the type of the tank which is provided on the steam engine.

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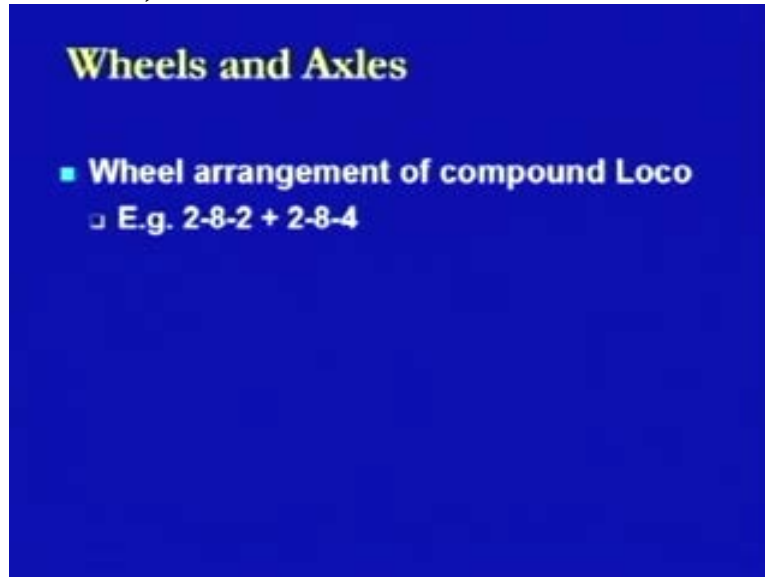
Wheels and Axles

- **Suffix is also used to indicate the type of tank provided.**
 - **'T' indicates a tank engine**
 - **'ST' for saddle tank,**
 - **'WT' for well tank,**
 - **'PT' for pannier tank, etc.**

In the case, the tank engine is being provided, then it is indicated using the alphabet T. If it is a saddle tank then it is denoted as ST, if it is well tank then it is denoted as WT and if it is pannier tank then it is denoted as PT. Likewise there are other cases too.

Now we take an example of a compound locomotive; the compound locomotive is a condition where there is a more attractive power which is required to haul the passenger or the freight.

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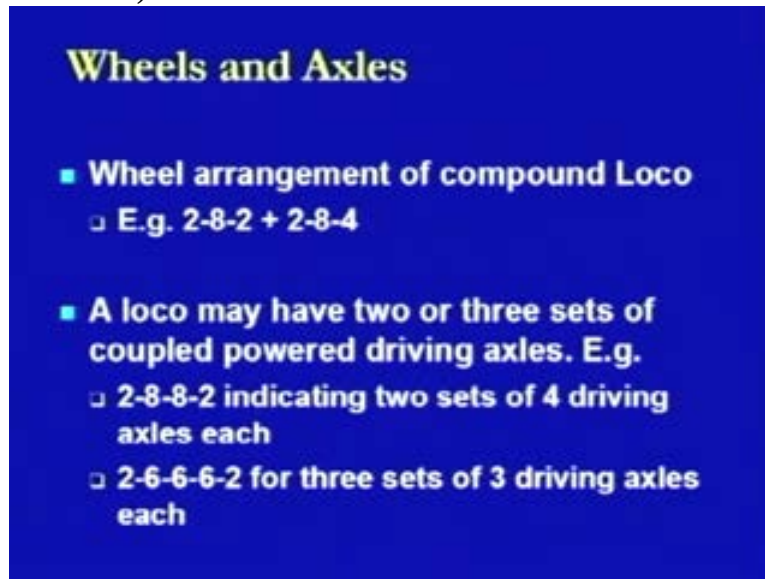


Generally, this is the condition which is found in the case of the freight transportation. The heavy amount of the freight which is to be transported and the trailing conditions governs the conditions where we require to provide two locomotives together so as to haul them. Here, this is an example of compound locomotive where two locomotive of condition 2-8-2 or 2-8-4 have been joined together so as to haul the traffic or the passengers or the freight. Again, if we go by the Whyte condition, Whyte system of classification of the locomotives of the wheel configuration then 2-8-2 means they have 2 front wheels, 8 medium or central wheels and 2 trailer wheels, in case of the first locomotives whereas in the case of the second locomotives we have 2 front wheels, 8 central condition wheels which are electrically driven, which are driven for the movement of the locomotives and then in this case we have 4 trailing wheels.

Now, another conditions too where the locomotives may have two or three sets of coupled power driving axles. Now in such conditions how we are going to define them or how we are going to categorize them? Some of the examples again show such type of conditions. Here the examples have been taken is 2-8-8-2. This 2-8-8-2 indicates that there are 2 sets of 4 driving axles. When we say there are 2 sets of 4 driving axles, it means we are having 8 wheels in one set and 8 wheels again in another set. That is why in the central location we are having 8 and 8, still we have 2 trailing and 2 front wheels been provided which are not being given any driving conditions or they are not been

coupled together. Similarly, there is an example of 2-6-6-6-2, and in this case there are 3 sets of 3 driving axles each.

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Wheels and Axles

- **Wheel arrangement of compound Loco**
 - E.g. 2-8-2 + 2-8-4
- **A loco may have two or three sets of coupled powered driving axles. E.g.**
 - 2-8-8-2 indicating two sets of 4 driving axles each
 - 2-6-6-6-2 for three sets of 3 driving axles each

So these are the different types of the classifications which are there for the steam locomotives depending on the type of the condition or type of the locomotive we are using and these type of the locomotives are going to be selected on the basis of the total amount of traffic or the total freight which needs to be transported.

Now, we can also look at the European arrangement. The European arrangement says that they count the axles then the wheels. As we have taken the example previously, here it was 2-5-2 condition where the wheels were counted with 2 front, 4 central and 2 trailing wheels. Here in this case, it will be transformed into 1-2-1 where there is 1 axle in the front condition, 1 axle in the trailing condition and there are 2 axles which have been connected to the power. So, that is why it is 1-2-1 or 1 dash 2 dash 1. Similarly, there are other conditions too like 1B1 and so on.

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Wheels and Axles

■ European arrangement

- European practice is to count axles than wheels.
- E.g. 121 (or 1-2-1); 1B1, etc.

Now, coming to the diesel and electric locomotives; in the case of diesel and electric locomotives, the wheel arrangements are more or less similar in nature. In these cases the powered axles are described using letters and unpowered axles if any there are indicated by the digits. Now in this case, the various digits we are using have been shown here. We can use A, B, C and D depending on the type of the conditions for which the vehicle or the locomotives or the wheel arrangements has to be identified. In case we are using A, it means it is single powered axle on a bogie. A bogie is a base which is provided at the base of the locomotives, which provides the motive power to the locomotive. Therefore, the locomotive has two structures; one is the upper structure on which the rest of the things have been placed and there is a bogie which is a supporting structure which has a powered axle and through which it will be moving.

Similarly, there is another case which is termed as 'Bo'. 'Bo' means there are set of two independently powered axles on a bogie. These two independently powered axles on a bogie, they are not a coupled condition. In the case of the coupled conditions the power will be used to transfer the attraction to the axles which has been attached to it whereas in this case the power will be given separately to the different axles. Similarly, the third condition is 'Co'. In case of the 'Co', the set of three independently powered axles are placed in the same bogie.

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Wheels and Axles

- **Wheel arrangement of Diesel and electric loco**
 - **Powered axles are described using letters and the unpowered axles (if any) are indicated by digits as -**
 - **'A': Single powered axle on a bogie**
 - **'Bo': A set of two independently powered axles on a bogie**
 - **'Co': A set of three independently powered axles on a bogie**
 - **'Do' or 'D': A set of 4 powered axles**

Then 'Do' or 'D', it denotes a set of four powered axles. So, this is a case where we are having a single bogie condition and in that single bogie condition these abbreviation have to be used. In case we are having more than one bogie system, there are two set bogie or three bogies being placed for the C locomotives, then the combination of all these alphabets can be used. We will be looking at those combinations also in a later while.

Now this one, this characterization which is being shown on this slide again pertains in to the diesel and electric locomotives where the combinations have been shown. In the case of the combinations, where two bogies have been used with each bogie having two separately powered axles, then it is transformed or this is indicated by 'Bo' and 'Bo'. When the three such bogies have provided with the same locomotives, then it is the condition Bo, Bo and Bo. Similarly, if there is a bogie in which three powered axles conditions have been provided on each bogie side, then it is Co-Co condition, that is, the two bogies being provided with three powered axles.

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Wheels and Axles

■ Wheel arrangement of Diesel and electric loco - Notations

- **'Bo-Bo': A loco with two bogies, each having two separately powered axles**
- **'Bo-Bo-Bo': A loco with three such bogies**
- **'Co-Co': A loco with two bogies each with three powered axles**

So, this is the combination condition which is being transformed into some indicative values. Now, there is also condition where instead of using Bo we can use simple B. When we are using simple B it indicates that the axles are not independent but they are coupled mechanically and so that the same motor drives all the axles in the bogie. So, this is another condition, another sort of wheel arrangement which is provided for the diesel and electric locomotives.

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Wheels and Axles

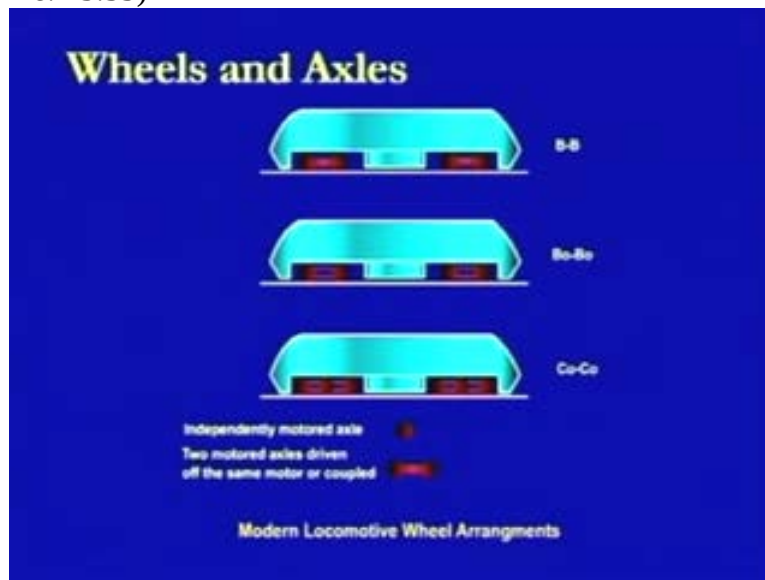
■ Wheel arrangement of Diesel and electric loco - Notations

- **'B-B': Indicate that the axles are not independent, but coupled mechanically – the same motor drives all axles in the bogie**

Now, in this diagram, what we can see is that all the three conditions have been shown. Like there is the condition, where the first condition, it is BB condition. When it is a BB condition, it means there are two motor axles driven of the same motor or they coupled condition. Then there is a Bo-Bo condition, where they have the independent motor axles

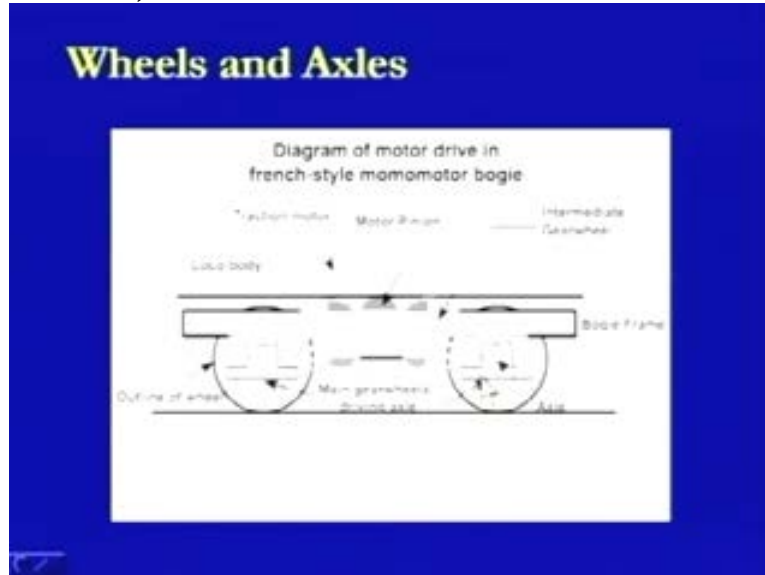
been provided and then there is a Co-Co conditions where again it is an independently motored axles being provided in this case. What we can see in this one, is that, in this case where the coupling is being provided, they have been shown the two wheels one at this point and one end this point or one end this point and one end this point, they have been jointed together by a broad or firm lining. Whereas in the case of the Bo and Bo condition, they are not been joined by a firm lining, they have been joined by a hollow lining condition. So, we have again the two wheels one on this one, one on this one. This means there is one axle on this side one axle on this side. Similarly, one axle on this side and one axle on this side means this is one bogie side and this is another bogie side to which is being provided for the same locomotive.

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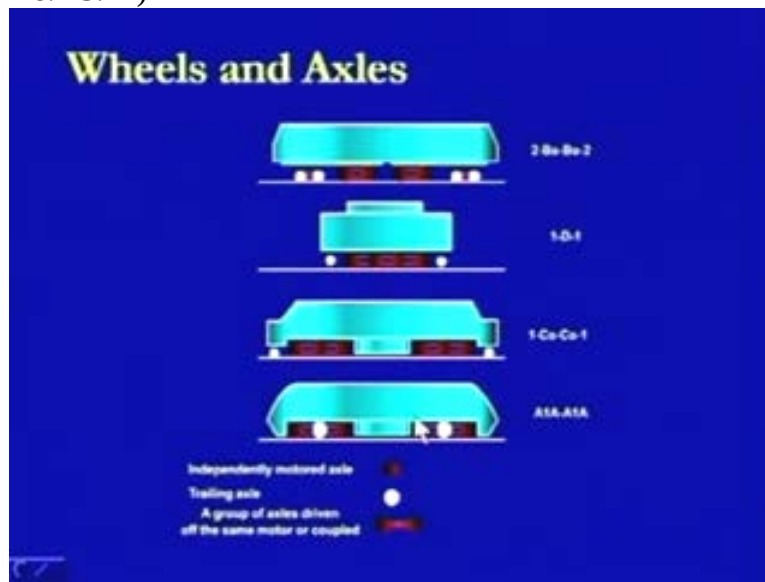
And then there is a power which is being transformed from this power side to the one this field or axle or this wheel and axle condition independently. Whereas in this case, the power is coming centrally to this one and then it is distributed to both the axle condition. The same is the condition in Co-Co where we are having three axle conditions and we are having two bogies. So this is one bogie and this is another bogie and then we have wheels like one wheel, second wheel and the third wheel. So, similarly on the other side.

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So, this is another diagram which shows condition how the two wheels or axles have been combined together in the coupled condition and the same motor which is providing the tactile power to the two wheels basis or the axles. Here, what we can see is that there is a motor pinion being provided at the centers of here. Then there is a traction motor which is being placed at this level, which provides the locomotive power to the vehicle. Now, from this motor pinion the power has to go to the wheels. So, that is why there is an intermediate gear wheel system which is provided, which connects the motor pinion with the wheel main gear wheel system. So, this is a main gear wheel system which is being connected here on this side and this is being connected here on this side. Now, this is one axle being provided here, there is another axle which is being provided here. They are the driving axles or in the center we can see the axle. So, this is one bogie side and in this one bogie frame that two wheel basis have been provided along with the coupled condition. So, that is how it is been shown in the coupled condition when we show diagrammatically, then what we do is we just join them by a broad lining.

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Now, this is the another conditions where the combinations can also be used; like we have a two Bo-Bo two condition which says that there are two front wheels and there are two trailing conditions and then in the center we have the Bo and Bo, that is, the two bogies have been provided with the independent wheels or the axle system. This is the one D one, one D one means the four axle conditions have been provided in the same bogie side and there is a one front and one trailing conditions. Similarly, one Co-Co one is the another condition where in there is a one front and one trailing axle being provided, that is, they have been shown in the white color and the Co-Co condition, that is being provided in the reddish color where again in this case there are two bogies; one on this side and one on this side and the same bogie again there are three wheel axles been provided in each of the bogies. Then there is A one A, A one A system where again we have, there is one central wheel which is the front or the trailing wheel and then there are two red wheel axle which have been provided on the two sides. Again, they are again in the independent condition. They are not been coupled together.

Now, in this case of the wheels and axle arrangements, the multiple unit locomotive are indicated by parenthesizing the unit specifications and prefixing the number corresponding to the number of units. It is a condition where the same side of the locomotive is been used in double or triple. If that is the condition, that is, if there are two unit locomotives and each unit of locomotive having one unpowered leading axle, one unpowered trailing axle and four coupled powered axles, then, they are going to be denoted by twice of 1-D-1 nomenclature. 1-D-1 is the specification of the locomotives and when we are placed twice it means we are using two locomotives of this specification so as to haul the freight or the passenger.

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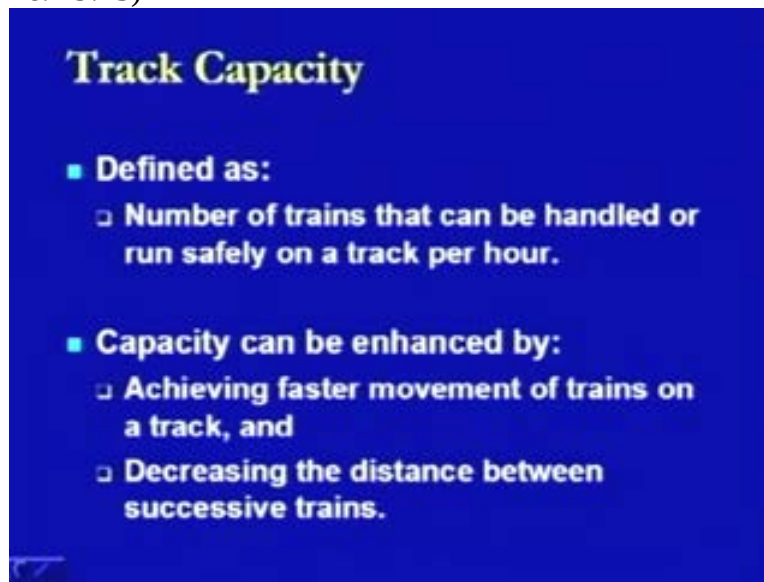
Wheels and Axles

- Multiple unit locos are indicated by parenthesizing the unit specifications and prefixing a number corresponding to the number of units
 - E.g., 2(1-D-1) for a 2-unit loco, each unit having one unpowered leading axle, one unpowered trailing axle, and 4 coupled powered axles.

Now this was all about the different types of the wheel or the axle arrangements which can be used in the steam locomotives or the diesel locomotives or in the electric locomotives. The once we have this idea of about different types of configuration, now we come to another aspects of the tracks, that is, the track capacity. Track capacity is defined as the number of trains that can be handled or run safely on a track per hour. It means depending on the number of tracks which have been provided or the number of directions in which the traffic can be moved, we can talk about the number of trains which can move per direction per track. When we have **illustrating** and then we can find out that how many trains can move in a either of the direction or in both of the directions taken together , that is, going to be defining the total track capacity of that section.

Now, in this track capacity, the one important aspect is and it always remains there so as to achieve more of the revenues and so as to become more revenue generation condition is that we have to enhance the capacity. Now there are certain ways by which the capacity can be enhanced; the two of the things which are more important have been listed here, the one case is that we can achieve the faster movements of trains on a track and that is, we are increasing the speed of the trains and if we can increase the speed of the trains it means the track capacity can be increased because we can move more of the trains on the same track.

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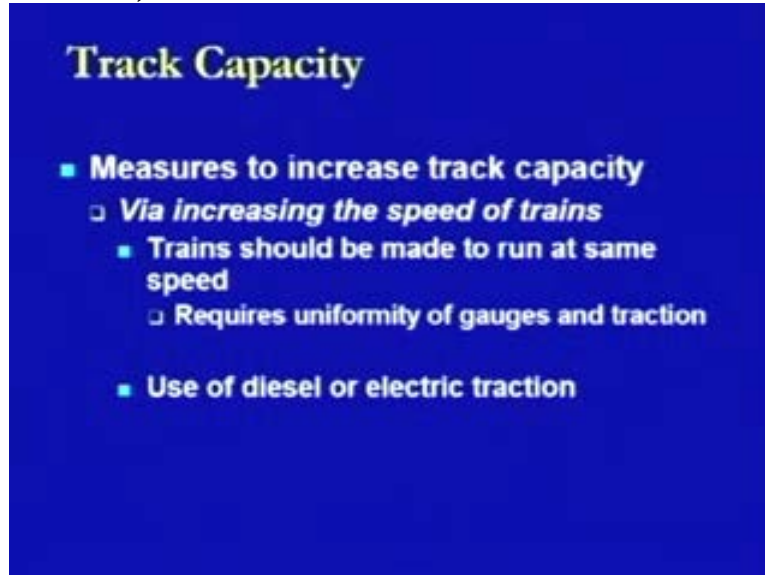
Track Capacity

- **Defined as:**
 - **Number of trains that can be handled or run safely on a track per hour.**
- **Capacity can be enhanced by:**
 - **Achieving faster movement of trains on a track, and**
 - **Decreasing the distance between successive trains.**

Another condition is decreasing the distance between the successive trains. It has another main safety emphasis here or the aspect here because if you are decreasing the distance between the two successive trains which are moving in the same direction on the same track, then there are chances of hazardous condition coming up. Therefore, the main emphasis here remains here is that how we can maintain a safer distance between the two trains so that no such hazardous condition is coming up. Now, we will be trying to look at certain measures by which the track capacity can be enhanced. As we have seen the two cases where we were taking up these two cases one by one and then we will be trying to look at certain measures which can be taken so that the track capacity can be increased.

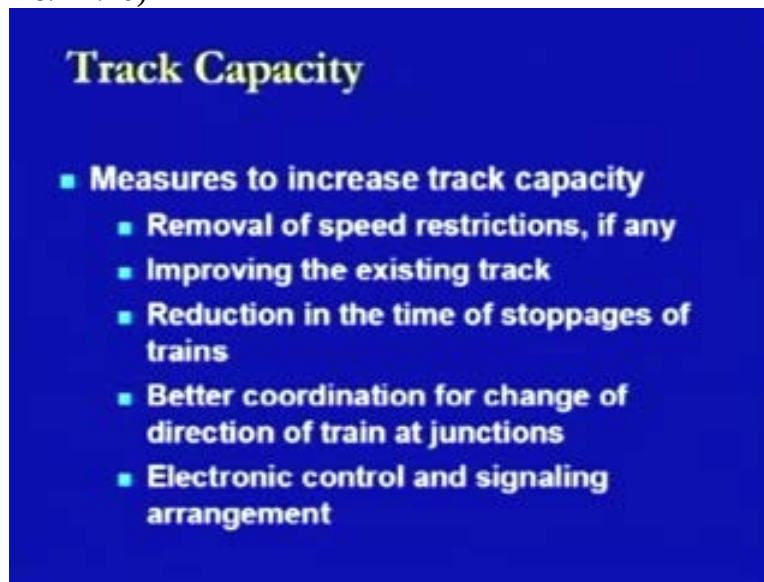
Now here in this case, the measure to increase track capacity is being taken by increasing the speed of the trains. Now, what will be the different ways by which the speed of the trains can be increased? The one is that we can make the train to move at the same speed on all the tracks. When the trains are moving with the same speed then there are chances that we will be having more efficiency than the normal conditions but then again this is not a possibility at all together in the most practical conditions. When all the trains are moving at the same speed then there is going to be a problem for the stopping of those trains at the intermediate stations. As soon as there are large numbers of intermediate stations, the same amount of the speed and maintaining that speed will be a bit difficult condition. Therefore, what is required is in this case the first aspect which need to be done is that we have to maintain the gauges uniformly and we have to provide the attractive powers as uniform as possible. One thing which is being done in that direction is the use of diesel electric traction instead of the steam locomotives which have been used from the initial starting.

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The electric traction or the diesel traction can be used us to provide the higher speed condition as compared to the steam locomotives. Of course, today with the technological advancements a large number of techniques have come by which we can achieve the speeds as high as 500 kilometers per hour but that is not the scope of discussion in this lecture. We will try to look at this aspect in some other lecture where we will be looking at high speed movements of the rails or trains. Another aspect of increasing the track capacity is in terms of the removal of the speed restrictions but those removals of the speed restriction can be done only if the geometric of the sections have been maintained in a most regular fashion. There is no such condition where the geometric restricts the speed by itself. If that is the condition then the geometric have to be rectified. Another thing is that improving the existing track. Of course, improvements always have this course of improving the things.

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If we can go for an improved tracked condition which is being maintained periodically there are all chances that the speeds can be maintained on those tracks and does not going to be a problems for again and again stopping the trains for the purpose of the maintenance of those tracks. As and when there is maintenance of the track and the vehicles or the trains will still remain moving then what we found is that we have to reduce the speed of those trains which are moving on those tracks. This is another aspect of increasing the track capacity.

Next aspect is that the reduction in the time of stoppages of the trains. What we found is that the number of stations the trains has been stopped for longer period of time because of certain reasons. We have to identify those reason and we have to find out the ways by which those stoppages can be reduced and optimized. If we can do that, then the total journey time will reduce and increase the overall journey the speed.

The better coordination for the change of the direction of train at junction is another aspect where we found that the most of the time is being lost as soon as the change in the direction is required. Whenever there is a change in the direction, what is being observed is that we have to use the same locomotive if the new locomotive is not available at that junction station or the station where the direction is to be changed. In that case what we have to do is we have to make a turnaround of the same locomotive which has brought the train at that location and then it will come to the another location of the train, that is, the rear end instead of the front end and it will be taking the train along with it and takes certain amount of time. So, that type of delay needs to be optimized again either by the provision of another locomotive or the providing mechanism by which this sort of the thing can be done in a much faster way.

Electronic control and signaling arrangement is another aspect of increasing the track capacity. If we have the most modern ways of the signaling systems or the electronic control system by which we can find out the movement of the trains on all the tracks

then there is a possibility of reducing the distance between the two trains which are moving on the same track in the same direction, still maintaining the safety and now increasing the track capacity. So, these are the some of the aspects which are associated with the increasing of the track capacity and they were also some effect in the speed of the movements of the train in the same tracks. Now we come to the aspect that is reducing the gap between the trains. What may be the different ways by which the gap of between the trains can be reduced? One such system is the multi aspect signaling system.

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In the case of the multi aspect signaling system we can provide a lesser distance between the moving trains on the same track. We will be discussing about the multi aspect signaling system and we will be taking up the signaling system or the safety control systems of the operational of the trains on the tracks in some other lecture.

Another aspect is decreasing the length of the section. When we talk about the decreasing the length of the section, it is done in terms of providing an opportunity for a vehicle, for a train which is moving at a higher speed and which requires a section where it can overtake the another speed which is train, which is moving at a lower speed. So, in this case if we decrease the length of the sections such opportunities will increase. If such opportunities cannot be increased by the lowering the length of the sections then the next thing which can be done is by increasing the length of the crossing sections or the loops. If we have increased the length of the crossing sections of the loops, again the feasibility of over taking the slower moving train by a faster moving train will increase and that is how we can provide a much faster services as compared to the normal conditions and when we are having much faster services in this case it means we are increasing the track capacity.

The next way of doing it, which is little more capital oriented is increasing the number of tracks or lines. It means, if there is a requirements or there is a heavy traffic which is moving in a certain direction then the one thing which is to be done is so as to provide

multiple tracks in the same direction, but then it requires a large number of resources. If the resources are available then another aspect which needs to be checked is the amount of land available to us for such type of development. So, there are certain intervalated aspects in this case, therefore, it is a little difficult so as to increase the number of tracks every time so as to increase the track capacity.

Interlocking of the sections and yards is another aspect. At most of the places now on Indian railway, we are having this inter locking facilities. Therefore, by provision of those interlocking facilities we have the potential of changing the trains from one lane to another track and that is how the loop conditions can be created and the trains can move at much faster and efficient movements can be achieved.

The next step which is been defined here is the use of centralized traffic control systems; this is related to the operations of the trains. This is also the safety measures and it relates to the total signaling systems which are being provided along with the interlocking systems which are provided along the sections between the two major stations where the centralized traffic control system have been provided. In this case of centralized traffic control systems, what we do is that one, we are sitting at one place with the big panel where the whole of the section have been shown and the movement of the trains are also defected on the front lines or the tracks which have been provided in that section. Therefore, by sitting at one place only we can find out the total movements of the train on different tracks and then from there itself we can control those movements by the operation of signals or by interlocking the different tracks. Again, we will be looking at this aspect and a little more to tell when we are taking of the signals under controlling systems.

Now some of the related aspects to increase the track capacity are listed here. One is the optimizing the yard operations, in the case of the yard there are number of operations which are carried out. If it is a big yard then the operations remains like the receiving of the train, the sorting of the train, the dispatching of the train. In other cases where the maintenance facilities or the servicing facilities have been provided, then we have the maintenance yards or the locomotive yards where the maintenance of the locomotives or the servicing of the wagons are taken up. All these aspects take a lot of time. Now, if we have to optimize these types of networks of different activities which are performed in any of the yard will probably again we can increase it, increase the track capacity.

Another thing is revising the standards to permit higher speeds on main tracks. As we have seen in the IR, Indian railways, specifications in one of the lectures; we have the broad gauge, meter gauge and the narrow gauge conditions and within the broad gauge conditions again we were having five categories as A, B, C, D and E. In the case of the A category of the broad gauge condition, what we have seen is that the speed can go up to a value of 160 kilometers per hour. Now, if we can increase, we can improve our standards so that we can permit higher values of the speeds on the main specifically then also we can increase the track capacity. The work is going on in this direction, probably in some period of time we will be having new specification related to high speeds tracks.

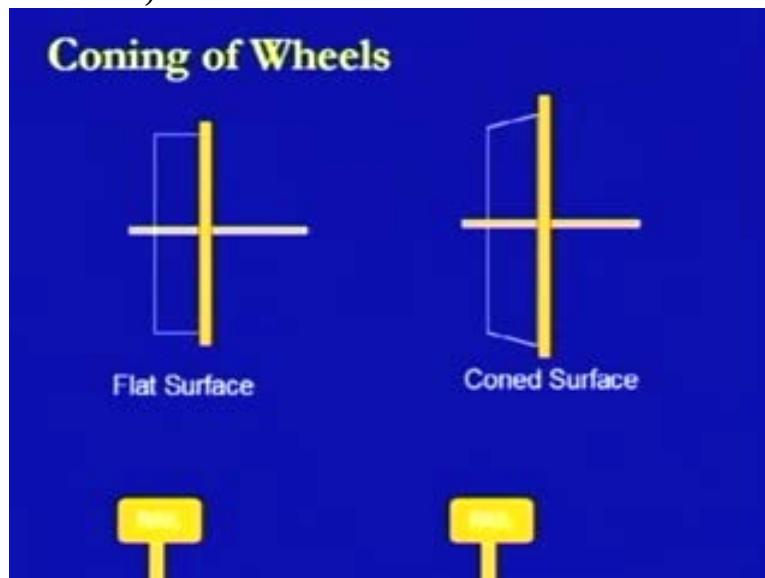
Adopting safety measures and telecommunication facilities for better movements is another way of improving the track capacity and the availability of relief mechanism in the case of the misshapenness is the another way of increasing the track capacity. If there is any accident which is taken place then how fast we can clear the tracks, how fast we can provide the relief, that is another way by which the track capacities can be increased.

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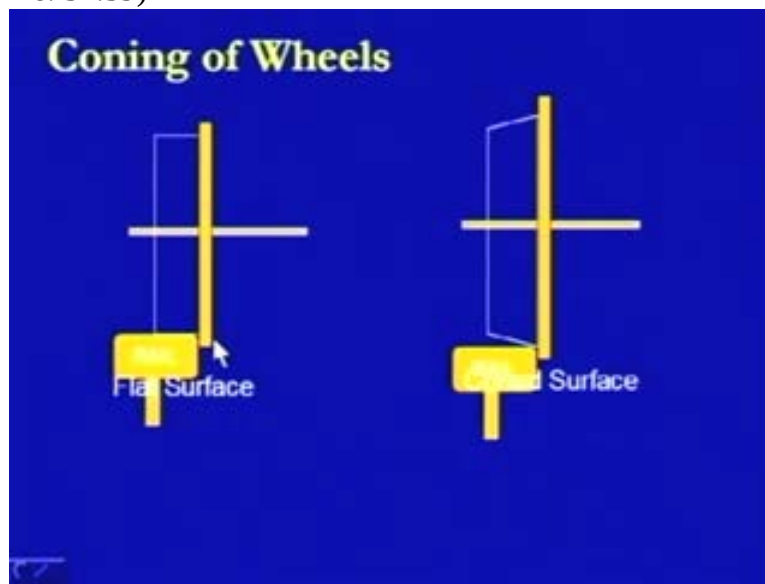
Now, after looking at the aspects of the previous one, that is we have seen about the track capacity, how we can increase the track capacity. Then the next associated feature with the wheels and the axles is the coning of the wheels. Now here in this case

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we are looking at the two conditions. There is one wheel where the flat surface is provided like this and like this. This is the axle being placed here which has the connectivity with the another wheel on the other side and this base is being provided with the flanges conditions on this side like this which is protruding outside on this side and protruding outside on this side. So, this is a flat surface condition and there is another condition where the wheel is being coned like this by making a taper at this side as well as making a taper at this side and the rest of the things ,that is, the stand meter or the excel condition or the flat conditions they remains the same. Now, if you look at this rail sections which have been provided at the bottom on which these wheels have to move. What we found is that this rail sections will come like this and therefore in this case there is a continuous connectivity of this wheel base at this position as well as if you are look at this side there is also the continuous connectivity of the front with the rail head at the side.

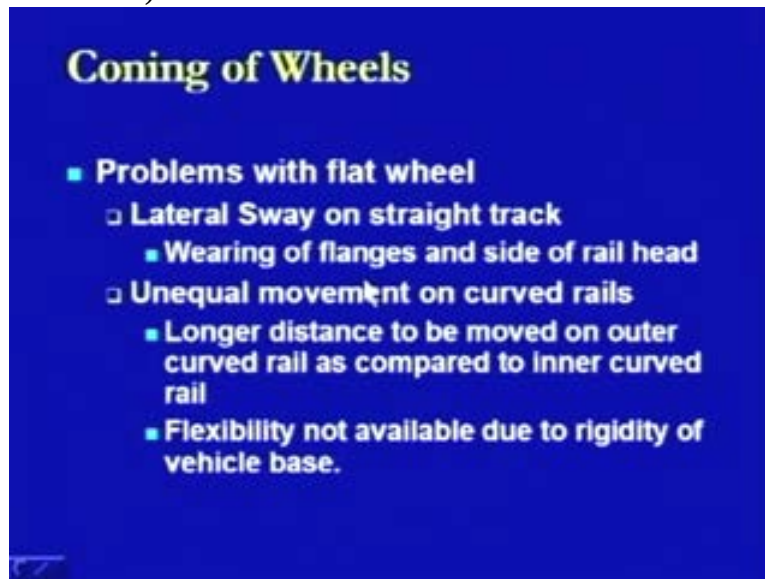
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Now, when we are having this type of flat surface condition or when we are having this type of tapered surface condition what is going to happen? In the case of this flat condition, we just think about a wheel condition of any vehicle or the road vehicle which is moving on any road. If we take the tyre, the tyre has this type of condition where it has the flat base and to that flat base all the loads get transferred to the rail section but then they remain at the same location, whatever the location is provided in that case. Therefore, certain problems associated with the flatter surfaces in the rail section because the rail section as we found here is the steel section and this is also a steel wheel base which is provided at the for a interruption of these to creates large many stresses at this location as well as this location whereas in this case there is a sort of a sleeping condition which gets created and this wheel keeps on moving this way or this way that is in lateral directions. So, we will try to compare whether we can provide this flat surface wheel base or we have to provide this cone surface wheel base in the coming slides.

Now, what we look is that there are certain problems associated with the flat wheel. One thing is that because of this condition where the flanges have been provided, there is a small distance between the flange and the rail head. Due to this small distance between the flange and the rail head there is a lateral sway which is provided on the track. You must have also observed yourself when you have been moving on any train that the train compartment vibrates in the sideward directions.

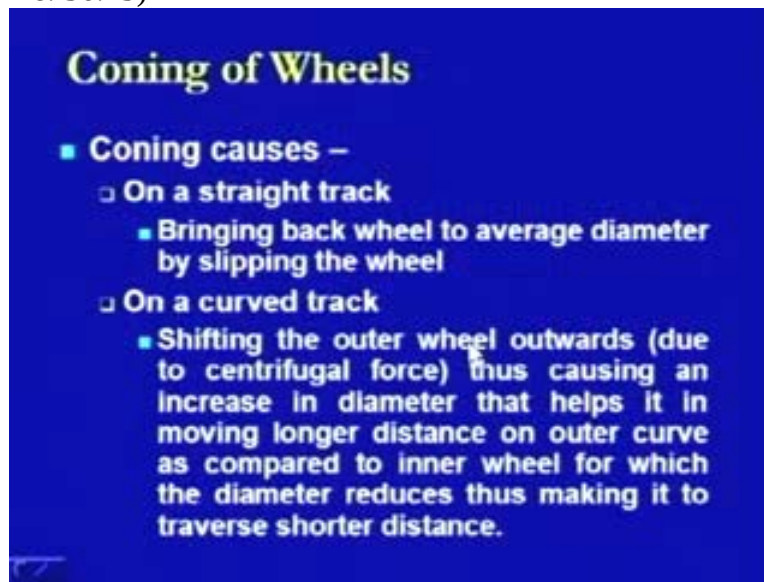
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When that compartment is moving in the sideward directions, that is, what is the lateral sway which is coming? As soon as there is a lateral sway, what happens is that it will create a condition of wearing of the flanges, at the same time it will also create the wearing of the side of the rail head. So, this is the one of the drawbacks of the flat wheels. Another condition which we can look at is in terms of the curved sections of the tracks. In the case of the curved sections of the tracks, if we take the radius of the curves of the two rail sections which have been placed parallel to each other on the curved section then what we found is that the radius of the inner condition is smaller than the radius of the outer condition and therefore when it transforms into the circumference there is a more distance which needs to be moved on the outer rail condition as compared to the inner rail condition.

It means in such condition when we are having the flat wheel condition we cannot do this because in the case of the flat wheel condition the circumference remains constant whether you are very near to the flange or you are away from the flange. When the diameter of is constant, it means the circumference movement which will be there in one rotation of the wheel will also remain constant. Therefore, there cannot be a distinction in the distance being moved on the inner rail or the outer rail or by the inner wheels or the outer wheels of the wheel base. When this flexibility is not available due to the rigidity of the wheel base then we have to look at certain other options by which we can or we can get some advantages of the movements using the wheels only and that is what is being provided by the coning of the wheels. The coning of the wheels causes on a straight track,

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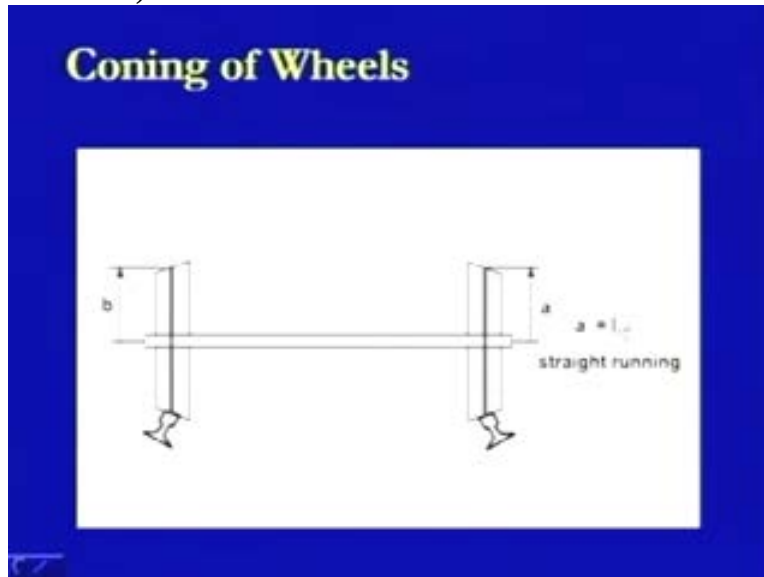
what it does is that, because it is a cone section as we have seen in the previous one slide. So, in that cone section as soon as there is a lateral sway in any of the direction there will be an increase in the diameter and because of this increase in the diameter it will try to reverse back to the average diameter condition and it is where the slipping of the wheel will take place. When the slipping of the wheel takes place, it will finally come to the equilibrium condition where the average diameter on the outer rail as well as on the inner rail will become same. As soon as there are both equal then it is a straight track condition where the train, where the vehicle will be moving on those rails in a uniform condition.

Now, when we look on the curve track condition what happens? When we are talking about the curve track sections there is a centrifugal force which acts at the outward direction. When there is this outward direction centrifugal force is acting the total track, the total compartment will try to move in outward direction literally. Then this type of movement take place, what will happen is that on the outer rails the diameter will increase whereas on the inner rails the diameter of the wheel will decrease. When this type of diameter is increasing on one rail and the diameter is decreasing on another rail the circumstantial movement moved in one rotation of the wheel will be different. Due to this differential wheel movements of the two wheels of the inner or the outer conditions we found that there is a moved distance which is being traveled on the outer track as compared to the inner track and that is how because of the coning of the wheels we can get, we can achieve what is required.

Now, in this diagram we are trying to show the same two conditions. This diagrams shows by straight running condition. We have this as a wheel which is of having a coning conditions in this directions, similarly we have a coning conditions in this directions and these are been jointed together by an axle in this way. At the centre locations of this wheels on these coning surfaces, we have the average diameter condition or what we can say is that this is A and B which has been shown here. The average radius

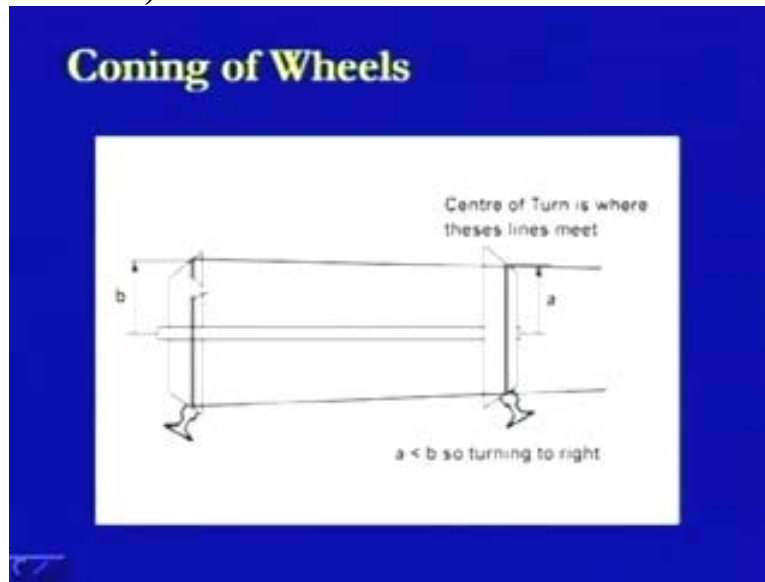
is half the wheels which have been connected on the same axle. As far as there is a straight running condition, the straight running can be achieved only if both of the wheels are moving in the same distance in one movement or one revolution of the wheel, and in that case this is possible only if that this radius of this wheel, that is A and the radius of this wheel, that is B, they are equal to each other.

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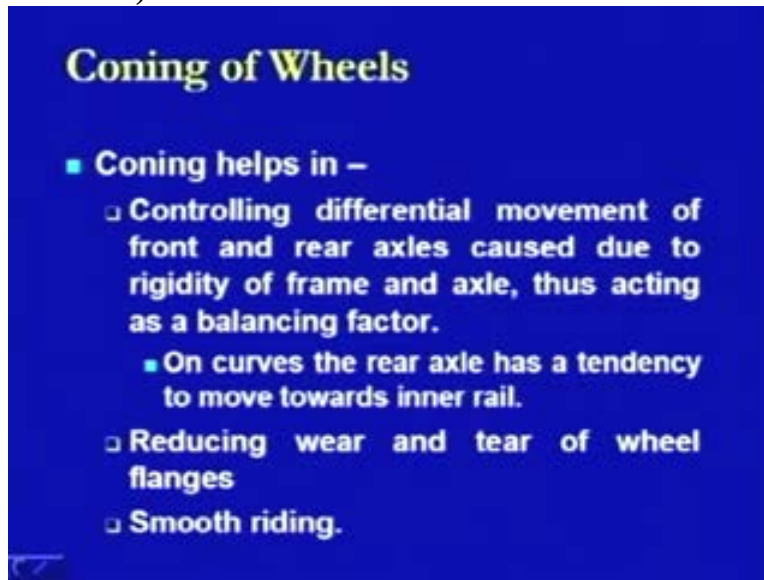
There is another condition in this diagram where we are taking our **cross** section in the case of the **cross** section, we are assuming in this diagram that the centrifugal force is acting towards the left hand side because the track is taking a turn towards the right hand side. So, if that is the condition which is happening, this whole wheel base will move in the laterally towards the outer direction like this, that is, towards the left hand side. When this movement is taking place in this direction, then what is happening is that the diameter of the wheel on the left hand side will increase on the rail section whereas the diameter of the wheel on the right hand side wheel section will decrease. It means here the B is greater than A. When B is greater than A, then the more distance will be moved on the outer rail this side whereas the lower distance will be moved on this side and it shows that when B is greater than A it is taking to the right turn. So, this is what is the advantage of making of the coning of the wheels.

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So, as soon as we have done this type of a coning of the wheels, we can achieve the different types of the movements which can be there in sections which are provided on any of the track. Therefore, what happens is that the coning helps in controlling differential movement of front and rear axles caused due to the rigidity of the frame and axle and thus acting as a balancing factor. In the case of the curves, what we have seen is the real axle has the tendency to move towards the inner rails and that is why there is, we have to control this type of phenomena. If you are not controlling this type of phenomena then there is another condition which gets created, that is, the derailment of the trains. Reducing the rear and tear of the wheel flanges is another condition because as soon as the diameter increases on one side, it tries to come back to the equilibrium condition and the equilibrium condition means it tries to come back to the average diameter condition.

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So therefore, as soon as there is a lateral sway and the wheels or the flanges strikes the rail head under outer wheel condition, it will start reverting back because of the coning of the wheel. As soon as its starts reverting back because of the coning of the wheels there will be lesser amount of rear and tear of wheel flanges and because there is a turning of the tracks and the coning of the wheels is helping us to attain the differential movements. So therefore, there is a smooth riding which will be attained on the track.

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Now in this case, this is a diagram which is trying to show that what is happening when we have a rail section which is being provided in this form where it is a horizontal surface at the top one and we have the wheel where the cone surface have been provided like this.

Now suppose this wheel is having a lateral sway, either it is moving towards the right or it is moving towards the left. This is how it is be having increase or decrease in the diameter on the rail head. What we have can find here is, there is a concentration or localization of the stresses at a certain point on the rail head. Now, at this concentration or centralization of the stresses is happening then there will be more wear and tear at this location where this type of connectivity will be taking place. At the same time because this connectivity is not there uniformly at this position, there is an eccentricity which will be created in this rail head. So, this type of eccentricity is getting created, it will create a problem to the rail sections because there will be some binding which will be created because of the eccentricity in this one. So, we have to look at these aspects in this case because the coning of the wheels also creates some problems and we have to rectify those problems so as to achieve a condition where everything remains constant, where everything remains in the equilibrium condition and the comfortable zoning can be attained.

So, what we can do is we have to look at two things, what are two problems which are there. One is the wear and tear due to the slipping action.

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Coning of Wheels

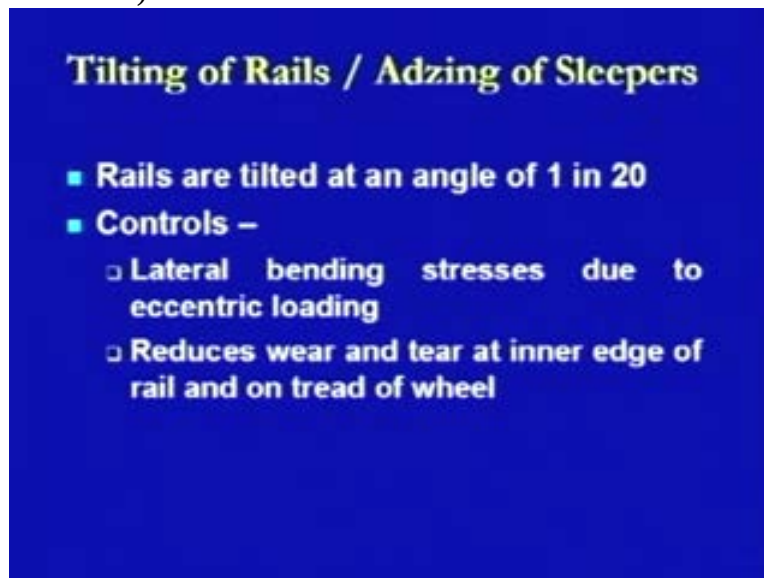
- **Problem with Coning of Wheels**
 - **Wear and tear due to slipping action**
 - **Slip of wheel = $\frac{[2\pi\theta/360]}{G} \times G$**
 - θ = angle made by rigid wheel base at center of the curve
 - **BG slip = 0.029 m per degree curve**
 - **Eccentric loading on rails**

The slipping action is defined in terms of the slip of the wheel which is governed by the angle which is been made by the rigid wheel base at the center of the curve. Here the theta is been shown as that angle. So, if we have this theta angle and therefore there is a movement which will be there as $2\pi\theta$ with respect to the 360 degree turning of the wheel and G is the gauge, then this total value of $2\pi\theta$ divided by 360 multiplied by the gauge value gives the slip of the wheel and this slip of the wheel in case of the broad gauge condition is equivalent to 0.029 meters per degree curve. So, because of this slip of the wheel condition there is a wear and tear action which will be taking place and there is I have just told you that in the previous diagram there is an eccentric loading on the rail sections and this eccentric loading on the rail section causes banding or bucking of the

rail sections. Therefore, we have to remove all those conditions. So there are certain measures which need to be taken with respect to the wheel section because the coning is already being provided on the wheels, and that is what is known as the tilting of the rails and the associated feature with that one is the adzing of sleepers.

In the case of the tilting of the rails, what we do is that the rails are tilted at an angle of 1 in 20. This angle 1 in 20 is the same angle at which the wheels have been coned. Therefore, where soon as we have the rails been tilted at the angle of 1 in 20 that top most surface of the rail head will come into contact with the base surface of the wheel and therefore there will not be any localization of the stresses, the whole of the stresses will be transformed or transferred by the total amount of the contact area which will be there and now in this case the total amount of contact area will remain the whole of the rail head or the whole of the width of the wheel of the train. Now, in this case, as soon as we have tilted the rails at the angle of 1 in 20, what all the controls which will be achieved? One control is that the lateral bending stresses due to the eccentric loading will be removed, they get eliminated because in this case now there is no eccentric loading.

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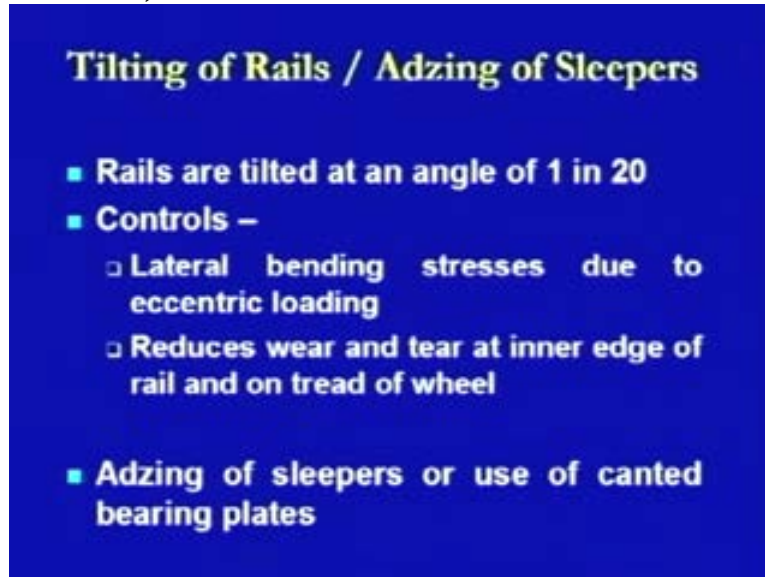


Therefore, there is no chance of banding taking place or buckling of the rail taking place. It also reduces the wear and tear at the inner edge of the rail as well as the tread of the wheel as we have seen in the previous one diagram where in the case of the horizontal rail section there is a central one point at the side of the rail head where the wearing was taking place and this was the trailing of the wheel was also becoming at that location only. If we are provided the tilting of the rail sections then it will reduce the wear and tear in this case.

Now, once we have done the total tilting of the rails, the rails have their foot and this foot is placed on the sleepers and then it is tied to the sleepers using the fastenings. Suppose the base of the rail is being tilted, then again what is going to happen? In this case, again

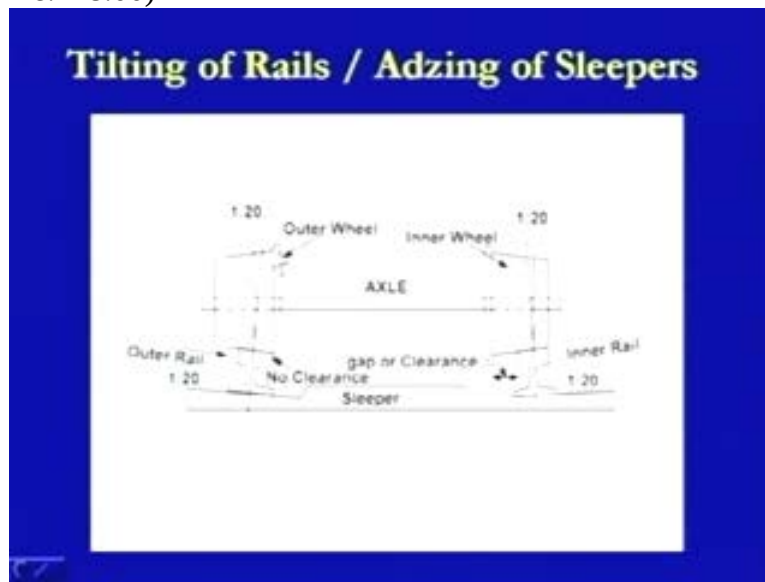
there will be the same sort of conditions as we have seen in the case of coning of the wheels but still not making the tilting of the rails. As soon as the base of the rail is being tilted there will again be a localization of the stresses at one point and because of this localization of stresses at one point, there will be more stresses being induced or higher stresses being induced and the indentation will take place in the sleeper. If the indentation is of a much higher value, then it may also track the sleeper at that location but that is failure condition which may be achieved at a much last stage. So therefore, there is another thing which is done which is known as adzing of sleepers.

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Adzing of sleepers means there is a group which is being cut at the base of the rail head and this group is also having an angle of 1 in 20. Therefore, in this case when the angle is 1 in 20, what will happen is that the rail base will get seated into that group. Now, we look at this diagram and try to correlate the tilting of the rails and the adzing of the sleepers in this diagram.

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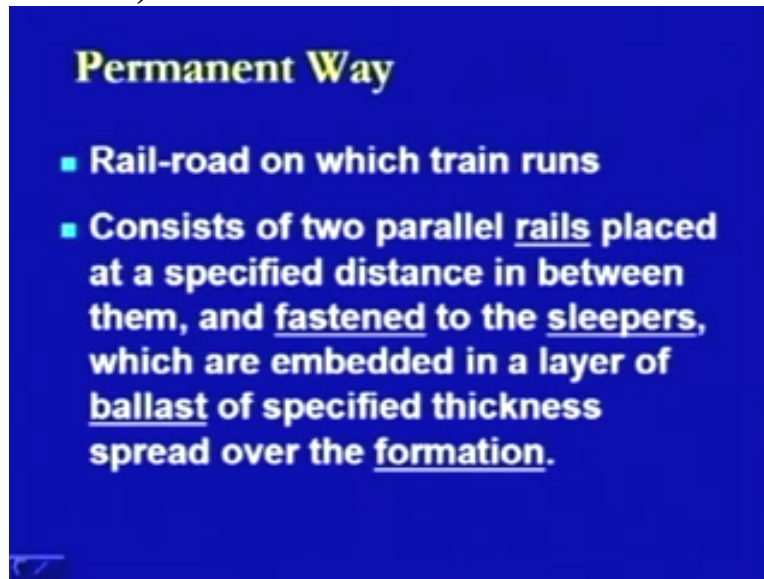
Here this is the wheel, this is the flange. This wheel is being having a cone condition and this angle is 1 in 20. This wheel is being connected by the rigid wheel base to another wheel on this side which is the also coned at 1 in 20. In the case of the tilting of the rails, if you are not doing the tilting of the rail then the rail will remain horizontal like this and therefore there will be only a single point of contact at this location whereas now as the rail is being tilted at 1 in 20 angle, therefore this whole of the surface is in constant touch with the wheel base. Therefore, the total amounts of the stresses of the loads are going to be transferred through all of these sections.

Now, another aspect which we were looking is the adzing of sleepers. If we have tilted the rail section like this then the base of the rail section will also get tilted and in this case if we have providing the straight sleeper like this one then again at this location there will be penetration of the rail in to the sleeper. That is why what we do is that we provide the tilting of the sleeper base also at this location. This may be in the form of adzing or may be in the form of making a groove in this location or providing a chair where in this rail is being seated into the chair which is attached to the sleeper so that it remains fixed in location and this sort of an angle making in the sleepers so as to seat the rail is known as adzing of sleepers. So therefore, we have a tilting of the rails instead of straight forward like this in the vertical direction it is been changed to this one, 1 in 20. Similarly, here instead of having it as a horizontal condition it is been transformed in 1 in 20. So, this is about the tilting of the rails and adzing of the sleepers.

Now the next thing which I am interested to take today is about the permanent way. Though I was interested in taking of this one in the previous one but because of shortage of the time we could not take it. We will just try to look at some of the aspects related to the permanent way. In the case of the permanent way, it is defined as rail roads on which the train runs or in a more detailed form, we can define it in the form of it consists of two parallel rails which are placed at a specified distance in between them and which are

fastened to the sleepers, which are embedded in a layer of ballast of specified thickness is spread over the formation.

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It means and in permanent way consists of certain components and those components are the rails, the sleepers, the fastenings, the ballast and the formation level. So, if we take all these things together that is constituting the permanent way. So we try to look at what are the requirements of any permanent way. In the case of any permanent way, as we are looking at different components, the very first component is the rail and the rails have to be placed at certain distance parallel to each other and that distance is nothing but is defined as gauge. Therefore, in this case the gauge should be correct and uniform. If the gauge is not correct or is not uniform throughout the rail section it will cause derailment of the rails.

Another aspect related is the cross levels of these rails which have been placed to the gauge distance. Here we have the two conditions; the one condition is related to the straight track and another condition is related to the curve section. In the case of the straight track the cross levels about the rail section has to be maintained at the same level whereas in the case of the curved section the cross levels will be different and the cross level of the outer rail with respect to the inner rail will be at a distance higher by that one into value of super elevation. We will take this super elevation when will discuss the geometric of the railway tracks.

Next aspect is related to the alignment. Alignment has to be straight as far as possible and it should be free of the kinks because the kinks are the points of weaknesses. At the same time they are the points of discomfort created to the passengers. The gradience needs to be uniform in general as far as possible. If they are uniform or they are gentle in that case we are going to achieve more comfortable journey than otherwise.

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Permanent Way - Requirements

- Gauge should be correct and uniform
- Cross levels of rails – Straight / curved section
- Alignment – Straight and free of kinks
- Gradient – Uniform and gentle

The next point is the resilience and the elasticity of the track. The resilient and the elasticity of the track is the another important aspect because there are large amounts of loads which are coming from the top and which are transferred through the rails or the sleeper to the ballast section or the for the machine level. So if the track is not resilient and gets deformed because of the loads which are coming from the top, then it is going to fail in the very short period of time. So that is why it is very important that the material which we are using is resilient and elastic in nature as far as possible. Another aspect associated with the requirements of the permanent way is drainage. Drainage has the direct consequence on stability. If there is a more of the drainage, it is going to be a detrimental to the life of the materials which have been used in the construction of the permanent way. Therefore, it is required that there is no water logging along the permanent way and the water should get drained as fast as possible.

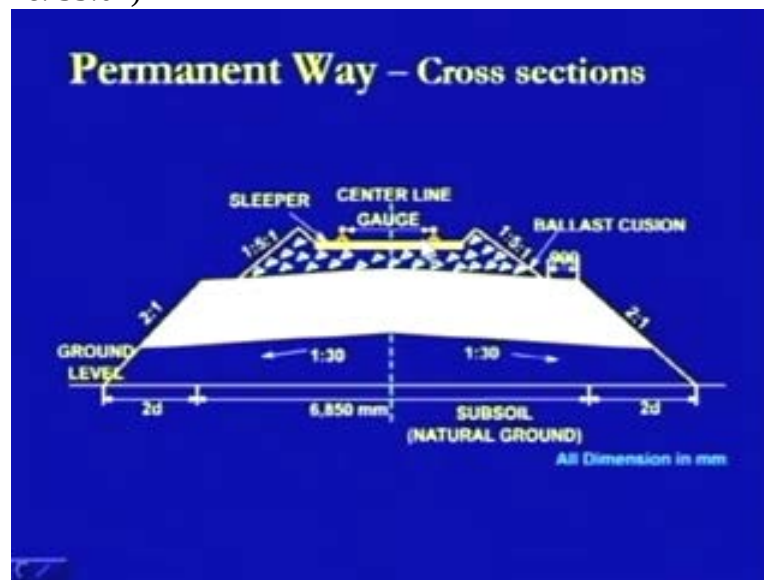
Lateral strength is another important aspect. As we have seen in the coning of the wheels there is a lateral sway which is taking place because of the small difference which is provided between the rail head and the flange of the wheel. Therefore, there is a short and vibrating condition which will get created when the train moves over those rails. Due to this condition the track should have lateral strength and this lateral strength comes from the **web** of the rail section; from the sleepers, the width of the sleepers and the ballast cushion which is provided in the railway track and finally they should be having the materials or the components which can be replaced or which can be renewed as easily as possible with the minimal amount of the maintenance cost.

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And obviously when we see about the maintenance cost and all these, finally the cost of construction, the cost of maintenance or the cost of operation of those railway permanent ways should be minimum. So, these are some of the important requirements of any of the permanent way which is to be provided. Here in this diagram a cross section of the permanent way has been shown.

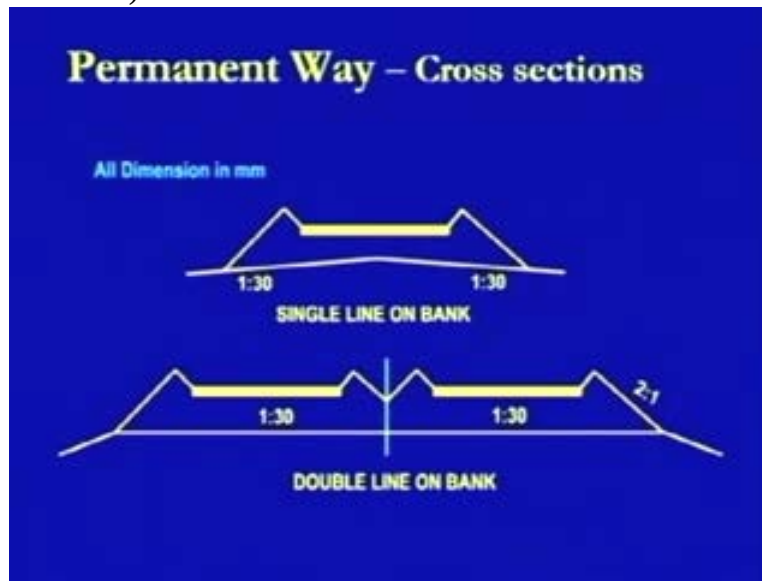
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Here what we can see is that a single track condition where this is a two rail sections which are been provided at a uniform distance which is termed as the gauge distance. Then this is the sleeper provided below the rail sections and on the side of the sleepers there is a ballast which is being provided. Below the sleeper section again there is a ballast cushion which is being provided. The thickness of this ballast cushion as we have

seen previously varies from 200 mm to 300 mm. Then there is an **alignment** on which the ballast cushion is resting. In the case of the ballast cushion the side slope is being taken as 1.5 is to 1, that is, from the stability of the slopes. In the case of this the slope is being taken as 2 is to 1. Now we look at another slide where the single line on bank or the double line on bank is being shown where the bottom 1 is to 30 slope is been provided for the drainage point of view.

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So dear students, today we have looked at some of the features related to the wheel and axle configurations. We have also looked at the track capacity and the methods by which we can increase the track capacity and then we have taken the associated feature of wheels, that is, the coning of wheels. Apart from these we have also seen about the permanent way, their requirements and the cross section. In the next lecture, now we will continue with the resistances which are offered by the permanent way and how it transforms into the attractive power or the rolling capacity of the locomotive. We stop at this point and good bye. See you in the next lecture. Thank you.