

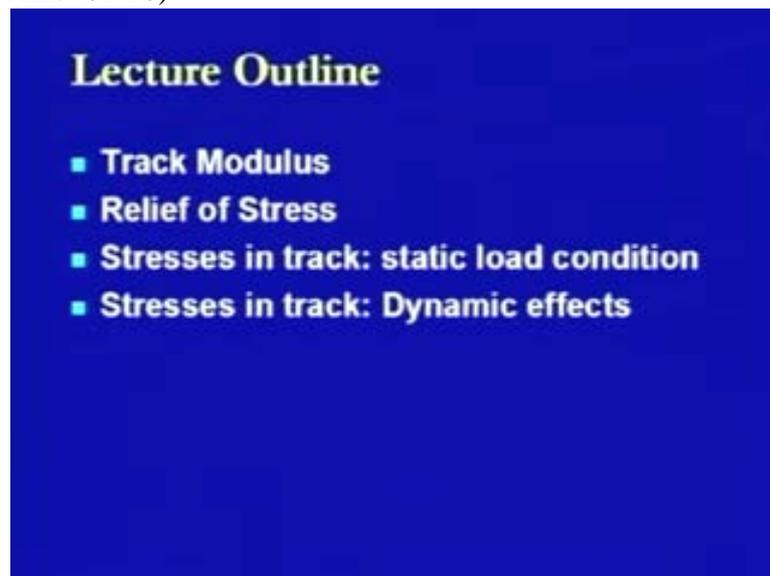
Transportation Engineering -II
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Lecture - 5
Track Modulus, Stresses in Track

Dear students, I welcome you back to the lecture series of course material on transportation engineering two. In the previous lectures, so far, we have discussed about the different resistances being offered on the track and the permanent way on its components. We have also seen about the requirements and the necessities of providing the permanent way. In continuation of that, today we will be discussing the related aspects of resistances, that is, track modulus and stresses in tracks.

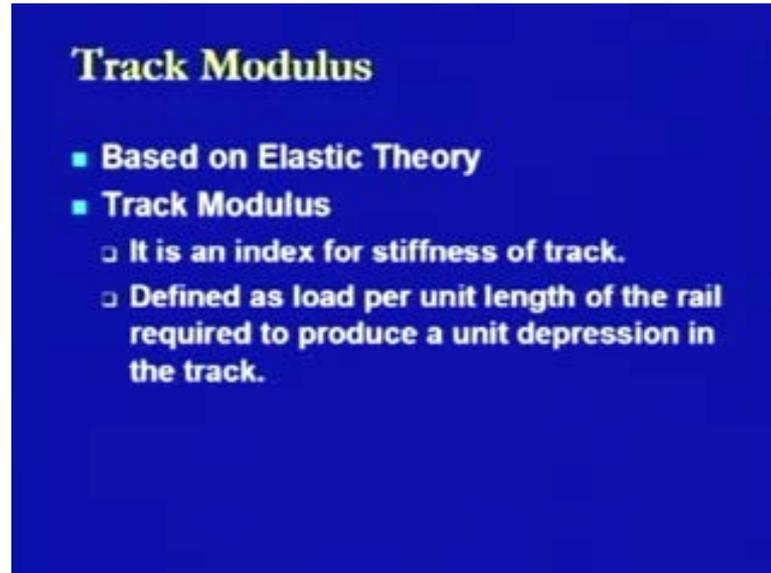
In this section the lecture which will be taken up, it has the outline as track modulus, relief of stresses, stresses in track under the static load condition and stresses in track under the dynamic effects.

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Now when you take up this stresses, it means we are talking about the different loads which are coming from different quarters. Some of these loads we have already discussed previously when we discussed about the resistances or when we have discussed about the coning of wheels because of which different loads are coming from the longitudinal direction or the lateral direction or in the vertical direction or the horizontal direction and likewise. Now, on the basis of all those resistances or the loads which have been offered on a track, we will be discussing the stresses.

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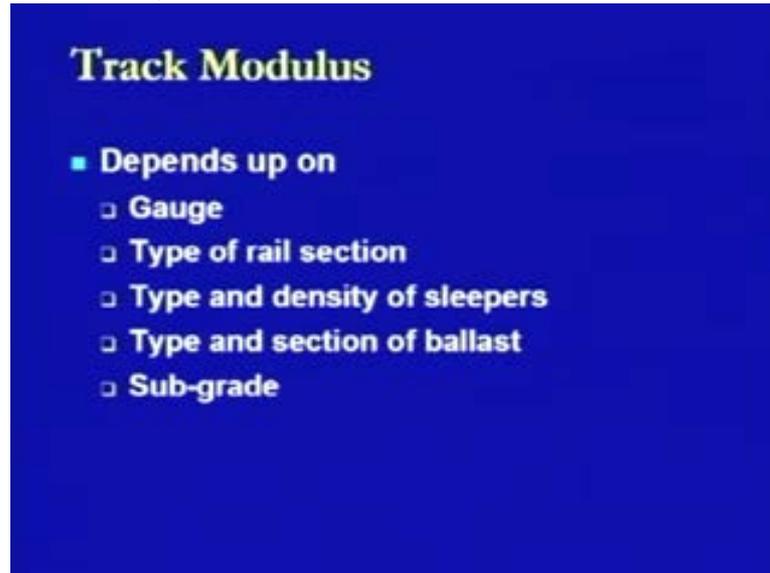
Track Modulus

- **Based on Elastic Theory**
- **Track Modulus**
 - **It is an index for stiffness of track.**
 - **Defined as load per unit length of the rail required to produce a unit depression in the track.**

First of all, we will be starting with the track modulus. The track modulus is based on the elastic theory. It is a thing which index, which defines the stiffness of the track. When we talk about this stiffness of the track, it means we are talking about the load bearing capacity in indirect form of the track. Whatever are the loads which are coming on the track, they should not create any deformation or they should not create any failure to the track. In that sense, if the loads have been removed then the track should come back to its original condition and that is where the elasticity comes into picture and because of this phenomena where we are talking about the depressions or we are talking about deformations which have been caused in any track and which have been removed, on the removal of the load from the track we are using the elastic theory.

In this elastic theory, here the track modulus is defined as the load per unit length of the rail required to produce a unit depression or deflection in the track. It means, here we are going to talk about the amount of depression or the deflection which is going to be caused because of the imposition of load at the top of the rail section, because of this imposition of the load at the top of the rail section, the deformation will come to the sleepers which have been provided at the bottom of the rail and on the basis of those depressions or deflections which have been caused which can be measured using the steam gauges, we can find out what is going to be the track modulus.

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This track modulus is dependent on number of factors. The factors are been listed here: it is gauge, type of rail section, type and density of sleepers, type and section of ballast and sub-grade. We just briefly make a discussion about what is going to be the effect of all these factors on the track modulus. Now if we talk about gauge, gauge as we have seen previously, they have broad gauge, meter gauge and narrow gauges in the Indian railways or the hill gauge also which is being used in some specific locations on Indian railways. In this case as the gauge increases because of the components of those permanent ways which also increases in size, the track modulus increases. Therefore, if there are more of the loads which are coming up at the top section, we require to provide a better track modulus so as to resist those loads which are coming from the top and this is why the bigger gauge is to be used.

Another thing which is a component of this track is the rail section. What type of rail section we are using is another important thing. Here when we are talking about the type of the rail section, we are mostly related to the sectional area of that rail section or we are also interested in the ultimate tensile strength of the rail section which will be there, which will be resisting the total loads which are coming from the top or from the sides. So, in that sense, we have to look at those rail sections which are heavier in nature, that is, as we have seen previously that some of the rail sections which have been used depending on the gauges; they are 52 kg per meter rail section or 60 kg per meter rail section or in the meter gauges we have 75R or 90R or 60R rail sections. So based on those rail sections we are going to have different track modulus. Similarly, when we are talking about the ultimate tensile strength, we may be having the ultimate tensile strength as 72 k g per mm square or in the new rail sections this ultimate tensile strength is taken as 90 kg per mm square. Therefore, if we are using a 90 kg per mm UTS section, obviously it is going to provide you a better track modulus as compared to the other section.

Similarly, when we discuss about the sleepers, here we are talking about the sleepers in terms of what type of sleepers we are going to use and second thing is what are the number of sleepers which have been used for rail length, because here the track modulus is being defined in terms of the unit rail length. So in that sense, if you talk

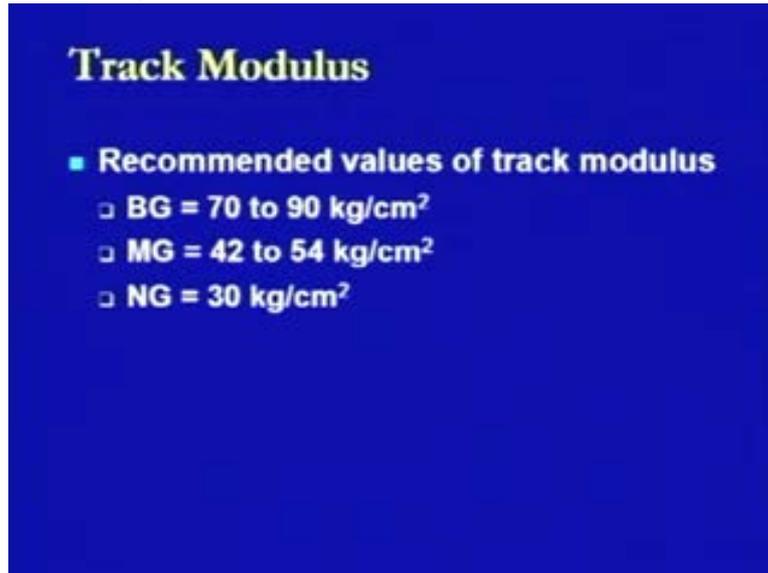
about the sleepers, we have a wide variety of sleepers available to us. Of course, these varieties of sleepers we will be discussing when we take up the lecture on sleepers exclusively but as far as the track modulus is concerned, as far as the different types of sleepers are concerned one thing which we can use is the concrete sleepers which are quite heavy sleepers in use on all those sections where the loads which are coming from the top are heavier or where the speeds are much higher. Similarly, when you talk about the density of sleepers, here we are going to define this density of sleepers in terms of the number of sleepers being used for rail length or in other form we can also talk about the number of sleepers which have been used per unit length of the rail section. So it means, if you have more of the sleepers at the bottom where in trying to provide more strength to the track and when we are trying to provide more strength to the track, it means the track modulus is also going to increase.

Similar is the case when you talk about the ballast section. Ballast section is the third component as we have seen previously in permanent way or a track. Here again we have different types of the ballast materials which can be used. We have the crushed slag or the ashes or the **cankers** or the crushed stone aggregates. Obviously, depending on the type of the material and its characteristics or the characteristics in terms of the load taking characteristics of those materials, we can define the track modulus. Better is the material, higher is going to be the track modulus. Similarly, when we talk about the section of the ballast as we have seen in the Indian railways specifications, the ballast power has been provided for ranging from 200 mm to 300 mm. More is the ballast power; obviously, more is going to be the track modulus in this sense.

The last component on which track modulus depends is the sub-grade. Sub-grade is the lowest or the lower most formation level on which all these components are resting. In that sense whatever is the material which has been used in this sub-grade is going to define the track modulus. This is a section or this is the layer which just provides a rebound to the total stresses or the loads which are coming from the top. Therefore, this is the final layer which is going to sustain the loads. If there is any failure on this section or this component of the track, then obviously the whole of the things are going to fail. In that sense, the sub-grade has to be defined in terms of the load taking capacity or the load bearing capacity of the material.

Here again the type of the material which has been used in that sub-grade is going to define the track modulus. In that sense, if the material is better or what are the soil characteristics? What is its gradation? What are the plasticity indexes etcetera, the different characteristics of the soil stratum. They are going to define the track modulus further. So it means that the track modulus is not the single thing which can be found out directly by using one component of a track because of the different components which have been associated with the track, we have to take all those components into consideration before finding out the value of the track modulus, but on the basis of the different components and their related values which can be there we can also compute this track modulus in some sense.

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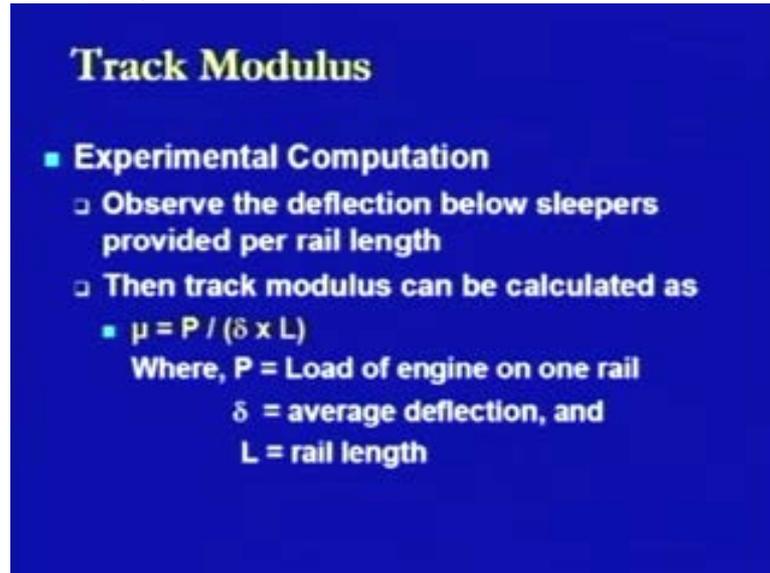
Track Modulus

- Recommended values of track modulus
 - BG = 70 to 90 kg/cm²
 - MG = 42 to 54 kg/cm²
 - NG = 30 kg/cm²

We will be looking at how we can compute those track modulus in the coming slide. Here the recommended values of the track modulus for the different gauges have been shown. What we can see is that if we go from the higher gauge to the lower gauge, that is, from the broad gauge to the meter gauge or from meter gauge to the narrow gauge the value of track modulus is decreasing. It is 70-90 kg per centimeter square in the case of the broad gauge whereas it is 40 to 54 kg per centimeter square in the case of meter gauge. Lastly in the case of narrow gauge this value is almost one third of what we are getting in broad gauge or you can see it ranges from one half to one third ,that is, it's around 30 kg per centimeter square

Coming to the computation of track modulus, as we have discussed in the definition, that track modulus is to be defined in terms of the load in terms of the unit length of the rail section and in terms of the deflections which have induced in that rail section because of the load. It means we have to take into consideration the load, the length and the deformations or the deflections and this is what is being taken in the formula which is being shown here as $\text{modulus} = P \text{ divided by } \Delta \text{ multiplied with } L$. So it means what we have to do is, is that this is the load which is coming from the top; so we know that this is the load of engine on one rail and L is the length of the rail section and delta is the average deflection. So this needs to be computed because this P is known previously, this L is also known previously. This is a standard value whereas this value is varying but we can look at the heaviest engine or the locomotive which is coming on that rail section and on the basis of that heaviest locomotive, we can take up this load value. So therefore, this P and L are more or less constant value as far as the track is concerned. The thing which is varying is delta and we have to compute this value of delta, that is, the average deflection.

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Track Modulus

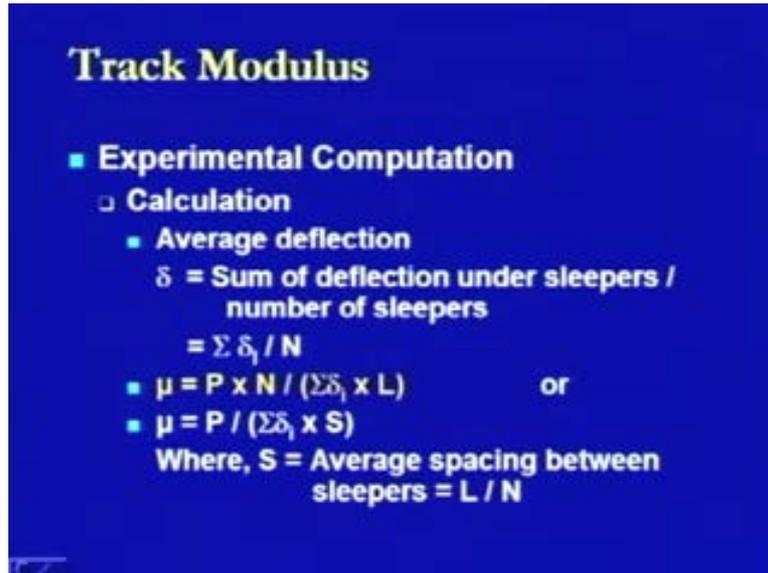
- **Experimental Computation**
 - **Observe the deflection below sleepers provided per rail length**
 - **Then track modulus can be calculated as**
 - $\mu = P / (\delta \times L)$

Where, P = Load of engine on one rail
 δ = average deflection, and
L = rail length

Now, so as to find out this average deflection, what is to be done is that we have to observe the deflection below sleepers provided per rail length. Now, here either we can do in the sense that we take a unit length of the rail section and then on that unit length of the rail section we take up the number of sleepers will be provided for that one but this is a little difficult situation because of the spacing of this sleepers which needs to be provided. We are not providing the sleepers adjacent to each other **or to each other**. In that sense, it is easier to compute the things based on the total section of the rail which is being manufactured by the company, which is roughly around 12-13 meters and then for that rail section or rail length there are number of sleepers being provided. So, for all those sleepers which have been provided below that rail length we compute the deflection and once we have computed this deflection then we can find out the average deflection. So, that is how we can compute the value of the track modulus, that is equals to the load divided by average deflection multiplied with the rail length.

Here again, the same average deflection has been shown that how we can compute this average deflection. In this case the delta 1 or delta i can say this is the deflection which is being caused at one sleeper provided below the rail and the number of sleepers which has been provided below the rail. See there are N numbers of sleepers being provided; therefore there will be N number of delta values available to us. So we can take the sum of all those N values of delta and then divide by N, we will get the average deflection. Say if you put this value in the previous formula which we have seen, then it becomes μ is equals to P into N divided by summation of all the deflections multiplied with the rail length L, and in this case if we take this value of L and N, that is, the rail length divided by the number of sleepers then it will transform into another standard value which is termed as the spacing of sleepers that is S. So S is nothing but is the average spacing between the sleepers and this is defined as L divided by N.

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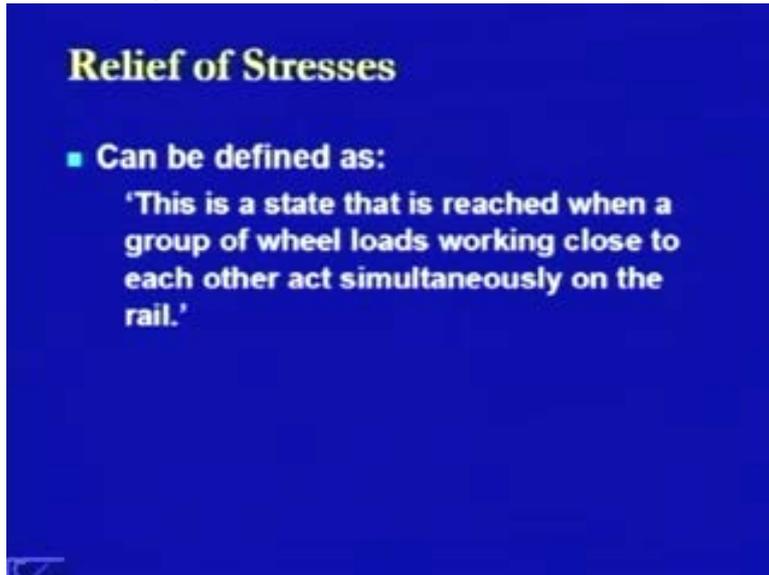
Track Modulus

- **Experimental Computation**
 - **Calculation**
 - **Average deflection**
 $\delta = \text{Sum of deflection under sleepers} / \text{number of sleepers}$
 $= \sum \delta_i / N$
 - $\mu = P \times N / (\sum \delta_i \times L)$ or
 - $\mu = P / (\sum \delta_i \times S)$
Where, $S = \text{Average spacing between sleepers} = L / N$

So, if you put this value in this case what we found is that the modulus of the track is nothing but it is the load applied or coming from the top on the track divided by the summation of the deflections on all the sleepers which have been provided below a rail length multiplied with the spacing of the sleepers, and as soon as this is another standard condition which is being created because this spacing of the sleepers also is defined previously as far as the specifications are concerned. Now as these specifications are known, we know the P value or we know the S value. The only thing which again needs to be measured is the deflections on all the sleepers provided on any of the rail length. So, again only one parameter is there out of the three parameters which needs to be experimentally computed and then we can finally compute mathematically the value of the track modulus. Now depending on the units which are being used in this case we can get this track modulus as tonne per square or kg per centimeter square or mm square. So this is how we can compute the value of the track modulus in the case of various tracks.

Another important thing is that whatever stresses are going to be induced in any track, is there any situation where these stresses get nullified or they get reduced because of certain other actions. If this type of situation is being created then it is going to be helpful to the track itself, and what we found is there are certain mechanism which are going to happen and that reduces the amount of stresses which have been induced in the track and this is what is known as the relief of stresses.

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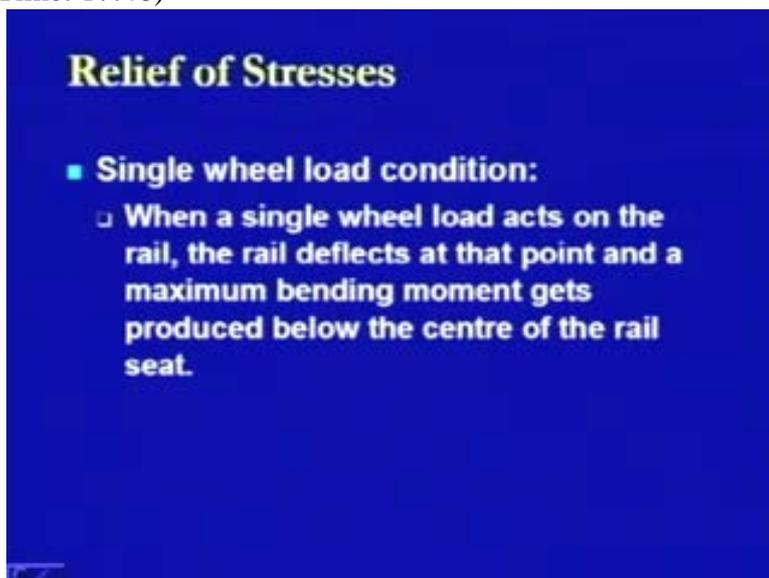


Relief of Stresses

- **Can be defined as:**
'This is a state that is reached when a group of wheel loads working close to each other act simultaneously on the rail.'

So therefore, this relief of stresses can be defined as the state that is reached when a group of wheel loads working close to each other acts simultaneously on the rail. Now as we have seen previously when we were trying to define and compute track modulus, as soon as the load is being applied from the top, there is deformation or depression that is created at the bottom on the rail section. Now, because of that load which is being caused at that point there is going to be certain bending moment and because of this bending moment there will be a positive or negative bending moment which will get created. So we have to look at the conditions which are going to create the relief of stresses. Now here, there are two types of conditions which can be there; one is there is only a single wheel load which is coming from the top, which is most ideal condition otherwise it is not happening in actual on the tracks, because on the tracks we have the moving rolling stock which is a combination of different moving parts that is locomotive and wagons.

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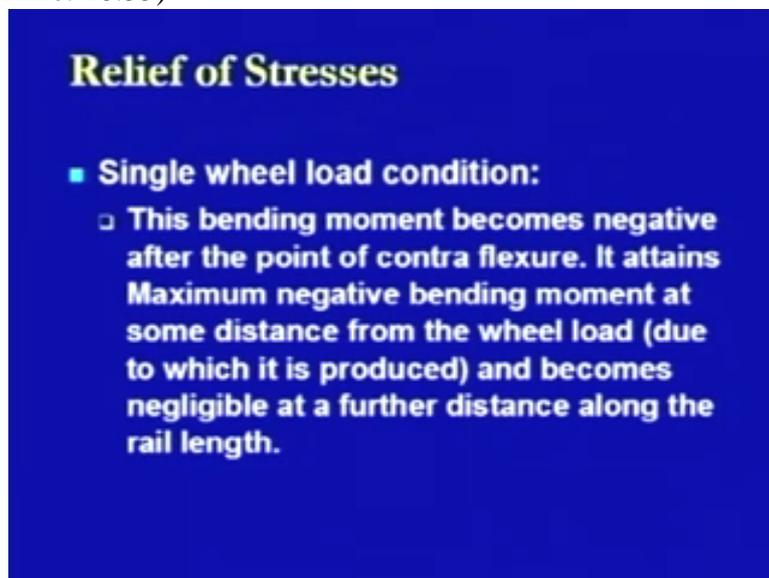


Relief of Stresses

- **Single wheel load condition:**
 - **When a single wheel load acts on the rail, the rail deflects at that point and a maximum bending moment gets produced below the centre of the rail seat.**

In that sense, there will be multiple wheels which will be coming one after the other on the track. So first of all we will be trying to look at the simpler case where there is only a single wheel load which is coming from the top and then how the bending moments are induced in this one and what is going to happen as far as the relief of stresses is concerned. Now when a single wheel load acts on the rail, rail deflects at that point and a maximum bending moment gets produced below the center of the rail seat. This is the standard statement which we can say as far as the bending moment is concerned. We have already computed bending moments when different conditions and the structure analysis, and you have seen that the bending moment which is being induced in any of that section is maximum at the point where the load is being applied. So, this is what it is trying to say that there is a maximum bending moment which is going to be produced below the center of the rail seat on the top of which the load is being applied.

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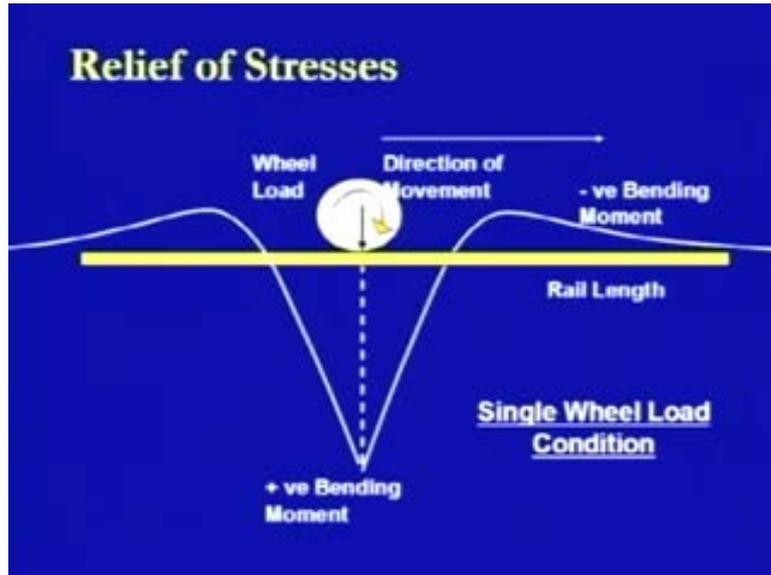
Relief of Stresses

- **Single wheel load condition:**
 - **This bending moment becomes negative after the point of contra flexure. It attains Maximum negative bending moment at some distance from the wheel load (due to which it is produced) and becomes negligible at a further distance along the rail length.**

Now this bending moment becomes negative after the point of contra flexure. So it depends on what is the notation, sign notation we have used if we are using the positive bending moment just below the load being applied. Then in that sense after the point of contra flexure it is going to change its sign. So therefore, if that is positive it will be negative or if that is negative then this will be positive. It attains the maximum negative bending moment at some distance from the wheel load. This is again another important thing, that is, we have also computed the same type of things wherever there is a linear or a curvilinear change in the bending moments being found out. So, this is not a difficult situation and this distance will be there at some distance from the wheel load at which the load is being applied and it becomes negligible if you go further from that point and obviously it is going to be 0 after certain point.

Now, this is a diagram which is trying to depict the same thing. Here what we see is that this is the single wheel which is provided and through this single wheel which is rotating in this direction, it is moving in this direction towards the right hand side which is being shown by this arrow.

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The load is being applied at this point, so this arrow is showing the load which is being applied at this point and there will be a rail seat at this level. This rail seat is going to be defined in terms of the rail and its connectivity with the sleeper at this point. Now in this condition the maximum or still bending moment is going to be induced and this value is showing the amount of maximum bending moment which is going to be induced right now. We are not interested in finding this value. What we are interested in is to understand what is happening here. Now, because of the curvilinear nature of this bending moment or its suspension what we found is that it goes something like a little straighter or exponentially this way. There is a point of contra flexure at this point after which there is a change in the sign of the bending moment. If we are taking this bending moment as positive then obviously this bending moment is negative.

Therefore, now as you see here, this is going like this. So at this point it is 0 and it is taking a maximum negative bending moment value at somewhere here. So, this is if we plot it somewhere here like this, then this is going to be at this point. So this is the distance at which the maximum negative bending moment will get created and this is how there is going to be a sort of a relief condition which is induced in this single wheel load condition. now if you are interested to evaluate the multiple load wheel load condition then the only thing which we have to do is to superimpose these type of diagrams, and if we superimpose all these type of diagrams then what we found is that there is much more relief of stresses which have been created.

So, we can also look at that condition. So there is a group of wheel loads; in the case of group of wheel loads the maximum positive bending moment produced below the center of the rail seat on which the wheel load under consideration is acting gets counteracted by the negative bending moment produced by the adjacent wheel load.

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Relief of Stresses

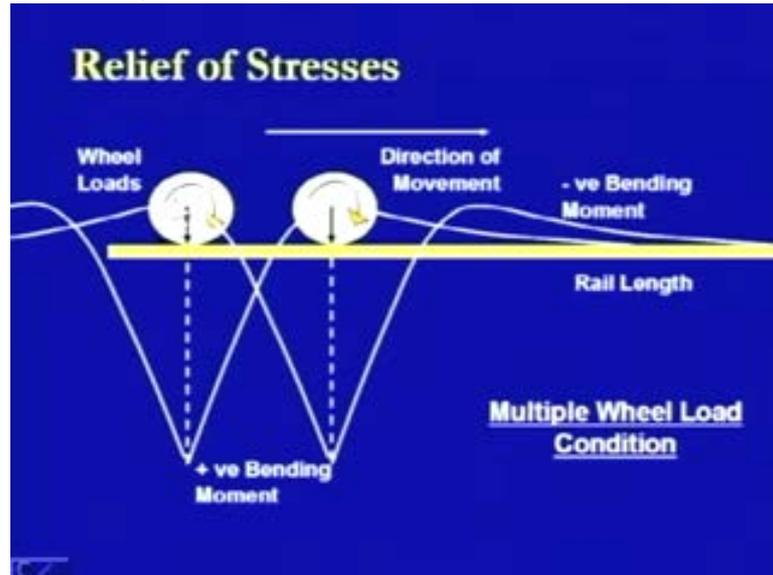
- **Group of wheel loads:**
 - In case of group of wheel loads, the maximum positive bending moment produced below the centre of rail seat on which the wheel load under consideration is acting gets counteracted by the negative bending moment produced by the adjacent wheel load.
 - Therefore, the net bending moment under the wheel considered will be less than the maximum positive bending moment.

So here again we are talking about the two types of the conditions, that is, we are having a positive bending moment which is being produced below the rail seat and after the point of contra flexure it is changing into a negative bending moment, but if there is another wheel which is coming adjacent to this wheel then again it will also be creating the same defect. Now as we have seen in the previous case, this one, like if suppose there is a wheel which comes at this location, so obviously there will be a positive bending moment which will get created at this location but its influence area will be doing something like this and because of this influence area there is going to be the relief of stress and therefore the net bending moment under the wheel considered will be less than the maximum positive bending moment.

This is what we can see in this diagram. In this diagram what we can see is that here this is a multiple load condition. Again, the direction of movement has been shown by these curvilinear arrows. These are two wheels being provided. The load is coming through these wheels on the rail length or this rail section. So therefore, this is arrow or this arrow, that is, showing the load, because of this load there is a positive bending moment at this location like this.

Similarly, there is a positive bending moment at this location like this. Now if you take just the diagram of this bending moment with respect to its point of contra flexure and further the negative moment, bending moments which are being used; what we found is that for this one if this is the positive bending moment and this is the positive bending moment from the wheel 2 and if you go backward then at this location we are getting the maximum negative bending moment because of this wheel load. So the effect of this wheel on the previous wheel is inducing the maximum negative bending moment at this location.

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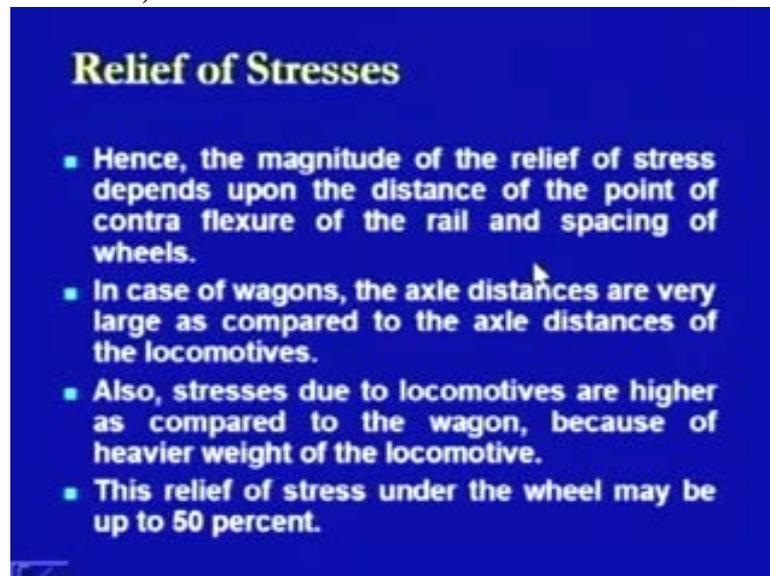
What is going to be the net effect is this positive bending moment minus this negative bending moment. Therefore, the total amount of bending moment which is being induced at the bottom of this wheel load is reducing as compared to the maximum this ordinate which is being induced in the single wheel load condition, and this is the advantage of providing the multiple wheels. Now when we are looking at all these relief of stresses with respect to this type of condition where the overlapping of the bending moment diagrams are there and because of that overlapping of the bending moment diagrams we are getting the advantage in terms of relief of stresses. There are certain controlling factors which we can see from this diagram itself.

What are the controlling factors which we found out is; one is the load which is coming from the top and because of this load what is the total amount of the bending moment which is being induced, the location of the point of contra flexure at this some distance from this application of this load and then what is the spacing of these two wheels, because if suppose this wheel is not being placed here and this wheel is being placed somewhere here, then probably because of this expansion of the bending moment diagram which goes something like this, that is becomes maximum here and then becomes 0 so there is not going to be any net effect as far as the reduction in the bending moment is concerned. So it means there is a limit upto which there can be spacing between two wheels by which we can have the relief of stresses.

So this is another important aspect so as to get the relief of stresses other than the amount of load which is being induced. If the loads are very less, obviously the bending moment will also be less. So if it is something like half probably it is coming someway here and therefore the diagram will also reduce. In that sense we cannot go for very small spacing between the wheels. Therefore, we have to tradeoff between what is going to be the amount of load which is coming from the top and what can be the minimum or the maximum spacing between these wheels so that we can achieve or we can get this advantage of relief of stresses. So this is quite an important thing which we have to look at in combination with the track modulus. Obviously, when we try to find out the different type of stresses because of the types of the loads which are going to be induced due to this moment of the wheels, we have to look at the track

modulus which becomes a quite an important part of the competition of the stresses. We will be looking at all those things further.

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Relief of Stresses

- Hence, the magnitude of the relief of stress depends upon the distance of the point of contra flexure of the rail and spacing of wheels.
- In case of wagons, the axle distances are very large as compared to the axle distances of the locomotives.
- Also, stresses due to locomotives are higher as compared to the wagon, because of heavier weight of the locomotive.
- This relief of stress under the wheel may be up to 50 percent.

So here what we found is the magnitude of relief of stress depends upon the distance of the point of contra flexure of the rail and the spacing of wheels. This is what becomes the conclusion as far as the relief of stresses is concerned and as I have told you that while fixing, while designing the wagons, while designing the locomotives, while designing the moments or the weights which are coming to the top of the rail sections and the design of the rail section, that is, what is going to be the height of the rail section? What is going to be the width of the rail section? Then what is going to be the width or foot of the rail section or just the connecting point, that is, the flange or the web of the rail section. We have to look at all these things then we have to look at the stresses being caused because of the rail section or the loads which are coming from the top.

Now in this sense, another thing is in case of wagons, the axle distances are very large but in the case of the locomotives, as we have seen previously also when we have looked at the various types of the locomotive; where we have defined them in terms of the number of axles or we have defined them in terms of the number of wheels, that how they are placed. So here what we found is that the axle distance of the locomotives is less as compared to the axle distances of vehicles. Now probably this is related to the amount of load which is coming through those locomotives or the wagons.

In the case of the locomotives, the load is much more as compared to the wagons and therefore so as to sustain, so as to provide that load to the bottom surfaces or the components of the track in a manner so that there is no failure or a permanent deformation which gets created, what we have to do is that we have to provide the lower axle distance in the case of the locomotives as compared to the wagons.

In the similar case what happens is as compared to the wagons because the weight of the locomotive is much higher as compared to the wagons. So when we are designing,

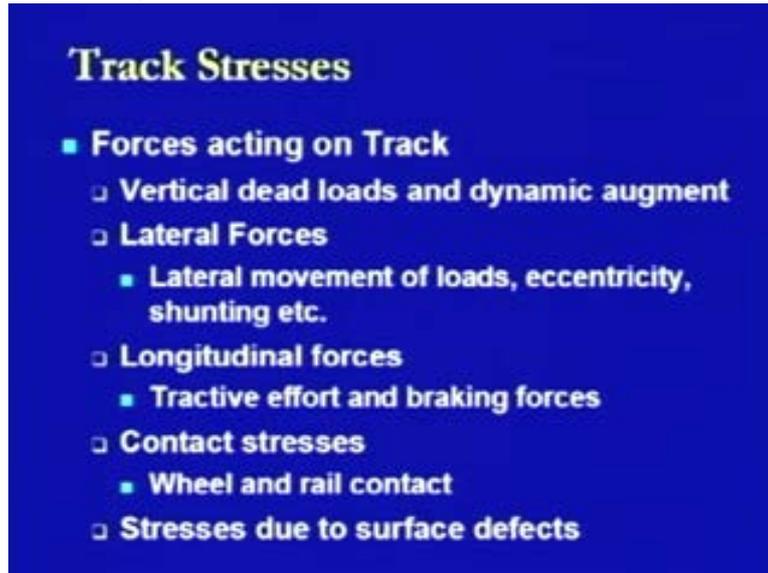
when we are trying to find out the track modulus or when we are trying to find out the stresses which have been induced in any of the component of the track then what is important is the locomotive.

And as we have seen, as we have defined the different types of the locomotives, what we have found out that the actual load of those locomotives that varies from something like 10 tons to around 25, 27 tons or 28 tons. So, it means there is a wide range in which the weight of the locomotive varies, but not necessarily on each and every track or on each and every section of the track all these locomotives **plan**. Therefore, what we have to do is that we have to first of all identify the types of the locomotives which are operating on any of the section or which are going to operate, or there is a feasibility of the operation of certain locomotives on that stretch and then on the basis of that we can find out the heaviest locomotive and for that heaviest locomotive the things can be designed.

In the case of this relief of stresses another point which is being observed because of the multiple wheels being provided is that this relief of stress under the wheel may be up to 50 percent. So this is the advantage of the multiple wheels which have been provided. So what we can see is that we are reducing it by half, so what is the maximum positive bending moment which is being induced below the rail seat is going to be just half of that one, because of the position of the wheel **by linear** to that one and because of that position of wheel to that one, the imposition of the negative maximum bending moment at the same location where the maximum positive bending moment is being induced because of the previous wheel load. So this is what is about the relief of stresses.

So, now we will be looking at the various types of the track stresses which are induced due to the types of the loads. Let us, first of all look at what are the different types of the loads of the forces which act on any of the track. What we found is that there are vertical dead loads and dynamic augments of those vertical dead loads which are coming on the track. They are the lateral forces, the lateral forces which are being caused or which are causing the lateral movements of the loads, which are caused due to the eccentricity or which are caused due to the types of these specific operations like shunting. The longitudinal forces which are becoming the cause of the actions like tractive efforts or the braking forces.

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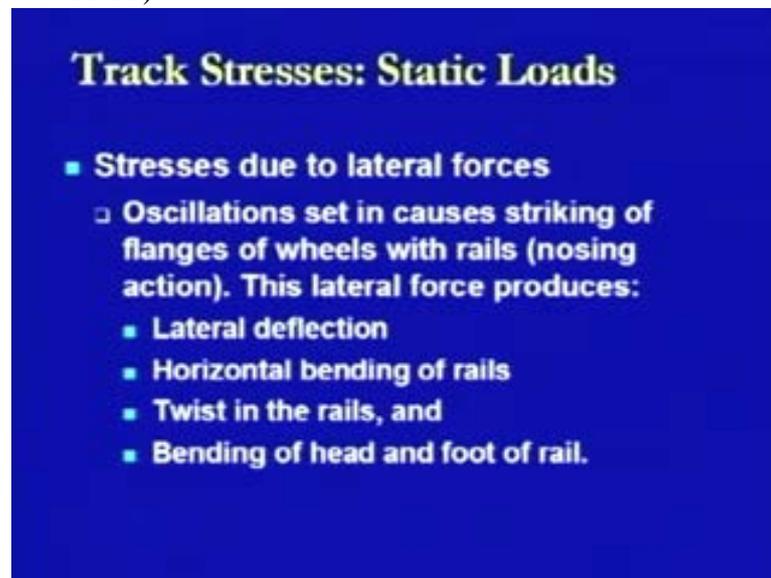
They are the contact stresses which are induced due to the contact of the wheel with the rail section or there are stresses which are caused due to the surface defects or the irregularities in the surfaces. So we will be looking at all these track stresses one by one. First of all we will look at the track stresses which are induced due to the static load conditions. Under the static load conditions the very first one which we can use or which we can define is the vertical loads. In the case of the vertical loads the main component is in terms of that load which is coming from the top. Now this dead load is nothing but the load of the locomotive, or the wagons, or the things which are being transported, it may be in terms of passengers or the freight. So we have the load of locomotives or we have the loads of the wagons in terms of the axle loads and that is to be taken as a dead load.

Another load will be the live load. Usually this is taken from the taken from the axle load diagrams which are prepared for the different types of locomotives or the types of the wagons and because of these loads or the dead loads the bending stresses are induced in the rail sections. We have seen in the previous diagrams when we have discussed about the relief of stresses that there is a load which is being induced causes the maximum positive bending moment at the **royal** seat or the maximum negative bending moment at some distance away from the point of application of the load. So that is what is the bending stress being induced in that one.

Another one is the stress which is being caused due to the lateral forces. In this case the oscillations are set and they cause the striking of flanges of wheels with the rails. This type of action where because of small distances which is being provided between the flanges and say the gauge condition, there is a lateral movement of the axle. Now this lateral movement of the axle and the flanges of the wheels, they strike the rail sections, that is, the head of the rail section or the side of the head of the rail section, that is what is known as the **noosing** action and because of this action or the oscillations or the sways different type of things happen. There is a lateral deflection which will be caused because of this oscillation; there can be the horizontal bending of the rails. This is another important thing because this may create some failure

conditions. There can be a twist in the rail sections depending on the amount of these oscillations which are there.

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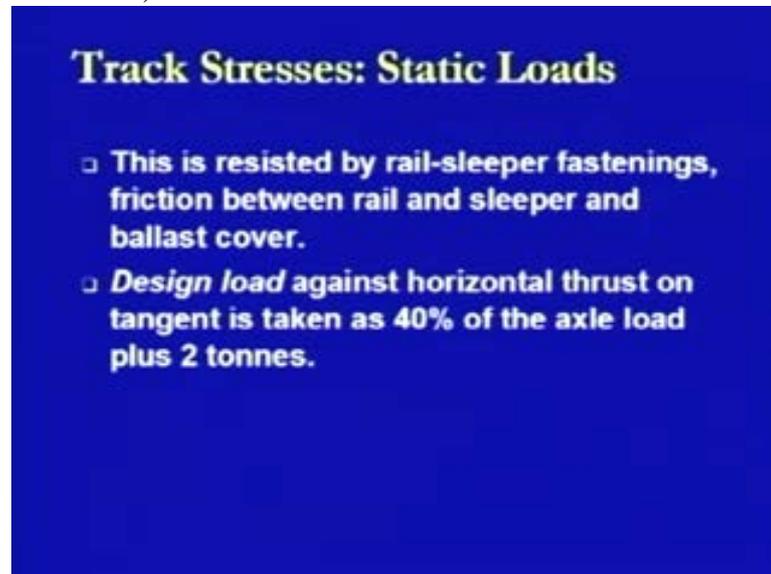
If these oscillations are much more at certain points or levels then in that case the twisting of the rail sections may also get created. The twisting of the rail section in sort of the bending which will be there and another thing is the bending of head or foot of the rail. Now, this is the thing which is being caused because of the application of the lateral force. Now when there is a contact between the flange of the wheel and the head of the rail then the force is being applied to the top of the rail section. Now when this force is being applied to the top of the rail section it is going to create an eccentric condition as far as the foot of the rail section is concerned because this is coming in terms of the horizontal movement and this eccentricity between the application of the load and the point at which it is being rigidly held with the sleeper, that is the foot. There will be a bending of the head and foot of the rail section. So, that is why, what we found is the different types of the irregularities or deformations which are caused in the rail sections at times or because of the heavy amount of the lateral forces which are being induced in any of the rail section and this is a very dangerous condition as far as the operation is concerned and may finally lead to some hazardous condition.

Now in this case, one we are talking about all these lateral forces as we have just seen that there can be a twisting condition at the foot of the rail section. It is going to be resisted by certain fastenings by which that rail section is being fastened to the sleeper and therefore the total amount of this load is going to be to those fastenings, and on the basis of this amount of load which is transferred to the fastenings those fastenings needs to be designed. We will be taking up these fastenings separately again and we will see that when we design those fastenings they are defined in terms of certain loads which come at the toe of those fastenings and therefore that is the minimum amount of load or the capacity which should be there for those fastenings and that is coming from this point of track stresses.

Another important thing is that there is going to be a friction between the rail and the sleeper because at times the rails are being placed in the chairs and chairs have been

attached to the sleepers, may be using certain padding or directly on the sleeper and there is some amount of friction, there is some amount of movement between the rail section or the chair, or the chair and the sleeper, or the rail section of the sleeper directly then that is going to create some friction.

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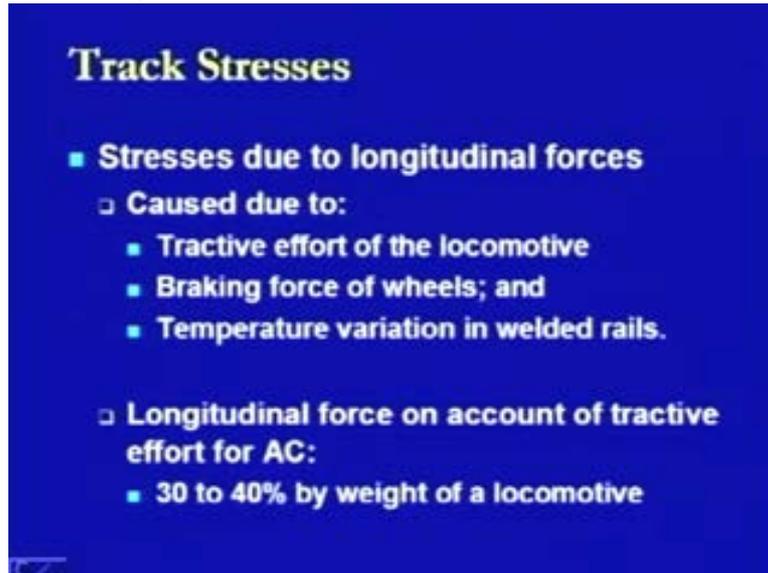
Track Stresses: Static Loads

- **This is resisted by rail-sleeper fastenings, friction between rail and sleeper and ballast cover.**
- **Design load against horizontal thrust on tangent is taken as 40% of the axle load plus 2 tonnes.**

The similar is the condition for the ballast cover because of these movements, because of the lateral movements the ballast cover becomes little loosened out and then this is another important thing because the ballast is being provided so as to provide the lateral strength or stability to the track and if this is loosing out then in that sense the total lateral strength or stability of the track will reduce. On the basis of the design, on the basis of the computations, on the basis of the experimental which is being taken up, what is being observed is that this design load against the horizontal thrust on tangent is taken as 40 percent of the axle load plus 2 tonnes. So, this is what is the value which is be defined by the Indian railways and this is how the lateral direction load is to be considered.

The another case is the stresses which are caused due to longitudinal forces. Now when we are talking about the longitudinal forces there is a train or the wheels which are moving in a certain direction on the rails, then what happens is that there are certain things which can happen during the movement. One thing is that you are on a stand still condition and you start moving. That is where the tractive effort comes into picture of the locomotive. Another thing is that we are under movement; you want to change the speed or there is a braking effort and therefore the braking force of the wheels will come into picture. There can be a starting reacceleration or acceleration conditions which can also be there when the movement is going on in any of the rail sections and lastly there is a variation in the temperature and due to this variation in the temperature there is some movement or there are certain stresses which are caused in the rail sections. These are the two things which can happen because of the temperature in any of the rail section.

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Track Stresses

- **Stresses due to longitudinal forces**
 - **Caused due to:**
 - **Tractive effort of the locomotive**
 - **Braking force of wheels; and**
 - **Temperature variation in welded rails.**
 - **Longitudinal force on account of tractive effort for AC:**
 - **30 to 40% by weight of a locomotive**

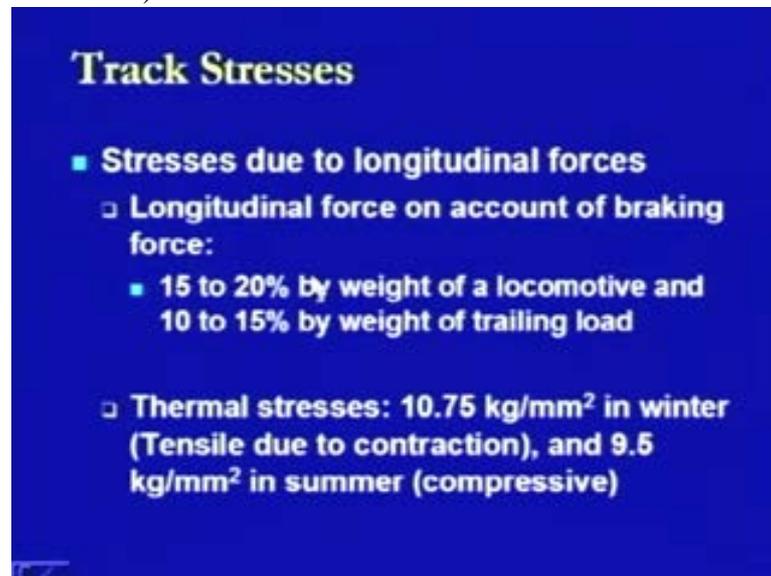
If there is a certain movement, then it is a sort of a creep condition or if that movement is being registered by the fastenings which are provided below at the top of the sleeper condition, then that is going to create certain stresses. So we have to look at the different types of stresses which have been caused because of the different factors in the longitudinal direction. Now if we look at the first condition where the tractive effort is being considered of any locomotive, that is, total amount of effort which is being induced by a locomotive as we have discussed in the previous lecture also where this tractive effort is being found out from the basis of the resistances being computed and friction being induced between the contacting surfaces. So on basis of this tractive effort which has already been computed what we found is the longitudinal force on account of the tractive effort is something like 30 to 40 percent by weight of a locomotive. So, this is the amount of force which will be there in the longitudinal direction.

Similarly, if we look at the stresses of the forces which are induced in longitudinal direction on account of braking or the application of the brakes, then that is going to be different for the different conditions, because we have the locomotive at the same time there are the trailing units in terms of the wagons which are attached to the locomotive. So it is little different in terms of that one. It is 15 to 20 percent by weight of a locomotive whereas in the case of the trailing load it is nothing but the wagons, maybe the passenger wagons or the freight wagons being attached to the locomotive; it is 10 to 15 percent by weight.

The third condition which is there is regarding the thermal stresses. What happens in this case is that as the temperature increases all the rail sections when they are laid on the track they are laid at a specified temperature and therefore if there is a variation with respect to that specified temperature there will be either contraction or there will be either expansion of the rail section. One this expansion or contraction of the rail section is being restricted because of the fastenings being provided between the rail section and the sleeper, then it induces thermal stresses. Now when these thermal stresses are being induced then there are going to create a problem at the fastening levels. That is why the fastening needs to take these stresses further and this is what is

defined in terms of either winter or summer condition because we have the two different type of behavior or the nature of stresses which will be going to be induced in any section.

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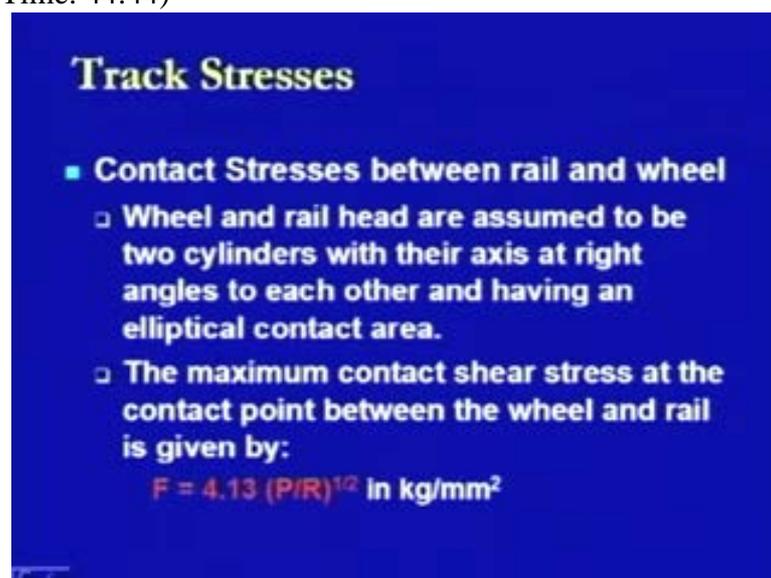


Track Stresses

- **Stresses due to longitudinal forces**
 - Longitudinal force on account of braking force:
 - 15 to 20% by weight of a locomotive and 10 to 15% by weight of trailing load
 - Thermal stresses: 10.75 kg/mm² in winter (Tensile due to contraction), and 9.5 kg/mm² in summer (compressive)

In the case of the winter, it is tensile due to contraction and the value is being given as 10.75 kg per mm square. Whereas in the case of the summer it is compressive in nature and the value is being define as 9.5 kg per mm square. So this is what we found out is that in the case of the longitudinal forces the values ranges from 40 percent of the weight of the locomotives in the case of the tractive effort 10 to 15, 15 to 20 percent in the case of the longitudinal forces and then there are certain fixed amount of thermal stresses which are induced.

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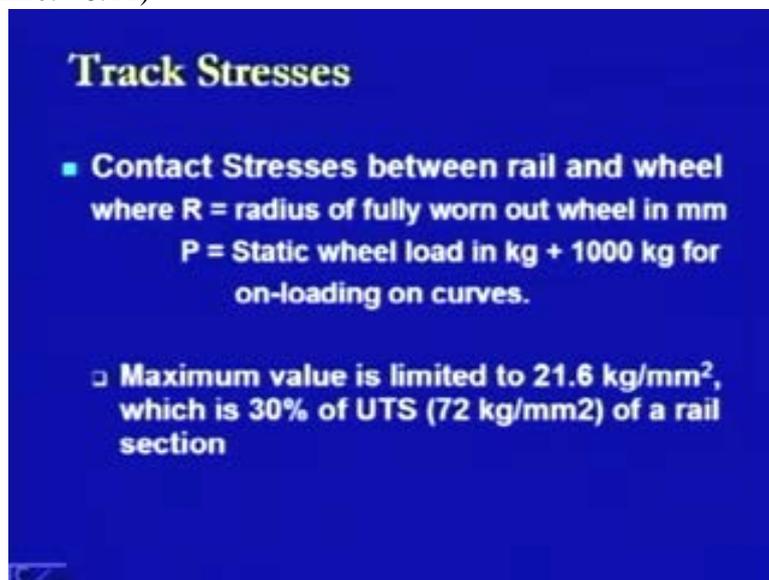
Track Stresses

- **Contact Stresses between rail and wheel**
 - Wheel and rail head are assumed to be two cylinders with their axis at right angles to each other and having an elliptical contact area.
 - The maximum contact shear stress at the contact point between the wheel and rail is given by:
 $F = 4.13 (P/R)^{1/2}$ in kg/mm²

Another condition which is creating the stress is the contact between the wheel and the rail. Now both are the steel sections and therefore because of this contract, what is going to happen is some amount of stress. Now when computing this stresses there are

certain assumptions being made. The assumption is that the wheel and the rail head are assumed to be two cylinders with their axis at right angles to each other and having an elliptical contact area. So we have an elliptical contact area through which the total amount of the force or the stresses are being transferred from the wheel to the rail section. At the same time both are assumed to be two cylinders which are having their directions at 90 degrees to each other. In that sense the maximum contact shear stress at the contact point between the wheel and the rail may be given by 4.13 multiplied by P divided by R and root of this one. Now depending on the units it can be in terms of kg per mm square. Here, in this case, the P is nothing but it is the static wheel load in kg and with that static wheel load in kg we add 1000 kg for on loading on curves. Similarly, R is the radius of the fully worn out wheel in mm. So these are the two values which are used in the formula and the maximum value is limited to 21.6 kg per mm square.

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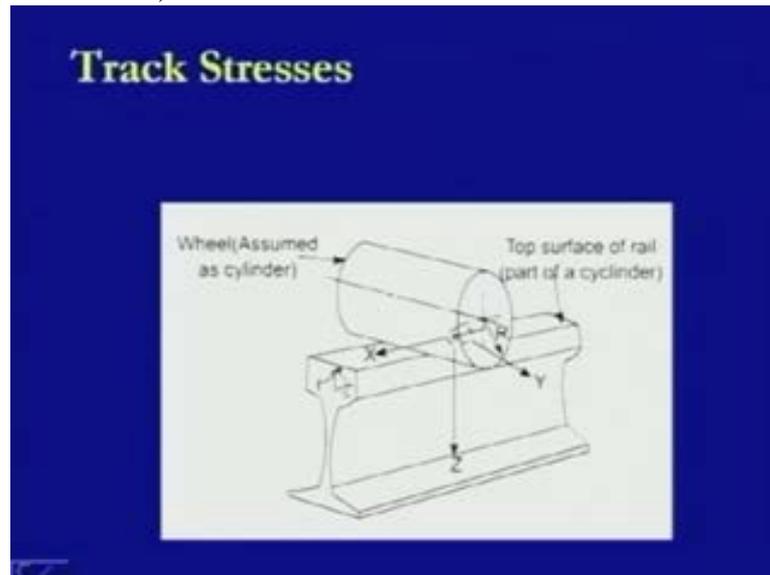


Track Stresses

- **Contact Stresses between rail and wheel**
where R = radius of fully worn out wheel in mm
P = Static wheel load in kg + 1000 kg for
on-loading on curves.
- **Maximum value is limited to 21.6 kg/mm²,
which is 30% of UTS (72 kg/mm²) of a rail
section**

Now this value of 21.6 kg per mm square is around 30 percent of UTS section. That is a section which is ultimate and strength of 72 kg per mm square. The new rail sections which are now in use, they are having the ultimate tensile strength of 90 kg per mm square. So in that sense this reduces further.

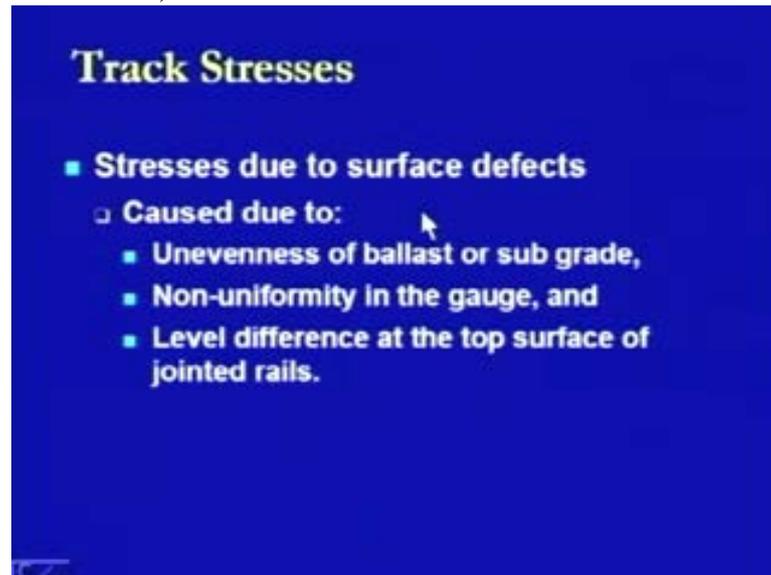
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Here in this diagram the same concept has been shown. Here, this is the rail section; this is the head of the rail, this is the **width** of the rail and this is the foot of the rail. On this rail section there is a wheel moving and this wheel is being shown in the form of a cylinder which is moving in this direction whereas this cylinder is having its size in this direction. So this is x direction and this is y direction. That is how they are having two different areas and this surface of contact between these two sections will be coming as the electrical section and z direction the load will be transferred.

So we are going to look at because of this type of movement the forces which are being induced in the x direction, that is, the longitudinal forces which are caused due to the tractive effort, or which are caused due to the braking, or which are caused due to the thermal stresses which are induced in the rail sections because of the fastenings being provided at the foot level, or we have also talked about the lateral forces which are induced in the lateral direction, that is, in this direction because of the sway, because of the oscillation of this wheel in this direction, and we have also seen about the vertical loads which are being transferred in the z direction which are basically the loads which are coming in this form. Obviously in all these conditions whether we are talking about the x condition or y condition or z condition of the loads being induced because of the movement, because of the speed, because of the rolling loads which are coming from one after the other, there are certain augmentations of the effects of all these loads. We will be also looking at those augmentations because of the speed etcetera.

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The another point which is there as far as that stress is concerned is the surface defects. Now these stresses may be caused due to the unevenness of the ballast section or the sub grade section. This is the lower most section or the second lower most section of the components of the track. If there is any unevenness in that section then it may result in certain amount of stresses. Another thing is the non-uniformity of the gauge. If the gauge is not uniform, if there is any non-uniformity which is coming in that one; obviously it is going to create some stresses. The next condition is the difference in the level of the rail section which are jointed together at certain locations. We found that there are different rail sections and the rail sections are being manufactured in certain rail length and therefore they need to be just jointed. Now when we are joining these rail sections by using fish plates or fish boards then there are chances that the difference is there at the top most surface of the rail. If that is happening then that will also create stresses and at the same time it will also be harmful for those rail sections because of the battering action of the wheel at that point. So these are the different types of stresses which are there.

These surface defects causes deflection as high as 1.5 times the depth of the flat or low spot at critical speed of 30 kilometers per hour. So that is amount of defects or deflections which have been caused in this one and additional bending moment is also caused because of the surface defects and this is roughly 370 tonnes centimeter for broad gauge group, that is, the category A route where the WDM 4 locomotive, that is a locomotive being manufactured for the broad gauge that is W, with the diesel operating condition that is D, for a mixed traffic that is M. This we have already seen when we have discussed the classification of locomotives.

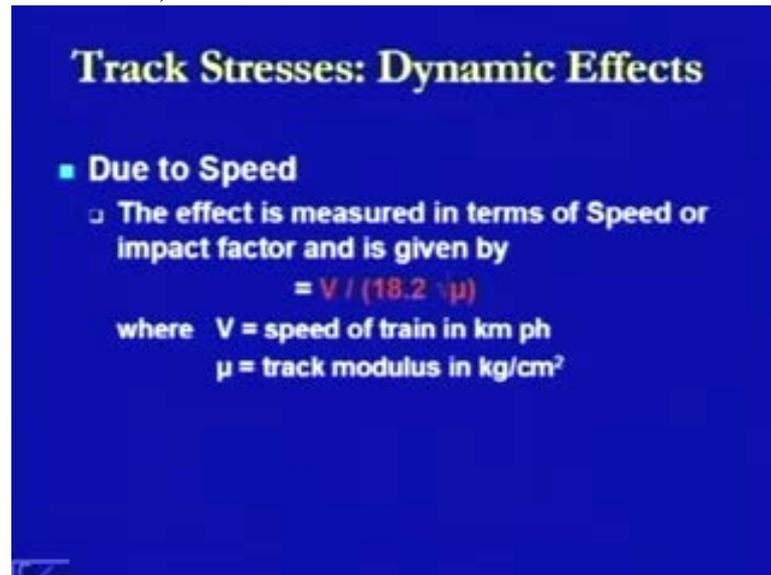
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Track Stresses

- **Stresses due to surface defects**
 - **Surface defects causes deflection as high as 1.5 times the depth of flat or low spot at critical speed of 30 km ph.**
 - **Additional BM is also caused (~ 370 t.cm for BG group – A route with WDM 4 locomotive).**

Another condition is the stresses which are induced due to the curves. Now, the main thing in this case is one the centrifugal force which is acting in the outward direction on the curve. Another thing is the rigidity of the wheel base. Now because of this rigidity of the wheel base where all the wheels, that is, the front or the leading wheels or the trailing wheel sections, they will not be moving in the same path, not following the same path there is going to be a certain stress condition. Similar is the case 1, super elevation is being provided so as to counter the centrifugal force. If the super-elevation provided is not sufficient so as to counter at the centrifugal force, then also there will be certain stresses which will be induced. In that case the excessive vertical load over normal wheel load on the inner or outer rail depends upon super-elevation and the speed of the wheel. The non-uniform distribution of pressure over outer and inner wheels is caused because of the rigid wheel base and the lateral movement of the axles in the outward direction or in the inner direction because of that rigid wheel base. So this also concept is being discussed previously if you remember. So this is all about the different types of track stresses which are induced because of any static load condition.

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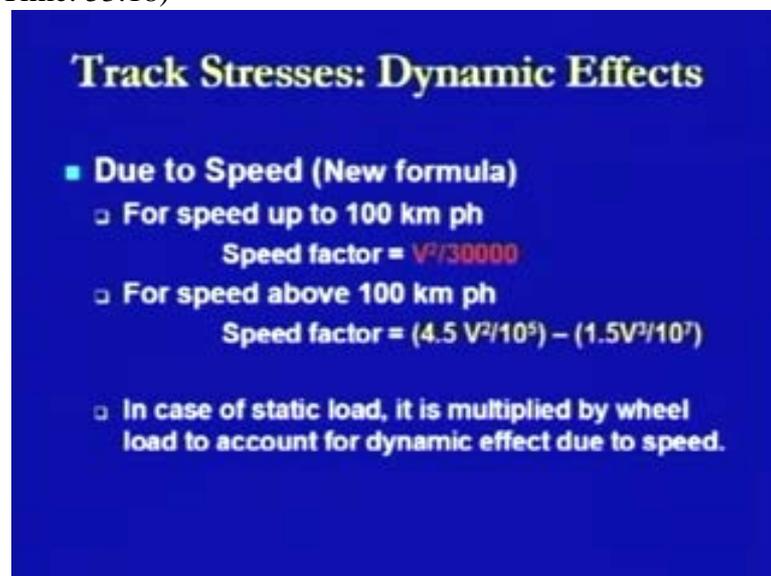


Track Stresses: Dynamic Effects

- **Due to Speed**
 - The effect is measured in terms of Speed or impact factor and is given by
$$= V / (18.2 \sqrt{\mu})$$
where V = speed of train in km ph
 μ = track modulus in kg/cm²

Now we talk about the dynamic effects here. In the case of the dynamic effects, it is because of the speed. The effect is measured in terms of the speed and this is defined as an impact factor which is computed as V divided by 18.2 under root μ , where μ is the track modulus in kg per centimeter square and V is the speed of the train in kilometers per hour. This is the previous formula which is being used as to identify the effect of the speed in terms of impact factor or speed factor.

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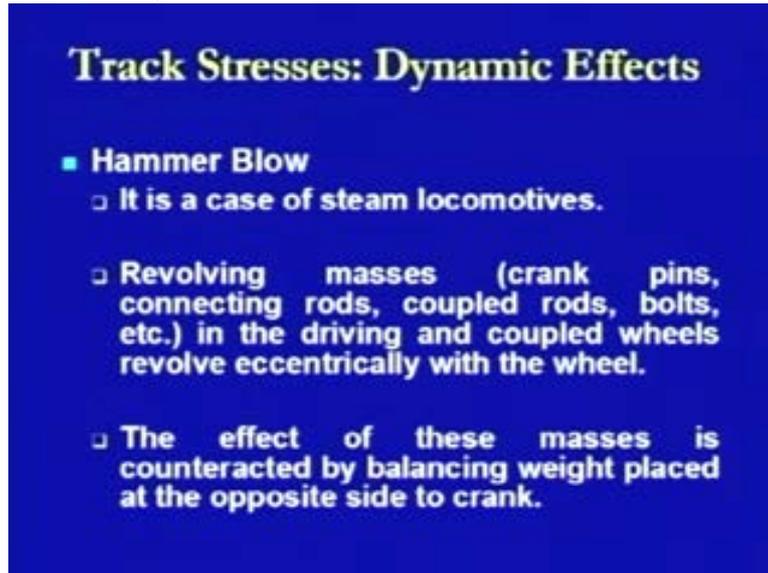


Track Stresses: Dynamic Effects

- **Due to Speed (New formula)**
 - For speed up to 100 km ph
Speed factor = $V^2/30000$
 - For speed above 100 km ph
Speed factor = $(4.5 V^2/10^5) - (1.5V^3/10^7)$
 - In case of static load, it is multiplied by wheel load to account for dynamic effect due to speed.

The another formula which is being given now and this is dependent on the speed range for a speed up to 100 kilometers per hour. Now it is defined as V square divided by 30000 whereas in the case of speed is above 100 kilometers per hour it is calculated as 4.5 V square divided by 10 raised to power 5 minus 1.5 V cube divided by 10 raised to power 7. In the case of static load, this is multiplied by wheel load to account for dynamic effect due to speed. So this is how this is taken into consideration.

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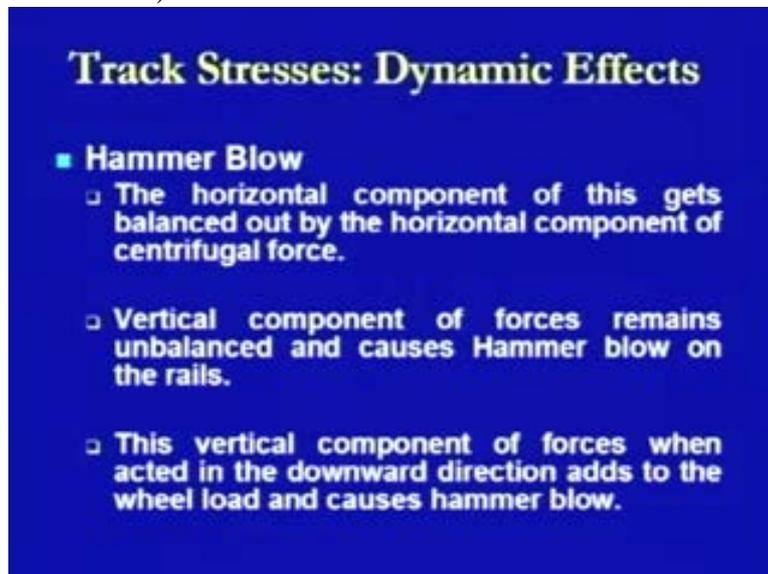


Track Stresses: Dynamic Effects

- **Hammer Blow**
 - It is a case of steam locomotives.
 - Revolving masses (crank pins, connecting rods, coupled rods, bolts, etc.) in the driving and coupled wheels revolve eccentrically with the wheel.
 - The effect of these masses is counteracted by balancing weight placed at the opposite side to crank.

Another aspect is hammer blow. This is the case mainly in the steam locomotives. What happens in this steam locomotive is that there are certain revolving masses. There are crank pins connecting rods, coupled rods, bolts etcetera and they are provided with driving and coupled wheels and when they revolve there is certain amount of eccentricity which is caused at that wheel section. The effect of these masses is counteracted by certain balancing weights which are placed at the opposite side to the crank.

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Track Stresses: Dynamic Effects

- **Hammer Blow**
 - The horizontal component of this gets balanced out by the horizontal component of centrifugal force.
 - Vertical component of forces remains unbalanced and causes Hammer blow on the rails.
 - This vertical component of forces when acted in the downward direction adds to the wheel load and causes hammer blow.

So in that sense what happens is there are certain vertical and the horizontal components which got induced because of all these weights or the balancing out of all those weights. The horizontal component will get balanced out by the horizontal component of the centrifugal force but the vertical component remains unbalanced and because of its movement in the downward direction it causes the hammer blow. In case it is moving in the upward direction then it will be relieving the stresses on that point.

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Track Stresses: Dynamic Effects



- When it acts in the upward direction it reduces the wheel load and causes uplift.

Here we can see in this diagram the moving parts. What we are finding is that this is the center of the wheel and this is the piston on their side and this is moving with this one. There are cranks wheel provided and they are the loads which are provided. These are revolving around the center of the wheel. So therefore, there is certain eccentricity which is being induced in this point here, similarly at this location here. So because of these eccentricities there are certain loads which are being attached at the other side so that it gets balanced out and this is how it works.

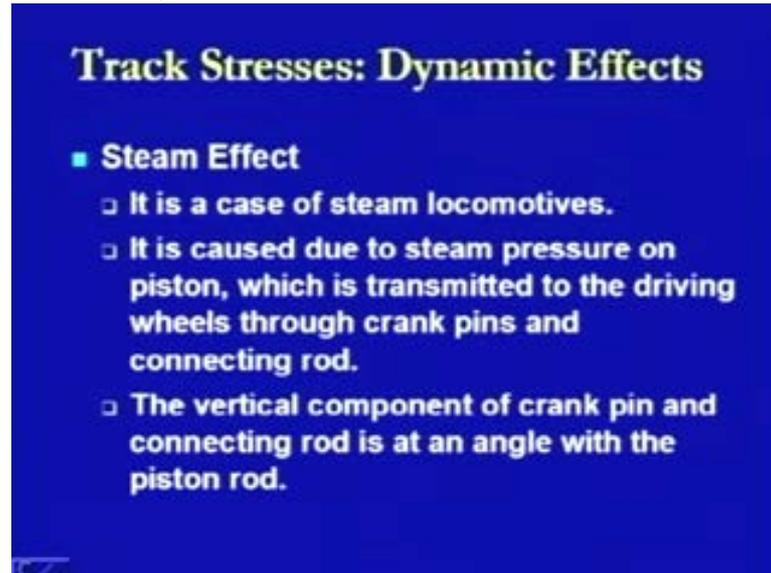
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Track Stresses: Dynamic Effects

- Hammer Blow
 - The magnitude of hammer blow on the rails can be computed using:
$$\text{Hammer blow} = (M/g) \times d \times (2\pi n)^2 \times \sin\theta$$
where M = net overweight in kg
 d = crank pin diameter in m
 n = no. of revolutions of wheel / sec
 θ = crank angle.

This hammer blow is computed by using the formula M divided by g , multiplied by d , multiplied by $2\pi n$ square of that, multiplied by the sine of theta; where M is the net overweight in kg, d is the crank pin diameter in meters, n is the number of revolutions of wheels per second and theta is the crank angle.

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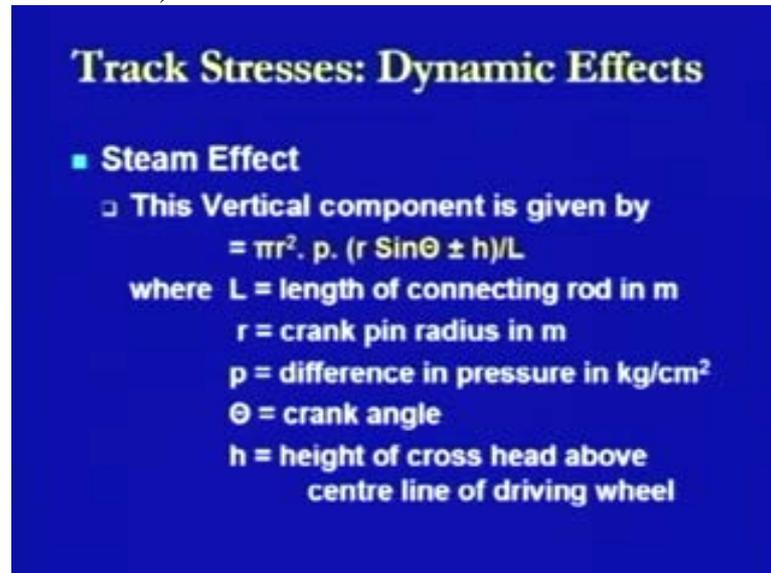


Track Stresses: Dynamic Effects

- **Steam Effect**
 - It is a case of steam locomotives.
 - It is caused due to steam pressure on piston, which is transmitted to the driving wheels through crank pins and connecting rod.
 - The vertical component of crank pin and connecting rod is at an angle with the piston rod.

Now the another effect in the steam locomotives is the steam effect which is condition which is caused due to the difference in the steam pressure on the piston and which is transmitted to the driving wheels causing crank pins and connecting rods. So in this sense what happens is that

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Track Stresses: Dynamic Effects

- **Steam Effect**
 - This Vertical component is given by
$$= \pi r^2 \cdot p \cdot (r \sin \theta \pm h) / L$$

where L = length of connecting rod in m
 r = crank pin radius in m
 p = difference in pressure in kg/cm^2
 θ = crank angle
 h = height of cross head above centre line of driving wheel

this is computed in terms of πr^2 , multiplied by p , multiplied by $r \sin \theta$ plus and minus h divided by L , where all the aggregations have been defined here; L is the length of connecting rods in meters, r is the crank pin radius, p is the difference in the pressure on the piston, θ is the crank angle and h is the height of the cross head above center line of driving wheel, positive or negative depending on by what value it is up or down of the driving wheel.

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Track Stresses: Dynamic Effects

■ Steam Effect

- **This force adds to the wheel load when crank pin is in the downward direction and subtracts the effect of the wheel load when it is in the upward direction.**
- **It is not in synchronization with the hammer blow caused due to balancing weights.**

What we see is that this force adds to the wheel load when crank pin is in the downward direction and subtracts the effect of the wheel load when it is in the upward direction and it is not in synchronization with the hammer blow caused due to the balancing weights.

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Track Stresses: Dynamic Effects

■ Inertia of reciprocating masses

- **The effect of inertia of the reciprocating masses and the acceleration caused, changes pressure on the piston and hence also changes the force in the connecting rod during the revolution of the wheel.**

There is another case of inertia of reciprocating masses, the effect of the inertia of reciprocating masses and the acceleration caused changes pressure on the piston. Hence, also changes the force in the connecting rod during the revolution of the wheel.

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Track Stresses: Dynamic Effects

- Inertia of reciprocating masses
 - This component is given by:
$$F_v = \frac{M}{g} \cdot r \cdot (2\pi n)^2 \cdot (\cos\theta + \frac{r}{L} \cos 2\theta) \cdot (r \sin\theta \pm h)/L$$

Where, M = mass of reciprocating parts, in kg
L = length of connecting rod, in m
n = number of revolutions per sec
r = crank pin radius in m
 θ = crank angle
h = height of cross head above centre line of driving wheel, in m

In this case, this component is given by F_v is equal to M divided by g, multiplied by r, multiplied by $2\pi n$ whole square. This is further multiplied with $\cos\theta$ plus r divided by L into \cos of twice of θ and is further multiplied with r sine θ plus minus h divided by L. Most of the abbreviations are the same has been used previously in the other equations and they have also been shown here. So, what we have seen today is that the various type- of stresses which can be induced in any of the track. It may be due to the static condition or the dynamic conditions. They are the relief of stresses and the track modulus.

Now we will continue with these track stresses in the different components of the tracks in the further lectures. I stop at this point and goodbye to you.