Advanced Design of Steel Structures

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Lecture - 15

Dynamic material strength

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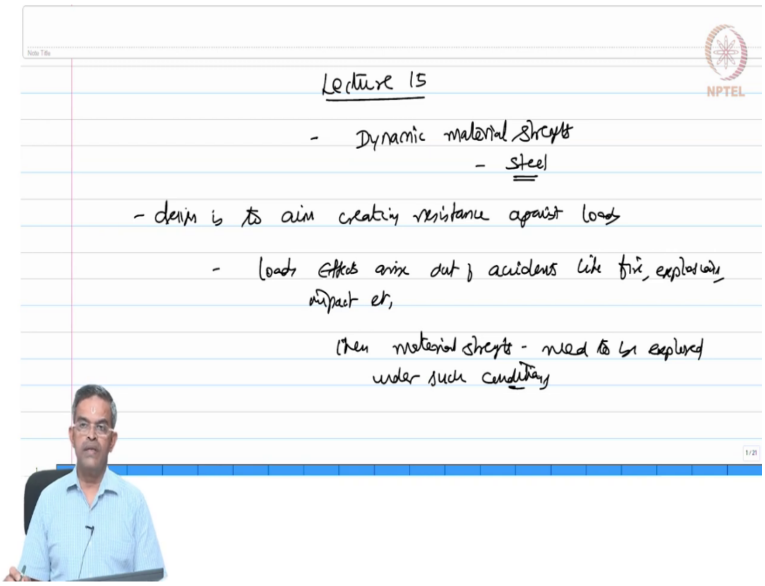

Friends, welcome to the 15th lecture on Advanced Steel Design course, in this lecture we are going to talk about the Dynamic material strength and the response criteria with respect to steel as a construction material. We already said the design of structures is to aim creating resistance against the loads, in fact, to be very clear if the load effects arise out of accidents like fire, explosion, and impact etcetera, Then, the material strengths need to be explored under such conditions because the material strength varies under such impulse loading or under such time variant dynamic loading.

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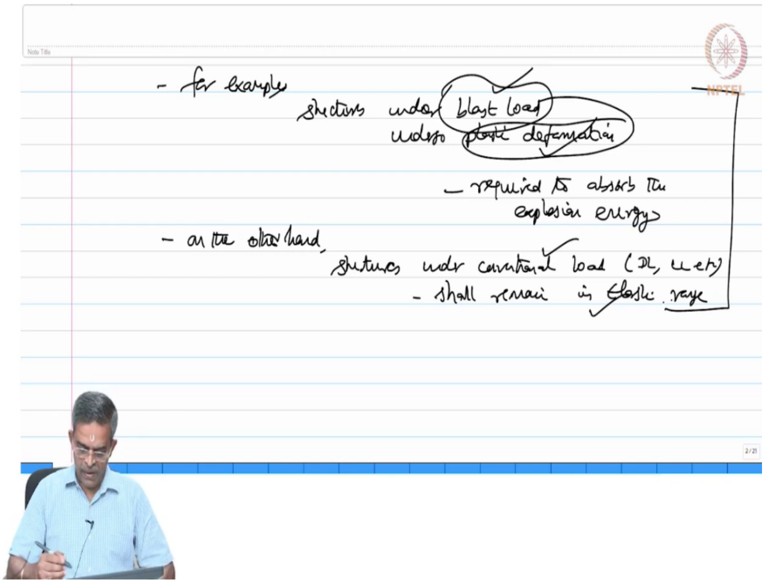

For example, structures under blast loads undergo plastic deformation, because this is required to absorb the explosion energy. Therefore, these types of loads also inherently affect the dynamic characteristics and strength of the material.

On the other hand, structures under conventional loads like dead load, live load, etcetera shall remain or continue to remain in elastic range. So, the design philosophy also intricately address the type of load and the preferred response. So, now, the design procedure itself is multi-dimensional, the design objective itself is varying, therefore, we cannot have a single design procedure which can address all kinds of loads and all kinds of materials.

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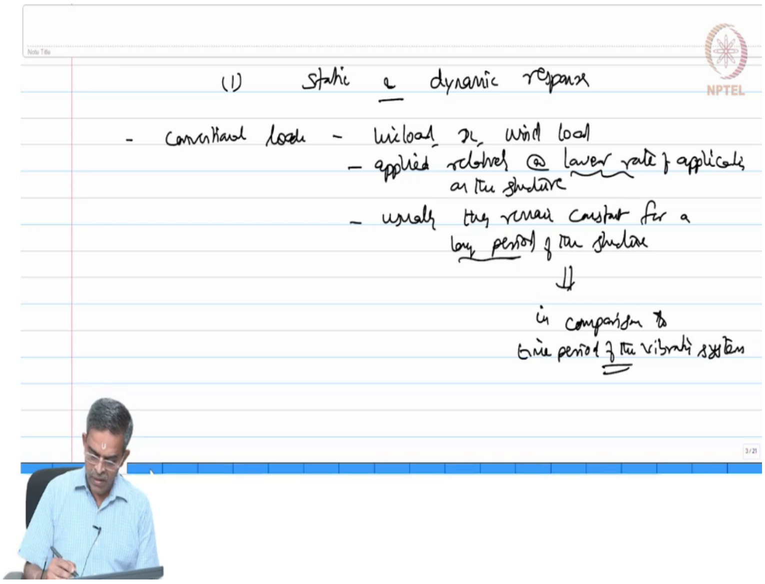

Having said this, let us quickly understand what is the difference between static and dynamic response, because it is very important for us to learn this very briefly, so that we know how the dynamic material strength is understood. Now, let us for example talk about conventional loads; conventional loads such as live load, dead load in fact, I would also call wind load as a conventional load.

They are generally applied relatively at a lower speed or lower rate of application on the structure. And usually they remain constant for a long period of the structure. Now, when I say I have to compare the lower rate, longer period, then this is generally in comparison to the time period of the vibrating system.

So, compared to the time period of the vibrating system these are all lower rate of application, longer period of stay, etcetera.

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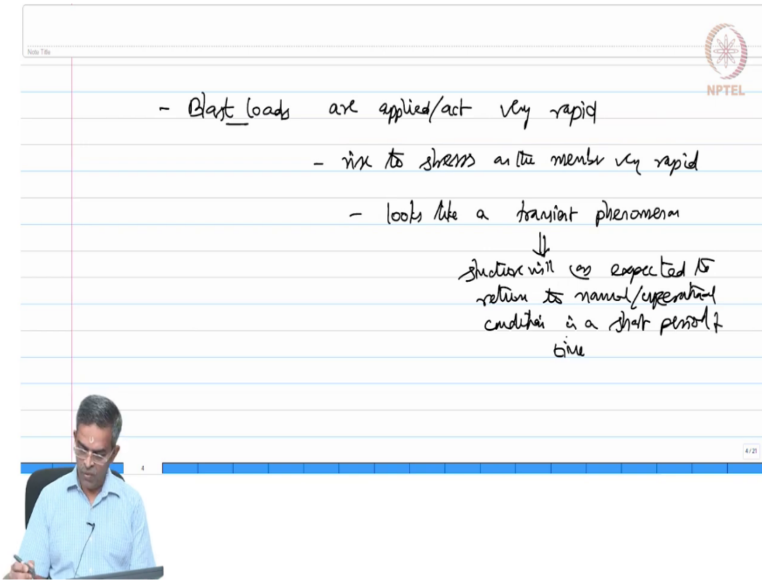

On the other hand, if you look at blast loads they are applied or act very rapidly and they will give rise to the stresses on the member very rapidly. So, one can very well say blast load looks like a transient phenomenon. So, what does it mean? The structure will or expected to return to normal, operational conditions in a short period of time. So, time period plays a role in understanding the effect of these loads on the structural systems.

Therefore, in relationship to this what will happen in the conventional design?

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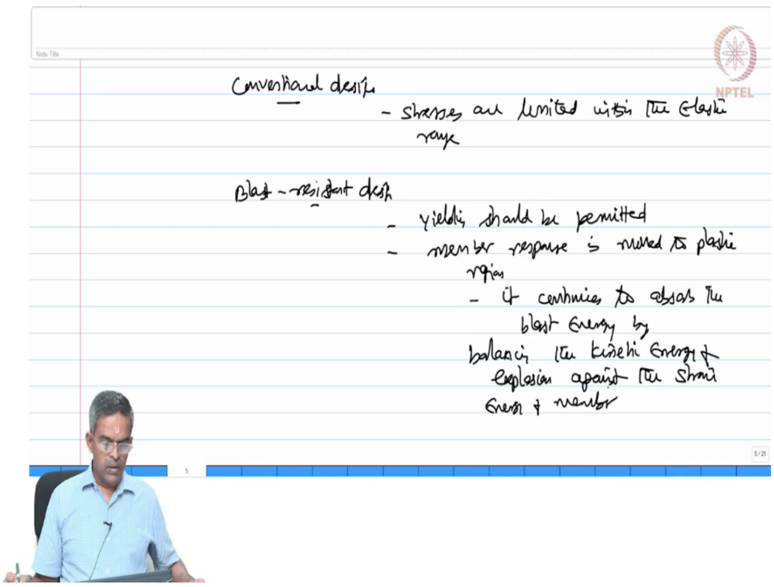

In the conventional design stresses are limited within the elastic range whereas, in blast resistant design for example, yielding should be permitted because it is one of the form of absorbing the explosion energy. So, since yielding is allowed member response is moved to plastic region. So, during this process it continues to absorb the blast loading or blast energy by balancing the kinetic energy of explosion against the strain energy of the member.

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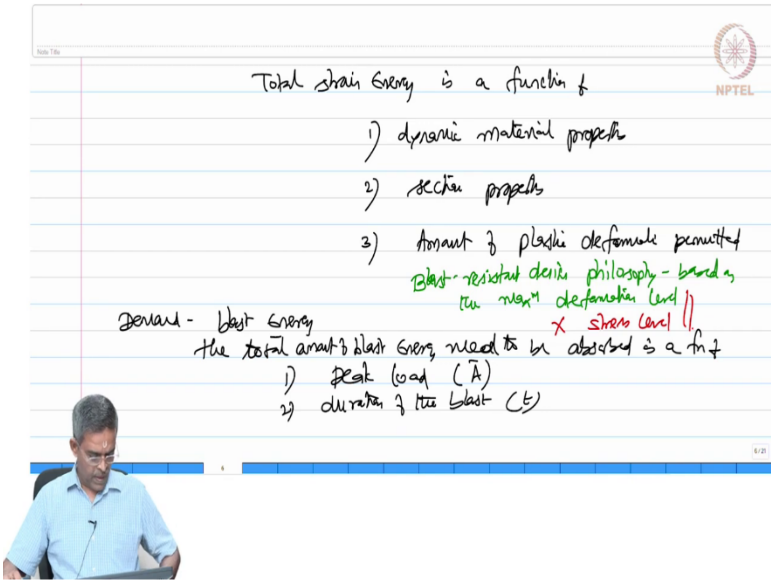

Now, when we accept this statement we say that now the total strain energy is a function of 1 dynamic material properties, and 2 section properties, and 3 the amount of plastic deformation permitted.

So, the total amount of blast energy required to be absorbed let us say we look into the demand. So, the demand is from the blast energy. So, the total amount of blast energy need to be absorbed should be a function of the peak load and of course, as you correctly guessed duration of the blast t and peak load let us say amplitude A bar.

So, now, the adequacy of the blast resistant design of structural systems is based on the maximum deformation rather than the stress level. So, now the blast resistant design philosophy should be based on the maximum deformation level it is not based on the stress level. So, therefore, a conventional design, which talks about the stress as an indicator in the design parameter is of no use under these kinds of loads.

Having said this let us see, how the material response, we have seen how the structure responds.

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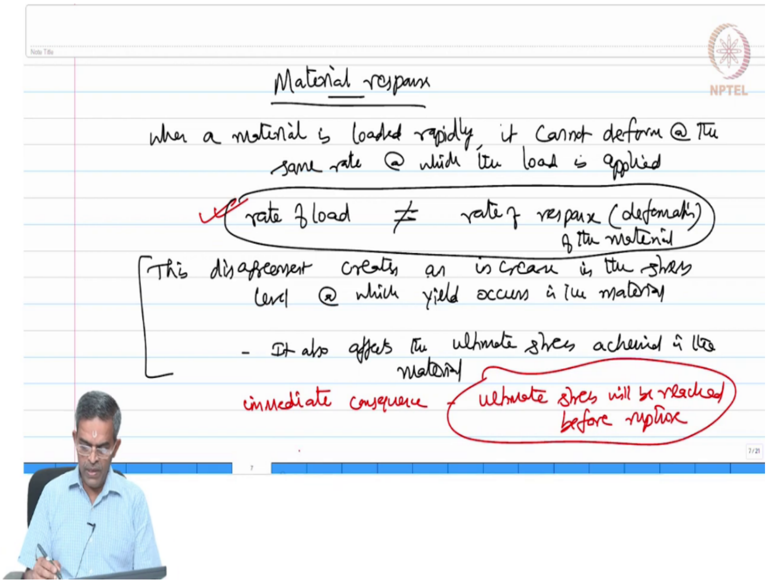

Now, let us see how the material response to this. When a material is loaded rapidly, it cannot deform at the same rate at which the load is applied. So, what I mean to say is the rate of loading cannot be equal to rate of response or rate of deformation of the material.

So, this disagreement creates an increase in the stress level at which yield occurs in the material. It also affects the ultimate stress achieved in the material. These are the two influence caused by this disagreement. So, what will be the immediate consequence of this? The immediate consequence will be ultimate stress will be reached before rupture that is the problem. That is a very interesting, understanding which we must know about the material behavior when this or such disagreement is seen.

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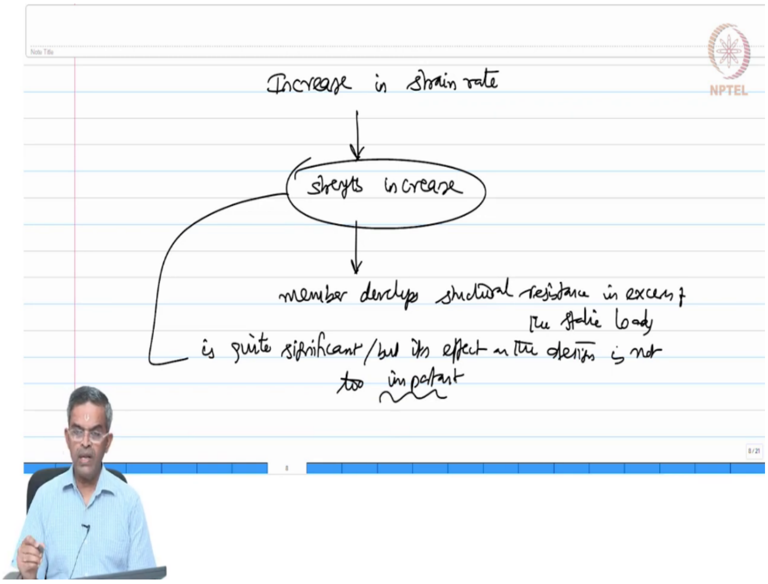

Having said this, we now clearly say increase in strain rate leads to strength increase, it leads further to a consequence that member develops structural resistance in excess of the static loads. So, this strength increase is quite significant, but its effect on the design is not too important because the rate of loading remains only for a very brief period compared to the service life of the structure therefore, this benefit of increase in strength cannot be accounted in the design as a significant parameter.

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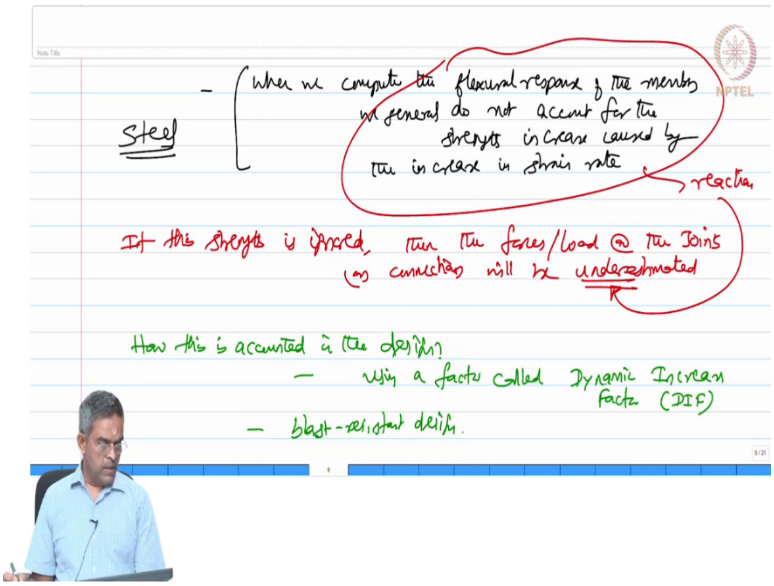

Having said this, when we compute the flexural response of the member, we generally do not account for the strength increase caused by the increase in strain rate. I mean this statement is kept in mind and applied to steel as a material. Please note that this in the background information is we are talking about steel as a construction material.

Now, if the strength is ignored as we said in the previous sentence then the forces or the loads at the joints or connections will be underestimated. Please understand why? Friends, please note this is an internal effect caused by the member. So, I should say this is a reaction, now this reaction will have a counter-effect on the joints.

So, whatever loads coming on the joints now whether it is external by the moment caused by the loads or internally caused by the material or the member behavior, you will be underestimating that there is the danger here there is a danger here you are underestimating that.

Now, you ask me a question; how this is accounted in the design? Because this has to be accounted in the design how? This is accounted in the design by using a factor called Dynamic Increase Factor, DIF. This is very much prevalent in blast resistant design or design under accidental loads.

Let us go at one step ahead.

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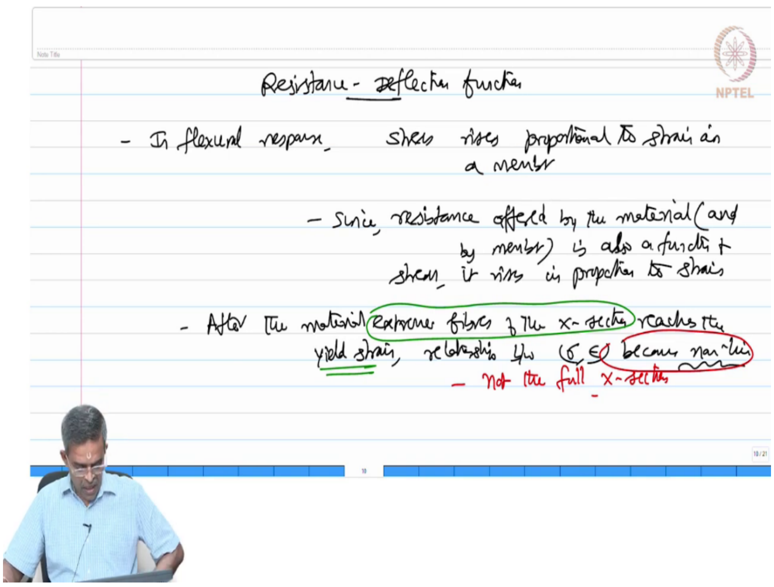

And discuss about the resistance deflection function. Generally friends, in flexural response stress rises proportional to strain in the membrane that is a usual practice, generally it rises like that. Since, resistance offered by the material primarily and by the member because form dominance is also a function of stress, it rises in proportion to strain.

So, after the material extreme fibers of the cross section reaches the yield point or the yield strain, relationship between stress and strain becomes non-linear. Please note very carefully here, this becomes non-linear only at that instance when the extreme fiber alone reaches yield strength not the full cross section.

only just when the extreme fiber reaches the yield strain stress strain behavior becomes non-linear immediately. There is no proportionality between the rate of increase of strain and the rate of increase of stress, they are no more linear right, I am talking about steel is a material in mind.

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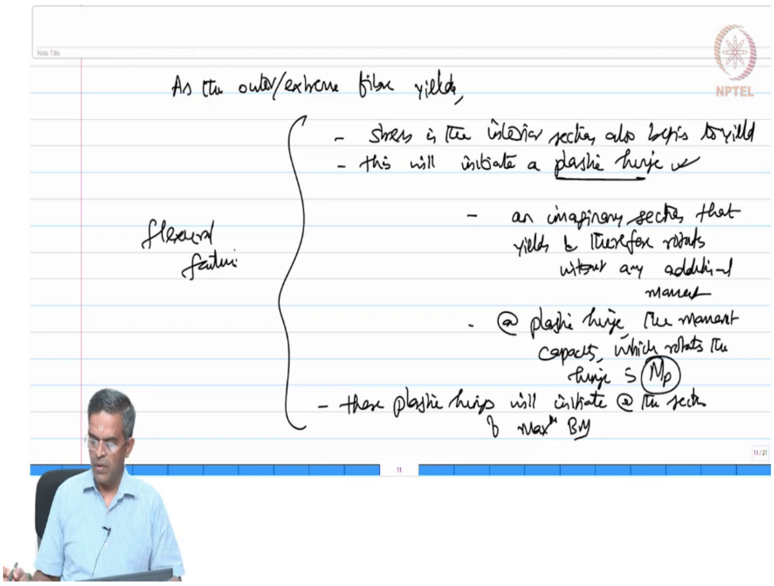

Having said this, further as the extreme fiber yields stress in the interior section also begins to yield, because the load will be transformed the strain will be transformed to the next adjacent fiber. So, that starts yielding now. And this will initiate a plastic hinge. We will talk about the plastic hinge and plastic design in detail in the next module lectures, but let us say it initiates a plastic hinge.

Plastic hinge is an imaginary section that yields and therefore, rotates without any additional moment, that is, at plastic hinge, the moment capacity, which makes the hinge to rotate is M_p, but any moment addition to this is not required we will keep on rotating at that moment . So, plastic hinge will be initiated.

So, where they will initiate as you correctly guessed, these plastic hinges will initiate at the sections of maximum bending moment. I am talking about flexural failure.

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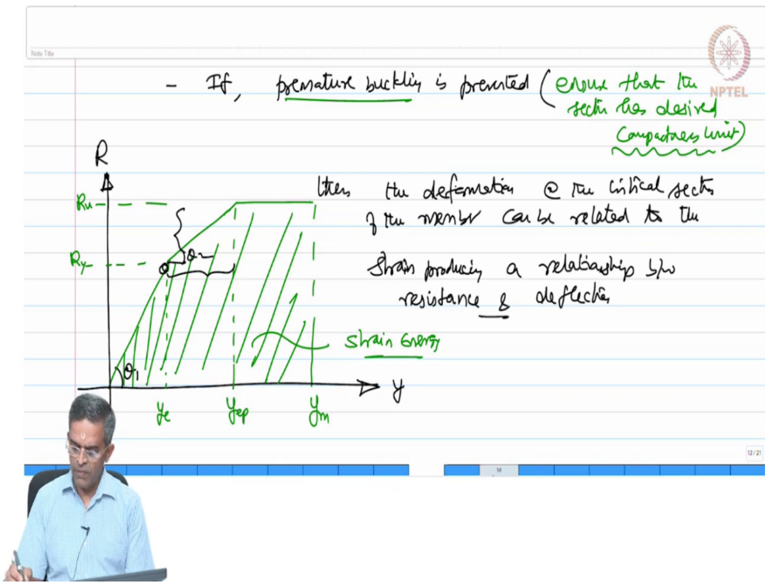

If, premature buckling is prevented we will talk about the buckling failure in detail, but let us know a hint here how do you prevent a premature buckling.

You ensure that the section has desired compactness limit. Compactness limit is a factor given in the code which depends on the cross sectional dimensions of the member and if that factor is satisfied the member or the sizing of the member will not initiate premature buckling. So, it is simply a geometric choice of a cross section right. For example, b/d, h/t, b/t_w, h/t_f etcetera.

So, if this is satisfied then premature buckling will not happen. Let us say if premature buckling is prevented, then the deformation at the critical section on the member can be related to the strain producing a relationship between resistance and deflection.

Let us try to plot this in the x axis, let me plot the deformation in the y axis, let me plot the resistance. Now, let the curve has three slopes, let us see different distinct points, we call this as y maximum, this is y yield point and this y elastic . W call the corresponding values as R y and Ru. So, area under this curve as we all know with respect to x axis will give me the strain energy.

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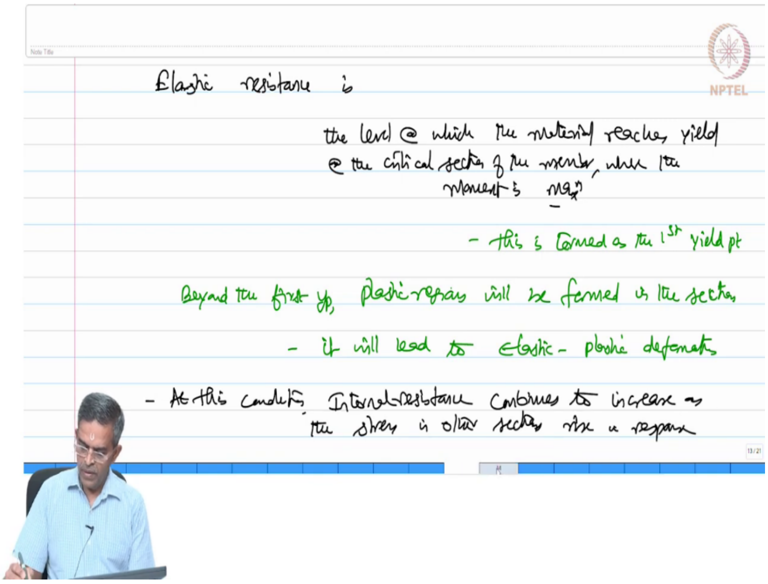

Having said this, let us say an elastic resistance is the level at which the material reaches yield at the critical location or critical section of the member, where the moment is maximum.

So, this is termed at the 1st yield. Now, beyond the first yield point plastic regions will be formed in the section and it will lead to elastic - plastic deformation. In this condition, internal resistance continues to decrease because plastic hinges are formed first yield has occurred internal resistance continue to increase as the stress in other locations or other sections rise in response.

So, response now will shift to the adjacent next critical sections and the response keeps on rising in adjacent sections.

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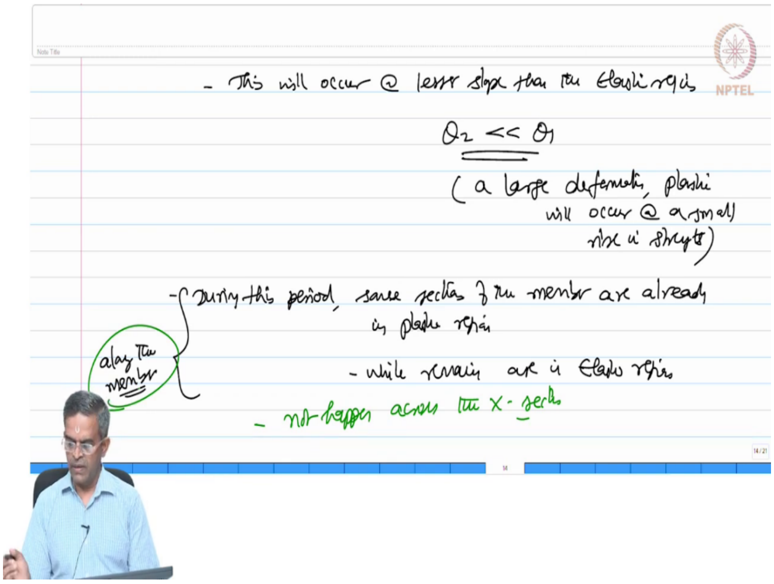

But this will occur at a lesser slope than the elastic region. Please see the curve, the slope of this if it is theta 1, if this is theta 2 theta 2 will be far lesser than theta 1 . It will occur it means a large deformation which is plastic will occur at a small rise in strength gain. So, up to this place up to this place is proportional beyond this it is not. That is what we are emphasizing here.

So, during this period some sections of the member are already in plastic region, while remaining are in elastic region and this variation will happen along the member not across the cross section. Please understand, this will not happen across the cross section, can you tell me why? Very simple the moment varies along the span.

The response is directly related to the moment demand. So, this variation will happen along the member and there will be a continuous shift of critical sections from a b c and so on, which will slowly get plasticized, while the remaining will become elastic.

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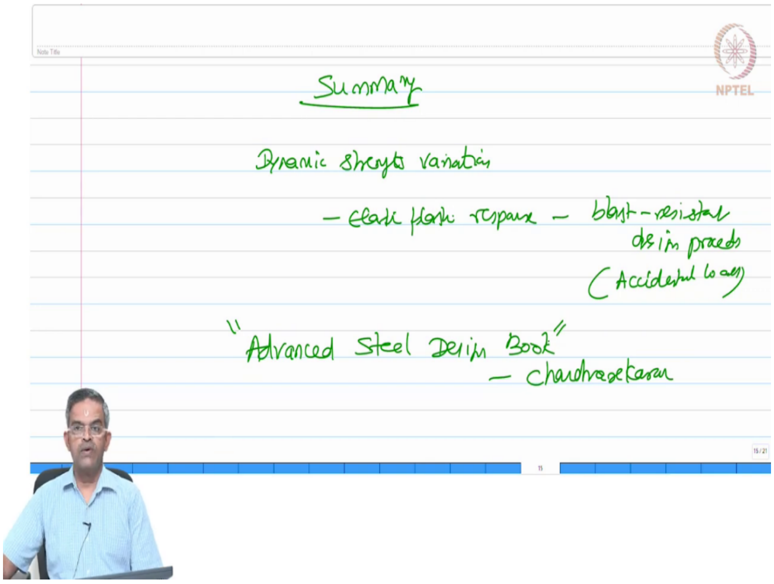

So, friends, in this lecture we are learning about the dynamic strength variation and elastic plastic response behavior under blast resistant design procedure, not necessarily blast I can even call this as accidental loads. So, hope you will be enjoying this and you will be following these lectures back to know more about this. Please have a look at my Advanced Steel Design book which is a very useful handout and gives more information about these processes for your comfortable pace of learning.

Thank you very much, have a good day.