Offshore structures under special loads including Fire resistance
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Module – 03
Fire Resistance
Lecture – 48
Material Strength II

Friends, we will continue to discuss the material strength under different varieties of loads including elevated temperatures in this lecture which is continuation of the previous lecture where we discussed, material strength characteristics under rapid load rates as we discussed in the last lecture.

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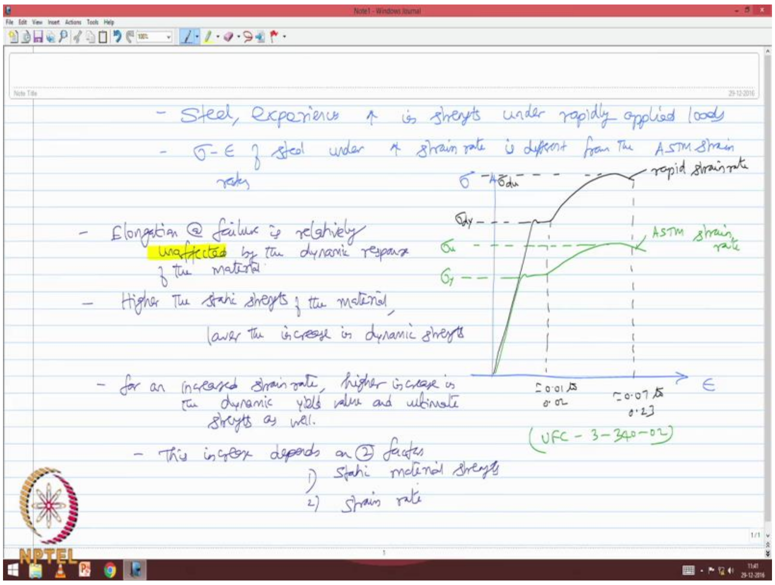

As we now understand, steel as a material, experiences increase in strength under rapidly applied loads. The stress strain behaviour of steel under increased strain rate is different from the ASTM strain rates as we talked in the last lecture. Just to capture back we said that the stress strain plot for two varieties of steel, let us say at rapid strain rate which can extend the strain, can go to till 0.07 to 0.23.

It shows a very designated yield plato in case of low carbon steel, whereas this value can be 0.01 to 0.02 and look at the values of stress, ultimate these stands for the dynamic strain rate and may be this value is the corresponding d-th yield. So if we look at the ASTM strain rate curve, it also follows a same style qualitatively, so this is ASTM strain rate where I can call this value as sigma u and this value as sigma yield. You will very well see here that depending upon the strain rate change; the strain energy adopted by the material is far different from the top at the standard strain rate which is being taken as a reference from UFC; 3; 340, 02.

So, this brings us back for a statement saying that elongation at failure is relatively unaffected by the dynamic response of the material. So, it is relatively unaffected by the dynamic response of the material, on the other hand higher the static strength of the material, lower the increase in dynamic strength. For an increased strain rate, we have also seen that there is a higher increase in the dynamic yield value and ultimate strength as well. Of course this increase depends on two factors namely, the static material strength and the strain rate.

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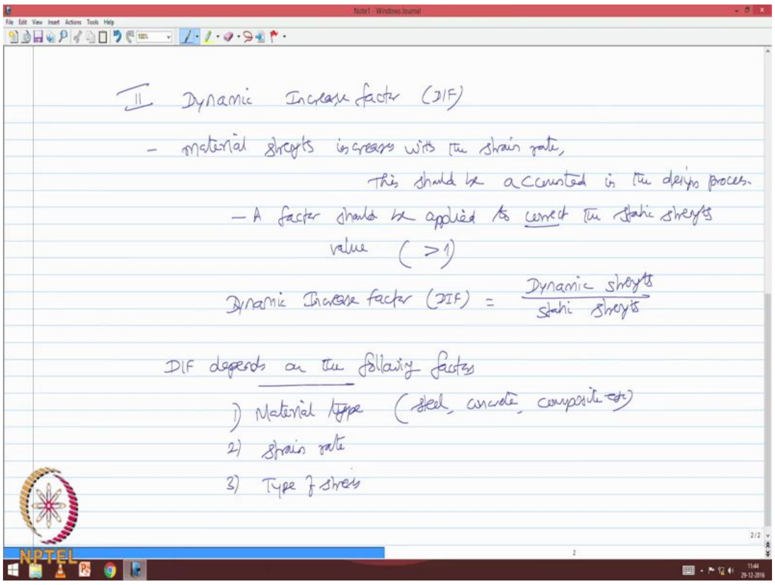

We also said that due to this rapid rate of loading, the strength increases which should be accounted in the design procedure. So, we will talk about now the Dynamic Increase Factor which is DIF, we agree that the material strength increases with the strain rate. Therefore, this should be accounted in the design, so a factor should be applied to correct the static strength values, the factor should be usually more than 1. So, the dynamic increase factor which we call as DIF is a ratio between the dynamic strength to that of the static strength. Of course DIF depends on the following factors, it depends on the material type for example, steel, concrete, composite etcetera they are different for different material type, two the strain rate because you know the material behaviour in terms of test and relationship is not same for brutal and ductile material for example, concrete and steel respectively.

Third, what is the type of stress we are looking for; or looking for axial stress, or looking for bending stress, etcetera? In fact axial stress tension or compression, so the nature of stress also vary and therefore the DIF, the dynamic increase factor is appropriately applied to the type of stress we are looking for, its enhancement under the dynamic loads.

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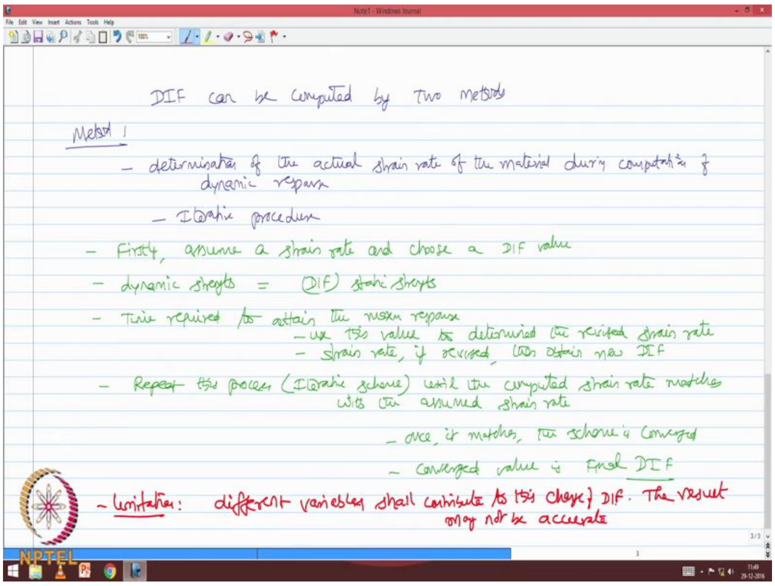

There are two methods available in the literature based on which DIF can be computed. The dynamic increase factor can be computed by two methods, let us see method one - the method one demands determination of the actual strain rate of the material during computation of dynamic response, this is an iterative procedure. Let us see what are the steps involved in this procedure, first assume a strain rate and choose a DIF value.

We all know that the dynamic strength can be computed; is nothing but DIF multiply by the static strength because DIF is the ratio of dynamic to static strength. Also note down the time required to reach the maximum response, to attain the maximum response and use this value to determine the revised strain rate. The moment the strain rate is revised then obtain new dynamic increase factor, repeat this process that is the iterative scheme; until the computed strain rate matches with the assumed strain rate. Once it matches, they can say the scheme is converged and the converged value is the final DIF. Please understand this method has a limitation, the limitation is different variables shall contribute to this change of DIF, so the result may not be accurate.

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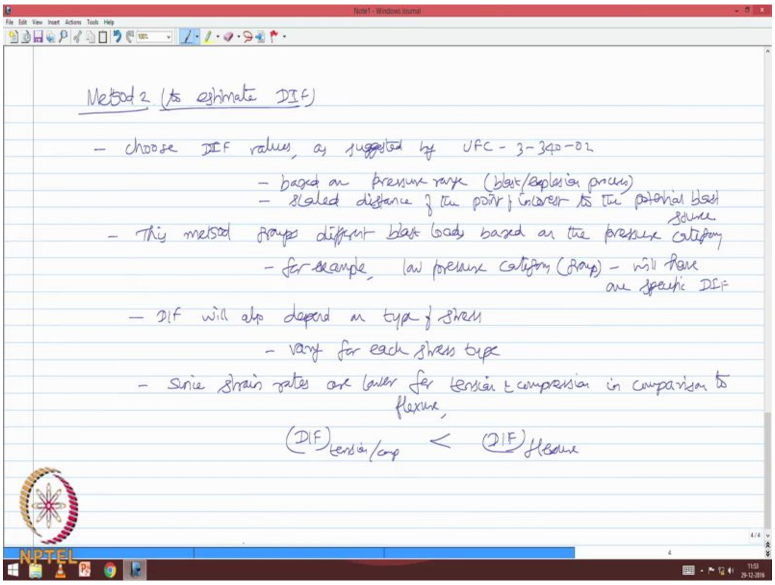

There is a second method by which we can estimate the DIF, choose DIF values as suggested by UFC; 3, 340; 02. These values are based on the pressure range of the blast waves or explosion process based on the scaled distance of the point of interest to the potential source of blast. So this method actually groups different blast loads based on the pressure category. For example, low pressure category or group will have one specific DIF. Of course the DIF will also depend on the type of stress which you are looking for, (Refer Time: 16:10) vary for each stress types; for example, since the strain rates are lower for tension and compression in comparison to flexure, DIF values for tension compression or lower then DIF values of flexure.

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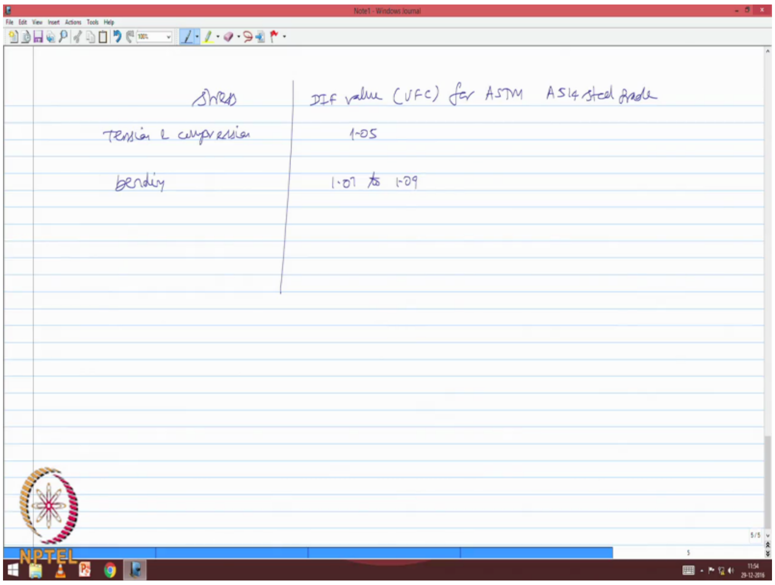

Typical values as given by UFC are as follows, for a given type of stress; the DIF value suggested by UFC for ASTM steel; A 514, a typical value I am indicating here. For tension and compression, the DIF value suggested is 1.05 and for bending that is for flexure; it is 1.07 to 1.09 as expected, the values of flexure or higher than that of axial tension or compression.

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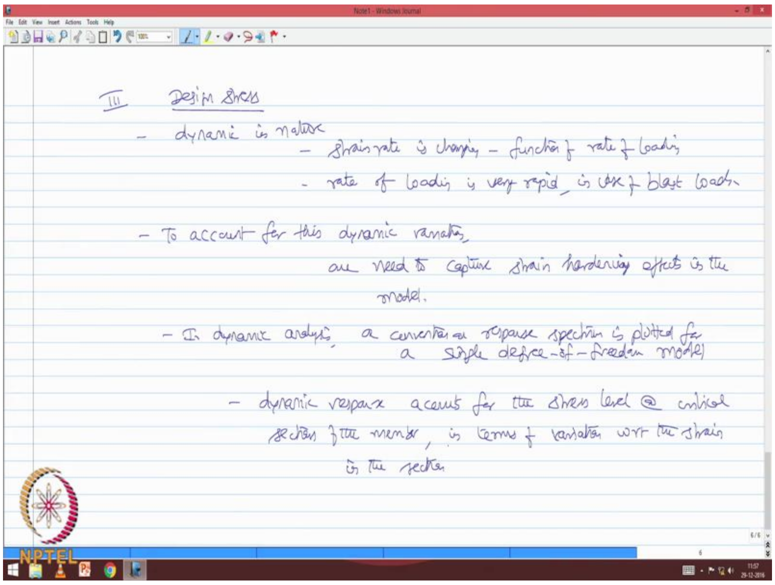

The next parameter of interest for material strength is the design stress. The design stress is all are now going to be dynamic in nature because the strain rate is changing and is a function of rate of loading, that is number 1; number 2, the rate of loading is very rapid in case of blast loads. So, to account for the dynamic variation one actually need to capture the strain hardening effects as some model in the model.

Generally in dynamic analysis or conventional; response spectrum is plotted for a single degree freedom system model. When we deal with dynamic response, it accounts for the stress level at critical sections of the member in terms of variation with respect to the strain in the section.

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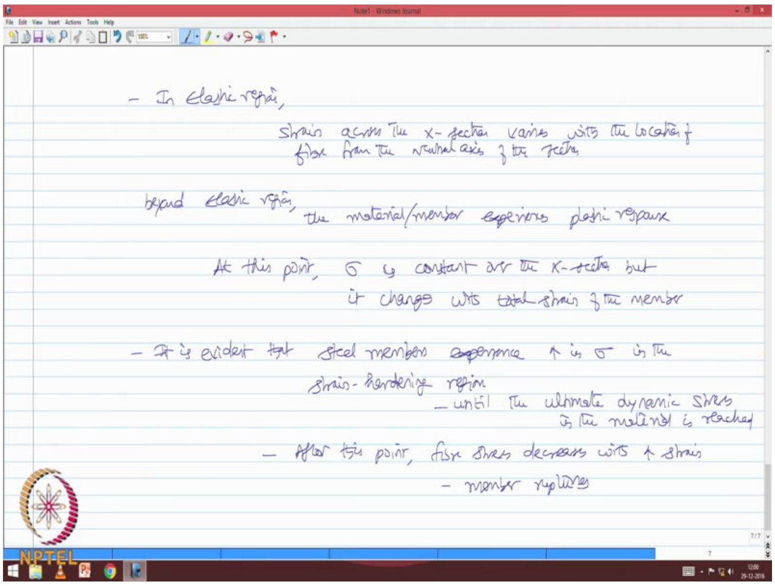

Of course in elastic region, strain across the cross section varies with the location of the fibre from the neutral axis of the section. Now beyond elastic region, the material and the member experiences plastic response. At this point, stress is constant over the cross section but it changes with the total strain of the member, so the variation is now shifted from the cross section to the member dimensions.

It is very evident from the literature that, steel members experience increase in stress in the strain hardening region. This is true until the ultimate dynamic stress state in the material is reached, of course after this point fibre stress decreases with increasing strain and ultimately the member ruptures.

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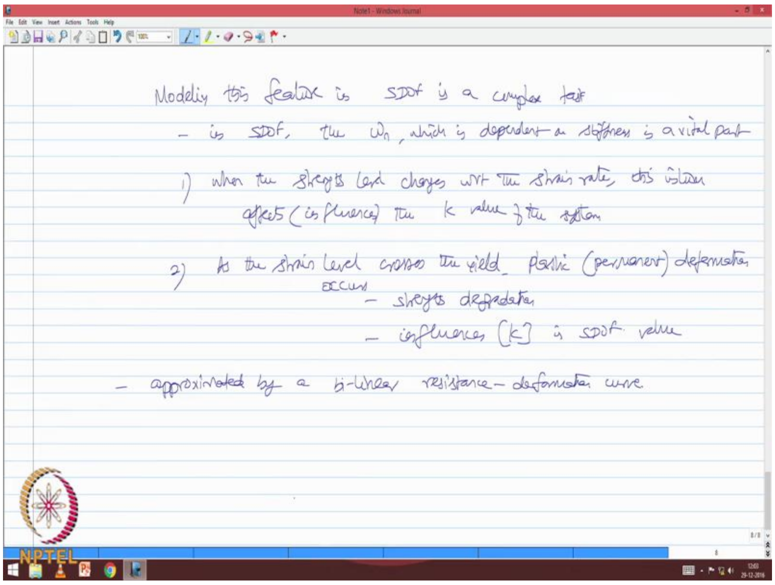

But interestingly modelling this feature in single degree of freedom system models is a complex task because in single degree freedom system model, the natural frequency which is dependent on stiffness is a vital part. When the strength level changes with respect to the strain rate, this in turn affects or I should say influences the stiffness value of the system; that is the first reason. Second reason is as the strain rate or as the strain level crosses the yield plastic or I should say permanent deformation occurs which is actually a sort of strength degradation.

So, this also influences the stiffness in single degree freedom value therefore, modelling this dynamic stress behaviour in single (Refer Time: 25:59) system model is actually complex. So, this is being approximated by a bi-linear resistance-deformation curve as suggested in the literature.

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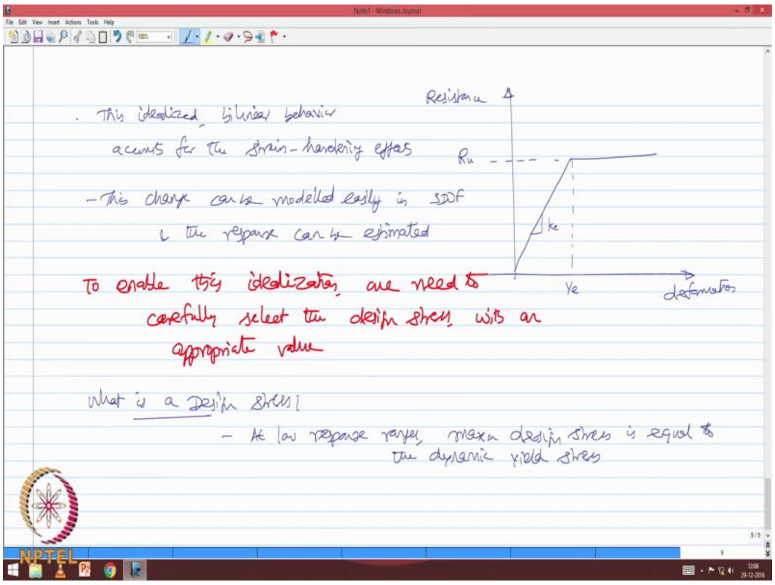

A typical curve looks like this, so this is my deformation, this is my resistance. We are looking for a bi-linear model, which is an idealized model. So, I initially consider this as my elastic stiffness and I take this value as my yield at elastic level and I consider this value as my resistance ultimate. So, this idealized curve; this idealized bi linear behaviour accounts for the strain hardening effects which is otherwise complex to be modelled in single degree freedom system behaviour.

So, now this change can be easily modelled in equivalent single degree freedom system and the response can be estimated. But please understand to enable this idealization, one need to carefully select the design stress with an appropriate value. Now the question comes what is the design stress, so in simple terms; at low response ranges, the maximum design stress is equal to the dynamic yield stress.

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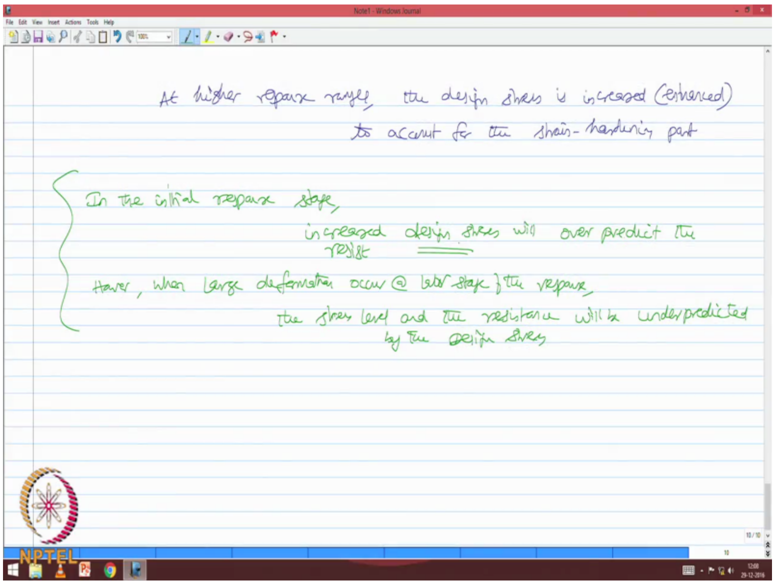

At higher response ranges, the design stress is increased I should say enhanced to account for the strain hardening part. Therefore in the initial response stage, the increased design stress will over predict the resistance because the design stresses are increased.

However when large deformations occur at later stage of the response, the stress level and the resistance will be under predicted by the design stress. So, it is very complex to have a single value which can be applied to the initial as well as large deformation stage. So, the design stress should be appropriately chosen by the enhanced factor such that it accounts for both nature of behaviour in the initial as well as in the stage where large deformation occurs in the system.

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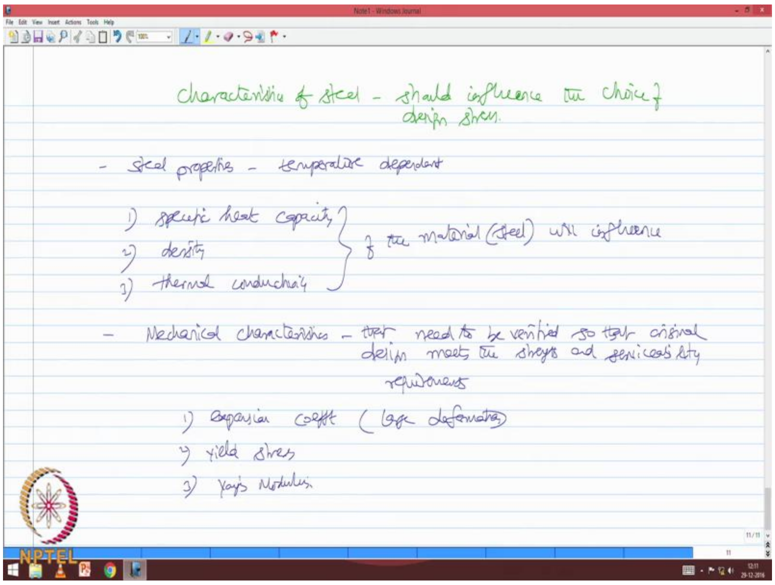

So, friends these characteristics of steel should influence the choice of design stress, but we are now looking forward for the steel properties, which are temperature dependent. Let us say a specific heat or specific heat capacity of the material, density of the material and thermal conductivity of the material, in my case let us say steel will influence his thermal characteristics. Then one should be interested to know; what are those mechanical characteristics that need to be verified so that original design meets the strength and serviceability requirements.

So, those characteristics are expansion coefficient because you are talking about large deformation to yield stress value and three modulus of elasticity or let us say Yang’s modulus.

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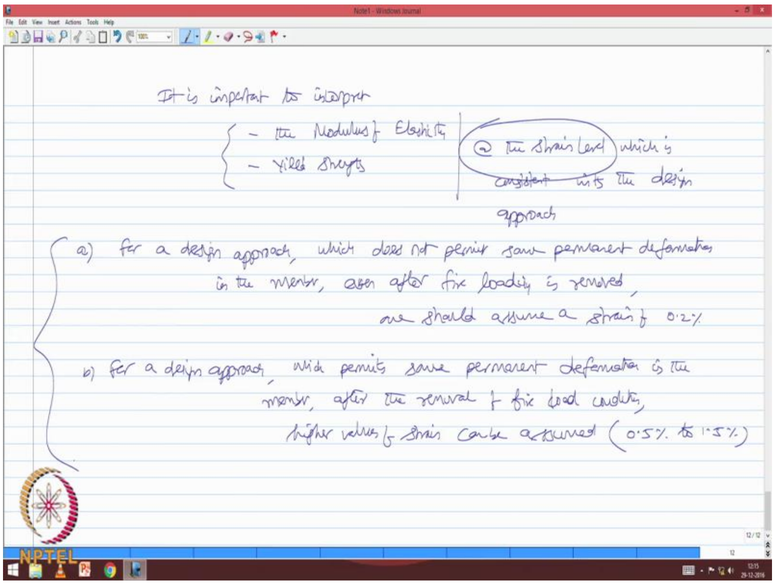

So, friends it is important to interpret the modulus of elasticity and yield strength. At the strain level which is consistent with the design approach because these properties are sensitive to the stain level. For example, for a design approach which does not permit some permanent deformation in the member even after fire conditions are remove or fire loading is removed then one should assume a strain of 0.2 percent. For a design approach, which permits some permanent deformation in the member after the removal of fire load, higher values of strain can be assumed, it can be as 0.5 percent to 1.5 percent.

So depending upon the strain level what you want to fix, your design approach should be compactable with the strain level.

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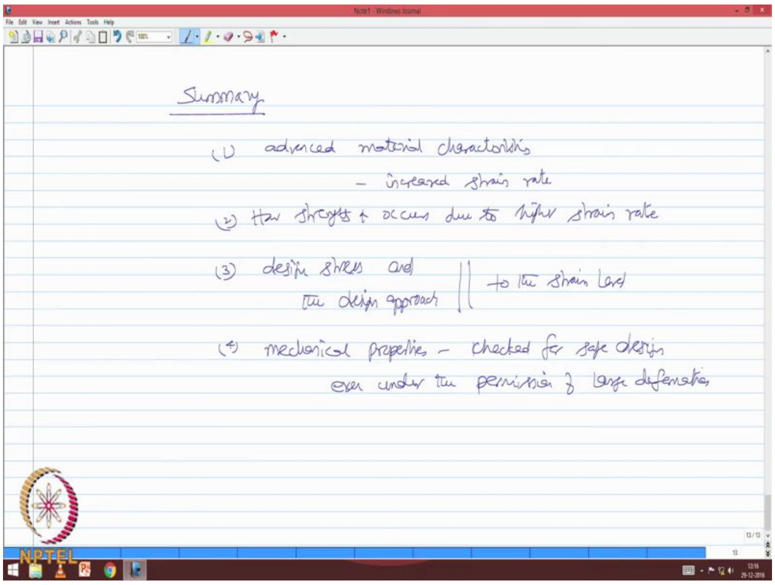

So, friends in this lecture we learnt advanced material characteristics under increased strain rate. We have also seen how strength increase occurs due to higher strain rate; we have also understood what would be the design stress and the design approach with respect to the strain level. We have also seen what are those mechanical properties which need to be checked for safe design even under the permission of large deformations.

Thank you very much.