Offshore structures under special loads including Fire resistance
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Module – 03
Fire Resistance
Lecture – 47
Material Strength I

Friends, welcome to the 47th lecture, titled material strength, under 3rd module, Fire Resistance. In the last set of lectures and Fire Resistance, we understood how to estimate blast wave over pressure around the circumference of any building module of top side offshore platforms, we know generally top side structures of offshore platforms are essentially constructed by steel or composites or to some extent rain force cement concrete members. It is interesting and important to understand how the material strength varies under high temperature or elevated temperature which essentially is a consequence of any occurrence of fire or explosion. So, in this lecture, we will discuss about details on material strength and then how to fix the design stresses which can be helpful to deal with the blast resistant design or in general fire resistance design of offshore structures.

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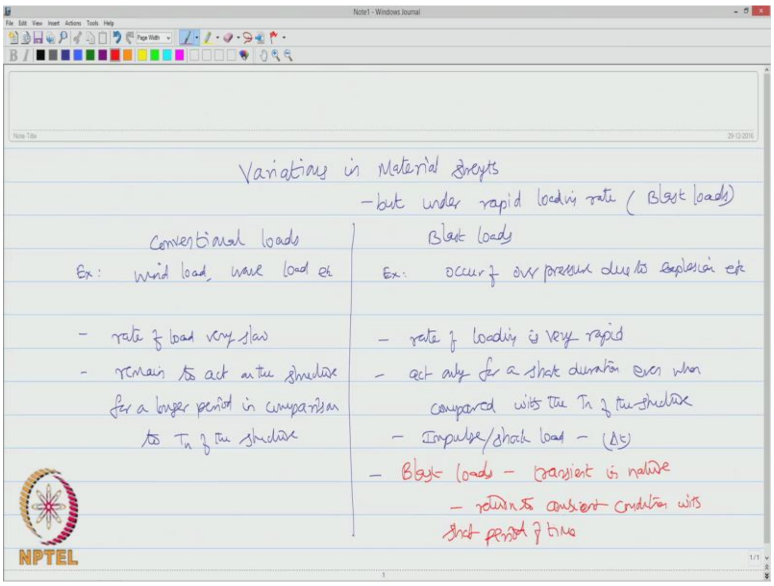

Let us try to understand the details of material strength variation, we are now focusing on variations in material strength, not necessarily under high elevated temperature, but under rapid loading rate for example, blast loads. Let us first understand what would be the difference, in the application of loads on offshore structures of blast loads compare to conventional environmental loads, let us say the comparison demands, understanding of conventional loads with that of blast loads, example could be wind load, wave load, etcetera; blast loads example could be occurrence of over pressure due to explosion, etcetera. Conventional loads do have rate of loading very slow, whereas in blast loads rate of loading is very rapid, convention loads remain to act on the structure for a longer period in comparison to the period of the structure, whereas blast loads at only for the short duration even when compared with the natural period of the structure.

This is the kind of impulse or shock load which acts only for delta t therefore, blast loads are essentially transient in nature, why transient because they will return to ambient conditions within short period of time.

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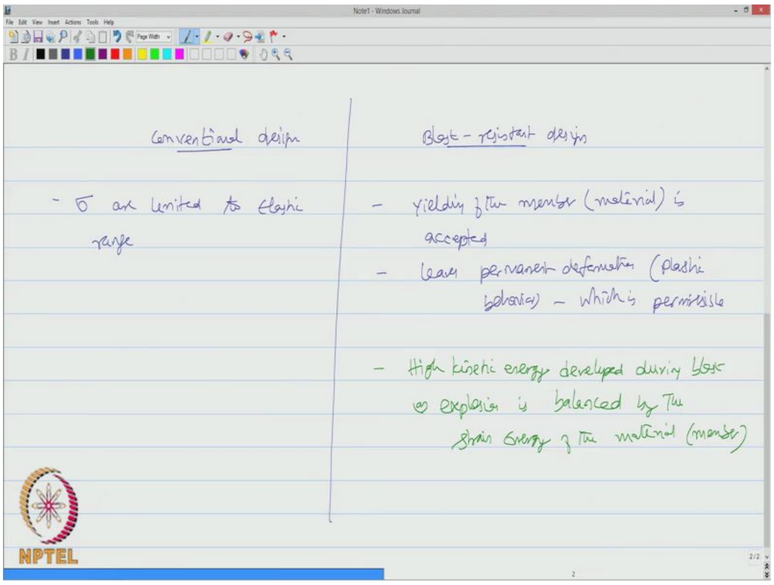

If that is the case what would be the difference between the conventional design or design under the conventional loads and let us a blast resistant design, in conventional design stresses are generally limited to in elastic range where as in blast resistant design yielding of the member. In fact, I would say material is accepted, when I say yielding accepted, it leads permanent deformation which I can call as plastic behavior which is permissible because high kinetic energy developed during blast of explosion is balanced by the strain energy of the material, I can say member.

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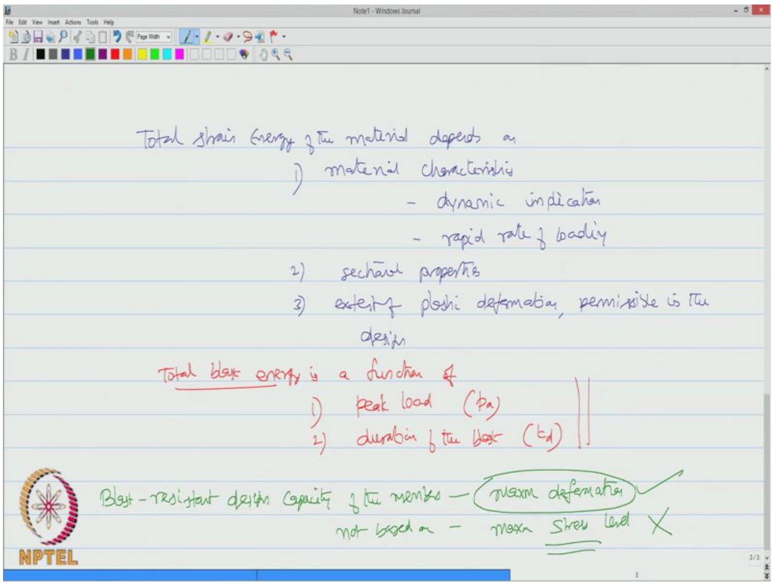

Now, the total strain energy of the material depends on, one - material characteristics, I should say these characteristics are those which vary with time therefore, they have a dynamic implication, why we are saying dynamic because here we talking about a very rapid rate of loading. The second of course, it depends on sectional properties, the cross section dimension, length of the member, boundary conditions, etcetera and thirdly the extent of plastic damage or plastic deformation permissible in the design. On the other hand, the total blast energy is a function of the peak load which we call as p a and 2, the duration of the blast, the total duration of the blast which we call t d which we discussed yesterday in last lecture in detail therefore, friends blast resistant design capacity of the members is based on maximum deformation and not based on maximum stress line.

Here that fundamental difference in the design procedure, we are here talking about deformation controlled or deformation restricted response of the system not strength base design.

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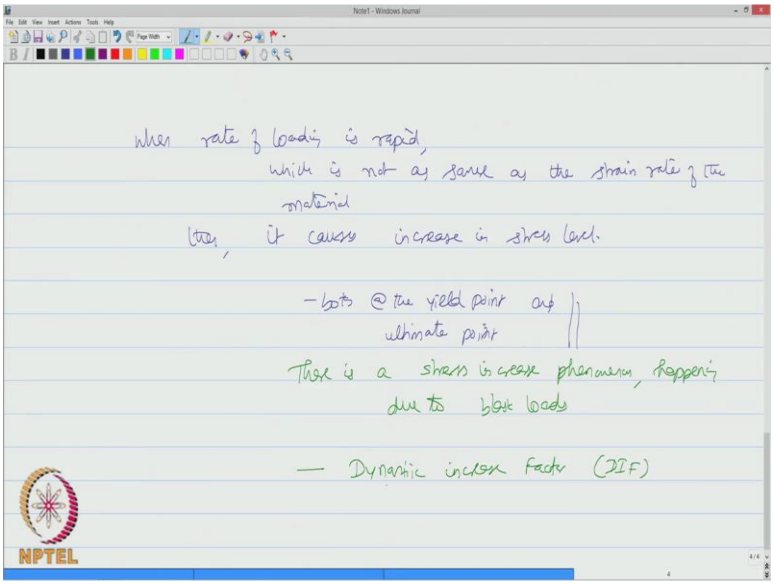

We already know that when rate of loading is rapid, which is not as same as the rate of increase or is not as same as the strain rate of the material then it causes increase in stress level both at the yield point and ultimate point. So, there is a strength increase or stress increase phenomena happening due to blast loads which is addressed as dynamic increase factor.

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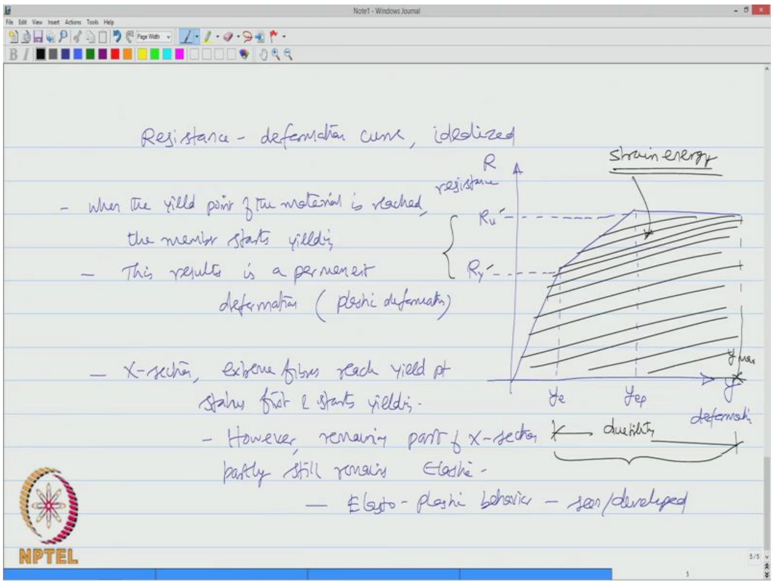

If you look at the resistance deformation curve which is idealized conceptually, initially on the plot of yield or response versus resistance, this is deformation and this is resistance you will see that initially, it will be linear till the yield point. So, we can call this as deformation at yield and the corresponding value of resistances; resistance at yield when the yield point is reached of the member or material is reached, the member starts yielding, this results in a permanent deformation which is addressed as plastic deformation.

In the given cross section, it is obvious to understand that extreme fibers reach yield point status first and starts yielding; however, remaining part of the cross section partly still remains elastic, it means there is an elastro plastic behavior which is seen or which is developed because of this, the slop of the curve changes, but it will still try to of a resistance with the different slop and we call this, let us say yield Elastro plastic and the corresponding stress can be ultimate because after the Elastro plastic yield level is reached then it does not it yield infinitely at the same load.

The area of this curve; area of this curve, we call this as maximum yield area of this curve is what we call as strain energy of the material which is going to compensate the blast energy of the explosion energy applied on or impinged upon the member. Under idealized condition we do agree that maximum yield to the elastic yield is what we call as ductility and this is my strength ratio between ultimate to the yield, he can see here that large deformation capacity is demanded from the material compare to the top the strength increment between the yield, then ultimate it is because of the amount of strain energy possessed with material, the blast resistance can be achieved. So, we should look forward for a material which has large ductility or deformation capacity even with the marginal increase in the strength.

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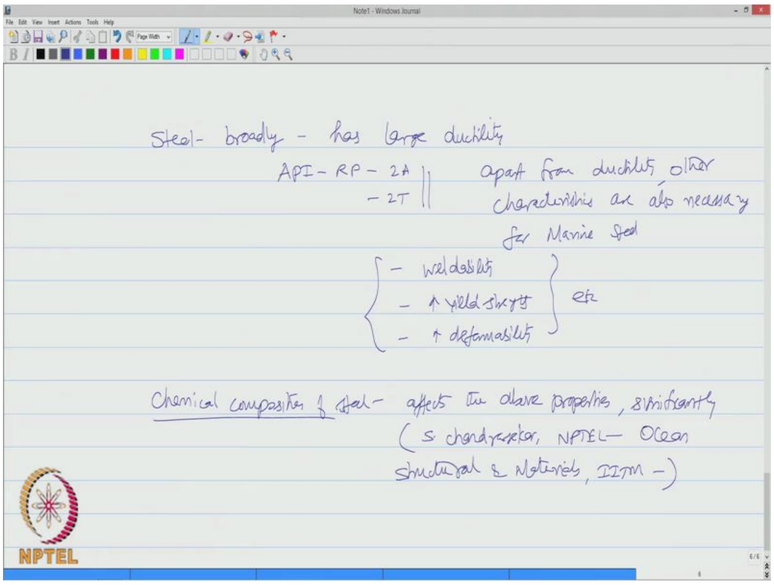

Now the question comes, steel broadly has large ductility, as we all agree, as recommended by API-RP, both 2A and 2T, we know that apart from ductility, other characteristics are also important for marine steel, for example, weld ability, high yield strength, high deformability, etcetera and we know that chemical composition of steel affects the above properties significantly, you can look into my course on NPTEL titled Ocean Structures and Materials, IIT Madras for more information.

Chemical composition matters, it affects or influences these properties which is necessary for steel to be used as constriction material in offshore structures.

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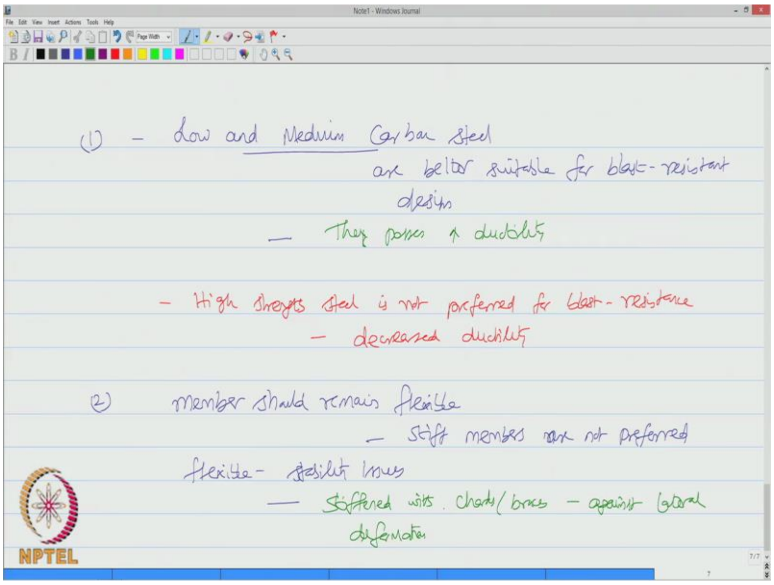

Under this statement, it is recommended that low and medium carbon steels are better suitable for blast resistant design because they posses high ductility.

Whereas high strength steel is not preferred for blast resistance, the main reason is it is got decreased ductility. So, friends please realize that when we say ductility or large ductility, we are talking about a very large strain energy because this is actually area of the curve with respect to x axis therefore, large ductility will give me large strain energy which can counteract the blast energy which is being applied or in pinched on the structure. That is the first choice we have.

The second recommendation is member should remain flexible, stiff members are structures with higher stiffness are not preferred. However, flexible members have stability issues therefore; we recommend that member should be stiffened with chocks and braces against lateral deformation.

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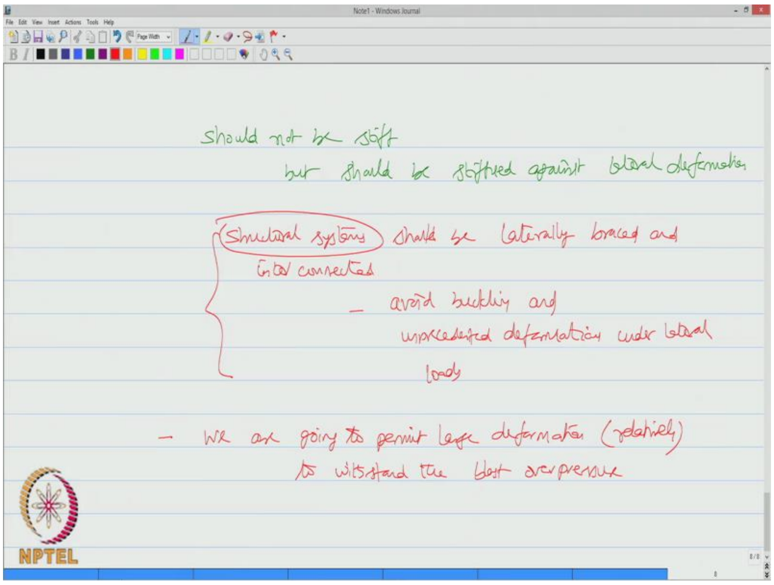

Please realize that we are saying that the structure should not be stiff, but should be stiffed against lateral deformation. So, structural systems should be laterally braced and inter connected because this will helps to avoid buckling and unprecedented deformations under lateral loads. One may ask me question; why this condition is imposed in blast strength design because in blast resistant design, we are going to permit large deformation and I should say relatively large; large deformation to with stand the blast over pressure. So, the structure is already deforming latterly because of its stability related issues which is cross section dependent, but not material dependent, please take care in the design that the structural systems should be sufficiently braced enough. So that they do not undergo unprecedented lateral deformation which will then get added up to the deformation cost by the blast loads on the members.

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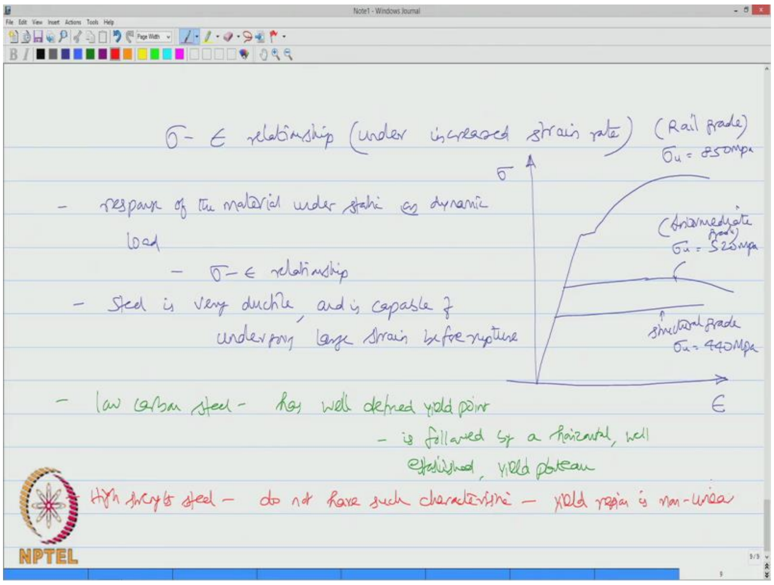

Under this braces, let us try to understand the stress, strain relationship under increased strain rate; a typical stress strain curve for a variety of steel is plotted the typical steel whose ultimate stress can be about 850 mega paschal, we can also have intermediate grade steel which is got more or less an horizontal yield Plato whose ultimate stress is about 520 mega Pascal, we can also have structural grade steel whose ultimate strength is about 440 mega Pascal. This steel is called rail grade steel, this steel is intermediate grade, this is structural grade.

It is important to understand that response of the material under static or dynamic load is essentially governed by the stress strain relationship. We also know that in general steel is very ductile and is capable of undergoing large strain before rupture. It is also seen from the literature that low carbon steel has a well defined yield point, which also is followed by a horizontal well established yield plateau, where as high strength steel do not have such characteristic and more over the yield region is highly non-linear.

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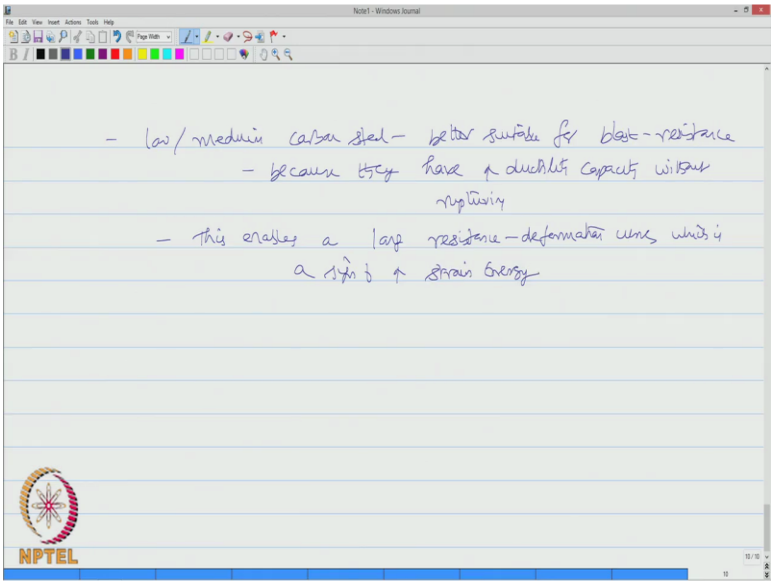

Therefore one can say that low and medium carbon steel are better suitable for blast resistance because they have high ductility capacity without rupturing. Therefore, this enables a long resistance deformation curve, which is a sign of high strain energy, we also said that due to rapid rate of apply loading the stress increases.

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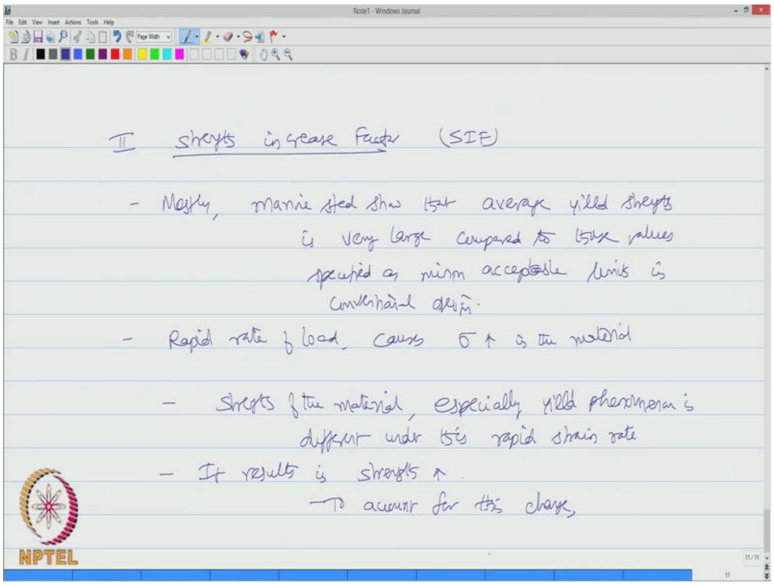

Let us focus on what is strength increase factor, say SIF, most of the marine steel show that average yield strength is very large compared to those values specified as minimum acceptable limits in conventional design. Also rapid rate of loading causes stress increment in the material. However, the strength of the material especially yield phenomena is different under this rapid strain rate, it results in strength increment. So, account this or to account for this change.

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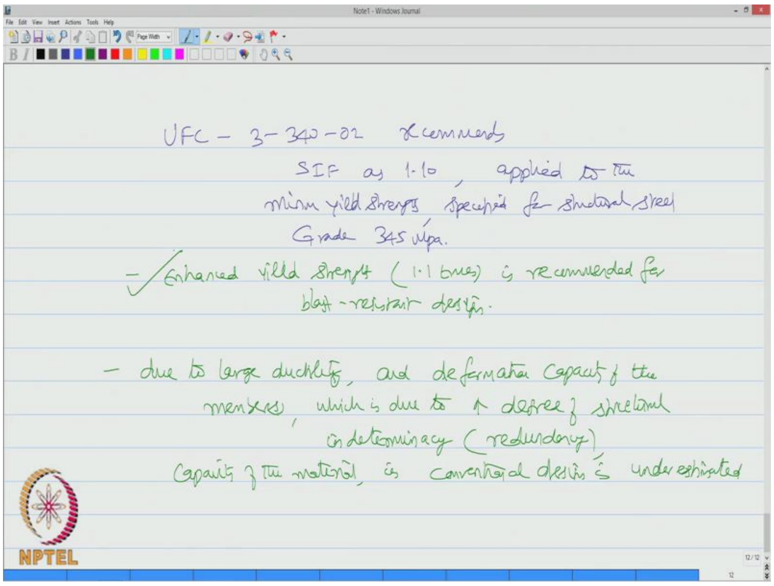

International course like UFC-3-340-02 recommends strength increase factor as 1.10 which can be applied to the minimum yield strength specified for structural steel grate 345 mega Pascal.

Now the interesting part is an enhanced yield strength of 1.1 times is recommended for blast resistant design, the fundamental question comes why do we allow 10 to 15 percent increase in the yield strength, we all agree that due to large ductility and deformation capacity of the member or members which essentially comes from which is due to high degree of structural indeterminacy, which also called as redundancy capacity of the material in conventional design is under estimated. So, the take care of the conservatism additional yield strength of 1.1 times is recommended by UFC.

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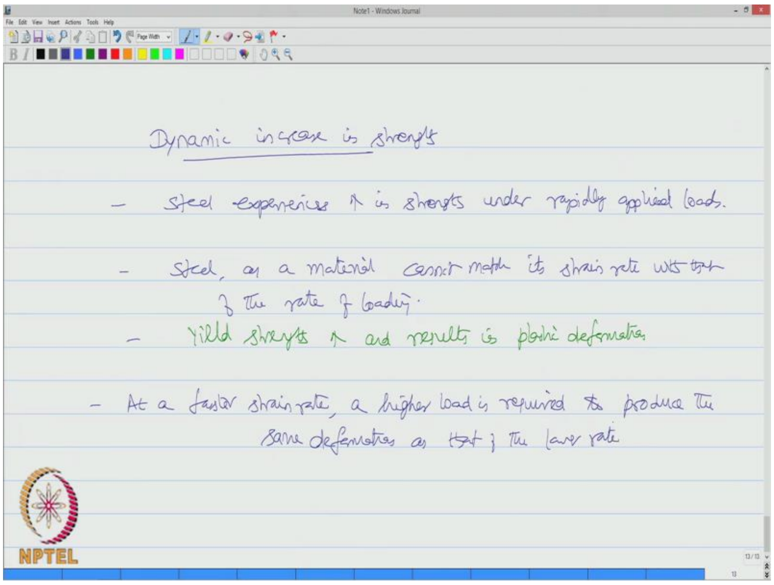

The next factor which is interesting to note is the dynamic increase in strength. We just knows stated that steel experiences increase in strength under rapidly applied loads steel as a material cannot match its strain rate with that of the rate of loading therefore, yield strength increases and results in plastic deformation. Therefore, it is also very important to note that at a faster strain rate, higher load is required to produce the same deformation to produce the same deformation as that of the lower rate.

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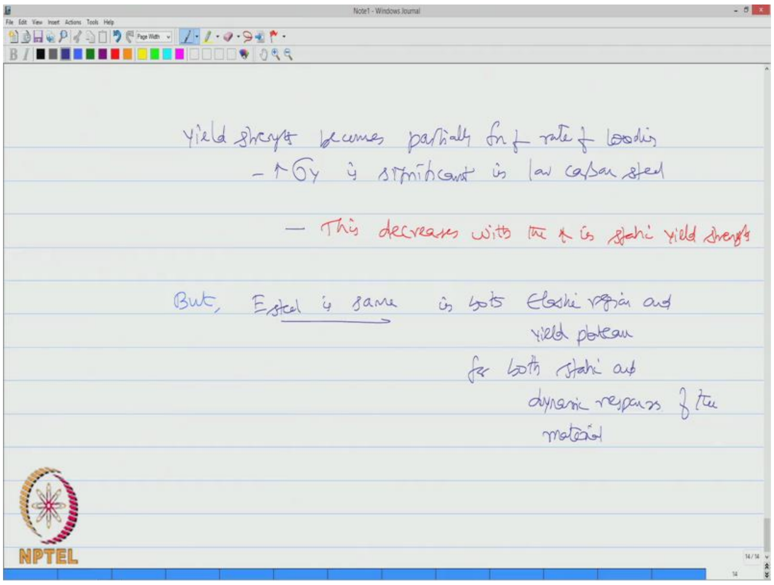

Therefore yield strength becomes partially function of rate of loading increase in yield strength is significant in low carbon steel of course, this decreases with the increase in static yield strength, but model of elasticity of steel is same in both elastic and elastic region and yield plateau for both static and dynamic responses of the material.

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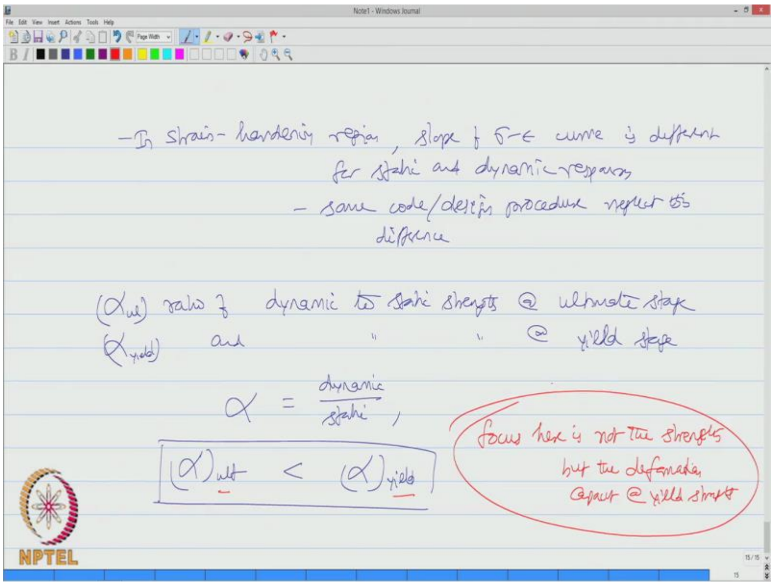

But look at the strain hardening region in strain hardening region, the slow posses strain curve is different for static and dynamic responses; some course some design procedures neglect this difference.

If you look at the ratio of dynamic to static strength at ultimate stage and at yield stage, let us say we call this ratio alpha ultimate stage, this is alpha yield stage where alpha is a ratio of dynamic to static strength, you see that alpha at ultimate stage is lesser than alpha worked out at yield. So, the focus here is not the strength because as the strain the stress value moves from the yield to ultimate the ratio is lower.

The focus here is not the strength, but the deformation capacity at yield strength. So, work only on this, it is because high carbon steel high strength steel do not show good ductility ratio and do not depict high strain energy, they are not preferred because we looking for the steel which is got high deformation capacity at yield level, not at the ultimate level. So, focus is not the strength, we can also plot this graphically and show as per UFC.

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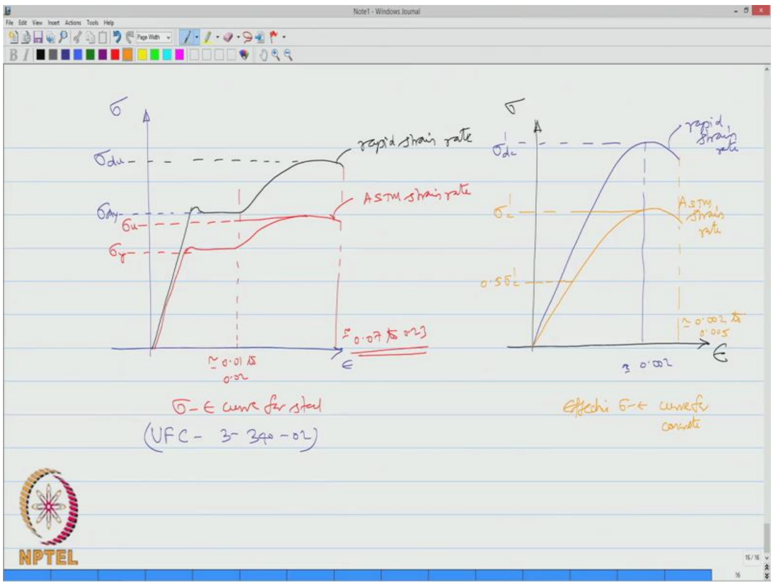

Let us say, we will take it for 2 cases steel which we plotting for stress versus strain based on UFC 3 340 02 typical curve for rapid strain rate shows this, let us say this value sigma du and one can say this is sigma d yield, if it try to plot this for a standard strain rate, initially slow is almost same, it is also yield plateau and the almost parallel, but this is as per ASTM strain rate and I call this value as sigma y which is generally issue and of course, this value sigma u.

Let us compare this value which is about 0.01 to 0.02 and this value varies from 0.07 to 0.23. So, that is a catch, this is for steel that is stress strain curve for steel on the other hand if you look at this curve; a concrete. The rapid strain rate shows the curve typically like this, where is the peak will be at about 0.002 approximately and we can call this as sigma dash d c and the slop of this curve is different, this is as per ACTM strain rate and where as this value can vary from 0.002 to 0.005 whereas you see that this value is about if this is sigma dash c, this will about 0.5 sigma dash, this is for effective stress strain curve for concrete. So, will looking forward for a material which can depict high deformability at the yield level and not at the ultimate strength level.

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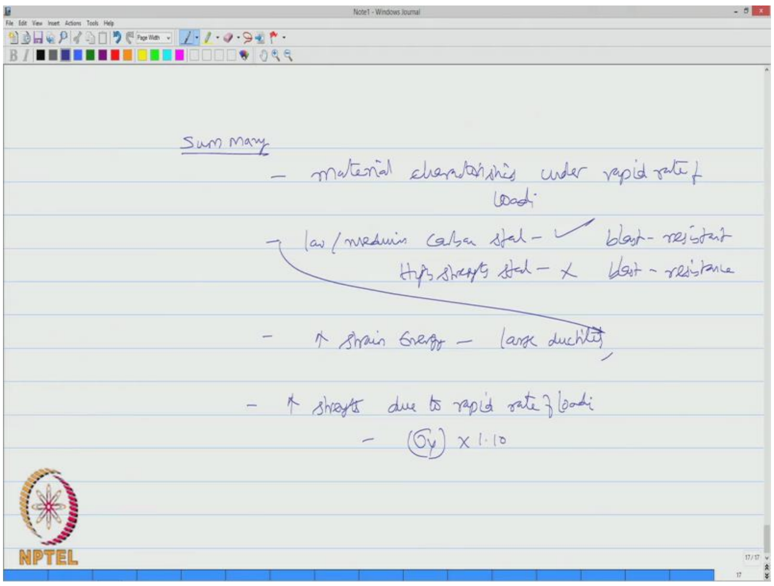

Friends, in this lecture, we are looking into the material strength, material characteristics under rapid rate of loading, we understood that low carbon and medium carbon steel are better suitable for blast resistance design, we have also realize that high strength; the steel is not a good candidate for blast resistant because of decrease deformability, we also agree that we are looking forward of a material which is got high strain energy capacity, which can be achieved with large ductility, which is inherent represent in low carbon and medium carbon steel whereas high strength steel does not possess this capability and we also understood that there is increase in strength due to rapid rate of loading. Therefore, blast resistant design procedures allow you to enhance the yield capacity by a factor of 1.10 to avoid conservative estimate of design parameters or design cross sections for members and under blast resistance loads.

Thank you very much.