Advanced Design of Steel Structures
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Lecture - 16
Material properties variations

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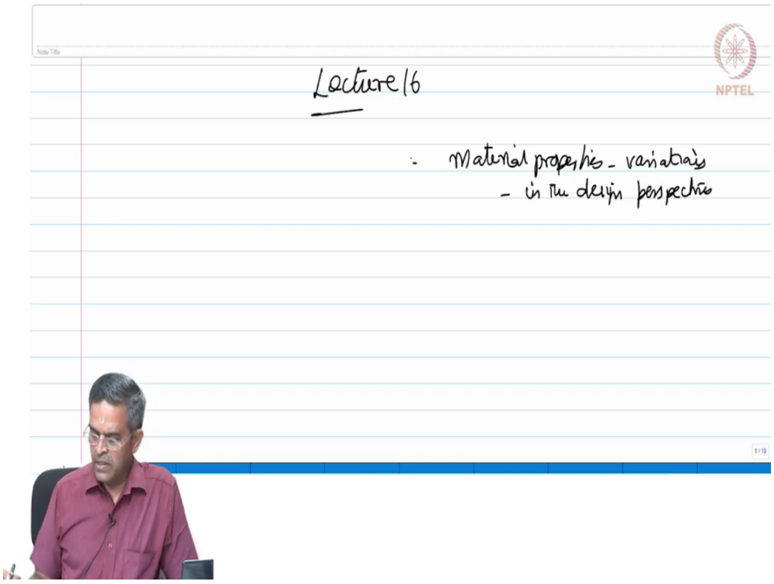

Welcome to the 16th lecture an Advanced Steel Design course friends. In this lecture, we are going to learn about, the Material properties and its variation in the design perspectives.

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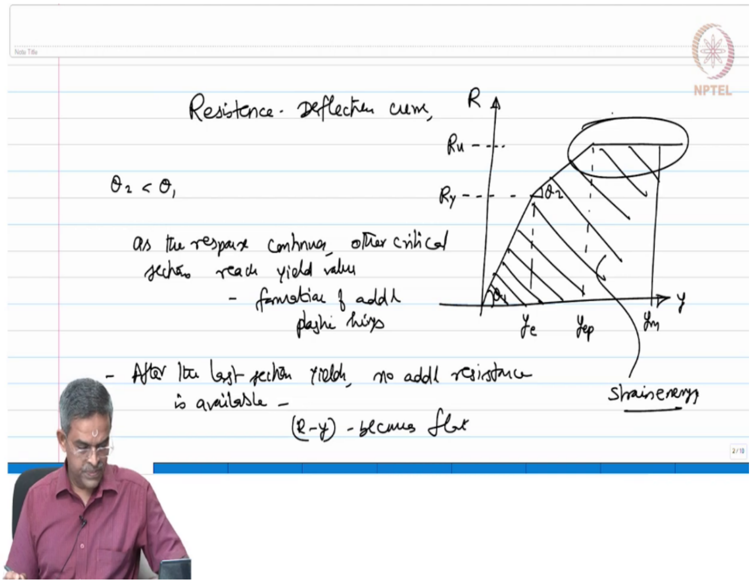

As we said in the last lecture, the resistance deflection curve, which is idealized as shown here - Deflection versus Resistance.

We have already seen, this becomes R ultimate and this becomes R yield. And of course, this becomes my deflection at yield and this becomes elastoplastic, and that becomes my maximum thing and we already know the area of this curve under the x axis will give me the strain energy. So, when the material reaches the yield point, reaches the yield point beyond that the slope changes, and the slope is lower compared to the earlier one which is in the elastic region.

As a response continues, other critical sections reach yield value and that will cause formation of additional plastic hinges. We will talk about this procedure much in detail in the next module on plastic design, but we are now talking about the resistance deflection curve. So, little bit let us try to understand what happens to my resistance curve.

So, at yield point changes the slope of resistance of deflection curve and hence, the section starts yielding after the last section yields no additional resistance is available is it not, because all critical sections I have been now yielded and therefore, the resistance deflection curve becomes flat. So, having understood this, let us try to apply more understanding on blast resistance with steel as a structural material.

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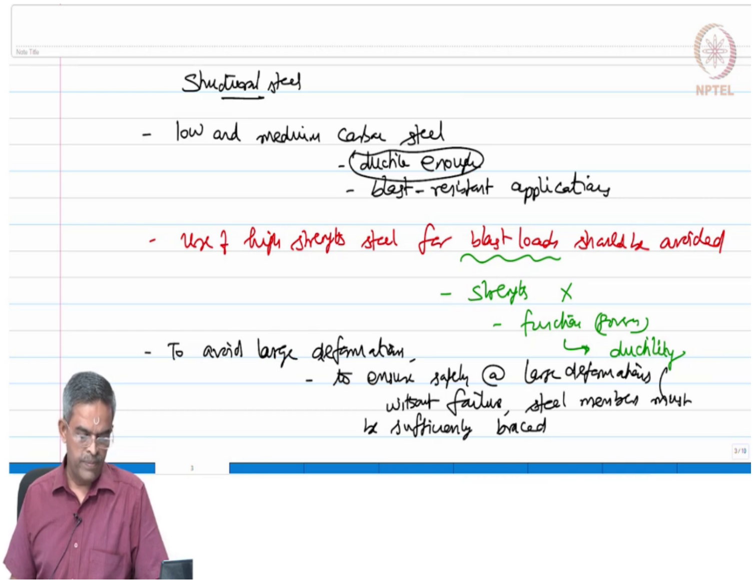

So, let us take structural steel and we are specifically talking about low and medium carbon steel. I think we already given this classification; you should be able to recollect them. We know that these two grades of steel are ductile enough and therefore, they can be used for blast loads or let us say blast-resistant applications. Because as I said, the structural form will start yielding on successive cross sections, which will lead to elastoplastic behavior of the material.

And therefore, we need to look for a material which is having a good ductility under blast loading of the structure. So, we should also put a caution here use of high strength steel for blast loads should be avoided. So, I think very well we notice here that based on certain types of loads on certain application strength will not govern; it is the function that governs. One of the functional characteristic of durability is that is a ductility and corrosion resistance.

Let us talk about ductility. So, therefore friends, to avoid large deformations, or to be very specific to achieve or to ensure safety at large deformations, let us put it like this. Because, when we talk about form resistant design, large deformations are large displacements; will be anyway a part of presence you cannot avoid that. So, to ensure safety at large displacements without failure, steel members must be sufficiently braced.

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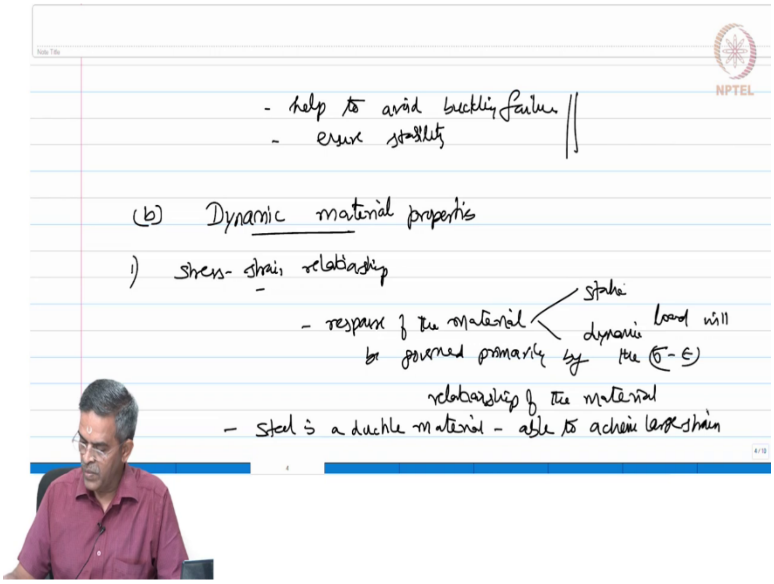

This will help; this will help to avoid buckling failure and ensure stability. So, now, let us go one step forward and look at the dynamic material properties. In this we will first start looking at the stress - strain relationship. Response of the material under static and dynamic load is governed by the stress - strain relationship, is it not; both under static and dynamic load will be governed primarily by the stress - strain relationship of the material.

We all know that steel is a ductile material and be able to and therefore, will be able to achieve large strain before rupture.

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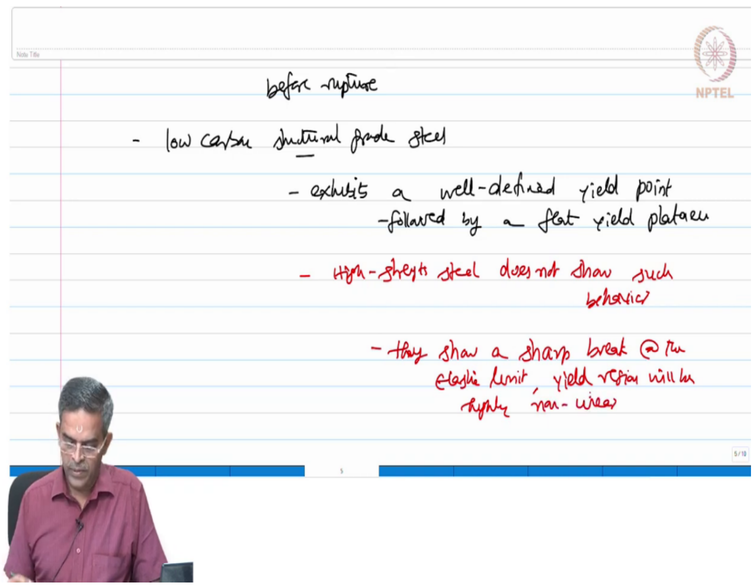

Having said this, let us say look at specifically a low carbon structural grade steel. A low carbon structural grade steel exhibits a well-defined yield point, which is followed by a flat yield plateau, but high strength steel does not show this behavior.

They show a sharp break at the elastic limit and the yield region will be highly non-linear.

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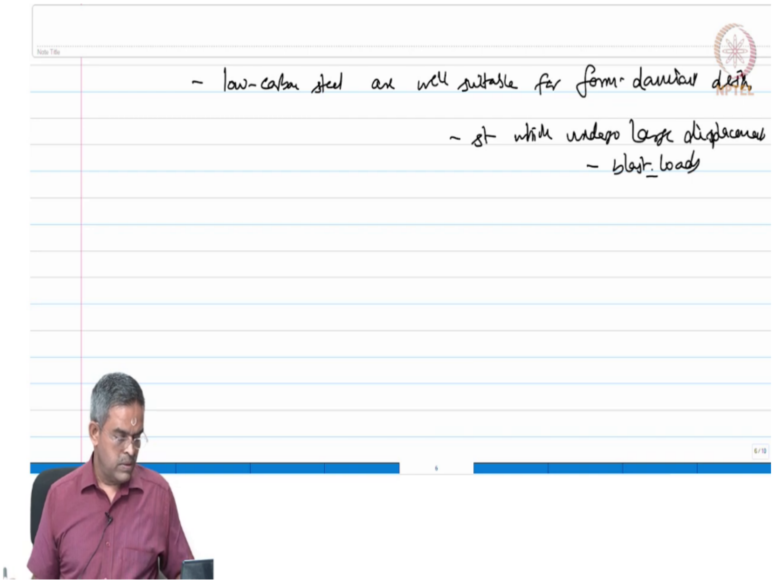

Therefore, we can say that low-carbon steel are well suitable for form dominant design are structures, which undergo large displacements; one example could be structures under blast loads.

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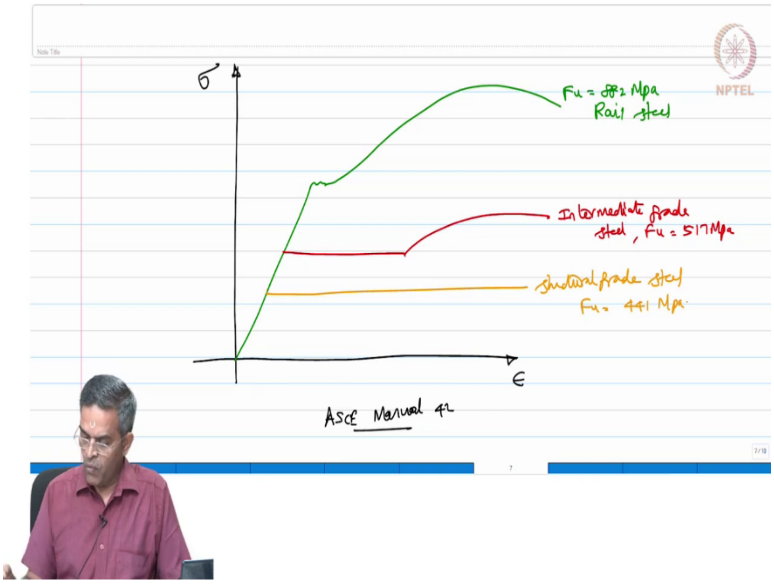

So, let us quickly look at the typical stress - strain curve has given by ASCE Manual. So, this is a typical stress - strain curve of ASCE Manual 42, I am just reproducing that here. It shows the initial slope with a small kink and this is Fu 882 Mpa steel is called as Rail steel. The other one has got the same slope, but goes flat plateau and then this intermediate grade steel, whose Fu is 517 Mpa.

We have one more steel which is much below this which shows a plateau which is structural grade steel; whose Fu is 441 Mpa.

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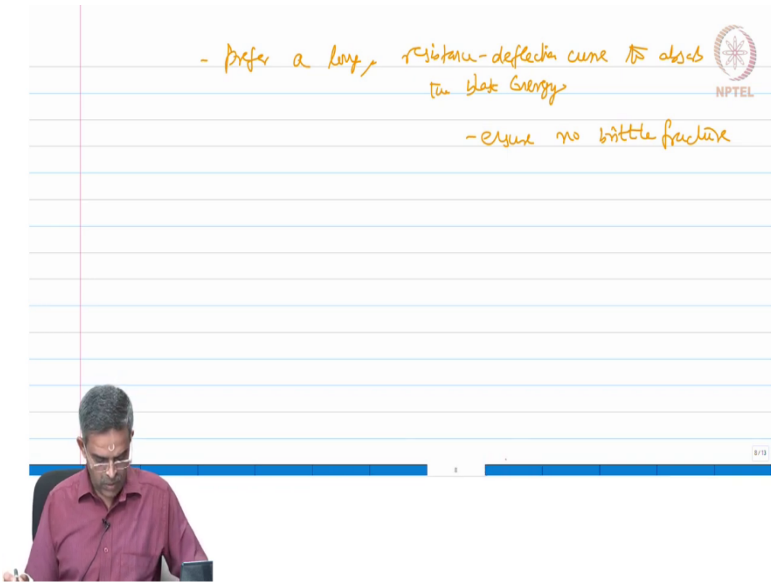

So, one can very well see here, I must go for one should prefer a long resistance deflection curve to absorb the blast energy and this will also ensure no brittle fracture.

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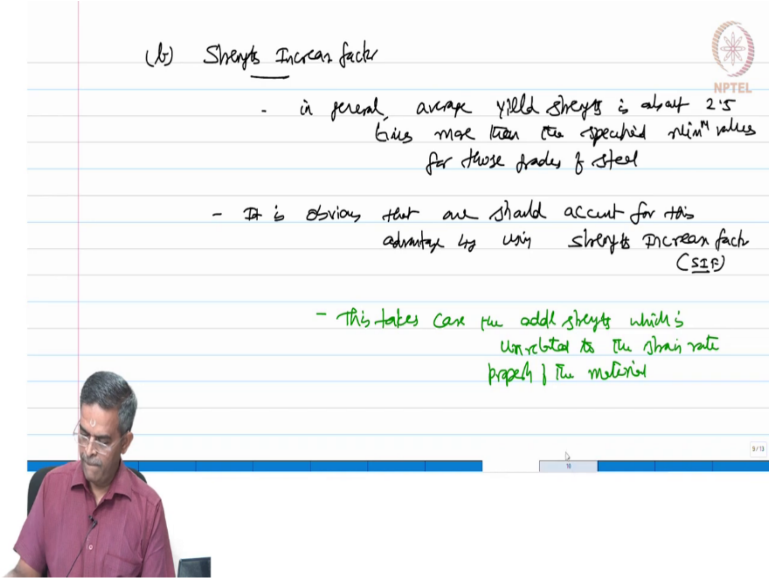

Now, let us talk about something called strength increase factor strength increase factor. In practice the average yield strength of the material is approximately 250% greater than the specimen minimum values. In general, average yield strength is about 2.5 times more than the specified minimum values for those grades of steel. Therefore, it is obvious that one should account for this advantage by using what is called strength increase factor. Let us say SIF.

This takes care of the additional strength, which is unrelated to the strain rate property of the material. Let us see one cross reference of a core. Let us say what does it say.

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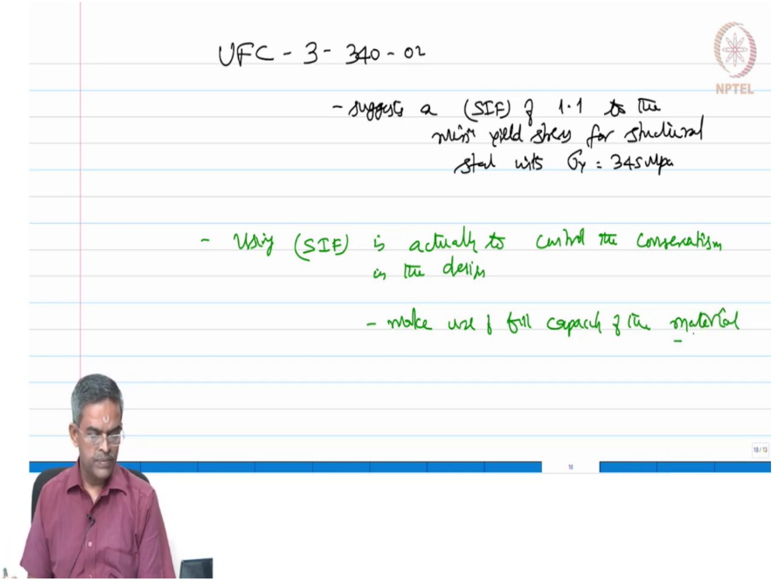

UFC – 3 – 340 – 02 suggests a strength increase factor of 1.1 to the minimum yield stress for structural steel with σ_y = 345 Mpa. Therefore friends, using strength increase factor is actually to control the conservatism in the design, and make use of full capacity of the material.

The next point related to the design of steel will be dynamic strength increase factor.

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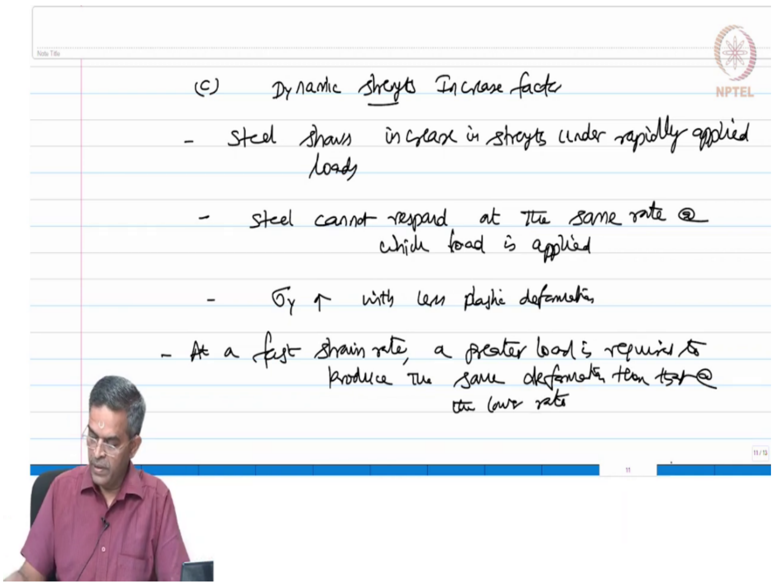

Now, one can say that steel is experiencing an increase in strength under rapidly applied loads. Steel cannot respond at the same rate at which the load is applied. There is a delay.

Therefore, yield strength increases with less plastic deformation that is the result. At a fast strain rate, a greater load is required to produce the same deformation than that at the lower rate.

I mean this is understood right the rate of loading is a very important parameter in stress - strain curve.

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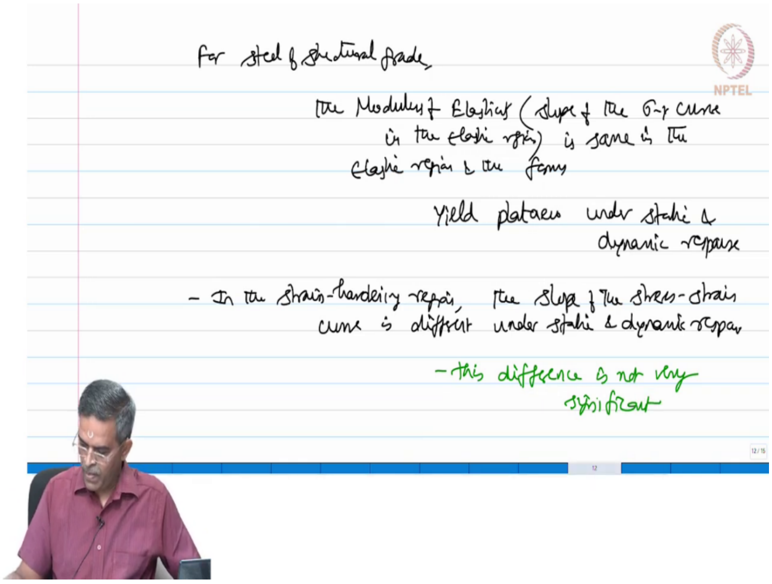

So, for steel of structural grade the modulus of elasticity, let us recollect what we understand by this; it is actually a slope of the stress - strain curve in the elastic region. So, the modulus of elasticity is same in the elastic region and forms a yield plateau for or under static and dynamic response.

In the strain hardening region, the slope of the stress - strain curve is different under static and dynamic response but, let us see that this difference is not very significant. There is a difference, but not very significant. But, there will be a difference, let us understand that.

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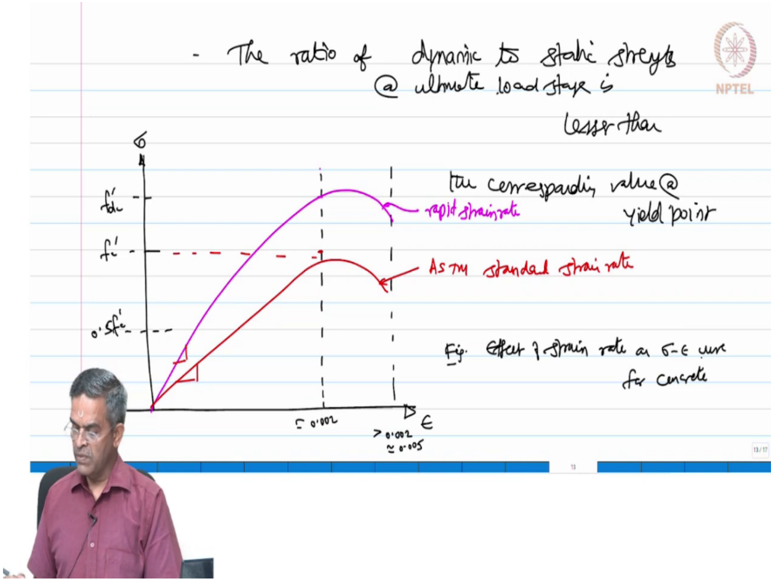

Therefore the ratio of dynamic to static strength at ultimate load state is lesser than the corresponding value at yield point. Let us try to see how does it look like using a figure. So, this is my strain, this is my stress axis. Let us draw a vertical line in an enlarged manner. So, approximately 0.002 and let us draw one more line which will be higher than 0.002, but closely to 0.005.

Let us draw horizontal axis as 0.5 fc dash. Let us say $f_c^{'}$ and $f_{dc}^{'}$ let us say this mistress sound. Let us draw the curve for rapid strain rate, it looks like this. It takes a slope and goes till here and come backs here, let us say it goes here it takes a slope goes here and come backs here. So, this is for rapid strain rate. Whereas, if you look at the ASTM standard strain rate there is a change in slope, it touches this point and comes down. This is ASTM standard strain rate.

So, there is a change in slope; so, the change in modulus of elasticity. So, this curve shows effect of strain rate on stress - strain curve for concrete, on the other hand let us see what happens when you look at steel.

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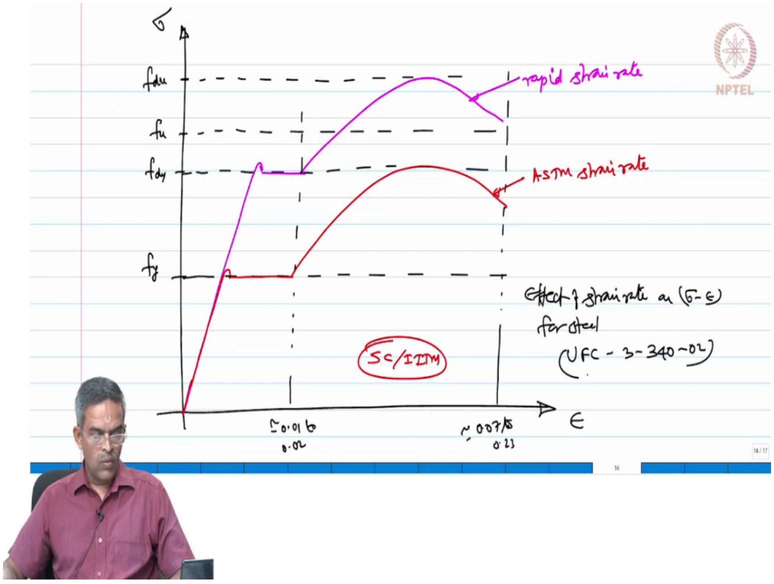

Let us draw a vertical line at approximately 0.001 to 0.02. Let us draw another line with large ductility at 0.07 approximately to 0.23.

Let us say this is my f_y and this is my f_{dy}, and let us say this is my f_u and this may f_{du}. I will have control points, let us have this control points. Now, let us plot the stress - strain curve under rapid strain rate and ASTM strain rate. Rapid strain rate and ASTM has the same slope for steel. So, let us say it goes till f_u, it goes till it crosses f_{du} takes a kink. It goes till f_{du} takes a kink and develops a plateau and then, goes to f_{du}. This is for rapid strain rate.

When you draw this for ASTM strain rate, it stops at f_y, slope is same develops a yield plateau, and goes till f_{dy} and comes. This is for ASTM strain rate. This is the curve which is effect of strain rate on stress strain curve for steel according to UFC – 3 - 340 - 02.

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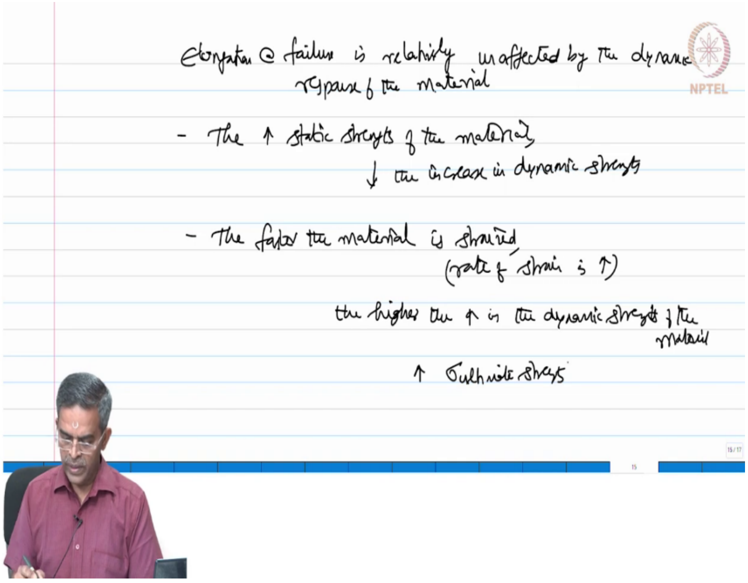

One can very well notice that elongation at failure is relatively unaffected by the dynamic response of the material.

The higher the static strength of the material, the lower the increase in dynamic strength; thus, faster the material is strained, that is rate of strain is higher. The higher the increase in the dynamic strength of the material; it also increases higher ultimate strength.

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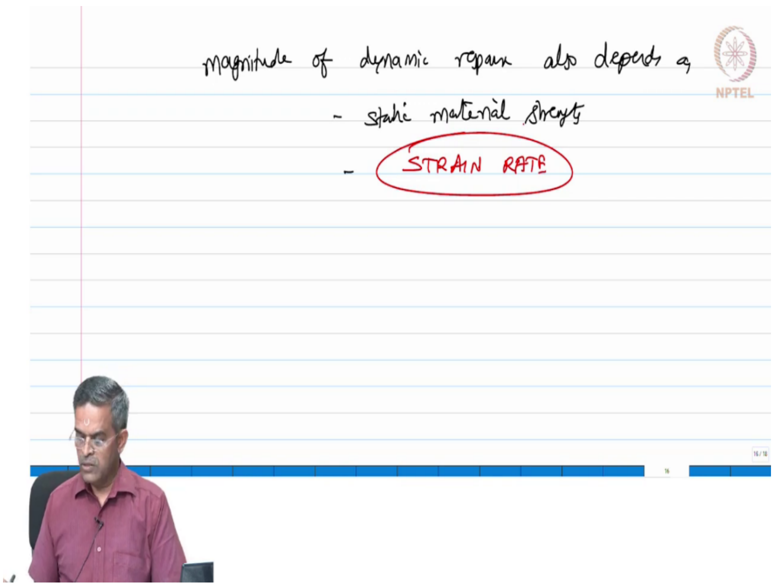

Therefore friends, magnitude of dynamic response also depends on static material strength and very importantly STRAIN RATE.

Let us look into the next factor, which is very interesting for us.

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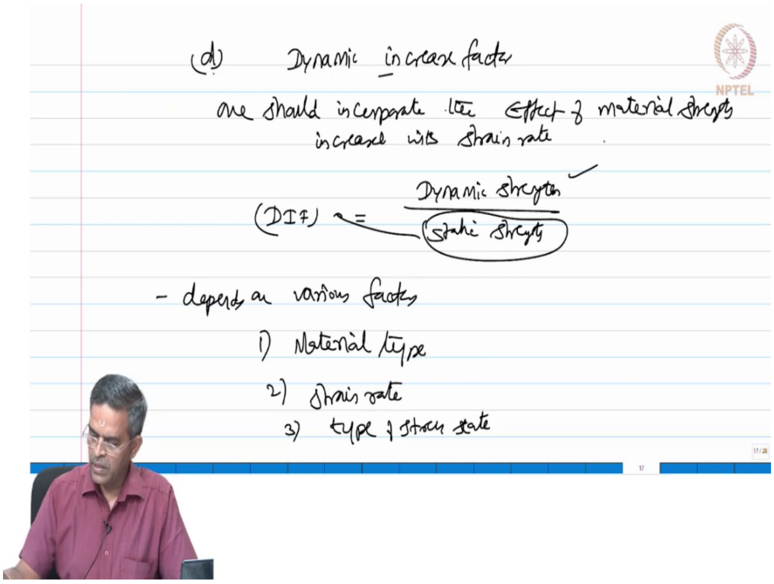

Which is dynamic increase factor; now, we want to incorporate. So, one should incorporate the effect of material strength increased with the strain rate, is it not. Just now we saw there is an increase. So, therefore, your dynamic increase factor is incorporated is a ratio of dynamic strength to static strength.

Now, this depends on various factors. 1 it depends on material type, it depends on strain rate, and depends on type of stress state. There are different methods to compute this.

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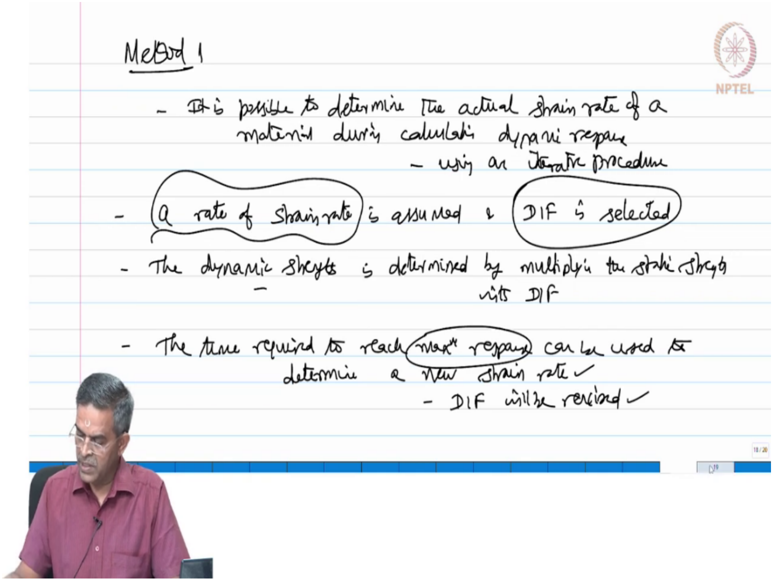

Let us see one by one quickly these methods. Let us say method 1, what we do is we know that it is possible to determine the actual strain rate of a material during calculation of dynamic response. This can be done using an iterative procedure.

What do we do this is - a rate of strain a strain rate is assumed and an appropriate DIF is selected. Now, the dynamic strength is determined by multiplying the static strength with DIF. We already know the equation see here, if we know the dynamic static strength. We can get the dynamic strength if we know the DIF. So, I get this ok then, the time required to reach the maximum response can be used to determine a new strain rate.

Therefore, DIF will be revised, because strain rate is changed for a given or a known assumed strain rate, you select a DIF; when the strain rate changes DIF is also revised. So, once DIF is revised you again obtain the dynamic strength. Now, try to find out the time taken for the maximum response to reach.

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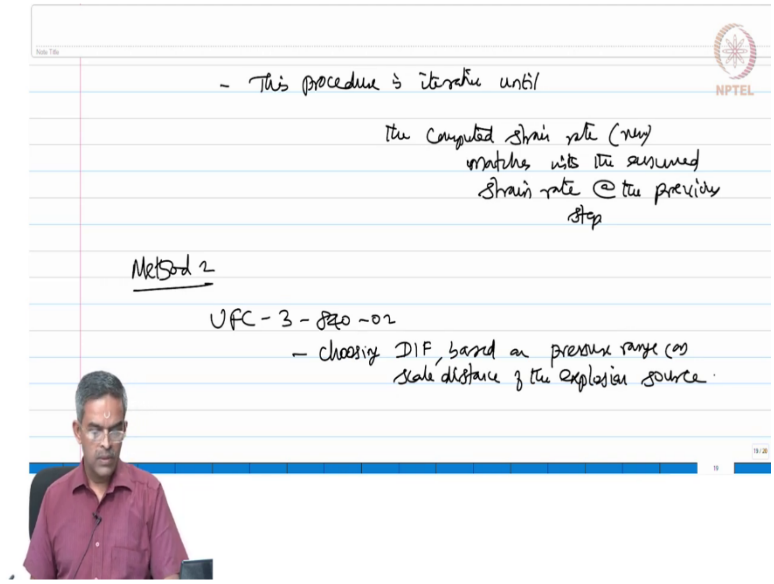

So, this process becomes iterative. So, this procedure is iterative until, the computed strain rate which is relatively new matches with the assumed strain rate at the previous step. So, there is one method by which I can compute this. There is another method by which we can do the dynamic increase factor. So, this is suggested as per UFC – 3 – 840 – 02 this code suggests choosing dynamic increase factor, based on pressure range or scaled distance of the explosion the method group's blast loads.

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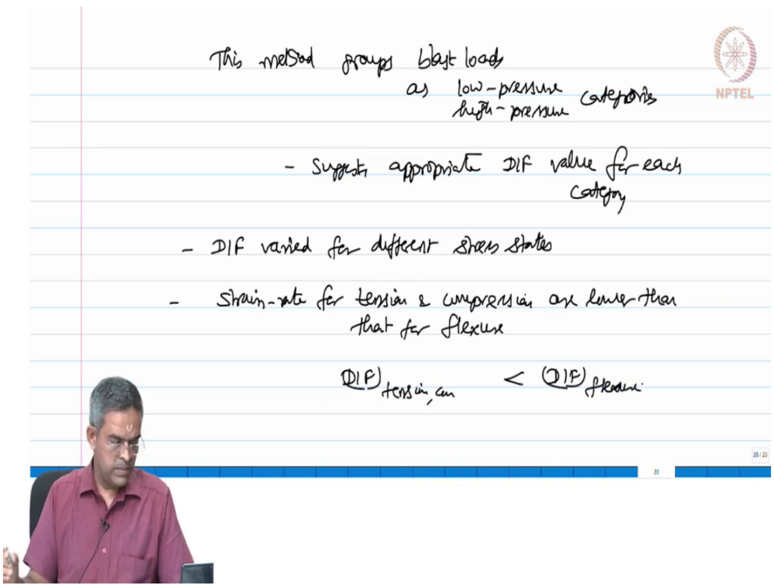

This method groups blast loads, as low - pressure and high - pressure categories and suggests appropriate DIF value for each category. DIF values also vary for different stress states.

Further, the strain rate for tension and compression are lower than that for flexure. Therefore, DIF values for tension and compression are lesser than DIF values for flexure. So, there is an advice given by the code,

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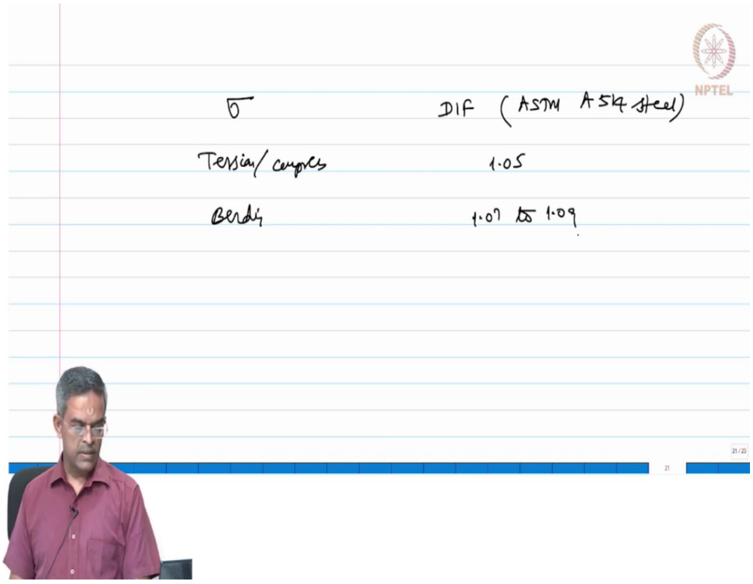

Depending upon the stress the DIF value suggested as per ASTM A 54 steel a sorry, A514 steel, it says for tension and compression. It suggests 1.05 and for bending that is flexure, it suggest 1.07 to 1.09. So, that is about 10% increase in the dynamic strength.

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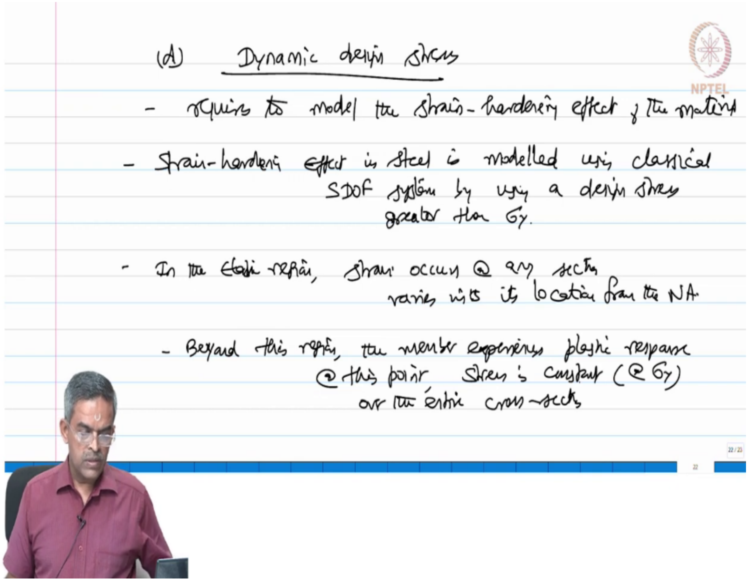

Having seen this, let us go to the dynamic design stress. So, the dynamic design stress requires to model the strain hardening effect of the material. Strain hardening effect in steel is modelled using classical single degree of freedom systems by using a design stress greater than the yield.

During the dynamic response the stress level of critical sections vary with strain of the section, we all know that. So, in the elastic region, strain occurs at a section at any section varies with its location from the neutral axis, we all know that. Beyond this region, the member experiences plastic response, because when the strain or the stress reaches yield value then, the member will experience plastic response. So, at this point, the stress is constant that is at σ_y over the entire cross section.

So, the steel member experiences increase in stress.

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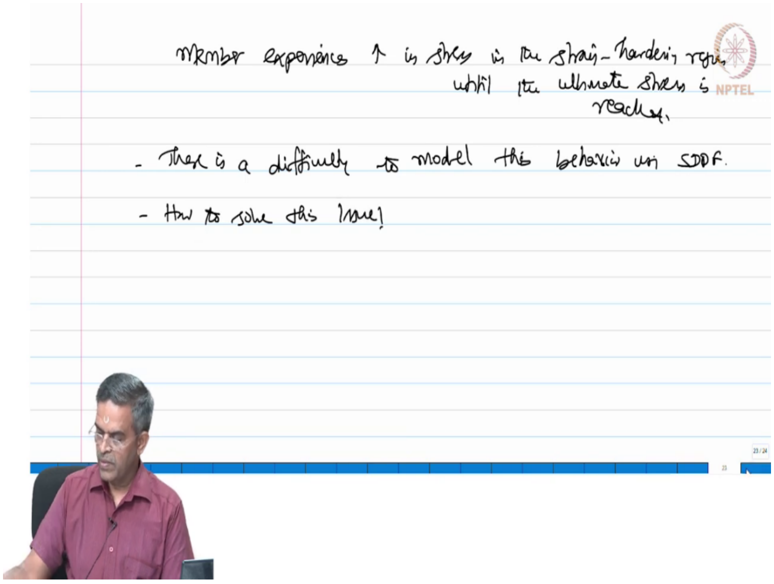

In the strain - hardening region until the ultimate stress is reached. So, after this point, the fibre stress decreases with increasing strain and rupture occurs we all know that. So, there will be a difficulty in modelling using this scenario in single degree freedom system.

So, to predict the dynamic response, it would be necessary to continuously vary the material stress with deformation. This variation is difficult to model in single degree of freedom systems, because this requires a complex resistance deflection curve at each point of time to be updated.

So, how to model this accurately. So, there is a difficulty to model this behavior using SDOF systems. So, how to then model this how to solve this difficulty.

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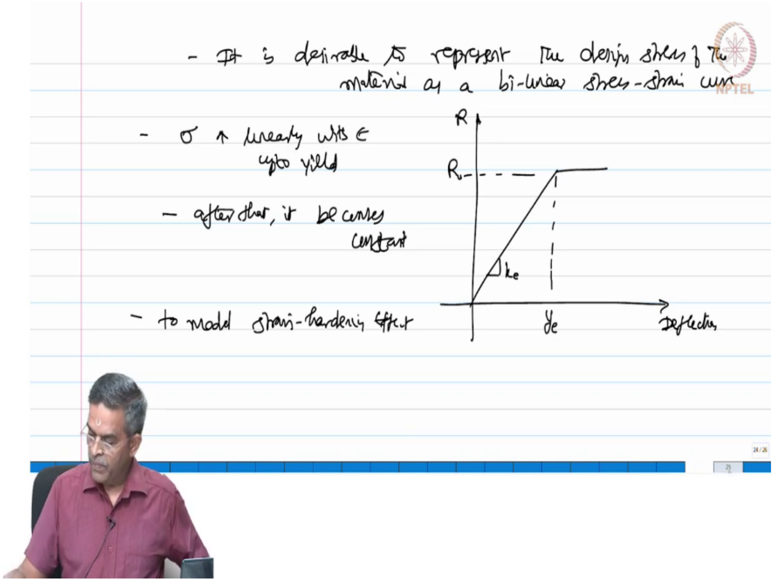

So, what do we do is it is desirable to represent the design stress of the material as a bi-linear stress strain curve.

So, we will express this as a bi-linear stress strain curve which will be the initial slope is k e and this becomes my strain at y e and this becomes my R u. So, this is my resistance sorry, this is my resistance; this is my yield, deformation or deflection. So, it is a bi-linear resistance deflection curve as you see here. So, it is desirable to represent the design stress using this curve.

In this curve we can see that stress increases linearly with strain up to yield, and after that it becomes constant. This produces a simple bi-linear resistance deflection curve, which can be included to model the strain hardening effect.

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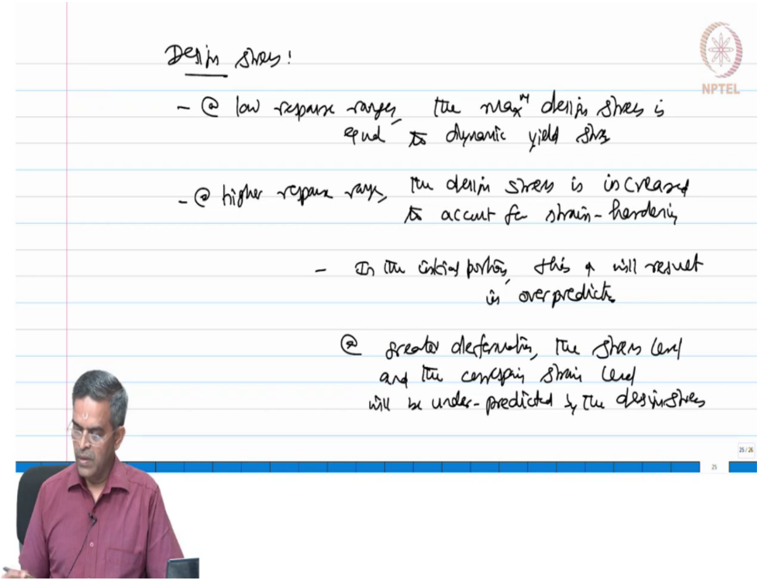

So, therefore, the design stress need to be computed from this. So, at low response ranges, the maximum design stress is equal to the dynamic design stress or dynamic yield stress.

At higher response ranges, the design stress is increased to account for strain hardening in the initial portion of the response this increased design stress will result in over prediction. This increase will result in over prediction, but at greater deformations at large deflections the stress level and the corresponding strain level will be under predicted by the design stress.

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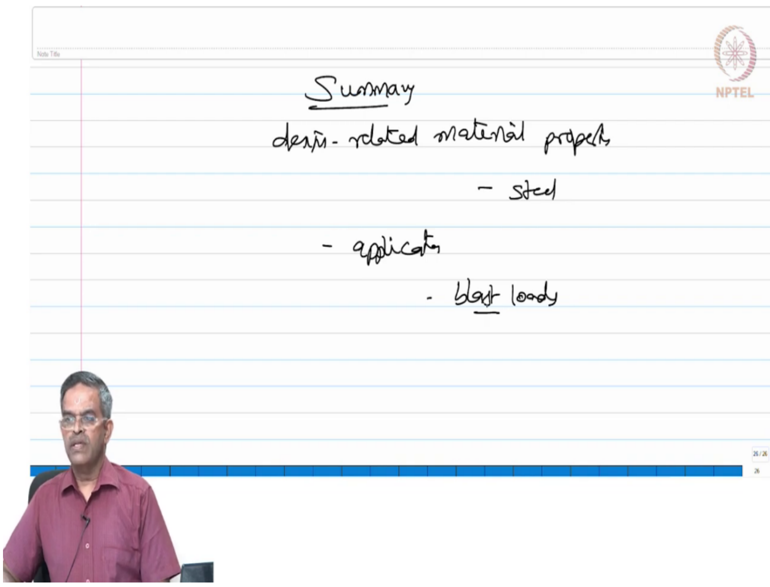

So friends, in this lecture we learnt, the design related material properties. We have taken the example as steel as a material. We discussed about its application for form resistant design; we also touched upon the loads like blast loads. So, I think this content will help you to know more about the variations in material characteristics.

Especially, steel when you look for its application which demands large deformations from the material side, because structural system undergoes large displacement, because of its either form dominance or because of the rate of strain of the load coming larger on the material which is a practice, in case of blast loads and impact loads.

Thank you very much, have a good day.