Advanced Design of Steel Structures
Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture - 06
Material Properties - 1

Let us see in the 6th lecture, what we are going to learn in the course of Advanced Steel Design of Structures.

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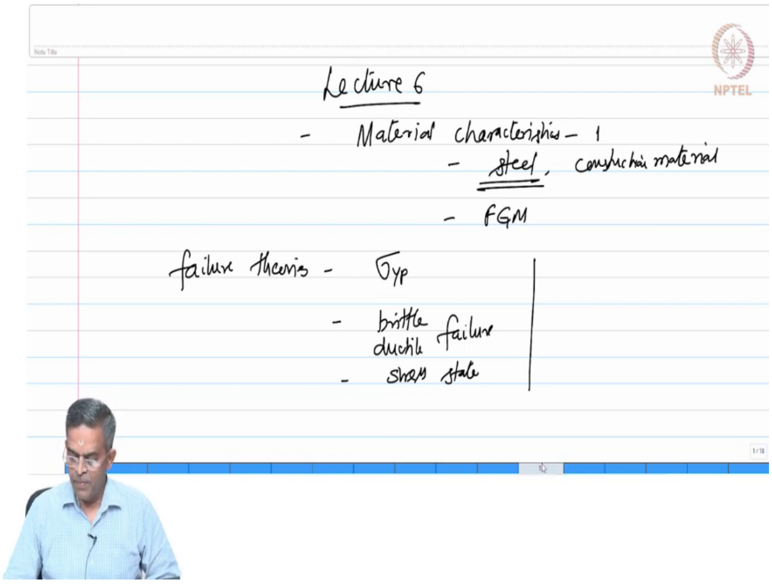

So, in this lecture, we are going to learn more about material characteristics, paying attention to steel as a very friendly, common, and intuitive construction material. To be very precise we will focus only on steel. We will also talk about functionally graded materials in the subsequent lecture. So, this will be material characteristic, lecture 1. We will have two lectures on this, we will focus on this.

So, friends let us recall that what you have learnt the last set of lectures is that failure theories will help us to quantify the stress and the failure state. It also helps us to declare the type of failure, essentially, is it a brittle or a ductile failure. We will also have some interesting link towards the stress state.

So, we have learnt the theories of failure. We understood the complexities and disagreements of various theories, in different quadrants of plots of these theories. We will quickly see one design example to highlight the importance of the failure theories.

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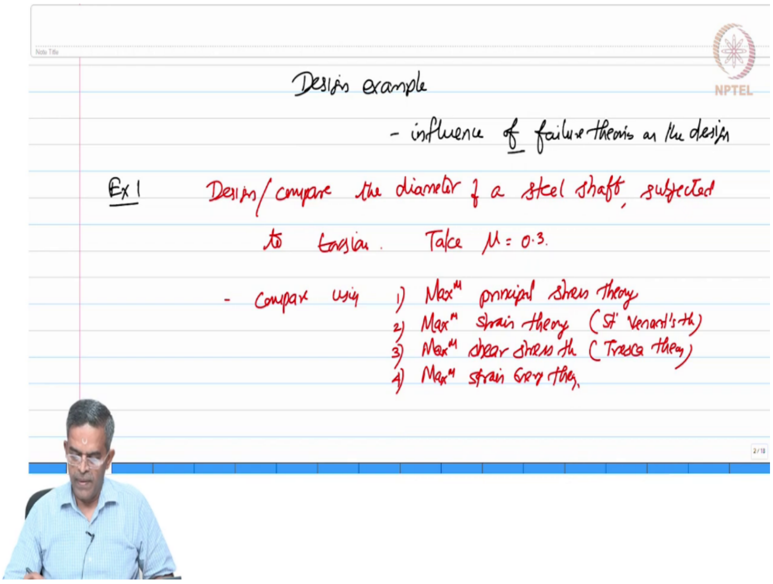

So, we will see quickly a design example to understand the influence of failure theories on the design. We will say example 1. The example is like this, design or compare, the diameter of a steel shaft, subjected to torsion take Poisson’s ratio as 0.3. Compare this using various theories that is maximum principal stress theory, maximum strain theory which is otherwise called as Saint Venant’s theory, maximum shear stress theory which is otherwise called as Tresca’s theory and using maximum strain energy theory.

Let us try to answer this question and understand the influence of choosing an appropriate failure theory on design of the circular shaft.

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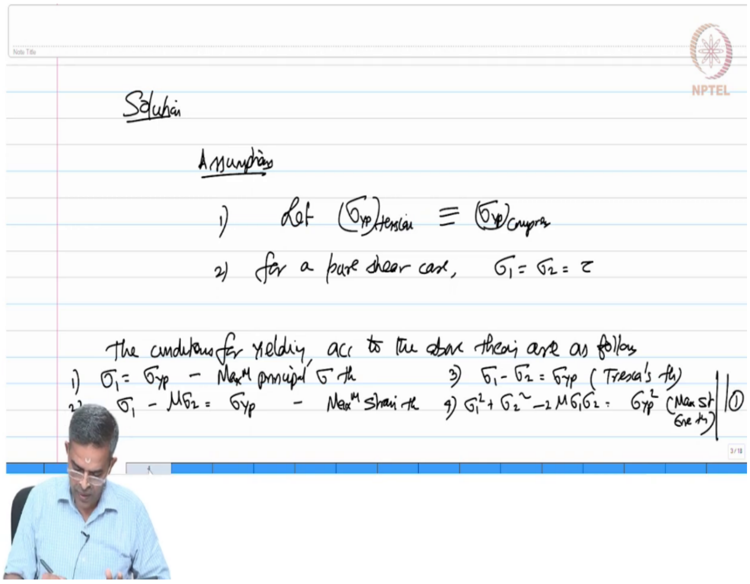

Let us make certain assumptions. The first assumption what we make is let the yield strength of the material in tension be identically equal to that in compression. Two, for a pure shear case we can always say the principal stresses are equal to the shear value.

Now, the conditions for yielding because yielding is a type of failure, we already said that. The conditions for yielding according to the above 4 theories are as follows. $\sigma_1 = \sigma_{yp}$, this is as per maximum principal stress theory. $\sigma_1 - \mu\sigma_2 = \sigma_{yp}$, this is according to maximum strain theory.

$\sigma_1 - \sigma_2 = \sigma_{yp}$, this is going to tresca's. $\sigma_1^2 + \sigma_2^2 - 2\mu\sigma_1\sigma_2 = \sigma_{yp}^2$ as per maximum strain energy theory for a biaxial stress state. We have already seen that in the last lecture.

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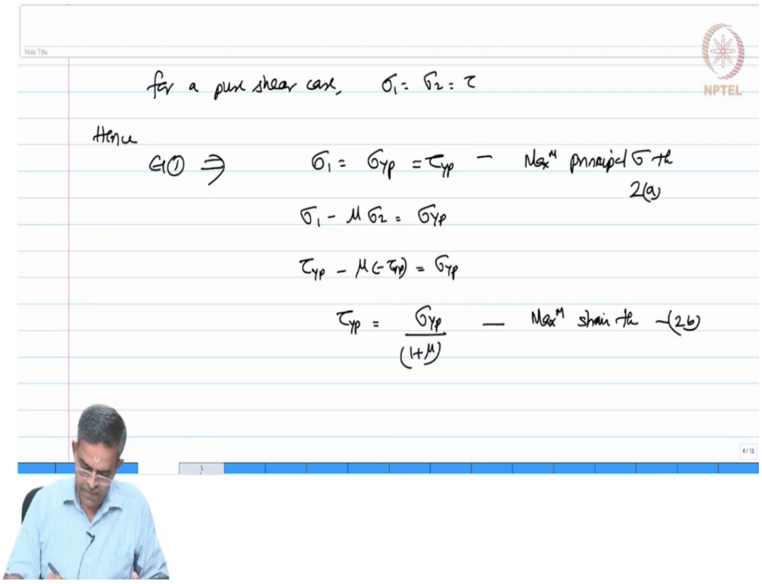

For a pure shear case, as we have assumed $\sigma_1 = \sigma_2 = \tau$, and hence let us call this equations as equation 1. Equation 1 can now become $\sigma_1 = \sigma_{yp} = \tau_{yp}$, this is for maximum principal stress theory. $\sigma_1 - \mu\sigma_2 = \sigma_{yp}$. So, $\tau_{yp} - \mu\,(-\tau_{yp}) = \sigma_{yp}$, which means $\tau_{yp} = \frac{\sigma_{yp}}{(1+\mu)}$. This is according to maximum strain theory.

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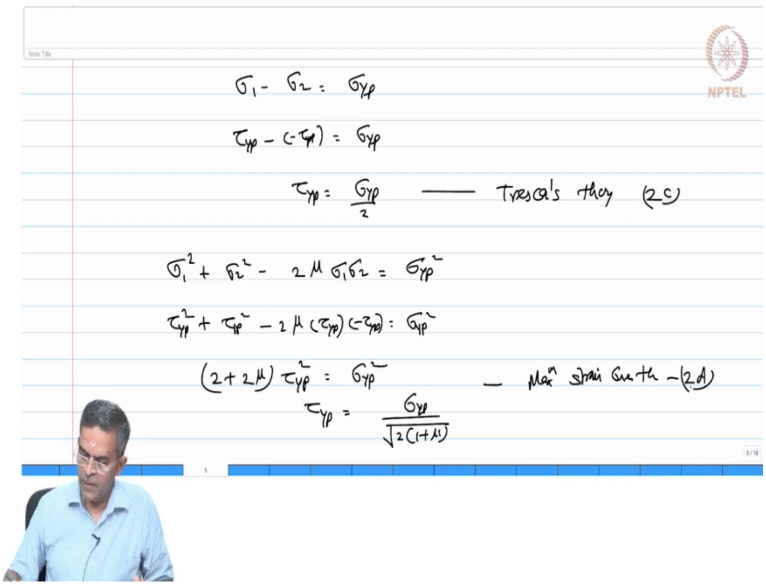

$\sigma_1 - \sigma_2 = \sigma_{yp}$. So, $\tau_{yp} - (-\tau_{yp}) = \sigma_{yp}$. So, $\tau_{yp} = \frac{\sigma_{yp}}{2}$. This is according to Tresca's theory.

$\sigma_1^2 + \sigma_2^2 - 2\mu\sigma_1\sigma_2 = \sigma_{yp}^2$.

So, $\tau_{yp}^2 + \tau_{yp}^2 - 2\mu\tau_{yp}\left(-\tau_{yp}\right) = \sigma_{yp}^2$, which is $(2 + 2\mu)\tau_{yp}^2 = \sigma_{yp}^2$,

which say $\tau_{yp} = \frac{\sigma_{yp}}{\sqrt{2(1+\mu)}}$. This is as per maximum strain energy theory.

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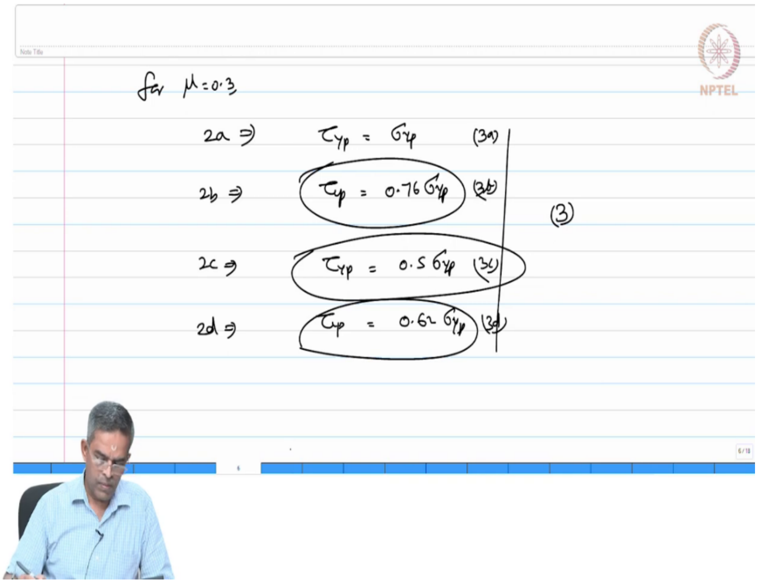

Having said this for $\mu = 0.3$, let us substitute these values in equation 2. Let us call these equations as 2 a, 2 b, 2 c and 2 d. Let us substitute them. So, 2 a will yield $\tau_{yp} = \sigma_{yp}$, 2 b will yield $\tau_{yp} = 0.76\sigma_{yp}$, 2 c will yield $\tau_{yp} = 0.5\sigma_{yp}$, and 2 d will yield $\tau_{yp} = 0.62\sigma_{yp}$.

Let me call this as equation 3. So, this is 3 a, this is 3 b, this is 3 c, this is 3 d. Let us apply this for the design and see what happens.

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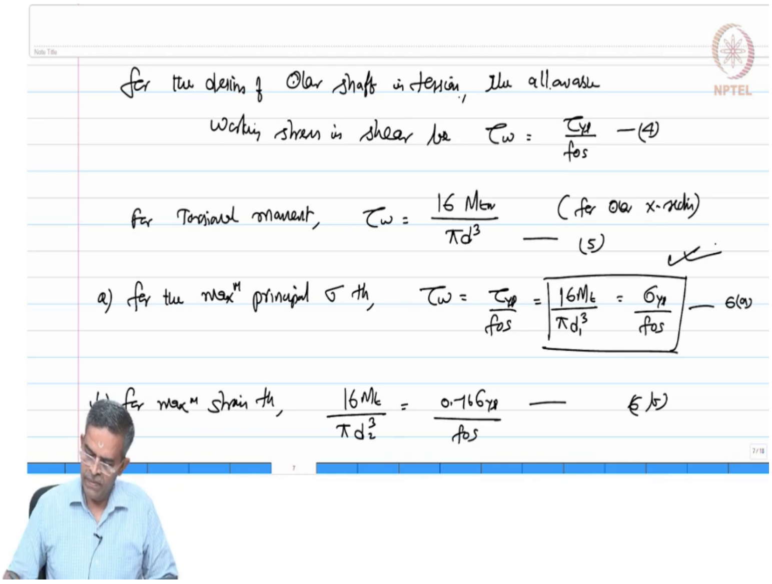

Now, for the design of circular shaft in tension, let us say the allowable working stress in shear be $\tau_w = \frac{\tau_{yp}}{Factor\ of\ safety}$. For torsional moment, acting on the shaft this $\tau_w = \frac{16M_t}{\pi d^3}$ for a circular cross section, the standard equation called equation number 4. Let us say we call this as 4, we call this equation number 5.

Now, for the maximum principal stress theory, $\tau_w = \frac{\tau_{yp}}{Factor\ of\ safety} = \frac{16M_t}{\pi d_1^3} = \frac{\sigma_{yp}}{Factor\ of\ safety}$ calls this equation number 6 a.

Now, for maximum strain theory $\frac{16M_t}{\pi d_2^3}$, let us say the diameter from maximum principal theory is d 1 and for the maximum strain theory is d 2, and so on, will be now equal to $\frac{16M_t}{\pi d_2^3} = \frac{0.76\sigma_{yp}}{FOS}$. Why 0.76? Please see this equation, 0.76 σ_{yp}, Let us call the equation 6 b.

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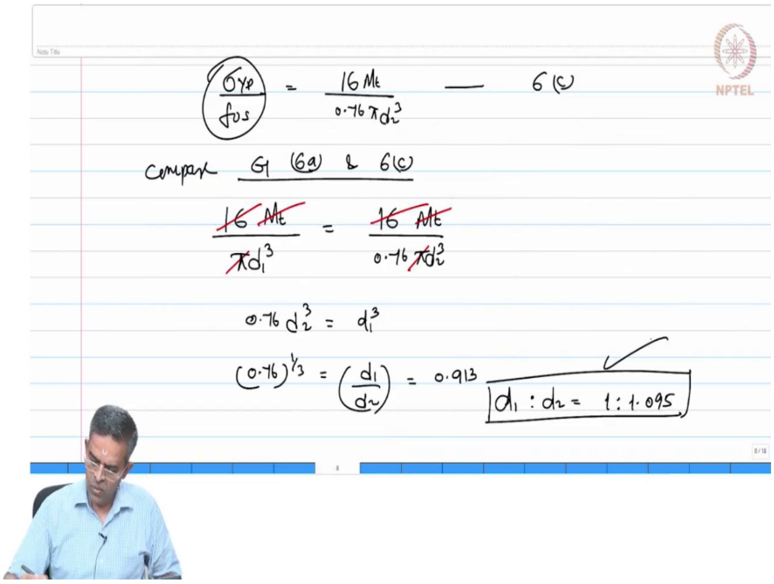

So, one can rewrite this equation 6 b as $\frac{\sigma_{yp}}{FOS} = \frac{16M_t}{0.76\pi d_2^3}$, I call this as equations 6 c. Now, let me compare equation 6 a and 6 c. So, what is 6 a? This is 6 a which is $\frac{16M_t}{\pi d_1^3}$. And 6 c is also; the left hand side are equal. So, let us compare them.

So, we can say that $\frac{16M_t}{\pi d_1^3} = \frac{16M_t}{0.76\pi d_2^3}$. So, when you do this; so, let us say we can simplify this as $0.76\, d_2^3 = d_1^3$. So, $(0.76)^{\frac{1}{3}} = \frac{d_1}{d_2} = 0.913$. so, this tells me that d 1 to d 2 is at the ratio of 1 is to 1.095.

So, now, let us take condition c, this is for the maximum shear stress theory.

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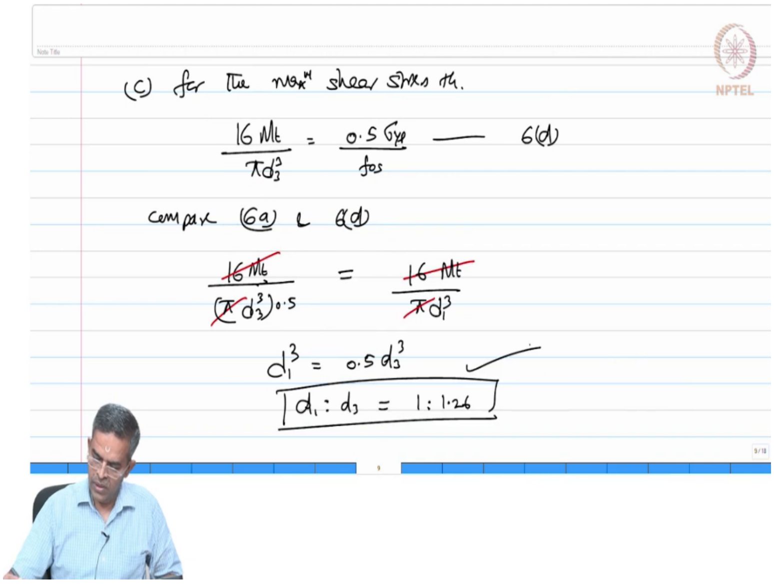

So, that is $\frac{16M_t}{\pi d_3^3} = \frac{0.5\sigma_{yp}}{FOS}$. Why 0.5? For 2 c, the condition is $\tau_{yp} = 0.5\sigma_{yp}$. So, I call this as 6 d.

Now, compare 6 a and 6 d. So, that tells me $\frac{16M_t}{\pi d_3^3(0.5)} = \frac{16M_t}{\pi d_1^3}$. Am I right? So, simplifying 16 Mt goes away, π goes away, so $d_1^3 = 0.5\, d_3^3$. So, now, I can say d_1 and d_3 will be at the ratio of 1 is to 1.26.

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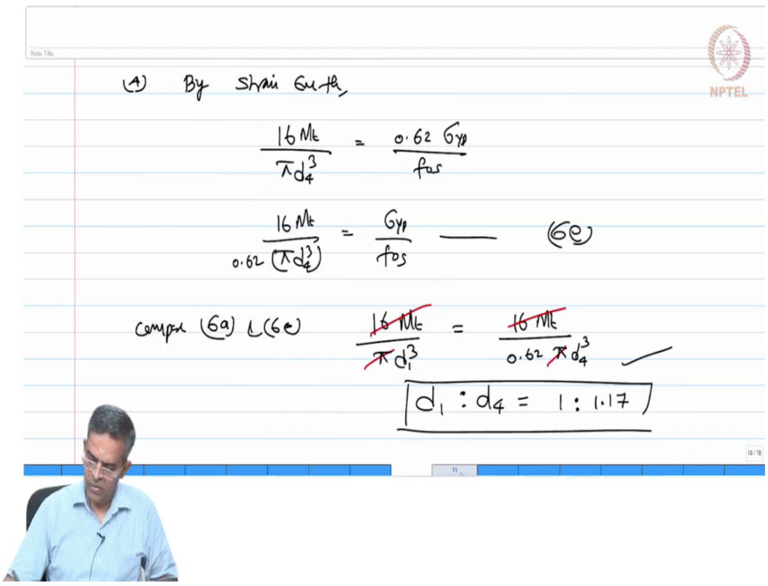

Let us do this for the 4th case, that is using strain energy theory $\frac{16M_t}{\pi d_4^3} = \frac{0.62\sigma_{yp}}{FOS}$. You can see it is 0.62. So, I can now say $\frac{16M_t}{\pi d_4^3} = \frac{0.62\sigma_{yp}}{FOS}$ I call this as 6 e.

Now, I compare 6 a and 6 e, so which will be $\frac{16M_t}{\pi d_4^3(0.62)} = \frac{16M_t}{\pi d_1^3}$. This tells me d_1 and d_4 will be in the ratio of 1 is to 1.17. So, now, friends I have the ratios of d_1 and d_2, d_1 and d_3, and d_1 and d_4.

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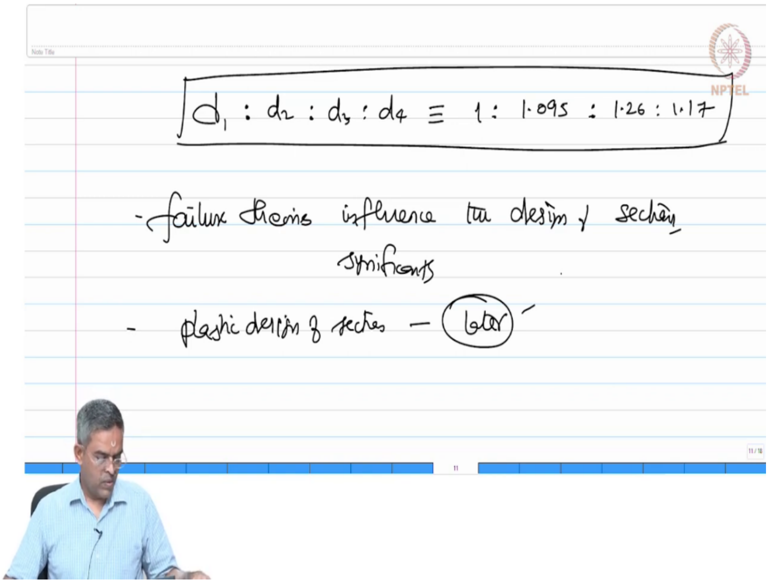

Let me quickly say d_1 with respect to d_2, d_3 and d_4 will be given by this relationship as 1, 1.095, 1.26, 1.17. Am I right? 1.17, 1.26, 1.095. So, that is the influence of choosing the diameter of the circular, shaft subjected to torsion from different failure theories. So, friends you see how the dimension or the cross sectional properties of the member vary significantly when you choose a failure theory.

So, failure theories affect the design, design of sections, significantly. It affects the plastic design of sections which I will show you later. So, this is a very simple design example to illustrate the influence of the failure theories on design of steel sections. Having said this, let us move on to the material properties or I should say material characteristics. Here we are going to talk exclusively about steel as a construction material.

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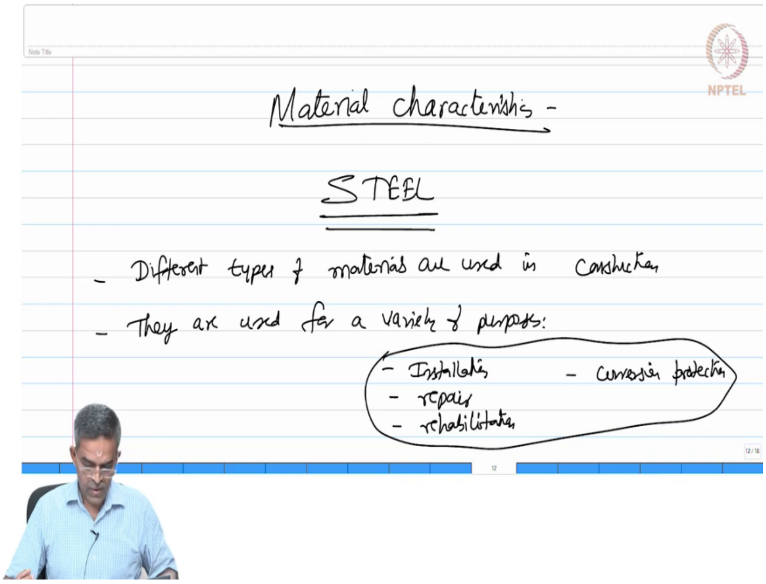

Now, friends we all know that different types of materials are used in construction. They are used for a variety of purpose. For example, installation and commissioning, you can also use material for repair and rehabilitation, you can also use material for corrosion protection etcetera. So, the application of material in construction industry is widely different. So, you cannot have a common material which can suffice the requirements of all types of needs of the construction industry.

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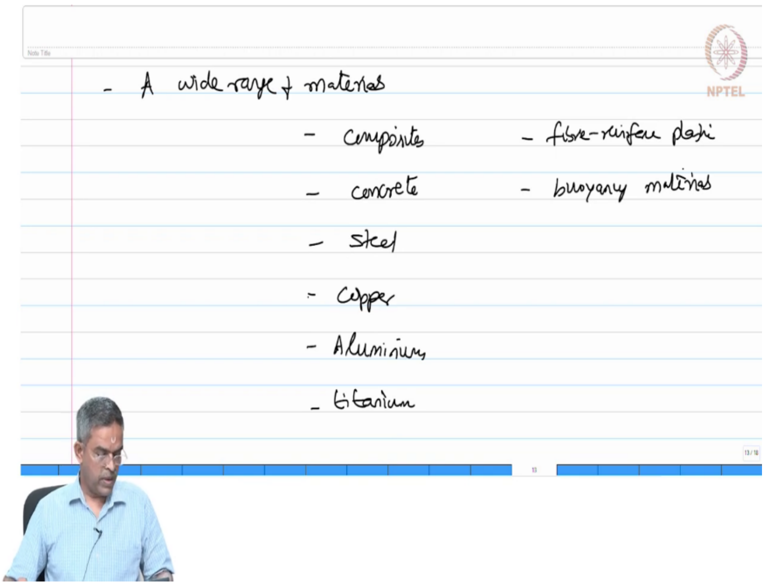

So, a wide range of materials like composites, concrete, steel, copper, aluminium, titanium, fiber-reinforced, plastics and other buoyancy materials are used in construction. Now, the question is when you have got such a wider choice of material then which governs the selection.

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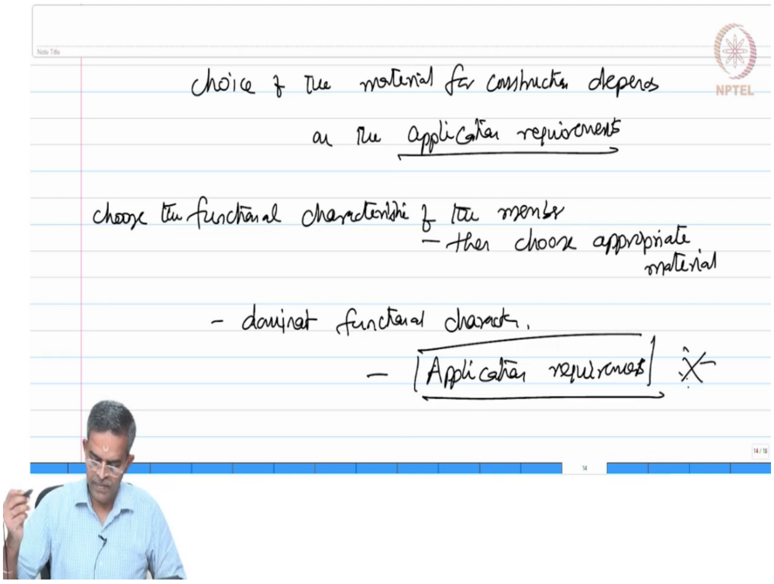

So, the choice of the material for construction depends on the application requirements. So, it is a new dimension we are talking about now. We do not take material first and then design the member. We first choose the functional characteristic of the member, then choose appropriate material.

One may ask me a question, if the member has multifunctional characteristics, then how do I choose the material. The answer is very simple. Look for the dominant functional characteristic. So, we say the material choice depends on application requirements. That is a very important statement we want to make here.

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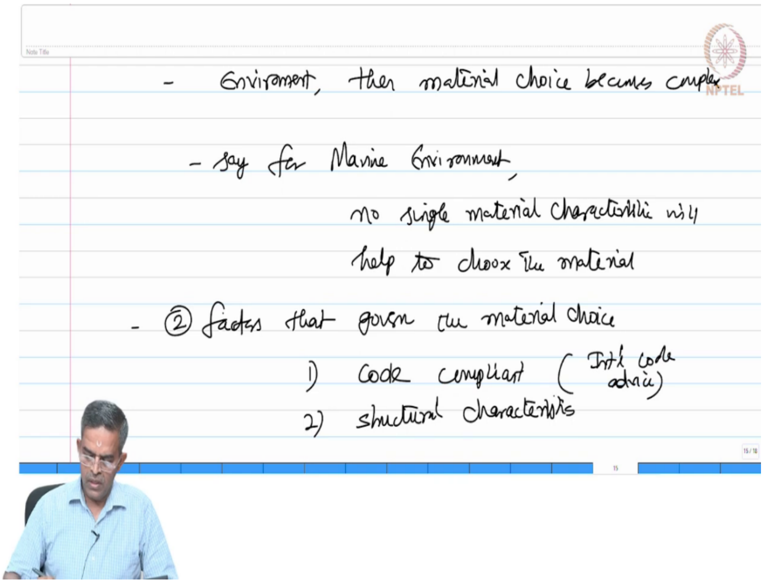

Now, when we talk about the environment, then material choice becomes complex. I can give an example. Say for marine environment, no single material or no single material characteristic will help us to choose the material. Therefore, a detailed knowledge of the structural characteristics and the relevant code compliancy are important.

So, now, two factors that govern the material choice. One is the functional application, that is the broad objective, within that the two factors could be, code compliant, I mean the material should be advised by the code, international codes, advice materials. If the material chosen by you does not reflect any international guidelines for the design you cannot use the material for construction. So, code compliance is very important.

Next would be the structural characteristics of the material. The moment we say structural characteristics, then the question comes what are those structural characteristics which are important.

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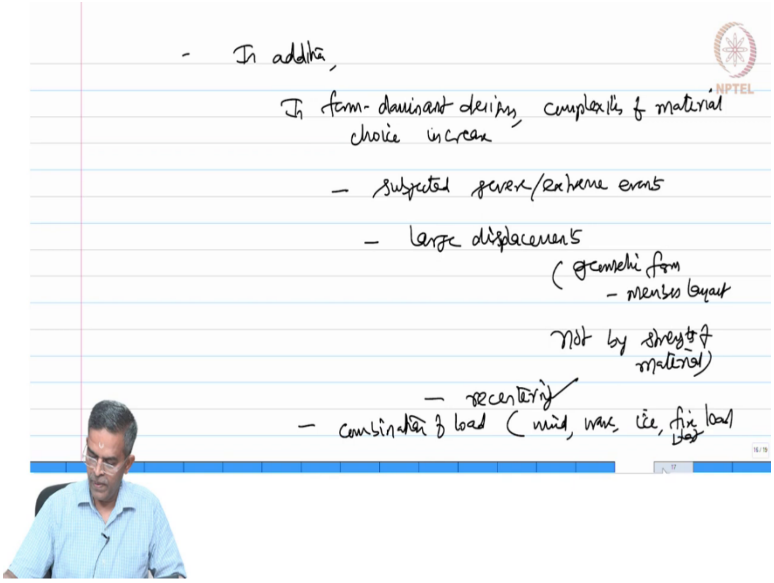

Before we look into them, let us say, in addition, when we talk about form dominant design, complexities increase. I will tell you why. Because form dominant design are subjected to severe or extreme events. They undergo large displacements. So, let me reiterate, form dominant structures resist loads by geometric form or arrangement of members. They do not resist the loads by the material strength. That is a very important property we learnt in couple of lectures earlier.

So, they do undergo large displacements, in fact, they are permitted to undergo large displacements and their large displacement only help them to counteract the loads provided they ensure recentering. Furthermore, they are also subjected to combination of loads such as wind, wave, ice loads, fire loads, blast loads etcetera.

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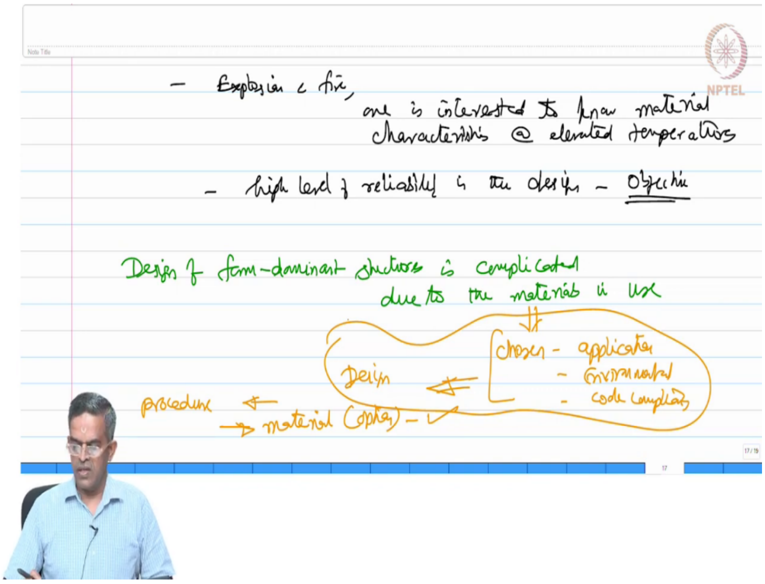

When we talk about explosion and fire, then one is interested to know the material characteristic at elevated temperatures. So, we are looking for a high level of reliability in the design. That is the foremost objective we have in the design. Therefore, we can say an interesting statement, design of form-dominant structures is complicated due to the materials in use. You may ask me a question why it is so. Please recollect the statement.

Materials are chosen based on application requirements, based on environmental conditions, based on code compliancy, and this should now tally with the design. So, earlier the conventional design is the other way. You choose a design procedure and material is selected from a limited option and design is carried out.

So, it is a reverse process whereas, in the present scenario it is entirely different. That is why we say when we talk about advanced steel design of structural systems, the design of structural system is no more conventional. Because structural system itself is getting innovative and novel because of form dominant aspect of the design which is a very very common and very recent innovation in structural system design, in structural engineering.

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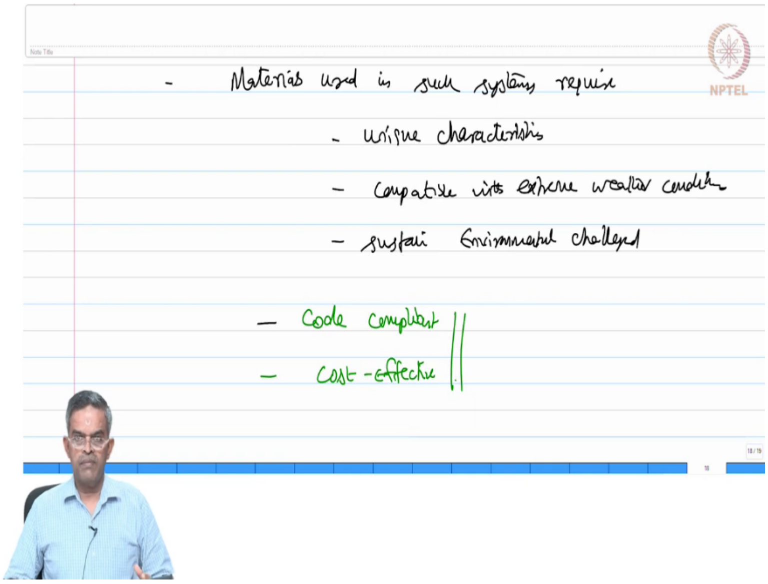

Having said this, we now agree that materials used in such systems or such structural systems require unique characteristics. They should be compatible with extreme weather conditions. They should sustain environmental challenges and apart from that, they should be code compliant and they should be cost-effective.

That is the two inherent requirement running parallel in a designer’s mind, when we talk about application material for any structural systems.

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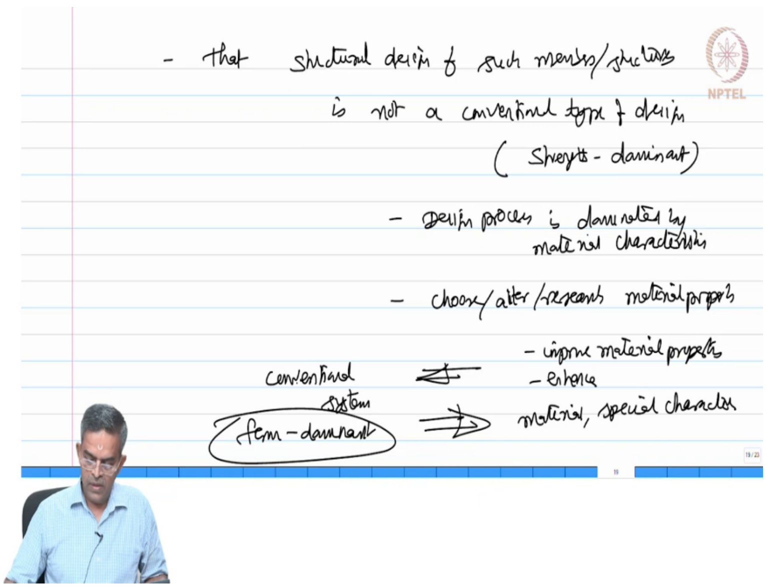

Having said this, we now agree that structural design of such members or structures is not a conventional design. The conventional design used to be strength dominant or strength governed design. So, in such strength governed designs, the design procedure or the design process is dominated by material characteristics.

So, in such designs people used to choose alter, research, material characteristics; improve material properties, enhance them to apply to the conventional design. Whereas, in the latest form dominant systems the process is reversed. The material should possess certain special characteristics. We should shoot the form dominance of the whole design.

Having said this, let us come to the selection of materials.

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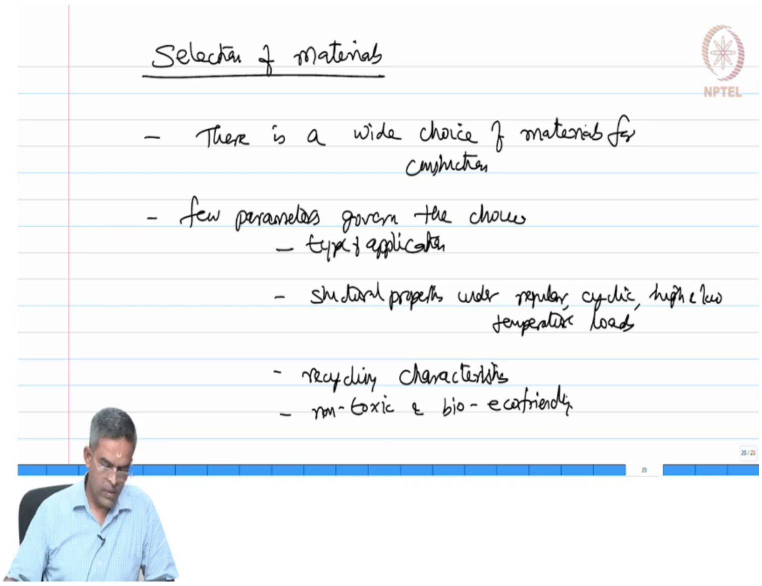

Now, we agree that there is a wide choice of materials for construction. We already listed them and we all agree on the statement. But few parameters govern the choice. Namely, type of application you are looking for. Two, structural properties of the material under regular, cyclic, high and low temperature loads.

We are also interested to look at the recycling characteristics of the material. We wanted to ensure that the material remains non-toxic and bio-ecofriendly. The material should also be sustainable for the entire service life of the structure.

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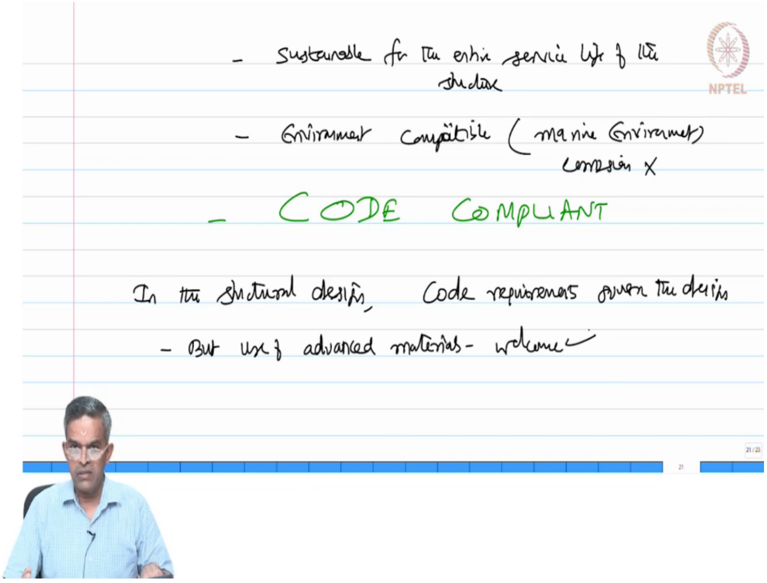

It should be environment compatible, especially when you talk about marine involvement. To be very specific corrosion is a very severe problem in marine environment. And above all whatever material is used, it should be code compliant codes should advise recommend this material for construction. Water may be the code, Indian international. There should be a code confirmation of using this material for that kind of application.

You may wonder how codes specifically say this material is useful for this kind of construction. I will cite certain examples and codes, where there are international codes which specifically say use this material of this characteristic for this kind of members. They are very very specific in recommending them for design.

Therefore friends, in the structural design we all agree that code requirements govern the design, but use of advanced materials are also welcome in the code. So, advanced materials are also inserted as an optional replacement of the existing conventional material.

So, when you talk about advanced, please think that, steel is not the only non-replaceable material for construction. I am going to give an alternative in this course. We will see how other materials can also replace steel with better structural characteristics. We are going to talk about that.

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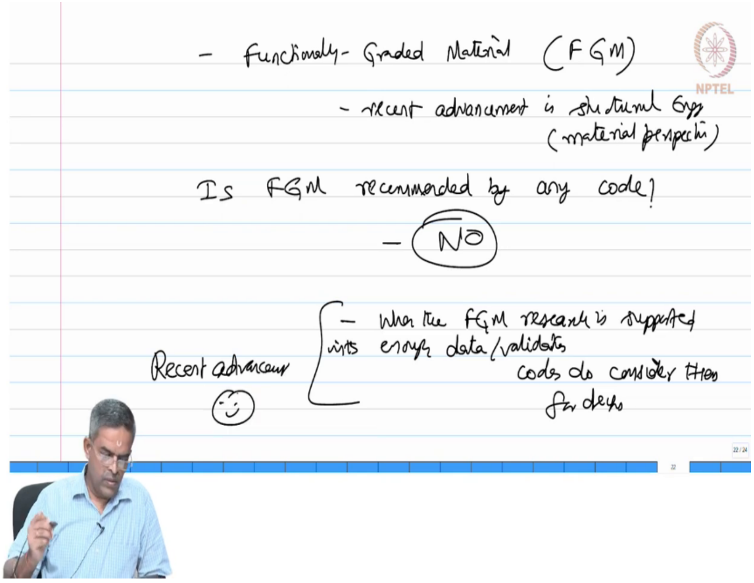

Functionally graded materials, abbreviated as FGM are the recent advancements in structural engineering, in material perspective. Now, the question is, is FGM recommended by any code? As of now the answer is a big no. But, however, when the material research is supported with enough data and validation, codes do consider them for design. That is the recent advancement we have.

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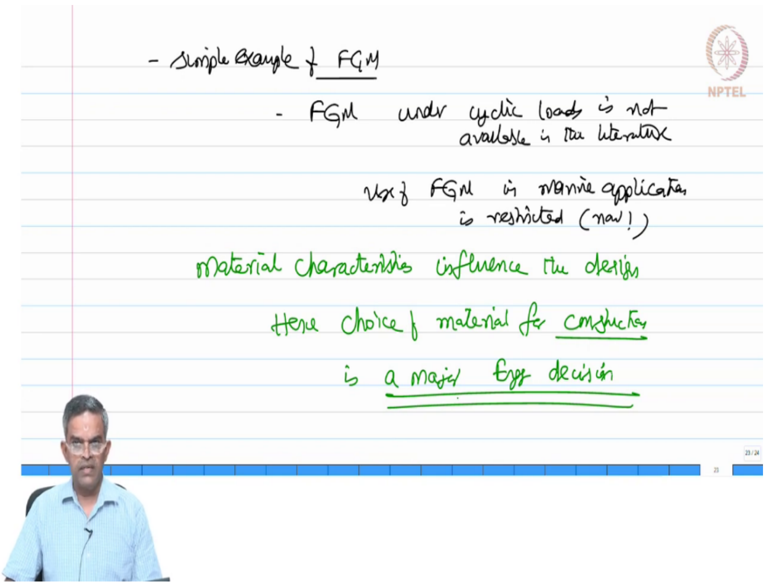

I can give a very simple example of FGM. We will talk about this in detail in the coming lectures. Simple example of FGM is that FGM under cyclic loads is not available in the literature. The structural properties of FGM and the cyclic loads is not enough it is very scarce in the literature.

Therefore, use of FGM in marine applications where cyclic load or reversal of loads is predominantly present is restricted as of now. But still, to assess the fatigue life, a conservative approach can be used, to compare the results and present it to the research board of material innovations. Material characteristics influence the design and hence choice of material for construction is a major engineering decision. So, that is a very interesting declaration we want to emphasize upon for the learners.

So, far in the conventional design, people were thinking that we have been given about choice of 1 or 2 materials. Let us say reinforced concrete, structural steel, sometimes composites. Use the relevant core, find out the critical stresses, check them for bending shear, torsion etcetera and let us say we declare the design is safe. That is all we have been doing for ages.

But under the present era friends, it is not sufficient. We have to look for advancements in the design, in the structural geometry, and application oriented structural systems, where the material choice governs the design and that becomes one of the major engineering decision in the whole project.

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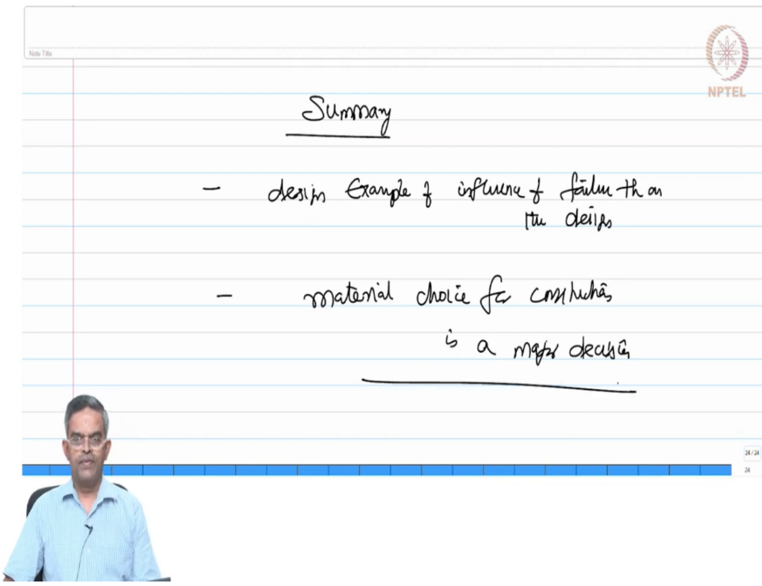

So, in this lecture friends, we learnt one design example of influence of failure theories on the design. We have also agreed that material choice for construction is a major decision.

Thank you very much. Have a good day.