Advanced Design of Steel Structures

Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture - 01
Form - dominant design - I

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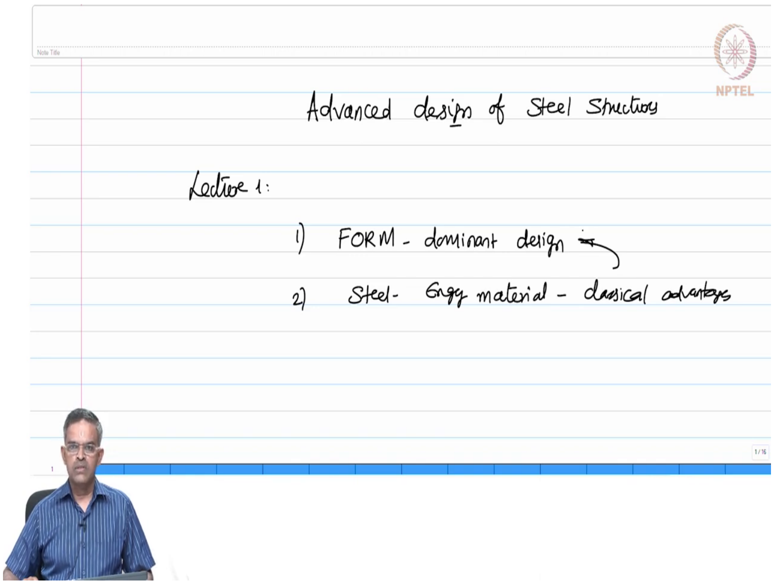

Friends, welcome to this lecture on Advanced Design of Steel Structures course. In this lecture, we are going to learn two things. We are going to understand what do we mean by form dominant design, what is specialty about this form dominant design, where are they applicable. And when we do a form dominant design approach what will be the basic essential challenges which come in the design principles we will learn about that in this lecture.

We will also try to learn more about steel as an engineering material which you must have studied, but we will see some classical advantages in connection to the form dominant design. So, friends this course is essentially open to multidisciplinary fraternity of civil structural engineering, mechanical engineering, offshore engineering, naval architecture, applied mechanics and aerospace engineering group both at the student and faculty level as well as for the practicing engineers.

We will do lot of solved examples, numerical examples in this course. We will also enable you to use matlab programs for solving the numerical examples. We will help you how to write these matlab codes very quickly for specific application of numerical examples we will also touch upon a variety of international codal provisions applicable to design of steel structures. So, friends, when we talk about advanced design where does the advancement comes from – that is a first question which one we like to know.

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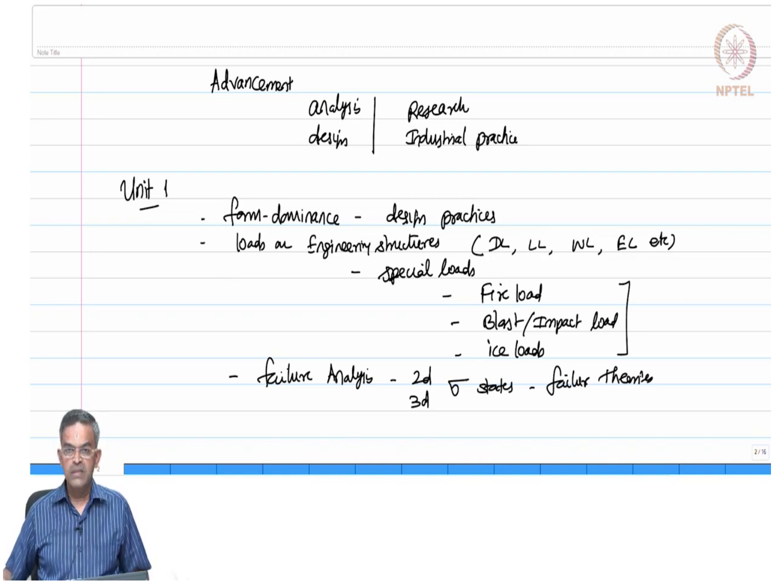

So, advancement essentially comes from the domains of analysis and design which are useful for both research and industrial practice. Let us quickly look at the glimpse of the course contents what we will be discussing under the title of this course. In unit 1, we will briefly discuss about the form dominance and how it is influencing the design practices. We will also talk about loads on engineering structures though we all know about the conventional loads which are acting on the engineering structures namely dead load, live load, wind load, earthquake load etcetera.

We will pay attention to some special loads which are unconventional and not discussed in many of the course contents. We will talk about fire load we will explain how to compute the blast and impact load. We will also talk about ice loads these are special loads which will be of quite interesting to many of you will be attending these lectures because they are highly unconventional.

But, they act on heavy industrial structures and very less material is available in the literature which explains this numerical modeling of these loads and how to handle the structural design under these loads. We will also talk about the failure analysis both in 2-dimensional and 3-dimensional stress states. What are the different failure theories and how these theories help to compute the failure load or the failure stress acting on a cross section under 2-dimensional and 3-dimensional stress states.

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Then we will also talk about material properties of steel both under normal temperature and high temperature because we are going to deal with the fire resistant design. Therefore, we must know the material properties of steel at higher temperature. We will also shortly discuss about the design codal provisions related to these codes and design methods. So, this will comprise unit 1 friends which will have a tutorials; set of tutorials and few important takeaway questions in the examination perspective as well as in learning and understanding perspective.

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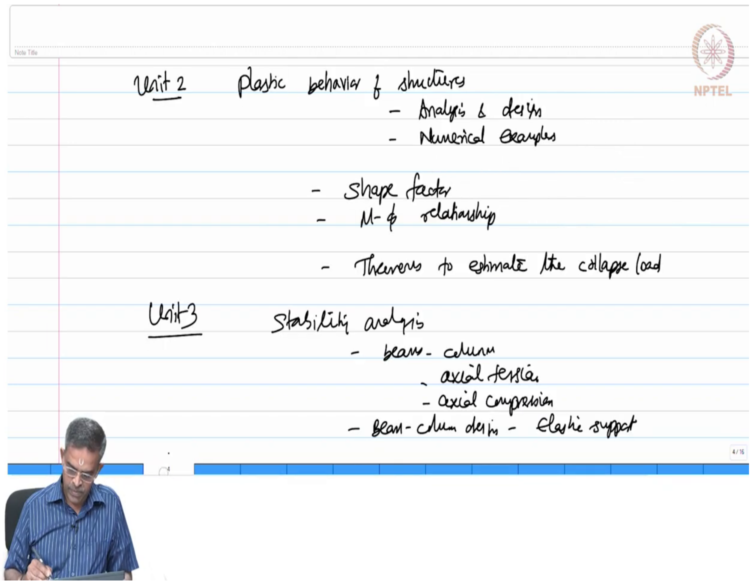

The next unit will deal with the plastic behavior of structures; we will deal with plastic analysis and design. We will do lot of numerical examples to compute the plastic load carrying capacity of sections. Then we will also talk about the importance of shape factor of different cross sections; then moment curvature relationships; then of course, theorems to estimate the collapse load in structures.

In unit 3 we are going to focus on stability analysis; we will start with beams, column connections under axial tension and axial compression. We will also discuss about beam column design under elastic support.

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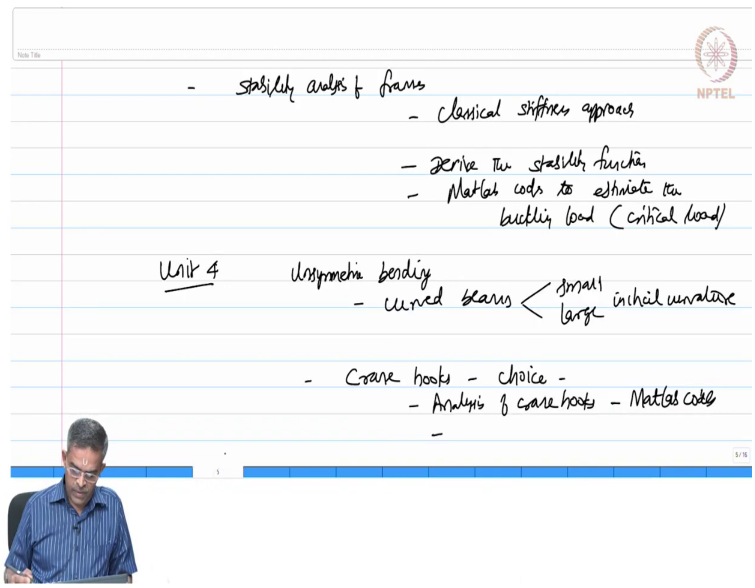

Then we will extend this to do stability analysis of frames. We will use a classical stiffness approach. We will derive the stability functions from the first principles. We will also use matlab codes to estimate the buckling load or what we call otherwise as critical load. In the next unit we are going to talk about unsymmetric bending. We will also deal with curved beams with small and large initial curvatures.

In industrial structures design of crane hooks in fact, choice of crane hook for a specific load carrying capacity plays a very important role. So, we will do analysis of crane hooks. We will also use matlab codes to solve the problems of estimating load capacity of crane hooks or estimating critical stresses in the cross-section of the crane hooks.

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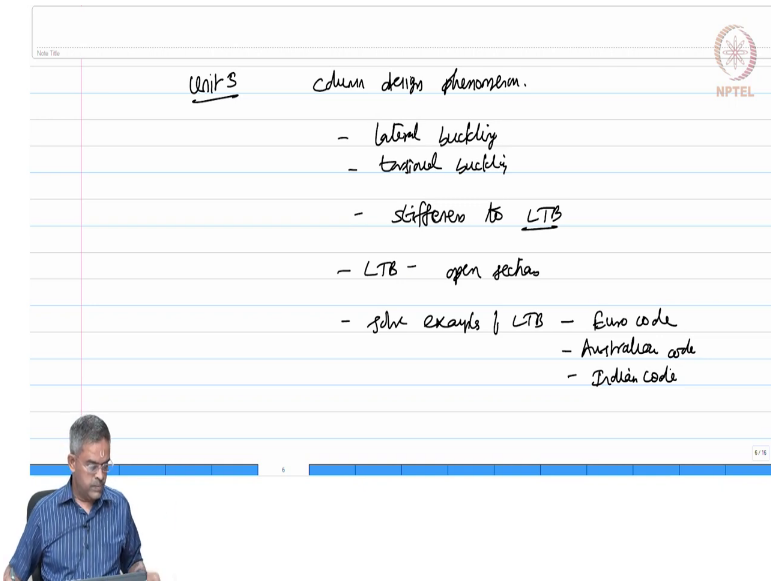

In the next unit, we will talk about column design phenomena where we will place emphasis on lateral buckling, torsional buckling. Then we will also talk about the design of stiffeners to take care of lateral torsional buckling. We will discuss about lateral torsional buckling in open sections. We will also solve examples of LTB from different codes we will take Euro code example we will also take Australian code example. Then we will discuss using Indian code.

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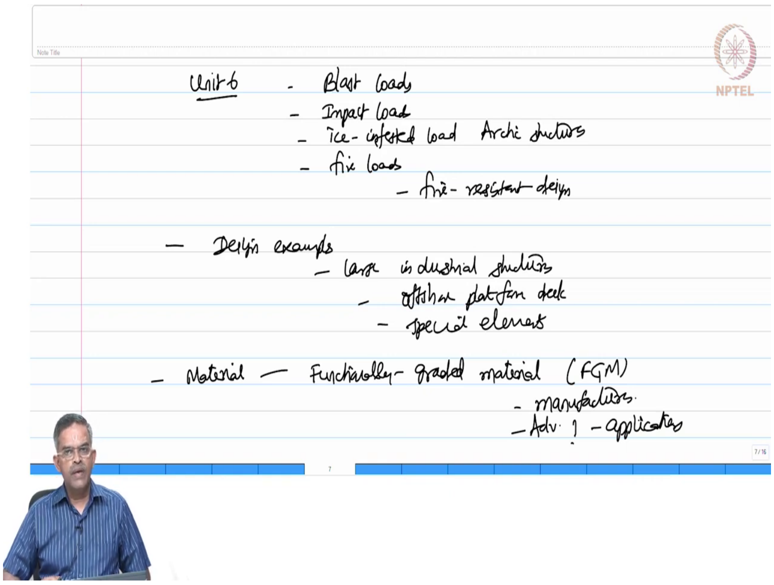

In the next unit we are going to talk about estimate of blast loads, impact loads, ice infested loads on arctic structures. We will also talk about fire loads and we will touch upon the concept of fire resistant design. We will also deal with design examples of large industrial structures, offshore platforms and other special elements. When we talk about material other than steel we are also going to introduce the advantage of functionally graded materials and their recent applications in offshore structures and other structural systems.

So, what is an FGM, how FGM is manufactured and what are the essential advantages of using FGM and their applications and limitations of using FGM, we will talk about this. So, friends, this course content has got many novel and advanced topics which will be very helpful for research as well as industrial practice purposes. So, let us join together to learn this course, understand the contents and pay attention to also get ourself, self-examined at the end of the course to earn a decent credit and a certificate from NPTEL.

So, having said this let us ask a question why steel is considered as a very important construction material you are coming to form dominance now .

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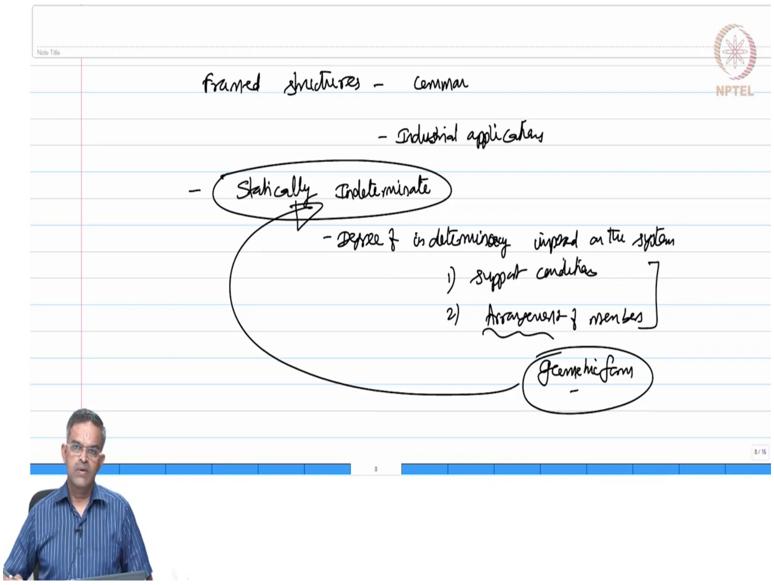

We know framed structures are very common for many industrial applications. The moment I say framed structures they are usually statically indeterminate. So, the degree of indeterminacy is imposed on the structural system by two ways: 1 – from the supports or support conditions; 2 – arrangement of members. Friends, the moment I say arrangement of members there is always a concept of geometric form playing a role here.

I am sure all of you will know what is called as a statically indeterminate structure. The degree of indeterminacy otherwise referred as redundancy enables higher load carrying capacity of the system which we have studied in conventional steel design of structures. So, the arrangement of members the geometric layout of members what we call as a geometric form helps us to get this redundancy.

So, the form dominant design is not a new concept. It is embedded in the design philosophy for the past many years which we have been learning in the classrooms and practicing in the industrial applications. We will talk about couple of simple examples to realize what is form dominance and where does it come from.

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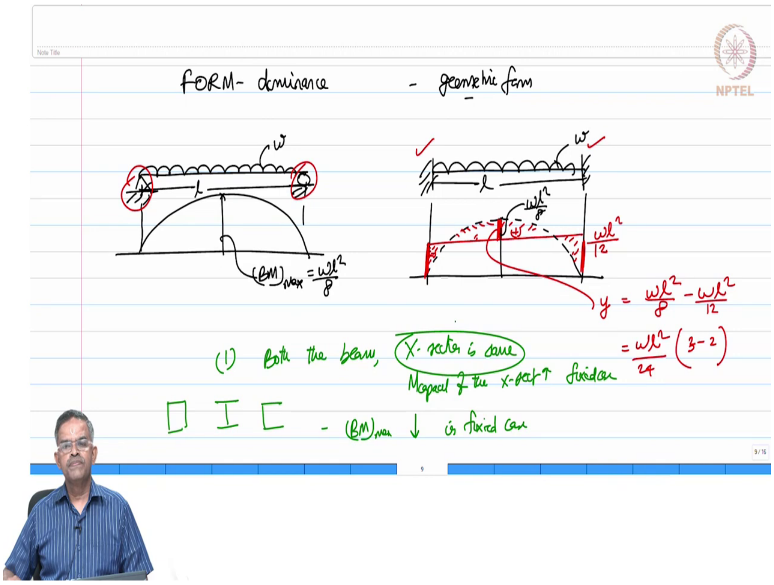

The moment I say form I am referring to geometric form . If I take a simply supported beam subjected uniform distributed load and try to draw the bending moment diagram and we all know the maximum bending moment will occur at the mid span which will be $wl^2/8$ where this is the load acting on the system and this is the span of the beam.

So, to make it form dominant let us replace this support system by a fixed support and apply the same intensity of load w over a span of l. If I now draw the bending moment diagram this will have two components I am super imposing both of them. One is of course, to simply support a bending momentum diagram whose ordinate is at the center will be $wl^2/8$, but this moment will be now compromised by a fixed moment at both the supports which is given by $wl^2/12$.

So, the net effective bending moment at the mid span is now reduced because you know this is negative and this is positive. So, just by converting or changing the support from a simply supported system to a fixed support system the net effective bending moment at the critical section is reduced. One can easily find out this reduction which is nothing but $wl^2/8$ - $wl^2/12$ which will be $wl^2/24$ of (3 – 2).

So, I get a great reduction in the net bending moment at the critical section just by changing the support system. So, this is a very simple illustrative example to understand how a form dominance plays a role. Please note a great understanding in this example. 1 – In both the beams if the cross-section is same, then the moment capacity of the cross-section is higher in the fixed case.

On the other hand, the maximum bending moment at the critical section is lesser in the fixed case. Material is same; it can be concrete, it can be steel, cross-section is same. It can be rectangular, it can be I – section, it can be a channel section. By keeping the cross-section same only we change the support condition which is one of the characteristic of form dominance help us to decrease the effective bending stress at the cross-section at the critical section or there is a reduction in bending moment, this concept is again not new.

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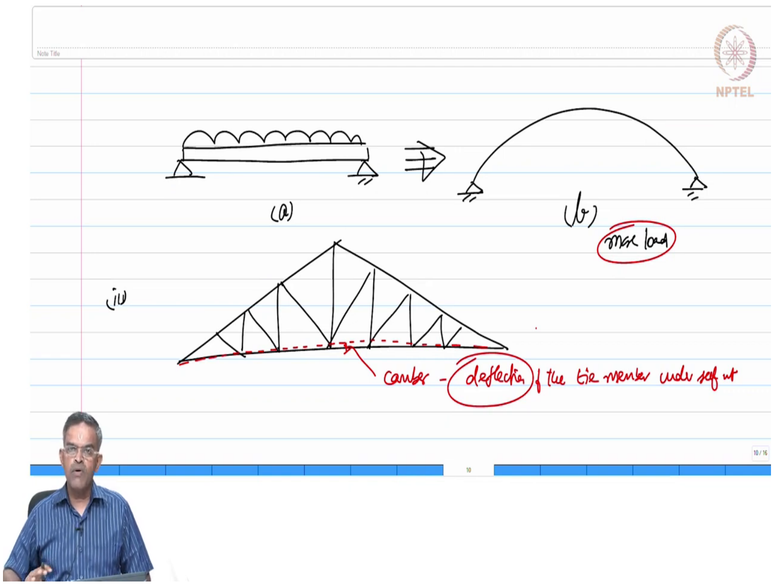

If I have a beam which is placed to carry a load which is uniform distributed, in olden days people replace this beam by an arch. And people understood it was self explained in the literature that the configuration (b) carries more load or capable of carrying more load compared to the configuration (a). When we talk about large span trusses the bottom chord members are not horizontal, but they are given a slight camber.

This camber is given to counteract the deflection of the tie member under self weight. So, the bottom members are lifted by a specific value usually the camber is suggested as per the design provisions of different types of trusses which are very common practice in industrial structures. So, form dominance which is used either to increase the load capacity or to control the deflection has been a practice in structural design which is not new.

We are not going to talk about this form dominance. we are going to talk about form dominance on industrial structures which are applicable for oil and gas exploration. I will give a very simple example again.

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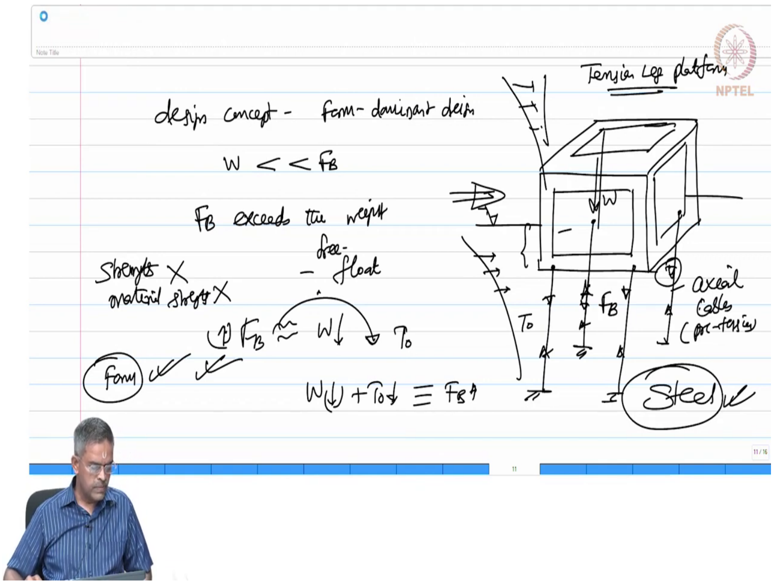

Let us say I have an oil platform which is essentially like a cube box. The box is not solid, it is hollow inside, but it is having a large size. When I place this box in water body, the immersed volume of this object will improvise buoyancy force. So, I have a design concept which is a form dominant design where the weight of the structural system is much lesser than the buoyancy.

So, the buoyancy exceeds the weight. So, what will happen when you have a system where the buoyancy exceeds the weight? The system will have a flotation capacity, the system will have a free flotation capacity. Now, the difference between this buoyancy force and the weight has got to be nullified. This comes from an axial tensile cable which is connected to the system which is used to pull this body down.

And, these are axially loaded cables which will be in pre-tension that is why I have marked tensile here. If I consider this as T_o which is acting downward so, w acting downward plus T_o acting downward should be now made equal to the buoyancy. Now, friends please note, the load acting on the structure which will be a wave load which will again be a wind load etcetera are not counteracted by the strength of the member.

So, the load is not counteracted by the strength of the member, it is not counteracted with the material strength, but counteracted by the geometric form. So, the geometric form helps the system to counteract the horizontal loads acting on the system. So, for such structural systems, steel is the most commonly preferred material being used. In industrial structures the example what I am citing here is referred as tension leg platform which is one of the classical offshore platform used for oil and gas exploration.

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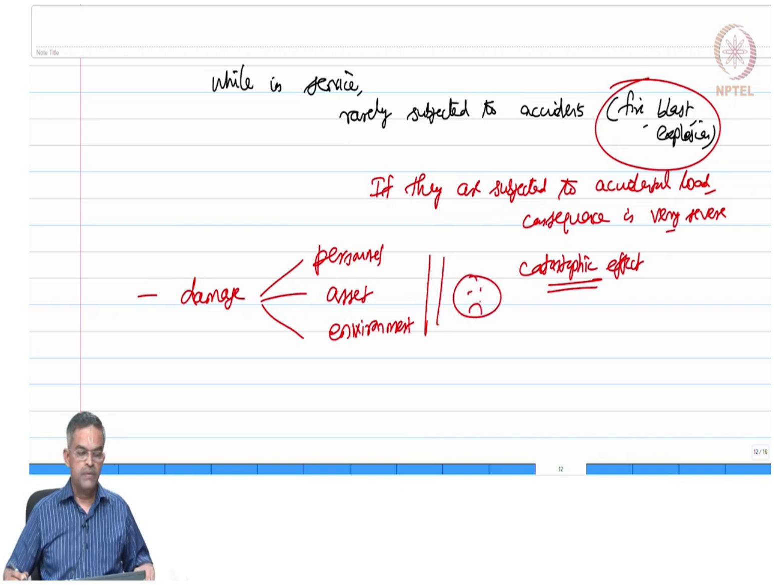

So, friends, framed structures which have high degree of redundancy help to improve the load carrying capacity and decrease the stress concentration on critical members. While they are in service these structures are rarely subjected to accidents such as fire, blast, explosion etcetera. But, if they are subjected then the consequence is very severe it will have a catastrophic effect and hence one should know how to estimate and how to design the structural system under these kinds of accidental loads.

So, they will cause damage to the personnel, to the asset and of course, to the environment. So, this should be avoided. This is not a desirable feature.

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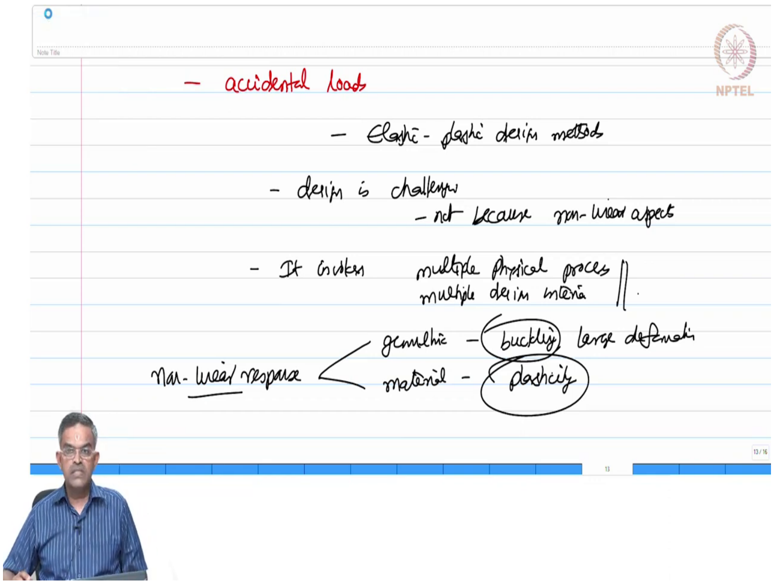

Further, when they are subjected to accidental loads under extreme conditions we need to understand the elastic plastic design methods which we will discuss in this course. The analysis and design of steel structures under extreme conditions and accidents is challenging not because they have non-linear aspects. It is because it invokes multiple physical process and multiple design criteria, that is important. The non-linear structural response of such systems arise from two sources, the non-linear response comes from two sources.

It can come from geometry which we call a geometric non-linearity which refers to buckling large deformation etcetera; can also come from material non-linearity which we call as plasticity. So, we must know how to handle the design of steel structural systems under both non-linear response categories for buckling and plastic loads which we will discuss in this course.

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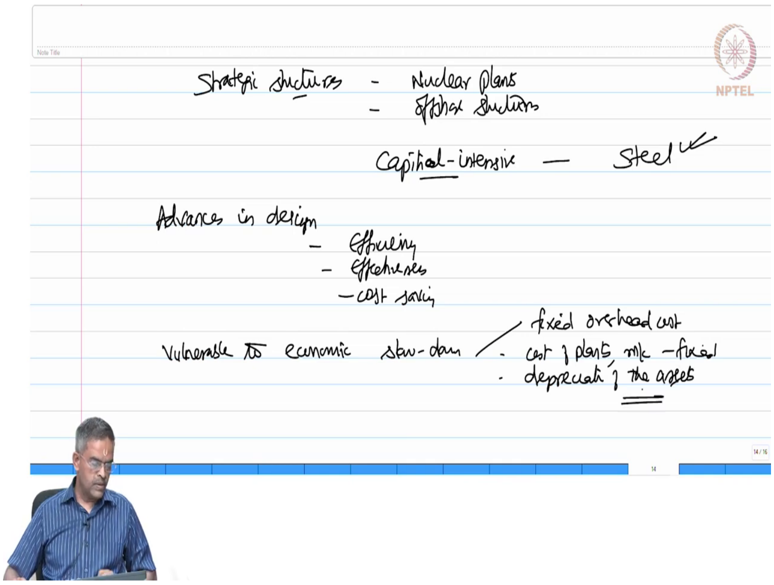

So, friends, having said this when we talk about strategic structures for example, nuclear power plants offshore structures etcetera they are capital intensive industry. So, the option given today to design a capital intensive structural systems is only steel. There is no other altered material available and people never tried any material for strategic structures.

There are many advances in design. The moment they say advances in design it means efficiency and effectiveness and cost saving. Furthermore, the capital intensive industries like strategic structural systems are also vulnerable to economic slowdown because of the many reasons. One is they have a fixed overhead cost; the cost of plants, equipment, machinery and appurtenances are fixed and there is a significant depreciation of the assets.

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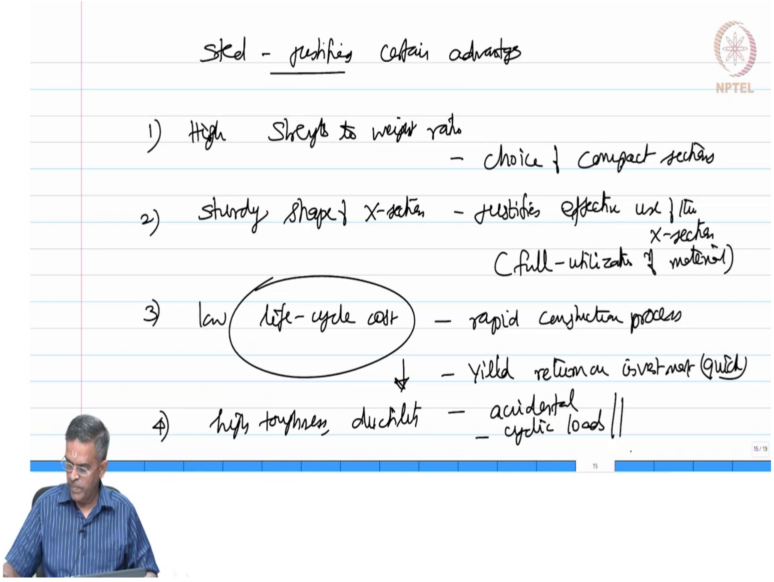

Steel as a construction material justifies certain advantages. It has got a very high strength to weight ratio which justifies the choice of compact sections to carry high stress concentration loads. The second advantage could be the sturdy shape of cross-section. This justifies effective use of the cross-section. So, I am talking about a full utilization of material.

Furthermore, it has a very low life cycle cost because steel construction is a rapid construction process. Considering this as a rapid process it can yield return on investment very fast. Therefore, the life cycle cost will be low. Furthermore, steel has got high toughness and ductility. This helps steel to withstand accidental loads and cyclic loads. Steel structural components become non replaceable for certain applications.

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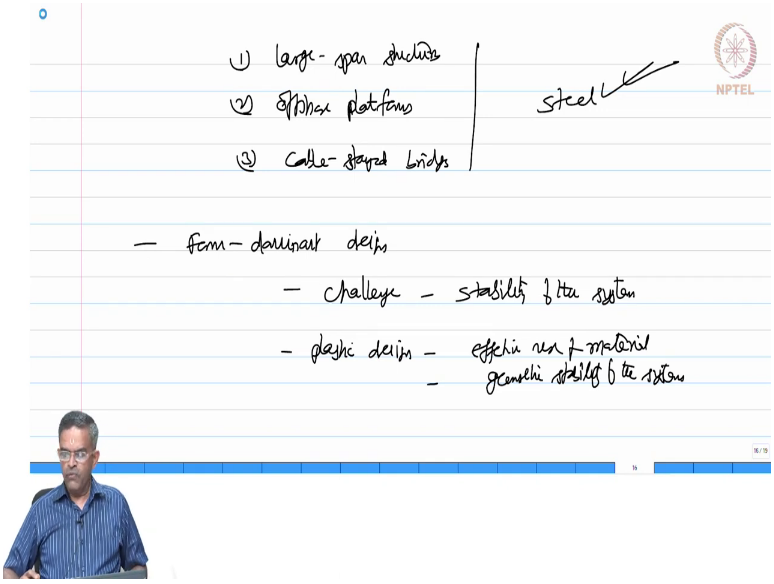

So, large span structures, offshore structures which are used for oil and gas exploration, cable stayed bridges where you cannot think of any alternate material except steel. However, when we talk about form dominant design, then the foremost challenge comes in the form dominant design is stability of the structural system. It is one of the essential feature which should be ensured in form dominant design.

Under extreme cases such as accidental loads and fire, plastic design plays a very important role, but when you use a plastic design philosophy though you say there is an effective use of material. But, we have to also ensure the geometric stability of the system.

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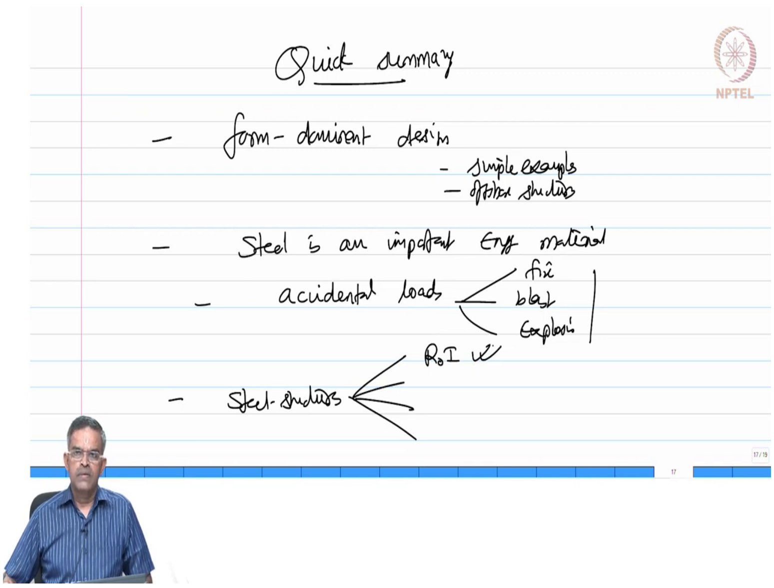

So, friends in this lecture we learnt few things. We understood the importance of form dominant design from simple examples to offshore structural examples. We have understood why steel is an important engineering material. We have also understood and we are curious to learn about the accidental loads that can occur on cross-sections such as fire blast loads explosion loads etcetera. We understood that steel structures have many advantages the foremost advantages return on investment is faster.

Low life cycle cost, high strength to weight ratio and quick rapid mode of construction. So, having said and realized the importance of steel as a engineering material and realize that form dominant designs are generally facilitated with steel as a construction material, it is very essential for us to learn the advanced analysis design procedures that govern this kind of structural systems in detail. So, friends, we come to this end of the lecture.

We have explained essentially the basic concepts of form dominance in this lecture. We have given you an overview about what we will be covering in the entire course.

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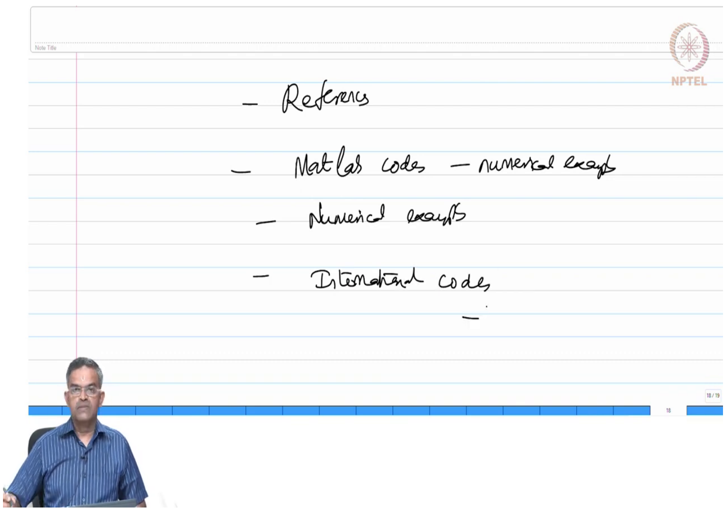

Look into the NPTEL website you will have references which are very useful for this course. of course, matlab codes available to solve the numerical examples will also be given to you and we will do lot of numerical examples in the class to explain the concepts. And, we will touch upon application of various international codes for design of steel structures.

Thank you very much. Stay safe. Have a good day. Bye.