Structural Systems in Architecture
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Module 1
Lecture – 2
Force System

So welcome to this NPTEL online certification course on Structural Systems in Architecture. This is module 1, the second lecture on force system.

The concepts to be covered today is:

- Mechanics
- Force
- System of Force
- Forces and its Impact

So, as we have already discussed about various principles and objectives of the structures and the structural systems in the first lecture, now today we will try to discuss the above mentioned four concepts in this second lecture. We will start with the mechanics, and go with the sequence with force, system of forces and then the forces and its impact.

The learning objective of this lecture is to understand what is the mechanics and what are its by-parts. How structural engineering relates with mechanics? We will also try to discuss the concept of force or how a force can be conceptualized; and what are the different type of forces. We will also try to identify the types of forces and how do they impact on any kind of object.

So, the intended learning objectives are:

- Understanding the Mechanics and it's by-parts.
- To Develop the Concept of Force.
- To Identify the types of force and its impact**.**

Now, let us start with the mechanics. Mechanics is a science or a field of engineering. It deals with the forces and in its effect on any object; and that object may be in rest, or may be in motion. So, both can be taken care of in a nutshell. If you see the mechanics, it has clear-cut three boundaries or three types. They are:

- Rigid Bodies: Engineering Mechanics
- Deformed Bodies: Solid Mechanics

- Fluids: Fluid Mechanics

The first is engineering mechanics, which about the rigid bodies, of course in the nature you cannot find even a single object which is purely rigid. The rigid bodies mechanics is called engineering mechanics where a force will be applied to the rigid objects and it will import some motion, or sometimes it may remain static. Even though, there will be no changes in the internal stress or the internal parameters.

The second one is the solid mechanics, which talks about the deformed or elastic bodies. More or less, what we see in day to day life are bodies with elastic material. So, even if it is in motion or static, it will gain some deformation.

The third one is the fluid mechanics. It is the domain of, air, water and other kind of fluids. When a force is applied on it, then what are the changes obtained? What happens to that particular fluid and how will it get compressed? What are the different parameters or parametric changes that comes under the fluid mechanics?

So now we go into the engineering mechanics which we will be into as I told you which is going to apply in a rigid body and the external force on a rigid body and what will be the effect of that particular rigid body depending upon the forces. In the engineering mechanics, it has further classification or the divisions. The first one is called statics which deals with the rigid body of course but the rigid body is under rest, it is not under any kind of a motion.

$$\sum F_X = 0; \qquad \sum F_Y = 0$$

So those are the typical formulas or the equations we use for the statics, the summation of forces in x direction is equal to 0 or maybe in the y direction is also equal to 0. This is the widely used equation for statics. We will discuss these equations in the next lecture. There is another part of the engineering mechanics or another sub part is the dynamics. Dynamics deals with the motion of forces on a body which is under the motion.

The dynamics has two further classifications. One is called kinematics and other is kinetics. The kinematics is a study on the dynamics or the bodies which are under the motion. It will study the forces, displacement, and geometry of the motions without addressing any cause of the movement. The typical equation for this is:

$$S = ut + \frac{1}{2} f t^2$$

This is for a linear kind of motion with initial velocity, time and the acceleration is that comes under the kinematics.

The second equation is:

$$R = \frac{u^2 Sin2\theta}{g}$$

This equation is widely used finding the range of a parabolic trajectory. These are the equations for geometry of motions.

The second part of the dynamics is called kinetics. Kinetics is a study of the mass and the motion of the body. So of course, in a particular motion a mass is also involved. The first equation given below is the conservation of the momentum.

$$MV = m_1 v_1 + m_2 v_2$$

This equation includes the mass and also the motion or the velocity.

The second is the energy equation is:

$$\frac{1}{2} m v^2 = mg\ (h_1 - h_2)$$

Let us assume that, here some object is falling from h_1 to h_2; through which the potential energy is converted to the kinetic energy and velocity. So those are involving of the particular mass and also the motion, so those are the kinetics. Kinematics you see there is no mass involving that.

Then next is solid mechanics. I have already mentioned that, it deals with forces. This is the science or engineering of deformed bodies under the action of the external force. Suppose, if you take a piece of rubber, or a spring and you press it, it will get deformed, or it will shrink; and if you again pull it, it will again get elongated, that means it will get elongate and then compressed.

So, here some kind of stress is going to involve. There will be Young's Modulus of elasticity, which are expressed in the formulae below.

$$\sigma = \frac{P}{A}$$

$$E = \frac{\sigma}{\epsilon}$$

Finally, the last one is the fluid mechanics. It deals with mechanics of compressive forces on the fluid & fluid particles.

So, you can see from the above figure that, mechanics has three typical classifications; engineering mechanics, solid mechanics and the fluid mechanics. Engineering mechanics have statics and dynamics and further the dynamics is again sub-classified to kinematics and kinetics. The statics deals with equilibrium, and free body etc. The kinematics deals with the

velocity, displacement and accelerations etc.

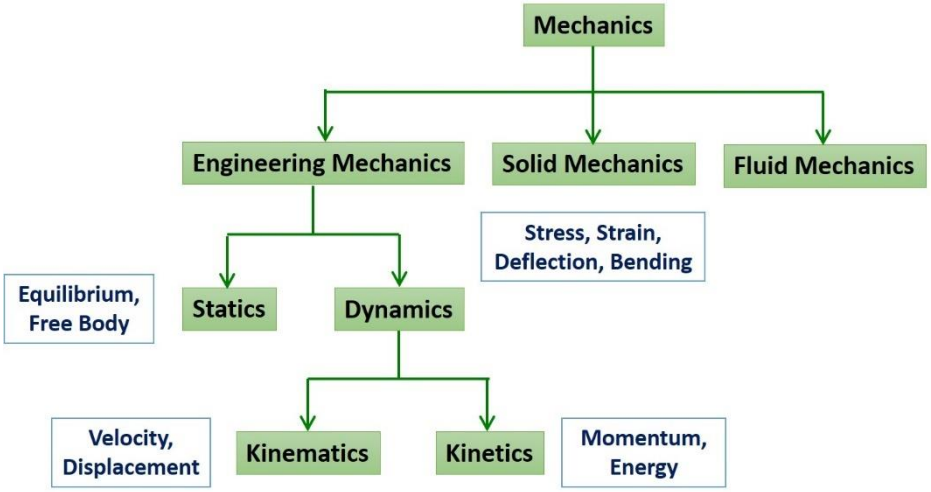

Figure 1: classification of mechanics

The kinetics deals with the energy, and momentum. Solid mechanics deal with the stress, strain, deflection, bending which is actually the some of the parameters for the deformed bodies.

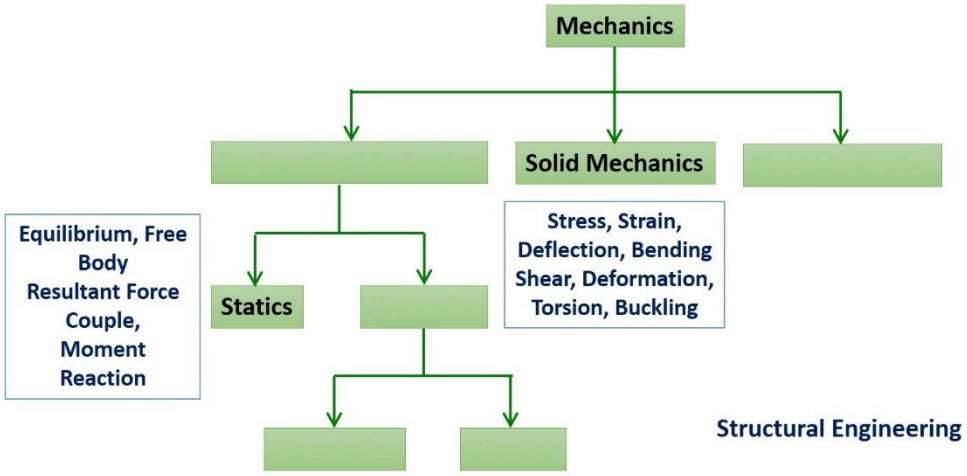

Figure 2: relation of mechanics with structural engineering

Now, in our structural engineering, as shown in Figure 2, I have to take these two parts, I mean I do not have to deal with the dynamics at present. Dynamics is also applicable in the structures, but those are not in the scope of this particular NPTEL course or this lecture course. So, first we will see some of the statics. Where we will try to understand about the free body diagrams, then the equilibrium conditions, the resultant forces, and how can it be evaluated.

After that, the reaction forces based on any kind of beam system. Then there will be discussions on force, couple, moments etc.; which are a basically a part of statics. The dynamics will definitely go into that and after that we will switch over to the solid mechanical systems or the

solid mechanics; where we will discuss on stress, strain, deflection, deformation, buckling, torsion etc.; and all these comes into the typical domain of the structural engineering.

Next let us discuss, what is force? We all know that; force is part and parcel of any kind of engineering. It may be the civil engineers, who deals with forces in a different form, the mechanical engineers, deals with in a different way for their machine designs. We deal with forces in a way that, we can design a building or any kind of structure. The force is defined as the action that tends to change the state of inertia. So, if something is in rest, and I want to change the state of inertia or from rest in to motion; that motion may be linear, or circular motion; by any such way it tries to change the inertia. On the other hand, the action that changes the shape of an elastic body, sometimes it may not go for motion that means it may remain as a static or the as a non-movable object; but it will change the volume, length etc., due to the application of force.

Now what are the characteristics of force? Force has mainly the four notable characteristics. They are:

i) Magnitude

ii) Direction

iii) Point of application

iv) Line of action

You all know that force is a vector quantity and it has magnitude and direction. So, if I say this is a force of X and if this is the positive X, so from the other or opposite side, this will be the negative side of the force, it will be a negative X. So, the magnitude, and the direction is there. The magnitude of the force is measured in the Newton.

The SI unit of force is Newton. In 1 Newton, it is 1 kg mass which is under an acceleration of 1 meter per second square. Then it has a point of application, that means the force is applied at a specific point. So, let me discuss with Figure 3.

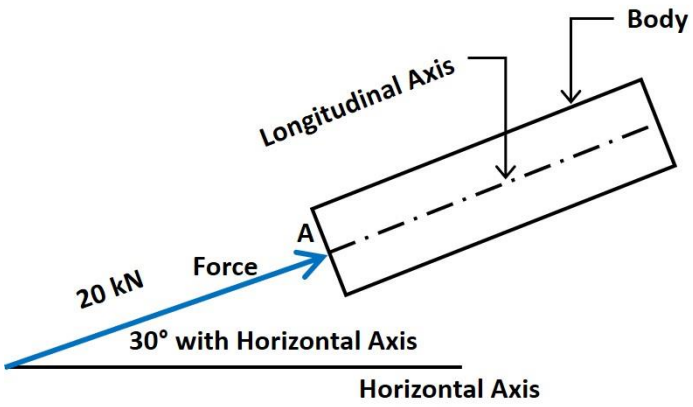

Figure 3: application of force

Let us assume that, there is a piece of metal rod; and I am applying a force of 20 kilo Newton at point A. Here, the 20 kilo Newton is the magnitude and A is the point of application.

The direction of the force is 30 degree with horizontal axis, and the line of action of the force is the central longitudinal axis.

So, those are the four typical characteristics of force that we have to understand.

What we have discussed till now is about single force. Now, let us move to force system. When a body is not under the action of a single force, maybe more than one forces; or a group bodies under the forces, it is called as a system of forces or force system. It is also classified into two broad types. One is called coplanar forces, when the action of the all the forces lies in the same plane, suppose I have five fingers, all are in the same plane. So, if I put the forces, the five forces from the five fingers acts on a same plane, but sometimes it can be non-coplanar forces too. So, system of force is more than one force, similar to five fingers, but instead of putting it to one plane, if I put in such a way that there are five forces in five different planes, they are non-coplanar forces; and this is another type. So, these are the two very broad classifications.

Now, I have some figures. In Figure 4, the left-hand side image is a crane, which is pulling some loads. So, you can see that, all the cable, and all the arms are under coplanar force. Whereas, if you consider the right-hand side image, that is a table, beneath the four legs there are some reactions and those four reactions are non-coplanar forces; because those four are not at all acting in a same plane. They are acting on four different planes.

Figure 4: force systems

The force system is broadly of two types, coplanar and the non-coplanar forces. In coplanar forces, we have further four classifications. Collinear forces, concurrent forces, non-concurrent forces and parallel forces (see Figure 5); and non-coplanar forces also have three sub-classifications. It does not have the collinear, but it has a concurrent, non-concurrent and the

parallel forces.

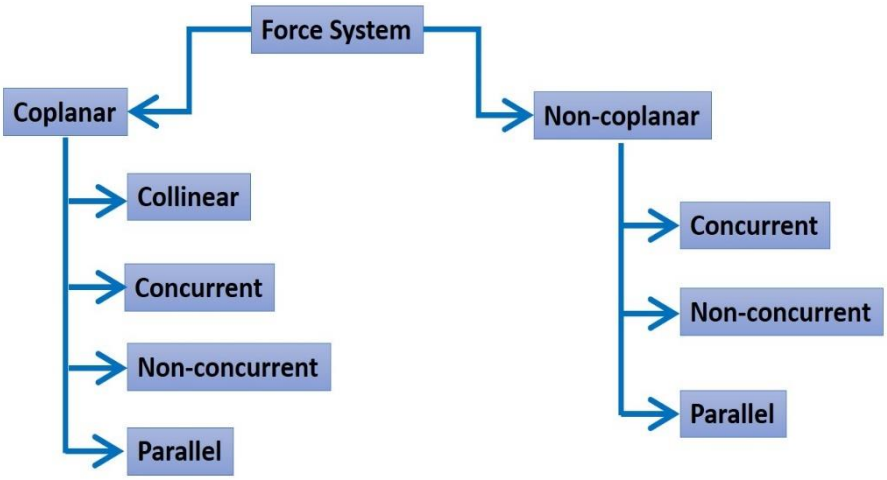

Figure 5: classification of force system

The classification and the further classification of forces are based on characteristics of the forces. The line of action of the entire force system is in same direction; for example, a tug of war, (see Figure 6) when two groups of people are pulling a particular rope, the line of action is in same direction. So, two forces are created which are in same plane and in same direction or maybe in opposite direction, but in the same line of action.

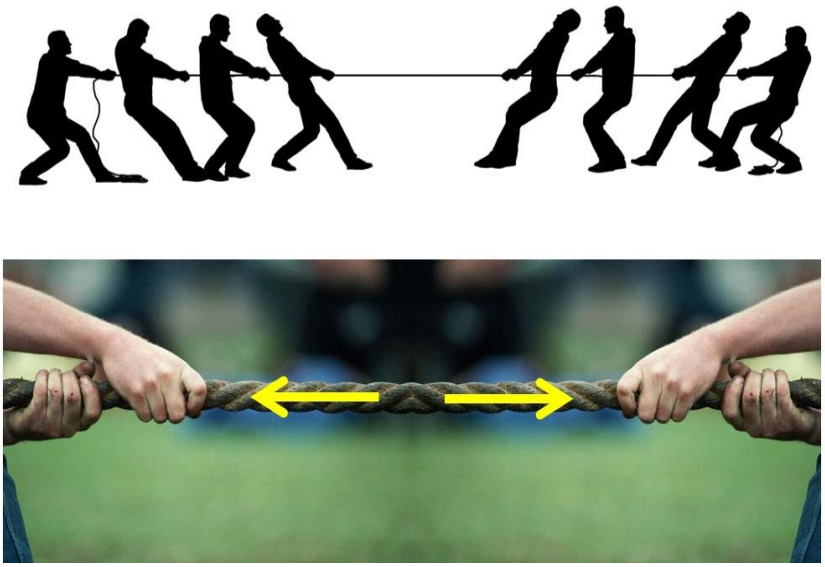

Figure 6: forces and line of action

Now, next is the concurrent force. When the line of action of the forces passes through a single point, it is concurrent force. In this case the forces may not be collinear, or in the same line of

action, or line of action may change; but it must pass through the same point. Here, let us take a truss as an example, assume that its a bridge truss. In Figure 7, you can see the three members of a truss, central member, and these three forces are not collinear; because their line of action is not same, it is in three different directions, but they are passing through a single point. So, they are called as the collinear forces.

Figure 7: concurrent forces

The next one is the coplanar forces. It is non-concurrent kind of force. Here the line of action is not passing through the same single point (see Figure 8). If we again consider the same example of a truss and take three different members as shown in Figure 8, here the line of action for each member is different, and they are not going to meet anywhere.

Figure 8: coplanar forces

They are called as coplanar forces, coplanar forces of non-concurrent type.

The last one is parallel force. Parallel forces are definite, it is non-concurrent, but it goes parallel to each other. Suppose, you take a railway coach engine and there are wheels; and all the load of that particular engine or may be of any other coach passes through the wheels. So, those wheels are grounding some force or some weight and those are the parallel force.

Figure 9: parallel force

In Figure 9 you can see that the forces are parallel, the wheels are circular and they are touching with the rail with a particular point, so it transmits the load through the radious of the wheels.
Let us see the flow chart in Figure 5 again, the coplanar and non-coplanar. Under coplanar we have collinear, concurrent, non-concurrent, and parallel force. Then in non-coplanar, we have concurrent, non-concurrent and parallel force.
Now we will discuss the sub-classification non-coplanar forces. They are not in the same plane, but they are concurrent, their line of action passes through the single point. Suppose a table or may be a tripod having three legs meeting in a single point, but these three forces are definitely not in a same plane. Therefore, it is concurrent but non-coplanar kind of force.

Figure 10: concurrent but non-coplanar force

The next is the non-concurrent force. Let us consider a particular tree, the branches of the tree are non-coplanar. From all the braches there are various types of forces in different locations depending upon the branches. Those are definitely not in the same plane as well as they are not passing through a same line of action.
As shown in figure 11, we can see that there are different lines of action. They are not at all passing through the same point of line of action. So, this is a non-coplanar non-concurrent kind of a force system.

Figure 11: non-coplanar non-concurrent force

Finally, the parallel force system. It is parallel but non-coplanar. Let us see the previous example of four-legged table again; where the forces are parallel but not in same plane.

Figure 12: non-coplanar parallel force

Now, next is to see what is the impact of force? The force, as you understand is the most active element a structure has to react to. So, if any structural system has to encounter a force, it is the most active and elementary phenomena.

So, from our discussions till now, we understood that force has some acting plane and the line of impact, but depending upon small action of a force and how it is actually applying on a particular structural member, we can have some products. What are the products? The first product is moment. Suppose, a force is applied at a particular point of action and there is a hinge or there is a pin support. So definitely by virtue of the force, the member will rotate; and moment will be generated. It will depend upon force and the distance from the hinge.

So, if you see in Figure 13, there are three different conditions of application of force and its impact.

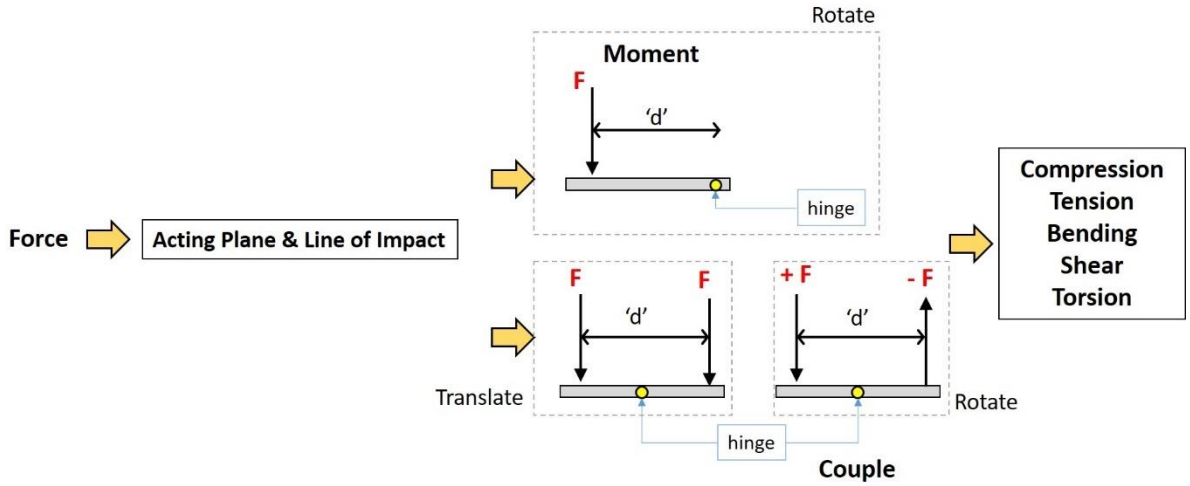

Figure 13: force and its impact

In each case there is a hinge, applied forces 'F' and a distance 'd' between force 'F' and the hinge. These three creates a moment. Here, I have not used anything other than a force, but there are some distance or separation, some support conditions, those are of course there.

In fist case, the hinge at the end of the object. When force 'F' is applied on the other end, it will rotate. Secondly, there may be a couple. Let us assume that, this is again the same object, but having the hinge at the center. Now if we provide two loads of equal magnitude 'F', then it is going to translate. In third case, again we will have the hinge at the same point and distance 'd', but the forces are of equal magnitude but in opposite direction as +F, and –F. So, in such case it is going to rotate.

So, depending upon the action of the force, we can have different types of changes, rotation, translation, and again rotation (see figure 13). This is called couple. So, these moments and the couple will come into the picture of force system. So, based on that, due to impact of force you can have a compression, tension, bending, shear, torsion etc.

So that means if there is a post and we apply forces from top and bottom, merging towards the centre, then it will give you compression, it will shorten. Whereas on the other hand, if we apply forces at both ends, moving outwards, then it will elongate. Then at both the ends, there may be moment, which may result into bending. Then the shear, torsion will also come.

Here, the discussion on the force and its impact will end this particular lecture today or the second lecture of this module.

In this lecture I have taken the reference of these 3 books, specially some of the initial chapters of these 3 books.

- **Reinforced Concrete Design** by Pillai & Menon, Tata McGraw Hill Publisher

- **Basic Structures for Engineers and Architects** by Philip Garrison, Blackwell Publisher
- **Understanding Structures:** ***An Introduction to Structural Analysis*** by Meta A. Sozen & T. Ichinose, CRC Press

Now in the conclusion, I can say that the mechanics is a subject and its relation with the structural engineering is discussed thoroughly. If you remember, we have the statics, and dynamics, that we have discussed. We also discussed and stated that the force is playing a major role in the structural system. It is an elementary phenomenon in a particular structural system. When it is applied, you can get the modified version of it as moment or couple or as bending, compression, tension, shear, and torsion.

The system of forces is also discussed along with its impact in the structural system. So, this is the end of the lecture number 2. In the next lecture, we will discuss the moment, couples, and static equilibrium. Thank you very much.