Structure and Architecture
Lecture 6

Long Span Structural Systems

Let's get into long span structures. We saw that long span structures can be classified into various different types and we also saw the different forms and different sizes, different shapes, different materials, different kinds of long span structures took. We also saw the beat beginnings from the early cathedrals and churches that were built during the renaissance and Gothic period from there till today, we have so many long span structures, such massive structures based on our functional requirement, congregational requirement and based on size and volume of things we operate today. We have so many long span structures today.

Now, we are going to look at long span structures and we are going to divide them into different other types but before that, we have to understand the different kinds of loading which acts on a long span structure. The first load anyway is always in any structure the dead load structure itself because any structure is made up of some or other material. When some or other material has a certain weight in itself, the weight of the material also acts as a weight of the structure. Initially dead loads are the ones which are making up most of the loads in many structures. Similarly, long span structures also have dead load as a major component. Next of course is the live load. The Live load is the sum of all loads which can be moved into or moved along the building. For example, people, furniture, other arrangements like partitions, all the electrical equipment, mechanical equipment, the service equipment that we put on to the building which can be moved from one place to another at some point of time are all live loads. Live loads also come up to a good amount of number when you take loading action into consideration. Next load is, the Wind load. If there is a structure where the dead weight and the live weight of the structure are the only loads which act on the structure, there are other loads which act from the environment. If there is a wind, especially in high rise buildings, the wind load has something which should be calculated very carefully because wind has the power to uproot buildings. We have also seen that during massive hurricanes and massive cyclones, trees and other buildings get damaged, because of the wind load. All buildings that we see around are all designed for wind load. The buildings are either designed so that the wind can go around the building or the buildings are strong enough to withstand the pressure of the wind itself.

There are other types of loads which also act on the building. There are some loads which are created due to the stresses by temperature differences, for example; we have a concept of thermal expansion. Any material when open to heat will expand and any material when cooled will contract. This difference in temperature, creates stresses within the elements. This also has some loading action. There are other sources which are created in the form of disruption, including ground movement, vibration, deformation, earthquakes, any other forms of natural disasters. All these loads are calculated into a large span structure to make it efficient and make it usable in a long period of time. If you have to divide long span structures into different systems, we have four major categories -

Form active systems, Vector active systems, Section active systems and Surface active systems. We will look at each of these systems in detail. First up, we have the 'Form active systems'. Form active systems as systems of non-rigid matter in which the redirection of forces is affected by particular form design and characteristic form stabilization. In simpler terms, any form, any element will have a certain form and the forms create a certain strength to the overall structure in which the structure itself can flexible, non-rigid in which the forces can be redirected or changed from one direction to another direction by a particular form of design. For example - tent structures. In a tent, we saw a mast and we the cloth which forms the element. These are flexible, non-rigid and at the same time the overall structure is flexible only because of the form of elements which are in action. Form active systems are again divided into many types of structures; Cable structures, Tent structures, Pneumatic structures and Arch structures. Let's look at some examples of each of these structures. These are cable structures and the picture on the top is a parallel cable structure. These are structures that are formed by an arch action. There is an arch, the arch is expanded, contracted, made larger, made smaller and arranged in different sizes, different locations and voila, the structure is formed by a series of arches. These are tented structures, masted structures, multiple tent structures, these are Pneumatic structures. Pneumatic structures are structures in which air is controlled within the element. We will be looking at Pneumatic structures in detail by the end of this episode.

The next system we are going to look at is, Vector Active systems. Vector Active systems are those that have short, solid, straight, linear members, in which the redirection of forces is effected by Vector partition i.e by multi directional splitting of single force simply to tension or compressive elements. These are elements where the overall structure is divided into multiple short solid straight elements. As in if there is a big elements, the element itself is made up of short, small, little elements in which the forces are completely redirected within the whole system in such a way that the forces are split into different members. There are some members that will take tension and some members that will take compression. For example; trusses. Trusses are the best examples for vector active systems. We have different kinds of Trusses, there are Flat trusses, Curved trusses and Space trusses. These are flat trusses for example, these are different types of flat trusses, the trusses which have the apex on the top and the apex at the bottom. There are curved trusses where you can have a curvilinear roof on top even though these are straight elements which are different straight element rigid truss which form the rigid overall curve but then if you look at the overall form, it looks like an arch, a curve, that is why we call it curved trusses even though none of these little elements are curved. All of these elements have straight lines.

Next type of system is Section active system. These are again systems of rigid, solid, linear elements in which redirection of forces is clearly affected by simple mobilization of sectional forces. For example, we have slabs, beams and other framed structures where, there are not small items but rigid, solid items, not to mention they are not small like a truss. Column can be as small as a three metre column or it could be something massive like a 12 - 15 meter column, even more. Similarly beams can be 4 metre beams or it can even 12m or 15 m beams depending upon the size, depending upon the loading pattern. Here the redirection of forces is affected by mobilization of sectional forces. The beam has a section and the section itself will carry both compressive and tensile loads. These are some of the sectional active systems, there are some beams, some slabs, lattice beams, single sectional beams, dual sectional beams, slabs, these are sections of a section active system where you can see the load action clearly, that is being transferred from a slab to a beam to the next element below. The last and final system which we are going to look at today is; Surface Active systems. These are flexible or rigid planes able to resist tension, compression or shear, in which the redirection of forces is effected by mobilization of sectional forces. For instance, we have Folded structures. We looked at folded plates in the previous episode where a plane of paper is not able to take up any load if it is not a plane of paper, at the same time when the plane of paper was folded, it was able to take immensely huge load which we did not expect it to take. Such is the effect of surface active system. These are some of the surface active systems. These again are, some of the examples of surface active systems.

Pneumatic Structures

Let's look at Pneumatic structures in detail. Pneumatic structures are a type of Form-active systems if we remember our four main classifications. Form-active systems were the first of the four and we saw Pneumatic structures as one of the examples of form-active systems. If you look at the etymology of pneumatic structures, the word Pneumatic is derived from the Greek word 'Pneuma' meaning breath of air. Thus, these are the structures that are supported clearly by air. These structures have been used by mankind for a thousand of years in the building technology but it was introduced to us in the construction field only about 40 years ago. Now, let us look at the fundamentals and the principles of Pneumatic structures, let's see how it works. This principle is simple, it uses a relatively thin membrane supported by a pressure difference. There is air outside the membrane and inside the membrane, there is a pressure difference between these two membranes. The pressure difference causes the membrane to stay afloat. Through increase of air pressure within, there are two advantages we get, the dead weight of the space is clearly balanced because the weight of the substance is not directly taken by the load itself but because of the difference in air pressure, the dead weight is clearly balanced. The membrane is stressed to a point where it cannot be indented by asymmetrical loading, its air,its a fluidic substance. It takes the shape of the structure that holds it. The membrane is stressed in such a way that, there is no one-point where the loading can become more or less thereby disrupting the whole structural system. That cannot happen in Pneumatic systems usually.

In this picture, you can see that there is this membrane which is being stressed on both sides and from the internal side, there is an air pressure which acts throughout the surface so that the membrane's size, form and shape is retained. On top there are wind loads, snow loads and of course there is a gravitational load that is happening. There are some foundation reactions that counteract the tension forces at the bottom. Thereby, the overall structure is retained in a perfect, intact condition. Here again, Pneumatic structures are classified into two major types. One is the air supported systems and the other is the air inflated systems. These are pictures of air supported systems on the left and there is an air inflated system on the right. Let's look at the technical differences between air supported systems and air-inflated systems. If you look at this slide, it states that the air-supported system consists of a single membrane supported by a small internal pressure difference. The internal volume of the building air is consequentially at a pressure higher than atmospheric pressure. For example, it consists of a single membrane, there is a small pressure difference between the external air and the internal air. Internal volume of the air is at a higher pressure than the atmospheric pressure because there is a higher pressure from the inside because there is an equal pressure that is applied on the membrane in such a way that the membrane is kept afloat. Whereas in air-inflated structure, it says that it is supported by pressurized air contained within an inflated building element. The internal volume of building here remains at atmospheric pressure. Here, it is supported by pressurized air with an inflated building element which means that there are no single elements but there are two elements and there is pressurized air happening within the thing. The internal air is at the same pressure as the atmospheric air. If you look at the pressure diagram, you'd see that there is one element from where there is an equal pressure acting from the inside and there are gravitational loads acting from the outside. The internal air pressure is higher than the external air pressure, thereby maintaining the rigidity of the form. Here, in an inflated structure, what happens is there are two membranes and there are internal pressures between the two membranes in such a way that, the whole system is kept afloat because of this internal pressure and the air inside and the air outside is of the same pressure.

There are four main components we need to understand. The first component is the 'envelope'. The envelope is the skin of the overall pneumatic structure or it could be made of practically any material that can be stretched or the usual materials that are made up of Polythene and other synthetic rubber and any other usual Pneumatic structure element. Another thing which we need to understand is about the pumping equipment where we need to have pumping equipment that constantly helps set up the system quickly. We need to understand how the airlocks act in an internal store. When you are entering or exiting a nomadic structure, when you open a door if there is a difference between the internal air and external air, the moment you open the door, the pressure difference is neutralized. We cannot allow that to happen. That is why we use an airlock system where the pressure remains the same way even after the door is opened. There is an air lock system which has been installed at all entrance doors which acts as a pressure barrier. Next is foundation, foundation depends upon longevity of the structure and it also depends upon the element kind of material which we will use. Next, we will be looking at different advantages and usual characteristics of Pneumatic structures. From the slide you can see that it is lightweight structure, it spans relatively large expanse when compared to other structures. When you are talking about light weight structure or large span structures, we are referring to very very large span structures because theoretically a Pneumatic structure does not have a ceiling limit of span, theoretically. Here we are talking about kilometers of expanse, kilometers that range from 30km - 40km range, which can theoretically be done by a Pneumatic structure.

Pneumatic structures are pretty safe when compared to other structures because even if there is a structural failure, there are no rigid elements that are going to fall off the building, we are not going to get trampled by slabs falling on top of us. All the elements are made up of fabric, it is also theft proof, it is also safe from external miscreance because the moment you use a knife or any sharp element on the surface of the building, a blast of sound is created which causes everyone to be alert and cause no theft to happen. The advantage we have here is, there is a quick erection and quick dismantling that takes place of these structures. Typically a 1 sq km area of Pneumatic structure can be dismantled in six hours and it takes only 10 hours to assemble them back together. The difference of four hours is because you need to put the poles and pegs in the right position. Other than that, to dismantle one sq km of Pneumatic structure, it only takes 6 hours. To assemble a structure it takes only 10 hours. It is economical when compared to a regular structure because this has the advantage of the relocation. A structure that can be used here can be used in some other city tomorrow and it can be used in some other place day after tomorrow which means you don't have to invest a lot of money on your building. It can be relocated, assembled, dismantled, erected at your will, that way it is economical. It also produces a lot of natural light inside. If you take a look at the picture in the corner here, you'd notice that there is a lot of natural light that can be brought inside the building. The amount of natural light that can be brought into the building ranges from 50 to 80% depending upon the material of the fabric.

We will look at some of the materials that we can use as the fabric. There are two basic types of materials that can be used here. Isotropic materials and Anisotropic materials. An Isotropic material produces the same elastic structural properties on either sides on any axis whereas Anisotropic material has different properties when you expand it in a different way. A simple example will be where there are fabrics where a woven fabric will only have two axis of threads. If you apply force on one particular axis the fabric tears up exactly at that particular spot, because it is anisotropic, it doesn't tear anyplace else. Anisotropic materials such as plastic films, fabric, fabrics such as rubber membranes, metal foils, all these materials can be used in the Pneumatic structures. Anisotropic materials we have woven fabric, gridded fabric and synthetic rubber which can be used to get Pneumatic structures.