Structural Systems in Architecture
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Module 1
Lecture – 1
Introduction to Structural System

Good Morning. Welcome to the NPTEL online certification course on structural systems in Architecture. So, this course is an 8-week course and it is floated basically for the students of Architecture. As you all know the NPTEL platform, and this course will be covering the various systems and the applications of the structure in the field of Architecture.

Let me introduce myself. I am Dr. S. P. Bhattacharya, Shankha Pratim Bhattacharya. I am a faculty in the Department of Architecture and Regional Planning, IIT Kharagpur. This is my second online NPTEL course. The first course was floated in the last two years. That was on Building Acoustics, with another professor of our department.

So today, we will go with the first module and the lecture number 1, 'the introduction to structures' which is the lecture title. In module-1 we will cover the Statics and Structural Systems which will take 5 lectures of half an hour duration.

The intention is to cover following concepts:

- Course Outline
- Course Key Features and Learning Objective
- Definition of Structure and Structural System
- Types of Structural System
- Objectives of Structural Engineering

So, I am going to cover these five concepts. We will start with the outline of the course, then the key features and the learning objective of the course, then we will define the structures and the structural system, then we will move into the types of structural systems and finally the objective of the structural engineering.

In learning objective, we will try to cover:

- Course Overview
- Basic Understanding of Structural System
- Requirement of Structure in Building

So, the learning objective of this particular half in our lecture today is, we will initiate the course overview. So, you will have an understanding on how the course will run and what are

the things to be done in the course. Then we will go to the basic understanding of the structural systems and then we will discuss some of the requirement of the structures in the building, or why a structure is required.

We will also try to understand that what are the considerations or special considerations for the structure needs to be taken, while an Architect decide upon the building design or the Architectural design of a building.

The tentative course outline is as follows:

Module 1:

Statics and Structural Systems

Structure and its Classification; Force System; Supports; Reaction; and Loading.

Module 2:

Strength of Materials

Theory of Elasticity; Material Properties; Shear and Bending Moments.

Module 3:

Structural Mechanics

Stress due to Bending and Shear; Theory of Column.

Module 4:

Frame Structure Analysis and Design

Analysis of Structural elements and Frame; The Application of different types of Structural Frames in Architecture; Design Principles of RCC and Steel Structures.

Module 5:

Truss and Space Frame

Structural Concept; Types of Truss; Analysis of Truss; and Application and Advantages of Truss and Space Frames.

Module 6:

Arch, Shell and Dome

Structural Concept; Types; Application and Advantages; and Case Study.

Module 7:

Tensile and Plate Structures

Structural Development and Concept; Types of tensile and plate; and Application and Advantages of Tensile and Plate Structures.

Module 8:

Special Structures

Pneumatic Structures; Tensegrity; Temporary Structures and Structures for Cost Effective Technology; Building Foundation; and High-rise Structural Systems.

So, in the course outline as I discussed, this lecture is going to cover the first concept. So, we have 8 modules, each module will run for one week. In the first module, we will discuss the statics and the structural systems, which is the first lecture today. We will also discuss the structures and its classification. We will discuss the force system, then the supports and then the reactions, and loading.

{In module 2 and the module 3, again two of this consecutive week we will discuss the structural mechanics, the part 1 and the part 2 where the theory of elasticity, the material properties, the bending and the shear, the stresses, different type of stresses due to the bending and the shear, the deflection of the members, structural members and some of the theory of the columns will be discussed.
So, as you all know the structures if you try to look into you have to know about some of the basics of the mechanics and some kind of the solid mechanics also. So, we will cover these modules 1 and the module 2 and also the module 3 in the whole.} [RE-RECORDING NEEDED]

The module 4, the fourth week, we will do the frame structure analysis and the design. So mostly the buildings are kind of frame structure.
So, what are the methods of analysis? We will discuss the structural element in the frames and the application of different type of frames in architecture, as well as the design principles for the RCC and the steel structure.
Then in the 5^{th}, 6^{th} and 7^{th} module, we will cover the whole lot of the structural concept, its application, advantage, disadvantage, and some of the case studies for various type of structural systems. In the module 5, we will include truss and space frame. They are the two very common and important types of structural systems what we see in today's world. We will also discuss the arch, shell and dome, another category of the structural systems in the module 6.

In module 7, we will discuss the tensile structures and the plate structures. So, in both the concept we will discuss for every component of the structural systems and the various applications in Architecture through some case studies.

The last module, the module number 8 will deal with special structures that includes the pneumatic structures, the tensegrity which are the typical type of structure which sometimes is employed in the buildings in a temporary kind of a shelter accommodating people in various forms.

We will also discuss some of the cost-effective technology used for the buildings and what are the structural impact of that, how to reduce the cost of the structures, particularly in the domain of the low cost building technology and we will also discuss the building foundation, because without the discussion of the foundation, the discussion of the structure or the knowledge of the structure cannot be completed.

At the end, we will discuss some of the high-rise structural systems also; but in a very brief form. So; these are the course outline for all the 8 modules.

Now, what are the key features of this course? Let us discuss the key feature, which will help you to understand how this course will move. As you all know or as I have already discussed that, this NPTEL lecture course on Structural Systems in Architecture is focused or designed especially for the students of Architecture, the B. Arch students in various universities and institutions in our country.

So, I have taken care of the syllabus of almost all the Institutes and as per the guidelines of Council of Architecture. We will discuss the concepts through the lectures, and we will also try to discuss few of the real-life examples, through some illustrations, figures, and notations. Further, the discussions will lead to the theories of structures or the theory behind the structural systems to be adapted. On the other hand, without the knowledge of theories, it will be very difficult to understand when and where we will use those kinds of structures.

The basic theory is very much important. So, we will demonstrate that one in a very conceptual state. It will have minimum mathematical computation, because we are not going to deal like the structural engineering, as well as, not as a civil engineering faculty do for the civil engineering students.

So, we must keep it in mind, or I must remember that; this course is only for the students of Architecture. Therefore, I will have to bypass those critical mathematical competitions, but we will cover some simple mathematical examples, formulas, and some of the small algorithms in very conceptual level. The prime focus of this course will be understanding the structural

systems, its advantages, and applications in Architectural design.

As you all know that, the focus of students of Architecture is on design or the Architectural design of building. So, when you will go for designing based on your design principles, philosophies, and design concepts, the building must stand by the structural system. As I have just now told that, there are various types of structural systems what you may use for your designs, but you must understand that which one will be advantageous, which one will be very much the appropriate for that particular design. Hence, you be able to understand and make decisions for your designs through this course.

The intended learning objectives of this course are:

- To clarify the fundamentals of structural engineering.
- To correlate the structural theories with structural behavior.
- To analyze and design basic structural elements.
- To compare and evaluate the various structural systems.
- To apply the appropriate structural system in various Design Studio exercises.
- To perform well and better in the competitive examinations and job interviews.

If you go through all the 8 weeks thoroughly, participate in assignments, and participate in our forum, it will clarify your fundamentals of structural engineering, and he various salient points of the fundamentals in structural engineering. It will correlate the theories of structure with its behavior. Therefore, we are also going to understand about, how the structural theories are developed based on the behavioral pattern of the structure.

You can analyze and design basic structural element. The third point will be very simple, and you can design simple structural elements; and I assume that you probably are not going to design the complicated one. You can compare and evaluate the various structural systems. This is very much important for students of architecture, because it will help you to design and apply or you can provide the various type of systems in your design.

In such cases, you will be able to provide specific and appropriate structures for respective designs, only if you have compared and evaluated the structure types. You can also apply and appreciate the structural systems in designs of the studio exercises.

I have already told that in your studio exercise, it will definitely improve your knowledge on applications of structural systems; as well as, last but not the least, you will be able to perform well in the competitive examinations and job interviews. When I say competitive examinations, I am focusing on the examinations like GATE or maybe some other examinations which are going to ask some of the basic questions on the structures.

Now let us come to the prime objective of the lecture number 1. What is a structure and how can you define a particular structure? The structure of a building or an object is responsible for maintaining its shape, and by virtue of some of the loads, the external loads. So external loads are always going to be applied in a structure or may be in any kind of a building. It is also to be remembered that, there are differences between structures and buildings.

You all know a building. On the other hand, when I say 'structure', it may be a bridge, a transmission tower, a dam etc. Therefore, we can say that, all the structures are having some kind of load, the external load which will be applied on the particular object. The loads actions are gravitational load by virtue of its weight; or sometimes it may be environmental loads like wind, earthquake or maybe some kind of tidal wave. So, it is understood that a structure has to take care of those.

It is important for a structure that, it should stand as a whole, and partially or may be at the individual level it should not break down or deform when any kind of load or forces are applied. Another important point is that it should not deflect or break. It must be able to safely transmit all the loads that has come or applied on the building or on that particular structural system.

Those resulting force must be grounded properly through some supportive system which is called the foundation. Finally, it should maintain integrity and the serviceability of the built form. What is the integrity and what is the serviceability? We will be able to discuss it today itself, a little bit later.

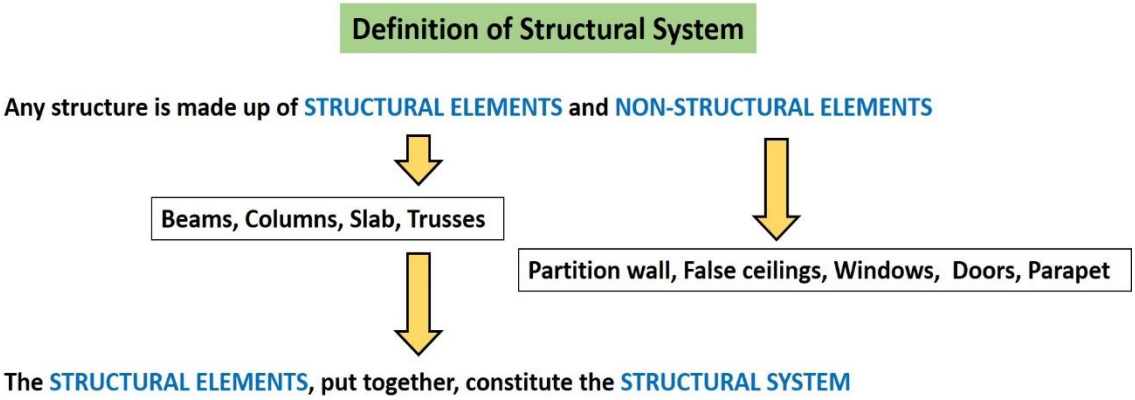
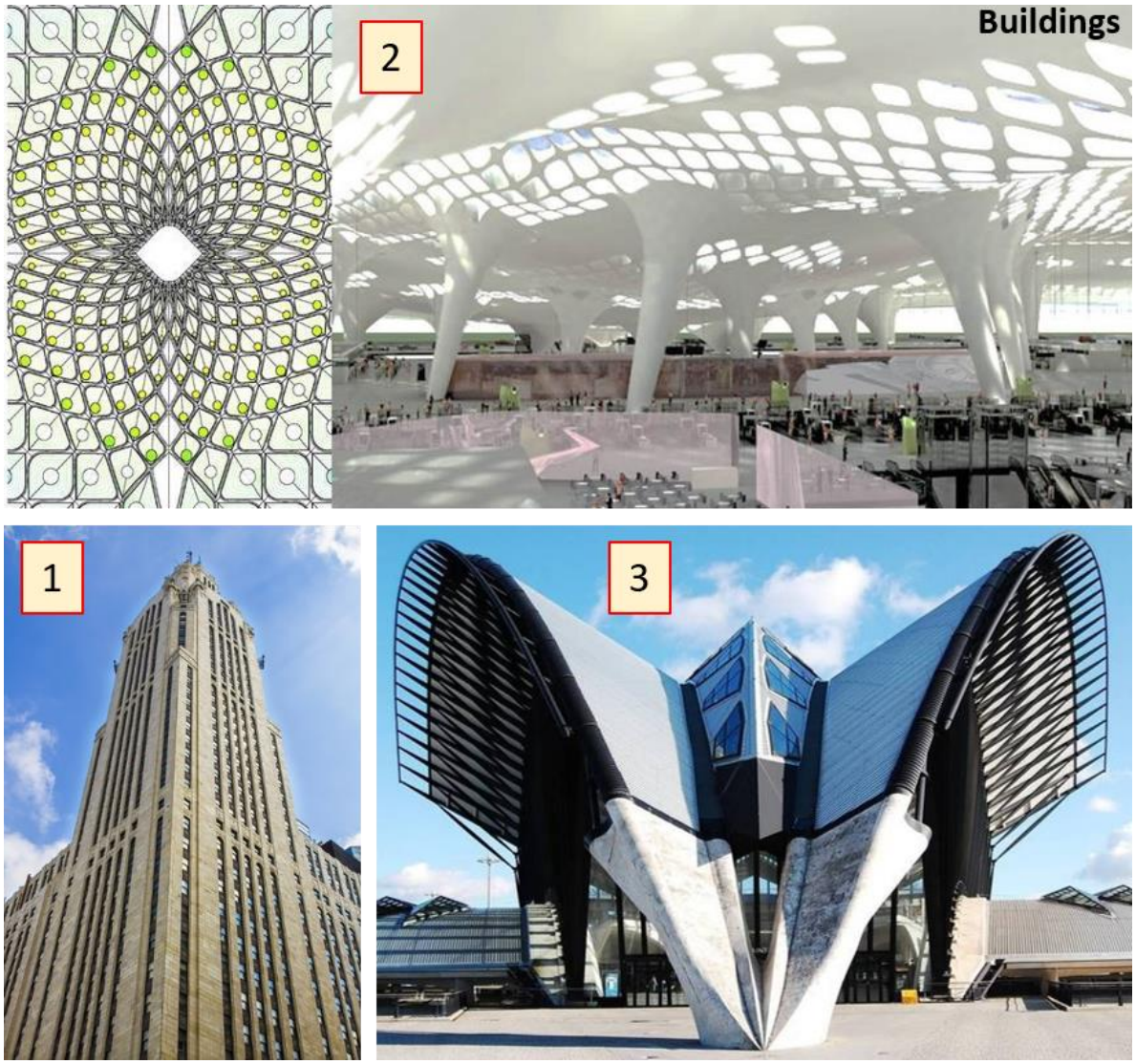


Figure 1: the structural system

I may say now that you are aware of the definition of the structure, which I have completed just now. So now, what is structural system? How can you define structural systems? There is a fine difference between a structure and the structural systems. Any structure is composed of the structural elements and non-structural elements. As I have shown in the figure above

(Figure 1), there are some structure elements, for example the beams, columns, slabs, trusses etc. So, when these elements are put together, you will get the structural system. Whereas the partition wall, false ceiling, door, window, parapet, wall and floor decor etc. are considered under the non-structural element.

So, if you put together the columns, beams, and the slab, you will get a structural system. Hence, we can say that the structural elements and the structural systems also do have differences.



Now, let us discuss about some types of the structures, which are applicable to different types of systems or different types of the objects. First of all, let us consider a building. Building is

Figure 2: the buildings

Source: https://www.arch2o.com/the-beauty-of-architectural-structures/
https://pixabay.com/photos/tower-building-structure-tall/

one of the key factors in Architecture. In Figure 2, you can see that there are three different images. In the image number 1, at the bottom left, it is a tall building, so it has different elements, and different structural systems.

The image number 2, at the top, is an arena, where there are long spans. The long span structural system requires are very light weighted structural systems, which is definitely very different from the tall building or the high-rise buildings. The third one, image number 3, at bottom left, is a curvilinear structural system, which is kind of an arch. When you see all the three different images, they are with different structural systems, but they are taking care of some of the building or the habitant.

While looking at structures, there are towers and the bridges too. The Eiffel Tower or maybe the Leaning Tower of the Pisa are the wonderful examples of structural systems, which are still standing tall since long period of the time. The central image in Figure 3, is the Vidyasagar Setu, Kolkata; which is located over the river on Ganga and connects Howrah and Kolkata. This is also a fabulous structural system which has been used for connectivity.

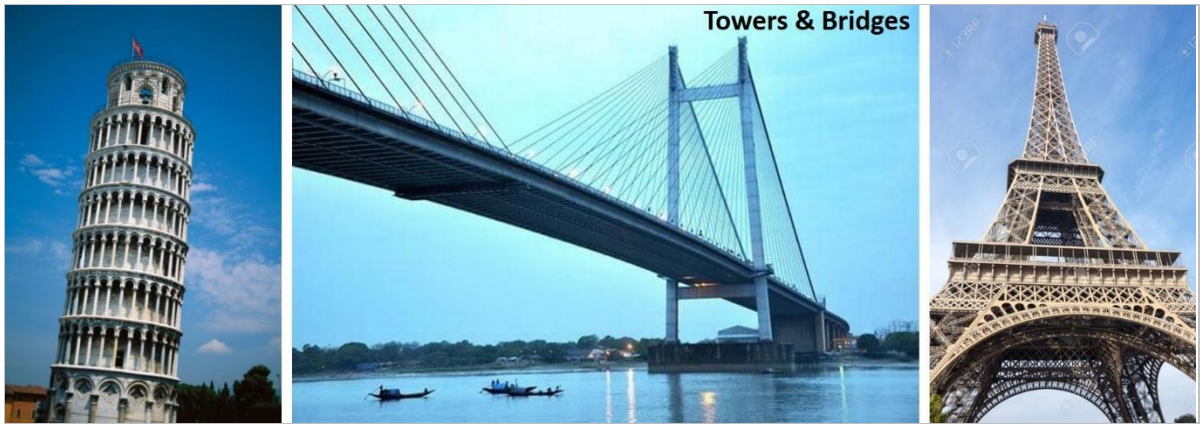


Figure 3: towers and bridges

Source: https://www.financialexpress.com/vidyasagar-setu/
https://www.123rf.com/photo
https://www.britannica.com/technology/

Hence, the structural systems can be applied for any kind of the buildings, towers, bridges etc. There are also different types of systems which are adapted for different kind of execution.

Now let us see and understand what the elements of structures are? They are beam, column, link, plate, membrane, cable etc.; and they are individual items. A beam is an individual item, as you know, it is horizontal in nature and takes the load in the gravitational direction or the downward direction. Whereas, column is a vertical member which takes the load in a different way, that is through its own axis. Again, the plates are also a 2-dimensional flat structure. So, these are the elements of structure; and now depending upon the geometry and orientation of those elements, you can have different type of vocabulary of the structure. For example: thin

and thick. What is thin and thick? Suppose a plate or a wall may vary in its thickness, it may be thin or thick. Like the grid and the dimensions. This is again a geometric property. What is a grid? In buildings or structures, it is the center to center distance between the footprint of the column. Then**,** what is dimension? What is linear and the curvilinear? As I just I told you, there are curves in arches and all which is the curvilinear. Linear is may be a straight beam, or a straight column. Inclined, is something what is not 90 degree or not straight. Yes, a wall may be inclined, a plate, a column, or a cable can also be inclined.

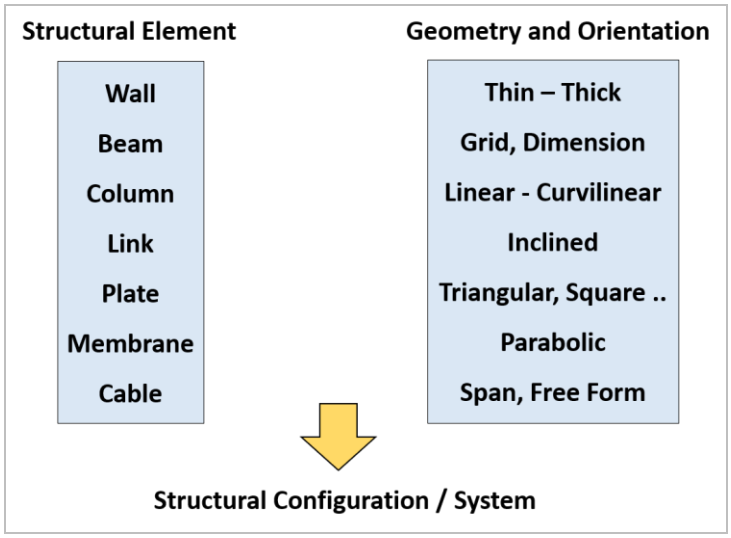


Figure 4: structural configuration

Then, there are some kinds of shapes triangular, square, parabolic etc. An arch, a cable etc.; may be parabolic in nature. Then the span; it is about how much is the center to center distance between the supports and free forms. Those are the geometry and the orientations. Now if you club those together, you will get different type of element and different type of geometrical orientations. So, there may be some permutation and combination amongst them, and then you can get some structural systems or the structural configurations.

Now, if you take the structural configuration, then you also have to take care of the nature of loading. You have to identify what kind of load is it. The load can be a concentrated load, heavy moment, wind, or seismic load; and every load has its own type of the impact. When you are going to select some structural systems or the configuration, then the loading factor also must be considered. As well as, you must take care of the material, which type of material you will use for your structure.

Let us suppose, you are going for a truss, it may be steel truss, RCC truss or of any such material. So, when you use any material, you need to know about the material properties; like ductility or the brittleness etc.

You should also know about the support systems; that how finally that particular structure has to be supported for stability. We have to see if it is of simply support, a cantilever out, a continuous support or a flexible support; because these are the typical type of support systems. So, if I go back to that again, it is the elements and the geometry that gives me the configuration. From the configuration, I know that this is the loading type, it is the material I am selecting and then this is the type of support system.

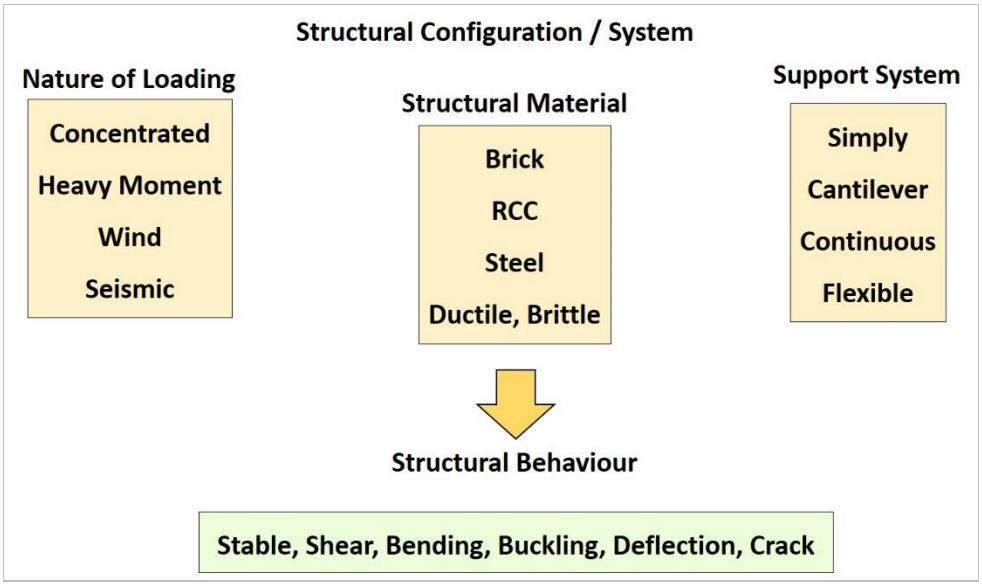


Figure 5: structural configuration and behaviour

After all these comes together, I can now analyze a structure and I will try to assess the behavior of the structure and what is its behavior? The behavior expresses if it is stable or unstable, it is a shear predominant, or it is a bending? The bending will come in totality with the material, loading and the support system. Then we will see; what will be the buckling character? How to bring to buckle? Is it going to buckle or not? How much will it deflect? Is it going to deflect much or it will be under control? Is it going to develop some cracks? Sometimes we may allow some unnoticeable kind of very micro cracks or sometimes we may not allow at all. So, as a result of all these behavior, configuration, and material, I will get some output, and based on that, I will now see some of the functions of Architecture.

When I see the Architectural function, I will see the economy, serviceability, durability, construction technology etc. It may be possible that some of the materials, some of the systems are not available at my place, in my country or maybe some part of the country. Hence, it is unnecessary to think of those kinds of materials or structural systems. Finally, you must not forget to look into the aesthetics of the building.

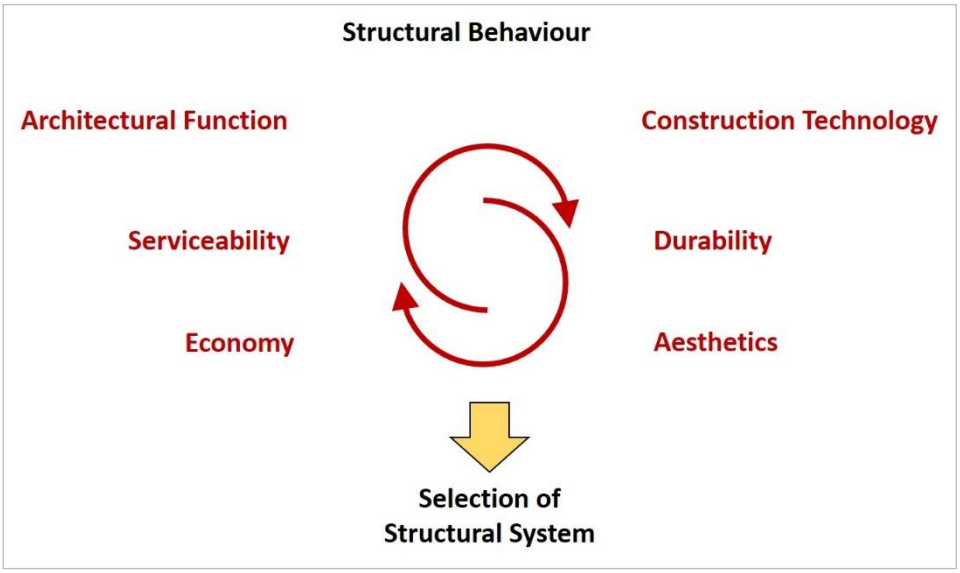


Figure 6: behaviour and selection of structural system

Once again, all these will lead to a situation of permutation combination, to select the typical or suitable structural system. So, for that we are going to have some selection criteria.

Figure 7: frames and trusses

Source: https://www.indiamart.com/proddetail/roofing-steel-truss-structure/
https://gharpedia.com/blog/what-is-a-reinforced-concrete-framed-structure/

Now what are the types of structural systems? If I go one by one, then I may have frames, trusses, space frames, arches, vaults, shell structures, dome, tensile structures, and plate structures. In Figure 7, you can see the image on left hand side, is a normal type of a building which is having frames. Frames mean the columns, beams, foundation and the slabs. On the other hand, we may have trusses also; in Figure 7, right hand side image. The trusses can be used for very long span applications.

We have sometimes the space frames which is again in the lower left corner given in the photograph where there are some kind of the 3-dimensional stresses can be used and the upper

right corner you see there a arch form of space frames can be also going to be used.

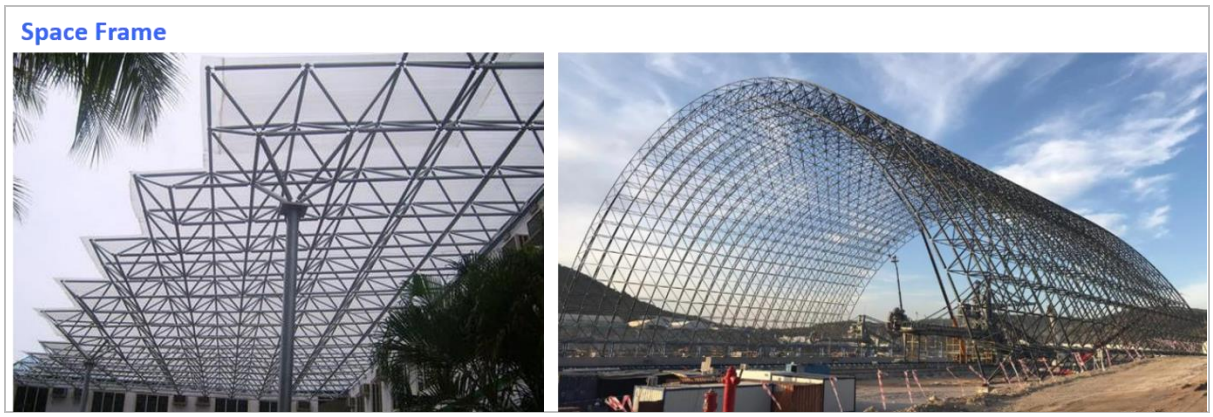


Figure 8: space frames

Source: https://www.designingbuildings.co.uk/wiki/Concrete_frame
http://www.polarkon.com.tr/en/space-frame-structures/

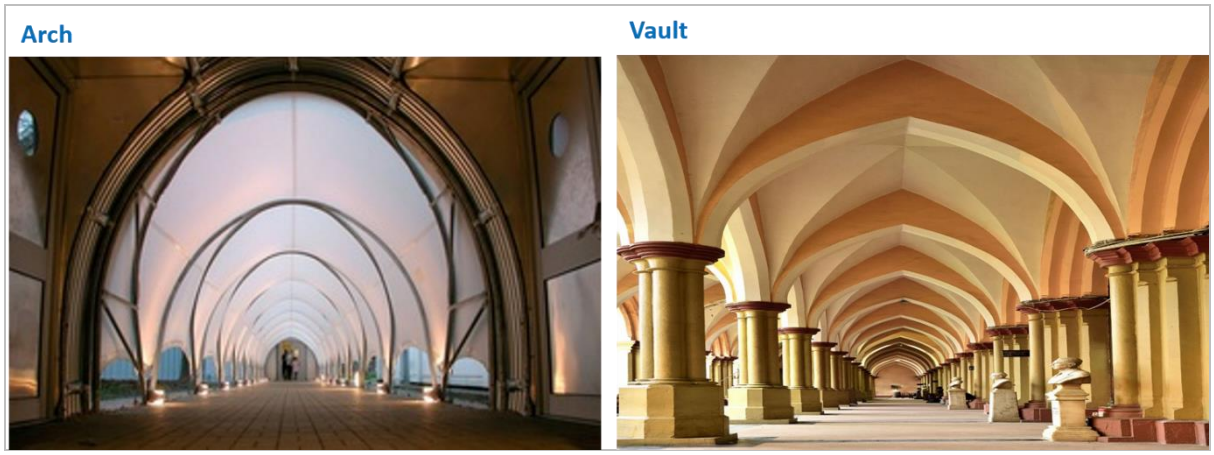


Figure 9: arch and vault

Source: https://fabricarchitect.com
https://www.calcuttahighcourt.gov.in/

In structural systems we can also have arches and vaults. Arch is a linear kind of character; whereas vault is of 3-dimensional. When two such walls or two such barrels are meets together perpendicularly, a vault will be created. In Figure 9, the image of vault is the corridor of the Calcutta High Court. You can see how interestingly the pillars, the columns are taking care of different flying arches in the different directions, creating a fabulous interior aesthetics with vaults.

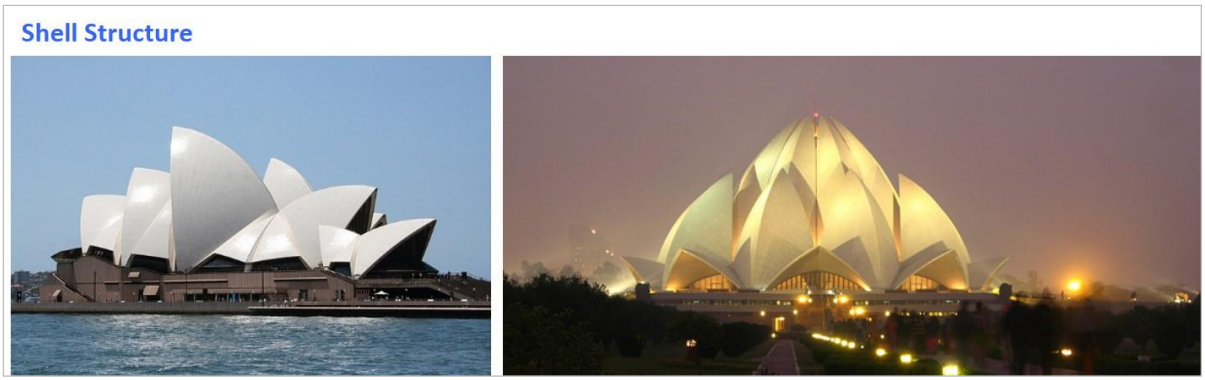


Figure 10: shell structure

Source: http://www.civilprojectsonline.com/building-construction/
https://timesofindia.indiatimes.com/

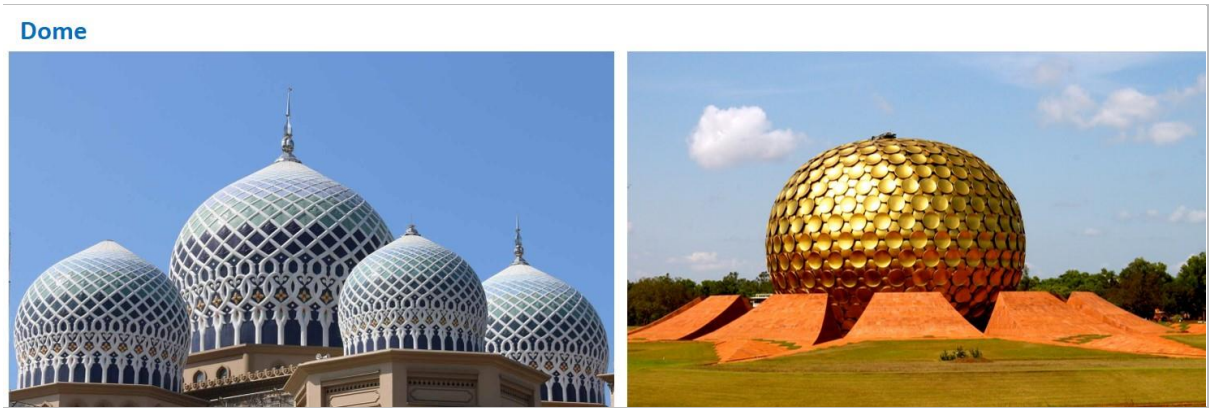


Figure 11: domes

Source: https://worldarchitecture.org/articles/
https://steemit.com/esteem/

The dome is another kind of prominent structure. When we see history of Architecture, it is observed that, domes were used as roof coverings since the time of Islamic or pre-Islamic periods. There were various types of illustration, decorations, as well as various type of forms that had been develop along the timeline of history of Architecture.

In Figure 11, the left-hand side image is an Islamic dome, which is very much predominant form in India as well as in many countries. The other image is the Matrimandir, which is in Auroville, Pondicherry.

Figure 12: tensile structure

Source: https://theconstructor.org/
http://www.globaltensilestructure.com/

The tensile structures are of another type. They are useful for stadiums, or arenas. It is a very lightweight, membrane kind of structure.

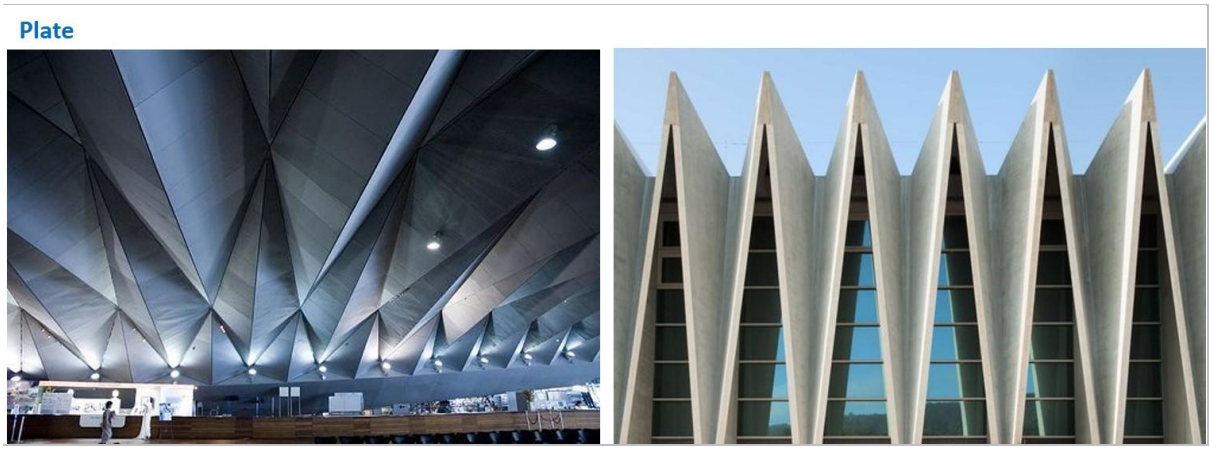


Figure 13: plate structure

Source: https://in.pinterest.com/

These structures are generated through plates. There are the different types of folded plate arrangements. They are also a solution for long span structural demands.

Now we can say that, we have gained a brief understanding on different types of structural systems.

Now, let us go to the last point that is, what are the objectives of structural engineering? The first objective definitely is safety. The safety is always first. In Figure 14, you can see that a child is sitting on a bench, so that bench must be able to take care of the given load. The four supporting legs of that bench has to be thick and, the thickness and the strength has to be such that it can tackle the load of the child.

Figure 14: safety

Source: https://www.researchgate.net/publication/229318

There should not be any kind of a cracking which is shown in the right-hand side image of Figure 14. These type huge cracks will of course create bad impact on a structure and definitely structure is going to fail. After failure, such cracks will appear and safety will remain questionable.

Figure 15: stability

Source: https://apps.peer.berkeley.edu/publications

Next is the stability. In Figure 15, in the left-hand side image you can see that one girl is pushing a small table. Similarly, when you push an object from the other direction it should not topple or buckle or maybe slide off. That means, a structure must have stability. The strength comes from the downward or the gravity load point of view; and the stability comes from that transverse or the lateral load point of view. In the right-hand side image of Figure 15, you can see a building, which is tilted because of the earthquake. But a structure should not fail like

this. It must have strength, bearing capacity, and gripping through the foundations. At any cost, it should not be unstable.

Figure 16: serviceability

Source: http://oregoncidc.blogspot.com

Another objective is serviceability. It may be stable, it may possess sufficient amount of safety, but sometimes the serviceability is not met. For example: the beam and the floor are deflected. If it is deflected, you cannot have any activity on that, you won't be able to put a chair, a table, or any load on it. It will also create a lot of problem while walking around.

Sometimes it may also give you psychological problems, and you may feel that the building is unsafe. So, all the serviceability criteria must be fulfilled.

Figure 17: durability

Source: https://www.deccanchronicle.com

Then definitely there is durability criteria for a structural system. You will design a structure for 80-100 years, so you need to see its resistance to corrosion, creep and shrinkage; as well as the edge phenomena which comes from the structure when the material gets old and gradually loses its strength.

Then another objective is the economy. You always have to see that how efficiently you can use the structural systems. It must be done in such a way that it meets all the objectives; and you design it within your budget. The other objectives are like ease of maintenance and fire resistivity of the structure. The ease of maintenance is another issue, because you always have to maintain the built structure, you can never say that the structure once built is forever. Also, the fire resistance is most important for safety and security.

Figure 18: the aesthetics

Source: https://www.nationalgeographic.com/
https://www.planetware.com/

Finally, the important issue in our case is the aesthetics. The structural system should also import sensible and appealing aesthetic to the structure on the building. Otherwise, if it goes other way around, it will be problematic. Therefore, I have written once that an engineer plays a major role to translate the imagination of an architect to ground it the reality through the structural systems.

So, you can see some wonderful compositions like the Taj Mahal or maybe like the Pyramid of Giza, they are very simple structures, which are very systematic. If you have such systematic compositions, and proceed following the objectives then, definitely your way of handling the structural systems for the design will also be eased. Here I am not saying that you should always go with the symmetrical building designs. It may be of asymmetry, but you have to look into that how those asymmetries can be taken care of and composed in a unique way, also the structural system of it. So, I have written in the last that, it is indeed a challenge and the responsibility of a structural engineer to design a structure appropriately for all architectural

purposes; and also, should maintain a right balance between the safety and economy.

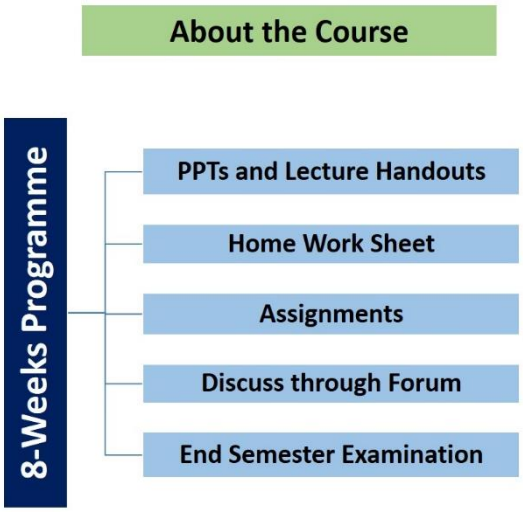


Figure 19: about the course

As we already told you, this is an 8-week course. Therefore, total 40 lectures with 40 PPTs; and for all these the handouts will be delivered. I will also give some home work sheets along with few of the lectures. The tentative solutions or some hints will also be provided for the homework, and it will be available on the forum. As a part of the course, we do have some assignments too. We have 8 assignments for all the 8 weeks, about these we will communicate through our forum. Two of our TAs, the teaching assistants will help you for this particular discussion. Finally, we will have end semester examination at end of this 8 weeks program.

For this lecture, I have referred the following two books:

- **Reinforced Concrete Design** by Pillai & Menon, Tata McGraw Hill Publisher
- **Basic Structures for Engineers and Architects** by Philip Garrison, Blackwell Publisher

The concluding remarks for this lecture are:

- NPTEL 8-Week course for “Structural Systems in Architecture” is introduced.
- An overview of structure and Structural System is discussed.
- Objectives of Structural Engineering are also stated.

In my next lecture, I will be discussing on the force system, covered under the same module. Thank you very much.