Structure and Architecture
Lecture 7

Reinforced Concrete

Reinforced concrete is a composite material in which concrete's relatively low tensile strength and ductility are counteracted by the inclusion of reinforcement having higher tensile strength and/or ductility. In simpler terms, concrete is just a mixture of aggregates, bonding material which is usually cement and water. This concrete itself is a very hard material and its compressive strengths and stresses are very good. It's a very strong material. In fact, concrete is not a very modern material. In Fact, it has been used for over a long time, even the Romans seemed to have used a form of concrete using porcelain and other available materials at that point of time. The great building, Pantheon Rome was also made of concrete. But reinforcing concrete was an idea that came up much later where concrete is reinforced with a composite material whereas concrete has a very low tensile strength, when the compressive strength of the concrete is really high, the tensile strength is very low. To counteract the low tensile strength, you introduce another material which has a higher tensile strength. Make this material into a composite material and we work in such a way that, the compressive strength of concrete with the tensile strength of steel or iron or any other material is combined together to form a very good composite material, that is what we do with reinforced concrete.

Let us trace back to how reinforced concrete came into picture. There are different types of structures and different components of structures can be built using reinforced concrete. You can build slabs, walls, beams, columns, foundations, frames and more. Not just these but we can also make buttresses, bridges and a lot of other structures; modern day tank holders, modern day blast proof rooms are being made of reinforced concrete. Sound proof, acoustically treated, fireproof rooms are also being made of reinforced concrete now a days.

Francois Coignet was a French industrialist, he was a pioneer in the development of structural prefabricated and reinforced concrete. A french industrialist who started working with reinforced concrete. In 1853, he was the first person to have built an iron reinforced concrete structure. He did not reinforce the concrete with any other material. He introduced iron into the concrete and built a four storey house in the suburbs of Paris first. He was one of the first people in the world to build a structure using reinforced concrete and it was as early as 1853, close to 150 years back. In 1854, the very next year, William B. Wilkinson, who was an English Builder, who also reinforced the concrete roof and floors in the two-storey house which we was constructing. Again he reinforced it with iron which was available. The roof and the floors' slabs which he was building was reinforced with iron. When you position reinforcement, you don't put reinforcement bars all over the concrete. You put it in specific places to understand where to put is what complex structural engineering calculations are all about. You need to know how much reinforcement to put and need to know where the reinforcement has to go. Usually reinforcement is represented in percentage or in kg per volume of concrete. When William Wilkinson, positioned reinforcement in his concrete, he demonstrated that unlike his predecessors, he had the knowledge of tensile stresses. He really possessed the knowledge of how concrete works in tension and how concrete works in compression, he really knew the difference between the tensile and compressive stresses. Hence, the positioning of the reinforcement areas was relatively accurate to the modern way of doing it. Later, Joseph Monier, a French gardener was granted a patent for reinforced flowerpots by means of mixing a wire mesh to a mortar shell. He made a normal flower pot, a small mortar shell, he took a wire mesh and mixed the wire mesh and mortal shell to make a flower pot which is very difficult to break. He was a gardener and he obviously had the problems of pots breaking during his lifetime, so he developed this idea so that the pots could not break easily. Who knew that this small idea of non-breakable flower pots could actually be the patent for reinforced concrete and thereby revolutionize the whole building industry at a later point of time. In 1877, Monier was granted another patent for reinforced concrete columns and girders with iron rods placed in a grid pattern. He began reinforcing all the columns, all the thick piers with reinforcement which were arranged in a grid fashion not in the usual way it is being done now with complex calculations. But in a rudimentary manner, he arranged reinforcement bars in a grid fashion. Monier undoubtedly knew that reinforcing the concrete would improve its inner cohesion but what we don't know about Monier is whether he knew or not how much concrete and steel were required, how much of reinforcement material was required to make the whole structure very stable. But he definitely knew that reinforcement in concrete will greatly improve its inner cohesion.

From the early bear beginnings, they've come up with great many things that have been achieved in concrete construction. Brutalism is a great style that developed immediately after the world war to make sure all government and major buildings were done in a quick fashion. The reconstruction of a lot of European cities, a lot European public buildings were of this style and from the bear beginnings of reinforced concrete, we have come a long way and it is time for us to recognize the people who lead the campaign of concrete construction and in that series we have two very great personalities of whom we will be discussing in this lecture. They are; Luigi Nervi and Robert Maillart.

Works of Robert Maillart

Robert Maillart was a Swiss engineer who lived between 1872 and 1940. He graduated from Federal Institute of Technology, Zurich. Although he was not great in studies, he was not keen in doing mathematics, calculations and other stuff while pursuing engineering. He was rather fond of what he was studying, he was rather brilliant at what he was doing. He often said that the calculations and mathematics made engineering a little too boring for his own good. He was very intuitive and always believed that intuition in structural design is a very important tool. He went on to use reinforced concrete in an extensive manner. He kind of revolutionized the use of reinforced concrete, he changed the way arches and bridges were built. He invented the three hinged arches, he invented the Deck-stiffened arch; he also invented beamless floor slabs, mushroom ceilings for large granary kind of spaces and he revolutionized the way bridges were built during his time.

Let's go on to visit a few of his projects. First project that we will be looking at is, Salginatobel Bridge in Schiers, Switzerland. This bridge was built in 1930. The first look of the bridge, look at the picture on the right hand side. This picture gives you an amazing view of the bridge, along with landscape, the coniferous trees in the background, very pristine location of what we could hope for. This is one of the very famous landmarks in the country and it is one of the few things that makes Switzerland the holiday destination for many people. This bridge is also being visited by a lot of designers, architects and structural engineers ever since, because of its sheer genius. This bridge is completely made from reinforced concrete. Its an arch bridge and after about 61 years, in 1991, it was declared an International Historic Civil Engineering Landmark.

Maillart also built a great number of warehouses and great number of granaries wherein you need a large amount of space to put all your grains, produce into that space. He designed huge volumes of spaces and one of the methods he used to design the huge volumes of spaces is the early use of reinforced concrete as mushroom columns. Look at the picture on the screen right now. You see the columns that branch out from the base. The whole load is carried towards the column because of these mushroom shaped fans. The load is carried from the slab to the column in a very easy manner. In the ancient period, we had column capitals which were the means of transferring road from the slab to the column. In reinforced concrete, the use of monolithic engineering, he has used the same method of using a column capital as a mushroom capital to transfer the load off the slab to the column very easily. Because of the use of mushroom columns, he has understood the stresses that occupy this area. The genius lies in understanding the stresses and that's what sets him apart in history. There are a number of bridges that he had designed during his lifetime and each bridge bears the same its own different way. Every bridge that he has ever built has his mark on it. He has his own signature on every bridge that he has ever built. If you take a look at the pictures, you have the Tavanasa Bridge and the Arve bridge. Both these bridges depict his sheer brilliance through the arch, the hinged arch and other elements to make this bridge look aesthetically more pleasing and at the same time, structurally more convenient. In this Arve bridge, the pillars that he has used has a typical X like shape here. This X like shape, when looked at for the first time, one would think that this wouldn't be able to bear much load and might crumble due to extra load but if you carefully pay attention to its details, you'd be able to appreciate the genius of this design. Maillart was a genius, he was born in Switzerland and was schooled at Zurich. Thereafter, he went to Russia where industrialization was at its peak at that point. There was a lot of scope for expansion, there was a lot of scope for building, they built a lot of industries, a lot of bridges in Russia. After Russia came into communalism and a lot of properties were seized by the government, all his bonds were seized by the government, he came back to Switzerland with no penny in his pocket and with a lot of debt in the bank. Thereafter, he built of bridges, a lot of structures, his best works were yet to come after he came back to Switzerland. These are some of his best works. This is the Zuoz Bridge and the Stauffacher Bridge. Both are arch bridges, the shallow arch bridge shows the true genius of his work. The size, the proportions, everything looks beautiful. Some of the other works by Maillart are seen in these pictures. You can look at how thin the slabs are to support this arch over here, there is an entire floor. The thickness of this slab is mesmerizing. These are the other structures which Maillart had designed. Look at the use of his support elements, the different ways in which he has arranged the trusses to take loads and columns that branch out to take loads at multiple points and collect them together to transfer them back to the base. A sheer genius when it comes to architectural creation.

Works of Pier Luigi Nervi

Nervi was an Italian engineer, he was born in 1891 and he studied at the university of Bologna. He was a professor of engineering at Rome university between 1946 and 1961 and he was known for being a structural engineer and an architect at the same time. He has designed several buildings, both structure and architecture. His innovative use of reinforced concrete took him to a whole new level. Even though Luigi was much later in period in chronological order than Maillart. Maillart was older and lived in a period that preceded Luigi. Luigi's famous works are; Stadio Artemio Franchi, in Florence, Italy. This was one of the early stadiums that he built. This was built in the year 1931, he designed the stadium, the stands. Thereafter, there was an addition to the stadium. There used to be a running court right here and the running court was removed and additional seats were built to accommodate more people for football worldcup. This is a football stadium that also housed rugby matches and football matches. This is a famous building that was designed by Nervi. This was the UNESCO World headquarters in Paris, France. This is a satellite image of the building from the top. The form, the shape is simply amazing. These are some of the pictures of UNESCO World Headquarters. Look at the span of the entrance arch. This is one of the interior spaces of the UNESCO World Headquarters. The use of columns here in a different manner makes the visitor enjoy its sheer beauty because these columns are designed in such a way that it gives a maximum free space in the bottom for people to walk round, sit and do other activities. Whereas, on the top this column becomes bigger and has an extended bracket that takes up additional load. These brackets take additional load from the middle of the span and then transfers it to the centre of the column.

All the load is kind of distributed to the bracket, to the column this way in a genius manner. Thereby, providing a large amount of space in the bottom for people to work. The UNESCO World headquarters in Paris was combined work of three famous architects; Marcel Breuer, Bernard Zehrfuss and Nervi. Nervi worked with Zehrfuss and Breuer to get this whole building done and even thought it was done by three different architects, there was also an entire validation team which is comprised of an international committee of five architects, including famous architects such as; Lucio Costa, Walter Gropius, Le Corbusier, Sven Markelius, Ernesto Nathan Rogers, also with the collaboration of the very famous Eero Saarinen. Eero Saarinen was the validation expert, he was the judge for many famous projects at that point of time. He was also a part of the validation team and this project.

Next up, we have the Pirelli Tower in Milan, Italy. He worked along with Gio Ponti on this project. This Pirelli tower was one of the first buildings that had tapered sides and it abandoned the customary block form. Usually skyscrapers had this idea of taking a square and extruded that square to form a cube. This is the usual thing that skyscrapers did at that point of time. The base was generally a square or a rectangle that was extruded, this was the form that usually skyscrapers took at that particular point of time. It is one of the very first buildings that changed the way skyscrapers have to look and it was characterized by this unique structural skeleton, curtain wall facades, tapered sides. This is how the plan looks, the central part, the slightly tapering middle, the greatly tapering ends that house the staircase, the lifts and other services. This is how the building looks.

Another interesting building that Luigi designed was not for scope centre, it's a cultural entertainment centre in Virginia. It comprises of a 11,000 - person arena, a 2,500-person theater known as Chrysler Hall and a 10,000 sq foot-exhibition hall and a 600-car parking garage. Such a large building and it also looks great, it was built in the year 1971, along with the waterfront, the building looks simply amazing. Look at the use of its external columns that extend outward to support the large dome the building has. Some other pictures of the building from the interior and from the sky level. The use of single column that support multiple beams takes the load and direct it to the bottom. Use of coffers. This is again a view of one single pier into two elements that are thin on the top, wider down the base, takes the load from the top and transfers it laterally onto the sides.