Introduction to Civil Engineering Profession
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Lecture – 03
Structural Conservation of Built Heritage

I am Arun Menon, I am a faculty member in structural engineering which is besides building sciences block. I did my bachelors in architecture and then I moved into civil engineering, did my M Tech at building technology and construction management and then I did my PhD in earthquake engineering and I focus on masonry and that is how this interest on historical masonry structures and monuments comes about.

So, as Professor Gettu was mentioning that logo that you see next to the IIT logo is the logo of the center that we run at the department of civil engineering referred to as the national center for safety of heritage structures. We are talking of structural safety, right. And we work on a number of projects in India and abroad, live projects; but we also do a lot of fundamental research in the subject of historical monuments or built heritage in a broader sense, ok.

So, today I will be talking to you about the subject of structural conservation of built heritage and how it is a highly interdisciplinary subject, where you can connect based on the kind of interest you have in different subjects of Arts and Science, right. And I will take you through one example that we have been recently working on, which gives you a perspective of how multidisciplinary or interdisciplinary the problem itself can be and challenging at times; where engineering comes in, engineering judgment has to be used and tools that are available to engineers and researchers would have to be utilized.

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Let me begin by asking you a question; why should we preserve our built heritage? What is built heritage and why should we be preserving it? The answer to this is a requires us to pause for a moment and understand what are we preserving and why are we preserving it, right. And what are we referring to as built heritage? Yeah either talking of monuments which may be historical monuments or heritage structures and to give a definition to a heritage structure or historical monument. It is a structure that was created in the past, some amount of time has passed from the time it was established and constructed to commemorate a historical event or a historical person or which has become important to a community.

This community can be a local community, it can be something that is very important to Chennai, it can be something that is very important to IIT, the community of IIT. So, it can be something that has become important to a community, a region, a state, a nation or the world at large, right. This has now become a part of our history and our cultural heritage. So, that was that is what would define the built part of the cultural heritage itself.

Such an entity starts becoming important from a point of view of symbolism and identity; it tells me about my roots, it is symbolic to me as a physical form that exists in my territory, right. What are we going to do about this? This was possibly not built when we were born or even our immediate ancestors were born; some of these were built 4000, 5000 years ago, some may be a few 100 years ago.

So, this is from a different period in time, why should we be bothered about protecting them; we should look at ourselves in the context of historical monuments and heritage structures as mere custodians of historical evidence. This is the physical historical evidence that is there on earth, on territories of how our ancestors lived and how their history unfolded, how their times unfolded. And our responsibility is only as custodians to hand it over to the next generation, so that historical evidence is available to them, to understand where they come from and what their land means in the context of life on this earth.

Preserving historical monuments, or preserving heritage structures does not mean that we have to go back to the ancient times and live like our ancestors lived; that is not the purpose at all. The purpose is to understand how life evolved and how did our ancestors live. We can draw inspiration from that, look at what is relevant in today's context and apply that and give new form to that inspiration and that is how we connect the history, the past to the present and the future, right.

One important example that we have been encountering is, how sustainable; we think sustainability is a buzzword of the 20 first century, right. Wherever you turn, in whichever field of engineering you look at you hear the term sustainability. Have you heard of the term sustainability?

Yes, it is not a 21st century buzzword; if you actually look at the lifestyle of our ancestors; sustainability was the basic approach to their lifestyles and what they did. And these structures are also historical evidence of a certain way of living which is possibly more sustainable and that is some way we can draw inspiration for in making this earth more sustainable; our activities on earth in a fashion that does not lead to exhaustion of resources that are meant for everybody.

So, that is the reason why we should protect built heritage as custodians; our generation is the custodian of this historical evidence. And we merely must preserve it and pass it on to the next generation.

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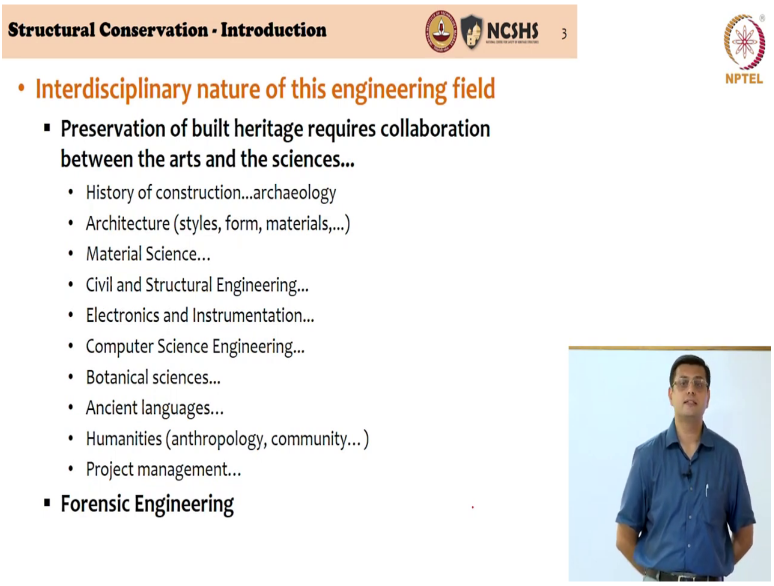

So, what about the subject of structural conservation? Right, that is what you saw on the first slide structural conservation of built heritage. What is structural conservation? Conservation or preservation implies preserving a physical entity. Structural conservation, I have used the word structural conservation; because here we are referring to the physical entity of buildings and the structure has to be protected only if the structure is protected will the building itself survived or what it contains survived.

So, its structural conservation that we are talking about, but it is a highly interdisciplinary field in engineering. And not only engineering it actually has boundaries with many other disciplines. And to give you probably not an exhaustive idea, but just to introduce you to what are the linkages with other subjects that you can have; there is a list that I have prepared. So, preservation of built heritage requires collaboration, fundamentally collaboration between the arts and the sciences.

You have entered an engineering college right; you need to engage with the arts and the humanities, because there is relevance to everything that you do in engineering to the human society. And that is the reason why we have courses in humanities that are interlinked throughout your engineering program; because you need to understand the value of what you are doing and how does it come back to the society, how does it come back to the community.

So, you cannot differentiate between arts and science, and particularly in fields such as conservation of built heritage it becomes primary to understand the linkage. So, many of you sitting here might have different interests; I had very different interest before I came to study architecture and engineering. And therefore, you can really connect to a certain passion that you have for a subject in this varied and interdisciplinary field. History of construction, history and history of construction and archaeology were you are studying about ruins and trying to reconstruct the way people lived in the past.

Architecture, some of you might be interested in knowing different materials that have been used, different forms, different styles of architecture, you need to link up with architecture. You need to learn, I mean you need to have to you may need to work with people who are in the area of material science and material engineering. Because in civil engineering there is a limit to which we study materials; you might need a material scientist to take you further and understand the composition, the atoms, the way the material itself is formed; civil and structural engineering and geotechnical engineering all disciplines of civil engineering.

Electronics and instrumentation; today we are depending heavily on electronics and instrumentation to understand how these structures behave; you can put sensors on these structures, you need to design these sensors and design the data acquisition systems and have automatic methods automatic techniques of getting information from these structures and understanding how they behave structurally. So, you need to engage with experts from electronics and instrumentation. Or you could have an interdisciplinary field of training and research for yourself; you can be a structural engineer and an electronics and instrumentation expert.

Computer science engineering, we are depending so heavily on computer science engineering; because of the programs and algorithms that you require to gather data from buildings, to process large data, the big data that we are talking about, to look at image processing, to look at image reconstructions you need expertise coming in from computer science and engineering.

Botanical sciences, would you ever think botanical sciences would be important in structural conservation; we have several cases where trees are growing on monuments. Have you seen trees growing on monuments? Definitely you would have seen trees growing on monuments.

In many cases you have to have some idea of the type of vegetation that is growing to be able to either remove it or preserve it. We have dealt with very strange situations where both the monument and the trees had to be preserved; the mandate in Angkor Wat in Cambodia where there are several temples, Angkor Wat is one of the temples at IIT Madras was working on. The mandate was that both the natural heritage, which is the trees growing on the structure and the monument have to be preserved together. You cannot remove the trees, very often we remove vegetation growing on trees on buildings; but here we had to keep both.

So, one had to have an understanding of what type of trees are we talking of, what is the density of the wood, what is the rate at which it will grow, what is the total weight coming on to the structure. And so, some expert from botanical sciences had to come in and give us specific inputs. Ancient languages, if you are interested in languages this is a fantastic field;

because many of the books that were written in the past on constructions, on sculpture, on different sciences in the country were in ancient languages.

They were written in Sanskrit, they were written in other ancient languages across the country; and so, this is another opportunity for someone who is interested in languages in ancient languages to connect and do reinterpretation of past history. Humanities, anthropology, community because very often these monuments are not sitting in isolation; they are actually sitting in the midst of human populations and people engage with these monuments in different ways. And so, an understanding of the community and social values also have to be addressed.

Project management, if you are doing a huge project of conserving a monument, you need to have someone who is trained in construction project management; who will be able to sequence and utilize resources, men, material, labor in a technical skill, in a proper and systematic manner. And very often the whole exercise is forensic in nature, right. You have heard of the word forensic? Yes. And why does forensic come into civil engineering?

Very often the damage that you see in these structures, you do not know why that is has occurred. You would actually have to play the role of a detective, and try and understand what was the reason for the damage; because unless you know the reason for the damage, you will not be able to come up with a remedy in the right manner.

So, you will have to put on your hat as a detective, but a building detective and then examine the structure and arrive at answers of what is the cause for damage, before you intervene in such historical constructions. These historical constructions have been here for hundreds of years, some of them thousands of years. So, you have to respect it, it is much it is been there for several centuries, probably before you; and therefore, it is with that respect that you must engage with these structures. And for that you need as much information as possible from these monuments, and very often we are acting as forensic engineers as far as historical monuments are concerned.

Very interesting, I had a very interesting training over the years. I was interested in medicine, but I did not make it to the medicine field. I got into architecture and engineering; but today I find myself as a building doctor; and I see a lot of parallel of course, the blood and goo is not there, but I do see a lot of parallel between what a doctor and a medical profession would be doing, a surgeon would be doing to what an engineer would be doing as far as rehabilitation of ancient buildings are concerned, right ok.

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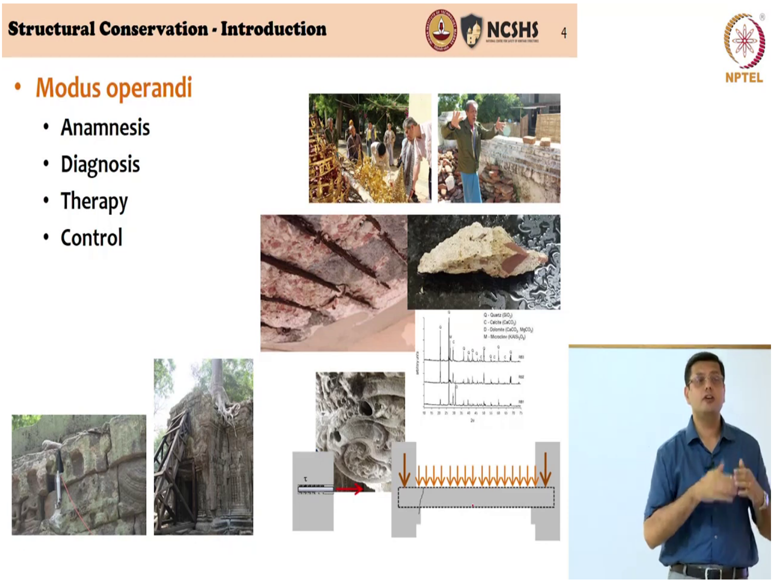

Having said that, how do you operate within structural conservation? There should be a process, there should be a methodology; a modus operandi of how you operate. And this is where I say it is very similar to how a doctor would operate. If when you are confronted with the problem, let us say your building is damaged; the first thing that you do is, referred to as a stage, is referred to anamnesis. And in the anamnesis stage you are basically asking random questions, ok. You are asking random questions to anybody who is engaging with the building and this is to try and make some sense of what the problem is, how long the problem has been there and so on.

If you go to a doctor, the doctor would ask you; let us say you have got a headache and you are going there, have you had good sleep in the last few days, or have you had temperature, what did you eat. You have these random questions that the doctor asks you, so that he can structure he or she can structure the problem to get a hold of what is happening, right. That stage is called anamnesis stage. Anamnesis stage instead of random questions, but the intention is to structure the whole understanding of what is happening.

So, in a monument you typically go and ask somebody; how long have you seen this crack in this building, do you know if there was something that happened that led to this crack appearing, do you see it increasing every month or every year. So, these are random questions that is the enquiry stage, it is call the anamnesis stage. The second stage is a diagnosis stage; there is a problem with the structure or there is a problem with you, your health the doctor has to diagnose it, right.

So, you come into the diagnosis stage. In the diagnosis stage you are trying to understand the root cause of the problem, and to do that the doctor may say; look I need your blood sample or I need some other samples from you, this will go to a laboratory, you will interpret the results and then tell you if something comes out of it.

Yes there is an infection, no there is no infection; you are able to arrive at based on actual measurements which are from the structure this is the diagnosis stage. In the diagnosis stage tests are required on samples from the structure or in the structure itself, ok. Blood test is blood is taken from your body and taken to a laboratory; if an ECG has to be taken, the instruments are put on to you that is right on the body itself. Similarly you could do tests on a building and then make measurements on the building directly.

Of course, with all this information there must be a therapy; the doctor may be able to arrive at what should be done to make you feel better. So, he or she would prescribe some medicines. Similarly for a building, you need to do some analysis and that is where structural engineering, geotechnical engineering and the courses that you will study would actually help you. You are able to understand what is happening to the structure and what would help the structure in performing better that is your therapy stage.

So, once therapy is prescribed, then the hope is the therapy is actually addressing the problem. The therapy must address the root cause of the problem. It may or may not; but how do you know it may or it is or it is not actually addressing the original problem. If the doctor gives you a one weeks prescription for medicines, you go have that and come back and your headache still persists or infection in the blood still persists, there is a problem; because the diagnosis is not probably right and the therapy is also not right.

So, what would the doctor need to do to check if the therapy is working, he or she started with some blood tests. After a week of therapy probably the doctor would say take some more tests or let me look at your symptoms and arrive at whether it is working or not. So, the final stage is actually the control stage, and in the control stage again it is about taking some materials and testing, or putting some sensors and instruments on the structure, and checking if the structure is performing well or is the problem still persisting. If there was a wall that was tilting and then some repair has to be has been done; and if the wall continues to tilt, because you are measuring the tilt in the wall then you have a problem on hand.

And therefore, these four stages anamnesis, diagnosis, therapy and control is cyclic in nature. After the control stage, if things are not working, something is missing; you have to reformulate your questions, you go back to the anamnesis stage, you have missed something and that is why I said it is you acting as a detective in identifying what the problem is to be able to arrive at a solution. So, this is not a linear process, this is a cyclic process; at some point you might stop, because you would have actually cracked the problem and had the right solution itself, ok.

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So, let me go to one example that I thought I should present to you to give you an idea of the interdisciplinarity of the subject and the excitement of the subject. So, which building are we looking at? This is the Rashtrapati Bhawan right and so, it was our fortune and a fantastic experience for us to be able to work on the structure. A few years ago, we were asked to look at a few problems that the Rashtrapati Bhavan or the presidential palace has, right.

So, very briefly this was not designed as the Rashtrapati Bhavan, this was originally designed for the Governor General of India. It was designed for it was designed by Edwin Lutyens as the viceroy's house; the designs were conceived in the beginning of the century, beginning of the last century, but then it was completed in the 1930s. 1915 was when the design was created, you know that in 1905 the capital of India was shifted from Calcutta to New Delhi and New Delhi was being constructed, because that was the capital of the sone ki chidiya, the Indian empire which the British was holding.

So, the presidential palace was built as the house of the viceroy; but then original designs they wanted it to look like a European building, with huge very big renaissance domes and Palladian windows. But over time they realized look we need to amalgamate this with some of the Indian designs, so they said you make some modifications to it; so that you get a new style of architecture which we today refer to as Indo-Saracenic style of architecture.

And the engineers and architects working under the British regime, at that time were required to actually devise a new style of architecture, combining Indian styles and European styles. And the Rashtrapati Bhavan is one of the later examples of how those Indo-saracenic style was perfected.

If you take time those, I believe some of you will be from Chennai earlier known as madras. If you go to old madras you will see a whole lot of buildings built in the late 1880s, late 1800s early 1900s which was the experimental grounds for the Indo-Saracenic architecture.

So, Indo-Saracenic architecture has it is roots here; very young architects and engineers Robert Chisholm for example, who was 24 years old was mandated to come up with a new style of architecture brought in from England, made to work in Chennai and he is made some masterpieces in Chennai. The Rashtrapati Bhavan is a later example where the style was perfected.

But so, this was an experimental style and lot of changes were being made. And then finally, in the important changes that we are done was the dome was changed, there was an original design of the dome; they changed the dome to a flatter Indian dome inspired from other structures and you see this sort of amalgamation in this structure.

So, let me come to the problems, they were fundamentally two problems; they were the huge dome that you see there, there were some cracks inside the dome and these cracks has been around for some time. So, the big question was after about 85 years, this building was being conserved in a holistic manner; they do what was referred to as a comprehensive conservation management plan in conservation parlance.

So, in that process, they also wanted to look at specific problems that this building was happening; one of the problems was, a crack that had a couple of cracks that had developed inside the massive dome. And the other problem was the sunshades of this structure and you will that is the second thing and quickly look at; the sun shades had significant problem. You know what sun shades are chhajja's, right. These sun shades are so important; but if they have problems that could be a tricky one to solve, because you can have material falling off and endangering people using the building.

So, this was why IIT was brought in, when the comprehensive conservation management plan was being developed a few years ago, a couple of years ago and we are still engaging with them at Rashtrapati Bhavan.

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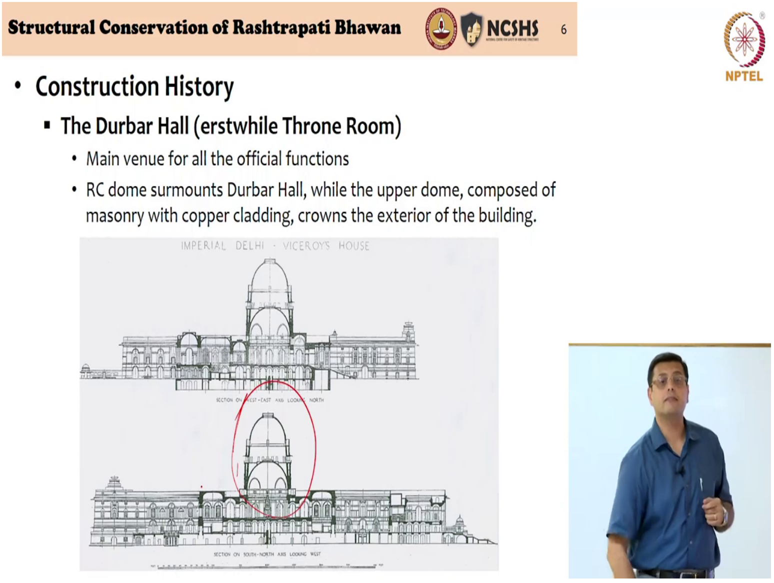

So, that is the original drawing, it is it was a good thing early 1900s; we had Edwin Lutyen's drawings and these drawings were on cloth. So, they would be as large as a room, you spread it out on the floor and you have all the details measured drawings. And so, we could look at the original designs and then look at what was constructed in the building and see if they were deviations and start understanding why the structure developed some damage.

So, the fundamental problem was the crack in the dome that we were looking at. And you have heard the name the Durbar Hall; you must have seen news, reports about the Durbar Hall, or functions happening in the Durbar Hall when the Padma awards or the Bharat Ratna is being presented, these functions are held in the Durbar Hall, ok.

The Durbar Hall was meant to be the viceroy's main room where he interacts with the guests; but today it is the place where official functions of the government are held including the distribution of the Padma awards. So, this what we are really trying to look at is actually the dome that is sitting there. The dome is right on top of the Durbar Hall and this dome is the one which has some distress.

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So, that is a picture of the Durbar Hall, you can see how the dome rises up; that is Durbar Hall the dome rises up. And the problem was can you see these two niches that is like a cutout in the dome. In fact, there are four such cutouts right and what you can see here; you can see 1, 2, 3 and 4.

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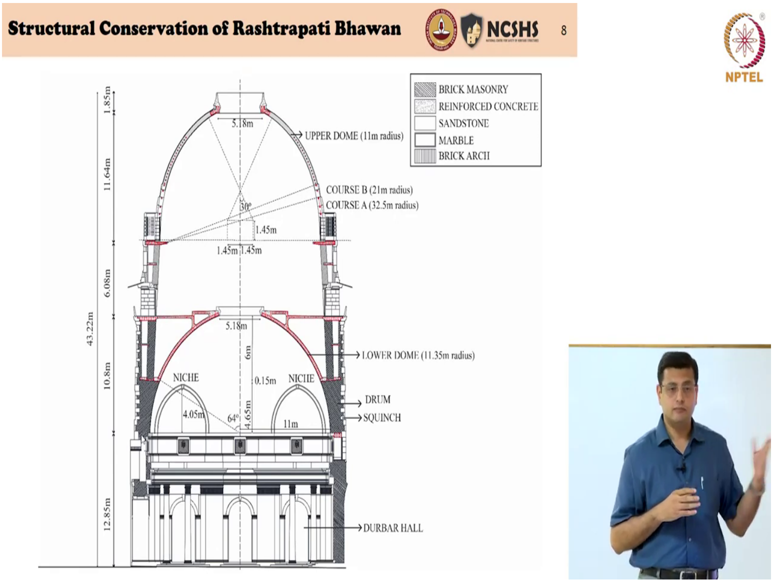

Now, on the north eastern and the north western corners where I have highlighted them in red, those two niches in the dome had cracks. One of the niches has a significant crack, you can see the red line here super post on this picture and on the other side there are two smaller cracks.

So, diametrically opposite, the northeastern and the north western niches had cracks. That is a cross section of the entire dome for you with the Durbar Hall at the bottom; that is the Durbar Hall and then this is the dome that we are looking at those are the niches. And in fact, from outside what you see is not the inner dome, but another dome that is constructed on top of it, ok.

So, this is where the cracks are and this is the dome that you see from outside. And the problem, the fundamental problem is domes are constructions which merely because of their shape would tend to open outwards; merely under their dead weight. You take a ball, a rubber ball sliced into two; take one hemisphere, place it on the ground and exert some pressure; the tendency of this hemisphere will be to open outwards. Particularly the lower portions of the ball would try to open outwards; which means, it would introduce what we refer to as circumferential tension and that is a characteristic of a dome.

Now, if you construct this in a material which has tensile resisting elements. Which is a tensile resisting element in construction materials; what can resist tension? Any material that can resist tension? What is tension? I stretch and it does not fail; no. Concrete is not a tensile resisting material, steel is a tensile resisting material and that is why you have reinforced concrete. You put reinforcement inside concrete, so that it carries tension, reinforced concrete carries tension.

Brick masonry is does not have tensile resistance. So, in the past when we were constructing massive buildings; we did not have tensile resisting materials. In the huge structures that you see in the past; think of the pyramids, think of the huge forts, think of the huge palaces, the huge temples they were not built with tensile resisting materials that is why they were massive.

In today's construction, in the last 100, 150 years we have introduced a large number of tension resisting materials; because we have introduced a large number of tension resisting materials, constructions are becoming more and more slender and optimized, because you can resist tension which can come because of any lateral load or any gravity load.

So, what is fundamental is when these domes tend to open outwards, they try to crack the dome; they would try to crack the dome. If you have tensile resisting material there; if you have steel there, it will actually prevent the dome from cracking. But if you do not have steel there, then the chances are the dome will crack. So, very interestingly when we examine the whole cross section, then we realized that while the upper dome was built of brick and steel; there was the red dots that you see are steel cables running inside and then if you come down, this red part is built in reinforced concrete.

So, again a part of the dome is built in reinforced concrete, there is reinforcement and hence it can resist and counteract the tention expected. But this black hatching that you see, this entire black hatching, the lower part of the main dome; exactly where the niche is coming, the lower part of the main dome, where the niche is coming was pure brick masonry with no steel reinforcement. So, as I said Edwin Lutyen's and all his team of engineers and architects were looking at an experimental structure. This size of an Indo-Saracenic building was not built in India before.

So, they were playing around with materials, they were playing around with forms and here you can actually see different materials being used in the same structure. That was possibly an experimentation which went slightly wrong. So, this part which is a critical part of the dome; if you look at this as a hemisphere, if you look at this as a hemisphere, you can see that the lower part of the hemisphere may open outwards and can develop cracks due to tention and in unfortunately in that location there was no steel. So, this was one fundamental problem; but then keep your eyes on these niches and I will tell you something more about the niches.

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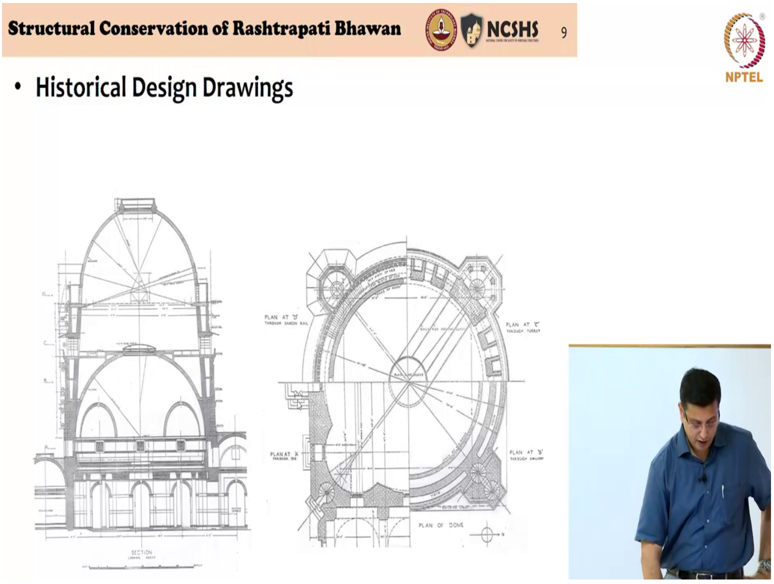

So, we looked at it is important and we were lucky that we had the original drawings of Sir Edwin Lutyen’s. We then compared it to the original, the actual structure and we hit upon another clue that might tell us, that might lead us to why the cracks happened on the northeastern corner and also showed up on the northwestern corner.

So, when we were examining the original drawings, this is the plan and you will learn in a few years, in a few months you will start learning about how plans can be made, projections can be made. This plan has four quadrants and each quadrant is at a different level, ok. So, when you examine that, this is the dome and then around the dome you have the small turrets that you can see, small elements that you can see that come out in, but you have a staircase inside and that is how it goes up.

Now, if we look at the original drawing and that is the reason why history of construction is very important in this subject. When we looked at the original drawing; in the four corners of the dome, Edwin Lutyen's had intended four spiral staircases, ok.

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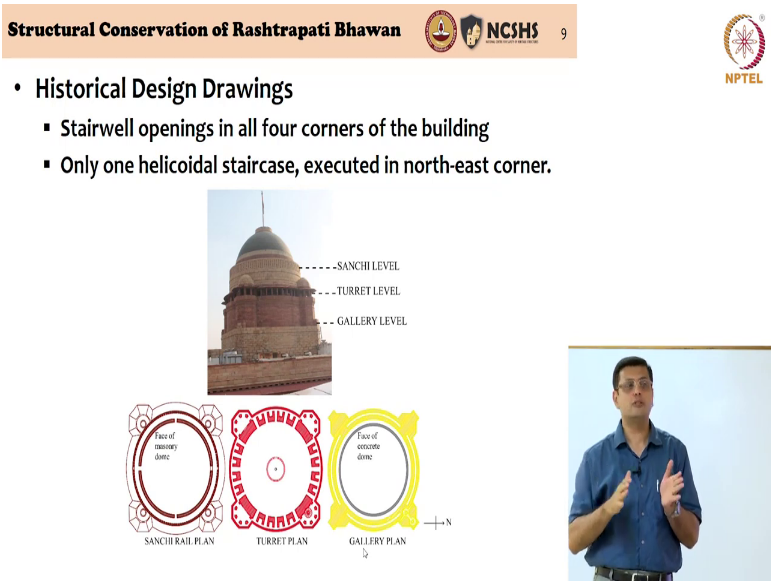

There were four spiral staircases intended in the structure in all four corners of the dome. But when the construction was completed there was only one spiral or helicoidal staircase that was constructed; whereas the other three locations did not have these spiral staircases.

So, while executing they had deviated from the original plan; which means, a certain symmetry that existed in the original design was deviated from. So, that is what we finally found that, there was a staircase opening, a helicoidal staircase opening only on the northeastern corner; whereas it was solid construction on the other three corners.

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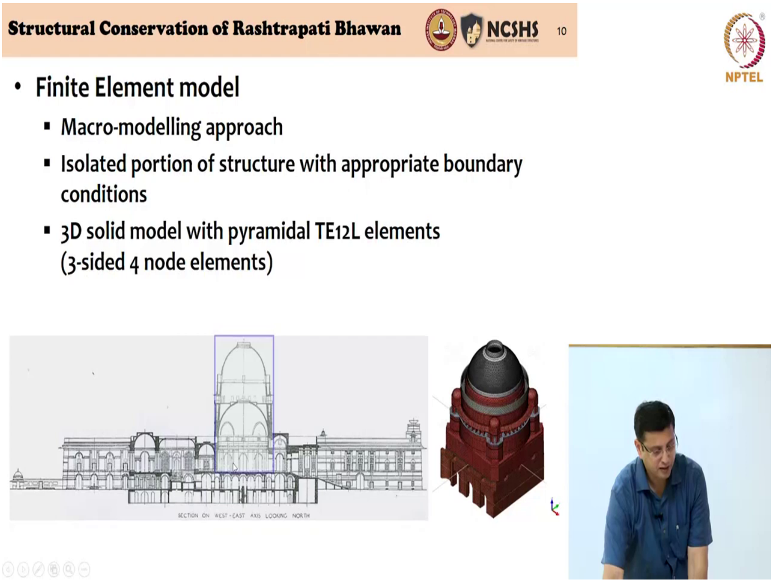

So, we actually had to now understand in a more detailed manner why this was cracking. So, it is a complex structure and therefore, while we do some basic hand calculations; we also depend on some complex computer based simulation, so that the behavior of the structure can be understood in a more rigorous manner.

So, we developed of the central portion of the structure as an isolated model. We developed a model of the computer model, this is computer structural model on which we can actually run analysis you can say ok; now apply gravity loads, now apply lateral forces, earthquakes or wind and so on. So, a computer model was developed and this computer model it is called finite element modeling, or a finite element analysis.

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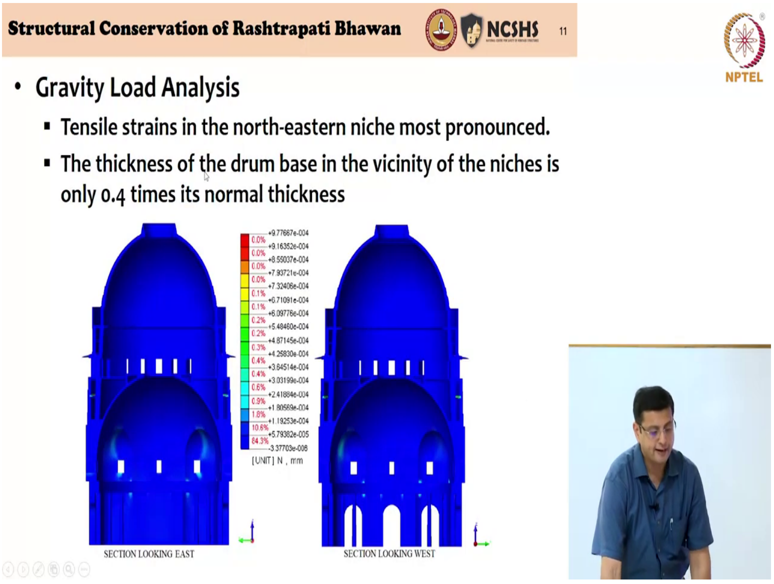

So, this is what was done and we carried out some analysis, some gravity load analysis, dead weight analysis and then we carried out some earthquake analysis as well; what would happen to the structure if there was an earthquake. But what was very interesting was, you saw the niches right; those niches, those four niches were carved out from the resisting material of the dome at locations where steel reinforcement was not provided.

So, material was very important there, that cross section was essential there; but in that important cross section, niches were carved out. So, the first thing is about 40 percent of the wall thickness was reduced in those four corners because of the presence of the niche that was one issue. The second problem was in the north eastern corner, it was further weakened by providing a stair well or a staircase opening. And the gravity load analysis clearly showed us;

you can see these light shades that change here, you can see that a light color coming in inside the niches and that is clearly the indication of formation of tension cracks.

So, even under the gravity load analysis, because of the niche in the design of the dome and the absence of tensile resisting elements and the presence of a stairwell in the northeastern corner and not in the other corners, the crack had actually formed. So, as I said this took us a few cycles to arrive at; it will iteratively arrived at this point; but it was almost forensic, because we had to chase this issue and arrive at what was happening in the structure, right.

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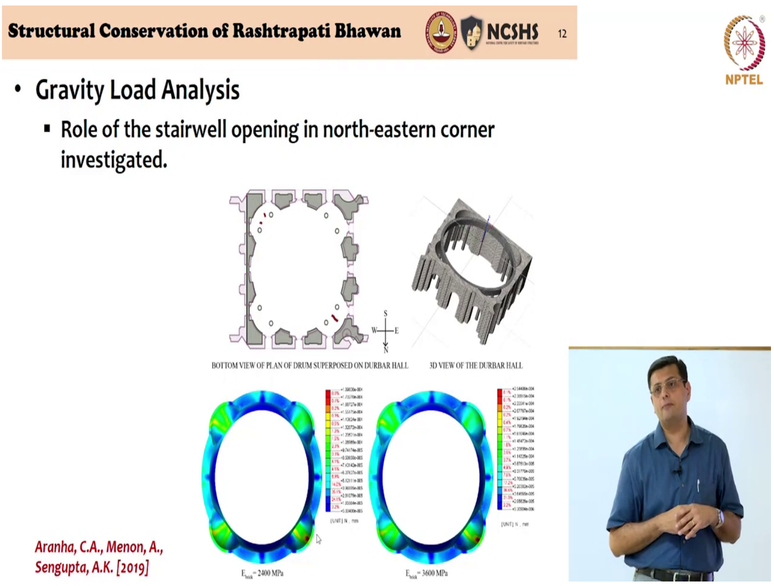

So, this is a section of the plan, cut section of the finite element model; we basically looked at what is the role that this stable opening was playing and it actually showed us that the presence of it was what was creating these tension cracks. Now, having understood what the problem is, we can now comfortably work on a solution; because we did not want to work on a solution without knowing what was happening, then you may be completely going wrong, right. So, this was the first aspect.

In fact, in the Moodle site there is a paper related to this, no need for you to read the paper, the slides are self-explanatory; but if you are interested in what was conducted it is a little complex, you could read the paper to get a better understanding and that is what is referred to at the bottom of the slide.

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The second thing which was a more critical problem was falling material from the sunshades, ok. So, that is again Rashtrapati Bhavan and we are talking of those sunshades which run wrap around the entire building, ok. Can you guess, what is the length of sunshades in this building? Yes, length of sunshades around this building; 1.2 kilometers, ok.

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So, these are not huge building and we had to deal with 1.2 kilometers of sunshades. Now, what was the problem; that is what you see as a sunshade, right. You see one major projection and beneath the projection there are some supports. The projection was 2 meters, it is a huge projection; sunshade in your house would be about 75 centimeters, but we are talking of a monumental building, here the sunshade was 1.2 meters long.

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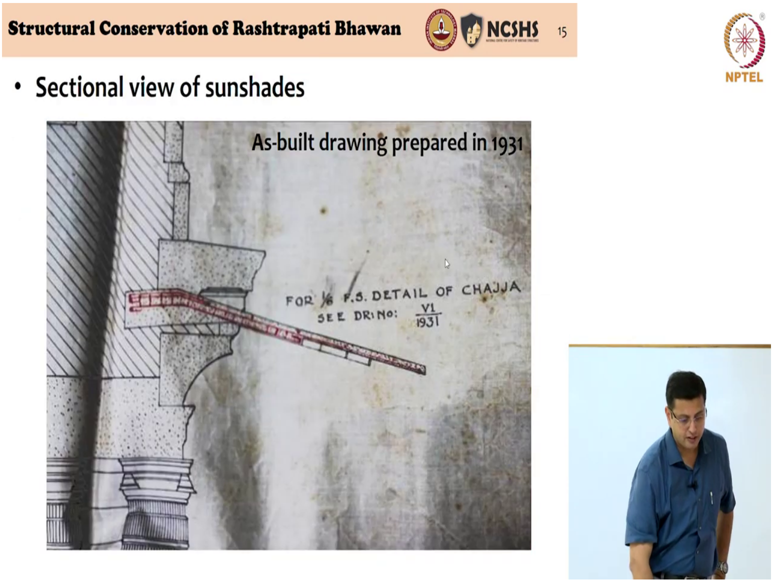

And we had original drawings. So, we went back to the original drawings, but in the original drawings, we saw somebody had made some correction, ok. So, as per Lutyen's design, Edwin Lutyen's the original design these were meant to be Chhajja's like in the Rajasthani architecture. If you have seen, there are large cornices and sun shades made out of sandstone; that are present in big buildings in Rajasthan in Western India. These people had drawn inspiration from ancient Indian architecture.

So, they wanted to bring this feature and the idea of Edwin Lutyen's was to have these massive sandstone, natural material sandstone sunshades; but in 1933 when they started construction, they were given a very short deadline. They said 1915 we started making these drawings, 1933 building is not built; they had to finish the building in a very short period of time, they could not wait to get so much of sandstone. And since there was a shortage, they ended up making these sunshades in concrete.

And when they made it in concrete, since a cantilever is expected to develop tension at the top surface, it will sag, it will hog and therefore, tension at the top and therefore, you need it tensile resisting material. They decided to make this in lime concrete; lime was chuna, lime was a material that was used for building construction early 1900s. They used that, put steel reinforcement inside and completed making all these sunshades.

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But the problem is today, that is the status of the sun shades; the sun shades at a height of about 50 feet and you have material that falls as you are walking in and out of the building. And you can imagine if a piece of lime concrete from a height of 50 feet where to hit anybody's head, you could actually have a fatal situation.

So, you have this is a problem in reinforced structures. So, you need someone who has an idea of material science, has an idea of electrochemical processes who is working on material characterization and material repair to come and help us. And that is what we actually did; we worked closely with our building technology group, where we have corrosion scientists and where we have people working on material repair and we had to start understanding why is this corroding so much.

And the fact was, the reason why it was corroding so much which we will appreciate; probably little later in a civil engineering program is when you have steel embedded within concrete, steel protects concrete sorry, concrete protects steel. Concrete is acting like a protecting layer for the steel, it does not allow moisture and air to diffuse and start the corrosion process which is an electrochemical process in the steel.

Unfortunately in this construction, concrete as we know today; cement concrete as we know today was not used, but lime concrete was used, because lime was what was abundantly available then. Today lime is not abundantly available, only cement is available; lime concrete was used, but lime concrete does not act as a good protector of steel. Lime concrete is highly porous, it actually allows the moisture and air to pass into it, does not act as a layer that is protecting steel and that is the reason why 80 years down the line almost all the steel is corroded.

So, here again detective hat, we had to really understand what was happening and we had to do a whole lot of tests. We were also worried you know that, after the republic day in; around the republic day the whole Rashtrapati Bhavan is lit up. Have you seen pictures before the republic date till beating the retreat, for a few days the whole building is lit up. Who lights them up? There is labour that climbs on to these sunshades and has to physically put the lighting onto the structure.

So, with so much of damage there is actually a possibility of some of the sun shades failing and becoming a danger to life. So, we actually had to understand, if these sunshades could fail if load was placed on it. So, we had to actually do a test and we were fortunate, because they allowed us to do a test on some of the sun shades, you try to take it to collapse or try to take it to failure.

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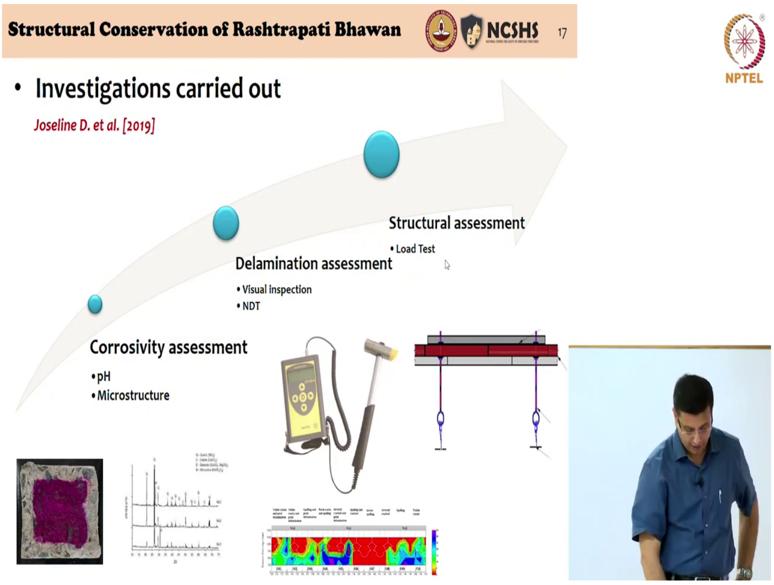

So, again some investigations had to be carried out. We had to understand how much of corrosion is happening and because of corrosion in the steel there was damage to the material and that had to be assessed. They then had to understand, it is 1.2 kilometers of sun shades; we could do a test in one location, but it may not be representative of another location.

So, we had to do a good coverage of the 1.2 kilometers to have a good idea of what was happening. And finally, we also had to do a load test on some of the sunshades to understand if the sunshades could fail in this sort of a situation. So, we did some laboratory tests to understand what was happening in the material, we had to do some non destructive tests, we did some tests on materials taken from the structure, take it to a laboratory and do some tests.

But to get a better coverage of the 1.2 kilometers of sunshades; over 8 days our team of researchers physically covered almost 30 percent of the 1.2 kilometers of sunshades, which is a good representative proportion of the actual structure. And finally, we did the load test, we actually put some cables and tried to make the sunshade fail and when it did not fail at load levels that we calculated; we were comfortable that you do not have a collapse of the sunshade.

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So, this is just a picture of the load test, we are pulling these sun shades down to simulate the weight of people standing on it and working to put the lights and take them off later.

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So, you can see our team there on top of Rashtrapati Bhavan sun shades. We got there with fire trucks, you know you have this massive Volvo truck which has a portion that can take you all the way up, put you there. So, this fire truck would come along with us and we were on the sunshades or beneath the sunshades doing all the tests and that is a picture taken by a drone of the work that was happening.

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Finally in the last few months, we have actually come out with a repair methodology and this repair methodology is being implemented; we have already implemented it on 10 meters of the sun shade.

And we are now checking, because control is important; we are now checking if it is working and we have 6 months of data which is monitoring. You see these cables in different locations, information on current in the electrochemical process of corrosion is being measured and it has now given us confidence that the technique we have applied seems to be working. And now a tender has been opened for the entire 1.2 kilometers of sunshades to be repaired.

So, this is really the whole project that we have been involved in. I was talking to you about the need for image reconstruction in heritage conservation, working with computer science engineers and that is something; this is in Maharashtra, in Raigarh fort where we actually are working to reconstruct some broken parts of Shivaji's fort. And we have used very simple tools, but numerical quantitative to be able to reconstruct broken parts of a structure and this is again something that requires interdisciplinary collaboration.

So, with that the idea was to tell you, how interdisciplinary a subject. This is it requires you to work as a forensic engineer; you have to look at repairing these structures, or protecting these structures. And those of you are interested can come and speak to us; we have a big group and it will be interesting to collaborate. I will stop here.