**Retrofitting and Rehabilitation of Civil Infrastructure**
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**Lecture 49**
**Introduction**

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Welcome to this particular lecture which is on Module 2. And in this module, in fact we are planning to discuss aspects on Retrofitting of Masonry Structures. And in this particular lecture, we will be talking primarily about certain introductory aspects of the masonry structures.

I had told you earlier that when we talk about the retrofitting of structural system, mainly we divide or group the entire structural system in three categories. We talk about the masonry structural system, we talk about the reinforced concrete structural system, and we will talk about the steel structural system.

So, today I am going to talk about certain aspects of retrofitting measures related to the masonry structural system. And I will just give you an introductory view about such masonry structural systems which we come across, what kind of distresses that we observe normally and how to take care of those.

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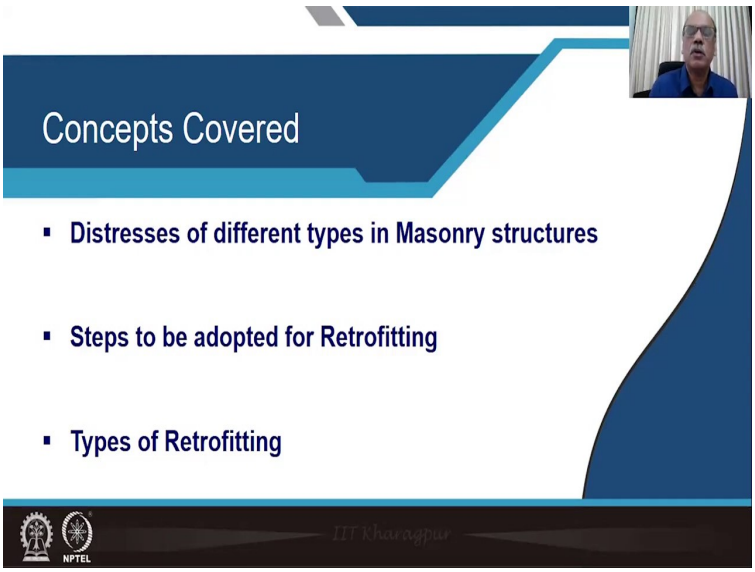


So, thereby, in this lecture I intend to look into different types of distresses that the masonry structures normally suffer. And I am concentrating primarily on the brick masonry system. And you will see that the kinds of distresses that we normally observe in this masonry structural system. And then, if we want to retrofit those distresses, how do we go systematically in a step-by-step manner so that we can retrofit the structure in an appropriate manner. So, we will try to look into those steps.

Also, we will try to look for the different kinds of retrofitting techniques that are available with us. Certain techniques have evolved over a period of time with expertise, with experience, and we try to make use of those techniques to take care of any retrofitting measures of masonry structural systems.

I must tell you over here that the retrofitting technique of a particular system is not unique in nature because looking into the kinds of distresses that the structural system have and also the kind of loading that the system will undergo, we may have to evolve or we may take help of different kinds of retrofitting techniques that are available with us.

And then either in isolation or in combination we can adopt these techniques so that we can retrofit the structural system in the most effective manner. And that is what is our objective, and that is what we try to look into in this particular lecture.

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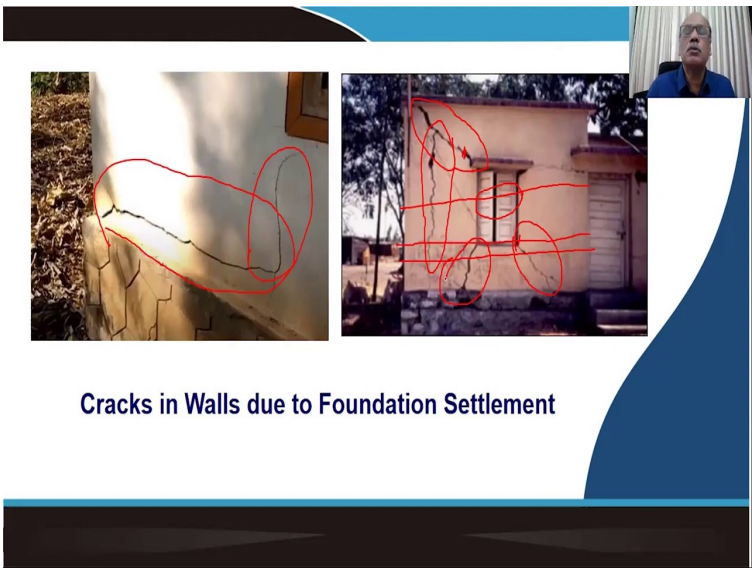


So, what I am going to do now, I am just showing you some of the pictures to show that what kind of distresses that we observe in masonry structural system. Before I proceed, I must tell you, I have a disclaimer that the pictures, the figures that I have taken up in this lecture, partly I have taken from the open sources that are available through internet and also some of the figures which are result of our work with our students, those are used. So, I would like to put that in record.

Now, here as you can see that we have certain kinds of distresses in this system like the wall has undergone cracking in this particular region, the crack has propagated to this part, and this has resulted primarily from the settlement of the foundation of the wall. It is showing that as if the wall is trying to get separated out in this particular region. So, when you observe this kind of distresses, it can be attributed to the settlement of the foundation.

Similar thing you can see in this picture also. You see the distresses in terms of cracking in the wall in this zone, in this particular zone as a diagonal crack. You see how wide this crack is again, in the diagonal crack, in the wall. Also, there is vertical crack that has happened in the system. So, these kind of cracks normally you encounter again for the settlement of the foundation system.

Now, here one aspect you must notice that in general let us say if I take a cross section here and if I want to calculate the compressive stress, is the total load that is coming divided by that cross-sectional area, will give me the stress, which is going to be uniform

across this. Now, as long as the wall is continuous up to the sill level of this window, you get that kind of uniform stress.

But when you come let us say to this particular cross section, now here, you have this much of opening in the entire length. So, this much goes off, thereby your area gets reduced and stress level increases. So, from this point to this point there is a jump in the stress. Now, because of this additional stresses that happen there is a concentration of the stresses at that corner and that gets further triggered, because in normal situation when we design we try to keep this stress well within the permissible limit of the material and thereby we do not see any distress.

But if this concentration of the stresses, there is a jump in the stress, if that gets triggered by this kind of movement of the wall or the settlement of the foundation, the crack initiates. And once such kind of crack gets initiated over, in this particular regions, it starts propagating with the further movement on the settlement of the foundation. Mind that settlement does not occur in a day. It happens over a period of time. And as a result, if there is some kind of distress in the wall, those distresses start propagating in a manner as the settlement of the wall progresses.

So, this is what has happened, what I am showing is the result of, for a longer period of time that the distresses have happened, and as you can see over here, that the thickness that the width of the crack also is substantial which can be seen with the naked eyes. So, these kind of distresses when it happens, it manifest into the situation where we say that yes this has happened because of the settlement of the foundation. Now, I had told you earlier that when you see something on the structural system, the kinds of distresses you try to understand that why such distresses have happened.

So, these are basically the effects that you see, and you try to relate the cause for which this has happened. And this is what is very important when you are really going to adopt that retrofitting measure. So, in the beginning, I am just trying to tell you the kinds of distresses that we normally encounter in case of masonry structural system. So, this is one kind of distresses that we can observe.

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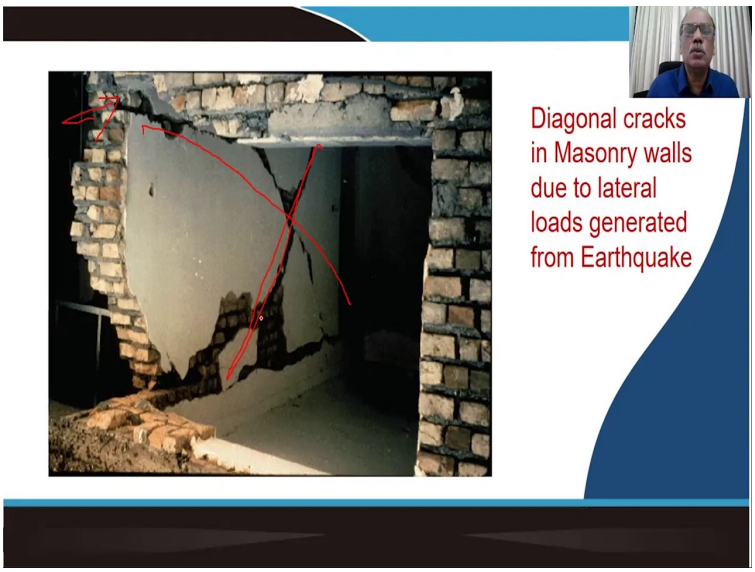


Secondly, many a times you will find, when the structural system particularly, the masonry structures are subjected to some kind of lateral loading because of the environmental loading conditions, either due to earthquake or wind, now these lateral loads tries to generate some kind of diagonal tension. And as a result as you can see over here, you have the cracking in the wall in the diagonal level.

So this kind of distresses do occur, particularly after some kind of environmental loading such as earthquake or wind where you find that these structures are subjected to some kind of a lateral load. And because of the lateral loading the moment that gets generated it causes tensions to develop in the wall region, which causes crack in the perpendicular direction.

So, that is how this kind of distresses have generated in the masonry one. In fact this is a picture that I have taken it up from the place where after month of the earthquake. So our job now is to find out the remedial measures after this kind of distresses have happened. Now, how do we do that, that is what we need to look in.

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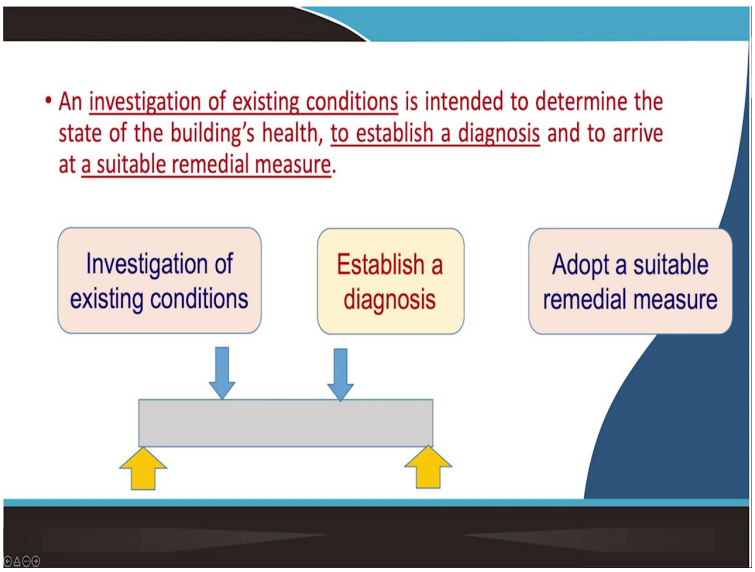


Now, I have told you several times in earlier module. We said that we need to carry on an investigation. An investigation of existing conditions are required to be done to determine the state of the building's health, to establish a diagnosis and to arrive at a suitable remedial measure. So you see, I have highlighted three aspects over here. One is the investigation of existing condition, second thing is to establish an appropriate diagnosis and third thing is to adopt a suitable remedial measure.

So, three aspects are to be done judiciously so that you can arrive at an appropriate retrofitting measure. And you may recall that in my previous lectures, in the previous module I have told several times that there are seven steps that are required to be adopted to arrive at a suitable retrofitting measure. Now, in those, the first few are devoted to the investigation of existing condition.

Now, for investigating the existing conditions what do we do? As I said earlier that we try to look for whether there are any existing documents available for the structure like drawings, detailing, design etcetera, we try to look for that we go to the site, see the condition of the building by visual inspection, try to find out the distresses at different parts and we take note of those distresses. Also, we try to think or try to correlate these kind of distresses with some known kind of phenomenon.

One aspect you must appreciate over here is that for a new structural system when we try to design a new structure we know what is the kind of loading a structural element will be

subjected to and for that what is the consequence, what is going to be the bending moment, what is going to be the shear force, what is going to be the deflection, those we can estimate. And to keep our structures within the permissible limit of those, we try to adopt or provide a suitable size.

Now, question is there we know the causes and we know what are going to be the consequences of those and how do we take care of that, that is taken care of the new structure. On the contrary, when we are talking about retrofitting of a structural system, what we are observing is the effect of some causes. And from effects, you will have to relate that what are the causes that have happened to produce such effects.

And so in that sense we are talking about an inverse, in the new design you are going in the forward direction, you know the loading, you can estimate the bending moment, you can estimate the shear force, you can come up with the requirement of the section.

But in this particular case what you are seeing is, effect of some actions and you will have to relate those, these effects to those actions. And once that can be identified, then we can take care of those causes in an appropriate manner so that the structure can be retrofitted in an appropriate sense.

So, when we are talking about investigation of existing condition, what we mean is that we need to look into the documents that are available, we need to visually inspect the structural system to identify the kind of distresses that have happened, we need to look into the material, we need to decide that what are the kinds of tests that we will undergo.

Supposing when we find that there is a possibility of the settlement of the wall because of which cracking has happened, we will try to find out that what is the kind of bearing capacity of the soil at which the foundation is resting, whether the data is available or not, if the bearing capacity value is not available with us, we try to estimate that or we do carry out some tests to find out what should be the bearing capacity at that level.

So, looking into the structural system we try to understand that, what are the kinds of tests that can be adopted, so that we can get some meaningful data. So, and you remember that we had spoken about the analysis methodology that we need to do. Now, while carrying out the analysis, you need certain data about the existing structures to be

fitting, and by carrying out these tests, we try to gather those material characteristics and we feed this material characteristic value to the analysis method, so that we can come up with the results which we can correlate with the existing system.

So, these are all part of the investigation process. You try to gather the document, if the document is available it is well and good, then what was the original conditions with which it was done, what was the original idea, what was the original loading, or, and what was the original material, what was the characteristics of those materials. So, all those data will be available. In the event you do not get those, then you need to regenerate those data through the test procedures that are available with us.

And once we collect these data, once we gather this data we try to analyze those data to understand that what is the health of existing structure. So, that is what we need to arrive at. And once we know the health of the existing structure in terms of how much stresses are getting developed because of the loading, whether the stresses are within the limit of value of the material or not, what is the kind of material characteristics we have, what is the strength of the material, whether it can withstand that kind of loading what we are adopting, and all these we need to establish through the existing condition.

Secondly, once you know the existing conditions and once you have observed the distresses, you need to arrive at an appropriate diagnosis. You have to tell that why these distresses have happened. And again I come back that when I say that when you see the crack, crack is the effect of some causes. Now, unless that cause is detected, unless the root cause of this effect is detected, and if that is not addressed, then your retrofitting is not going to be successful.

So, it is very important that you identify the distress and try to relate that effect to the root cause of the problem which is causing this. I just like to give you an example where, in fact, let us say you I am sure all of you must have tested it in reinforced concrete beam, and let us say we have two loads, two concentrated loads that we are applying. So, it is a simply supported beam that we have adopted over here. This is one support, and this is another support over here.

And in this, you are applying two concentrated loads, concentrated load here and concentrated load here. Now, for this, let us say these are two equal concentrated loads

that you have applied. Then you know, if you draw the shear force diagram, this particular part of the beam is devoid of any shear stress, or shear force will not be there. Shear force in this region is zero, so thereby there will not be any shear stresses. But there will be bending over here. So in this region you will get a pure bending.

And if you actually carry out this test and keep on applying the load, you will find that in this region you will get vertical cracks are getting generated. You will get some kind of vertical cracks. Now you can infer, so in a beam actually in practice if you see vertical cracks, you say that it is happening because of the flexural maxima, not because of the bending, whereas in the region where you have the effect of both bending and the shear, in this region you will find that the cracks are happening which are in an incline, so diagonal kind of cracking, it happens.

So, when you get inclined cracking, that shows that you have some kind of effect of both bending and shear. Now, this example I am telling you over here just to give you an idea that, so from the test the concept that has been created to our mind that whenever we see vertical cracks in reinforced concrete system, we can say that well there is, predominantly the flexural actions are happening. Because of that, it has happened. Now, why that is happening, we need to check.

So, similarly for the masonry systems, when we are getting some kind of distresses, getting some kind of cracks in the system, we need to understand that why those cracks are getting generated, what is that which are causing these cracks. And if we can diagnose that, if we can identify that, our job next will be to address that cause in an appropriate manner so that further these kind of effects do not develop. And that is what actually the retrofitting is.

But without identifying the root cause, without diagnosing the problem properly, if you just try to repair the generated distresses then the retrofitting is not going to be effective, because again the cracks will generate, because you have not attended to the root cause of the problem. So, the second step is very, very important. After you have developed the existing conditions, after you have investigated it, try to relate the effects that you have seen to the cause of the problem.

And then, thirdly you try to adopt the remedial measures, suitable retrofitting techniques in an appropriate manner. As I said, I will talk about several such techniques that are available to retrofit masonry system. So, either in isolation or in combinations of these techniques, you can adopt so that you get a proper retrofitting system for a structural one.

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So, we have talked about this. Just to remind you once again that we have spoken about different kinds of tests both in terms of non-destructive as well as the destructive test. Non-destructive test for masonry, normally for any structure for that matter that we do not intervene in the structural system in that sense, we do not disturb the structural system and it does not alter the member properties as such.

So, basically, visual inspection you do. You try to find out the hardness of the surface by a suitable measuring technique. We try to send pulse from one side right back where on the other, again without disturbing the structural system. But sometimes we try to test the material, well this is disturbing in some sense, and of course if some distressed part is there and from which you can extract the material and do it, you are not going to disturb that extent material.

So, with that material, we try to carry out some chemical analysis of it, which you call as a Petrographic examination.

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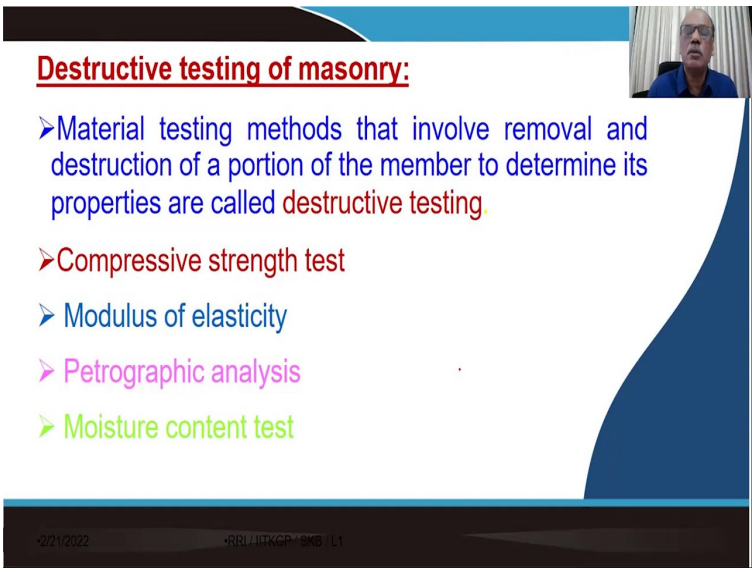


And when we talk about the destructive tests, there of course we intervene in the structural system and we try to extract some material from the structural system which we try to test and gather the data. And the data that we try to establish are what is the existing compressive strength, we can take a code even from the masonry system comprising the brake and the mortar which we can extract from the system and test under compressive load to find out what is the compressive strength which can be extrapolated for the compressive strength of the existing structure.

We do try to establish the modulus of elasticity of the material that is existing. I will explain to you in a minute that how we do that. Petrographic analysis as I said, that is, you can call it as a non-destructive or destructive test. It is basically a chemical test that we do with the material. We try to extract the material. If you are trying to extract the material from deeper inside of the masonry wall, then naturally you need to disturb and then you carry out the petrographic analysis.

We do carry out the moisture content test for the masonry system. This is very, very important because we need to know whether it is keeping the moisture inside intact and whether that is causing any problem to the system or not.

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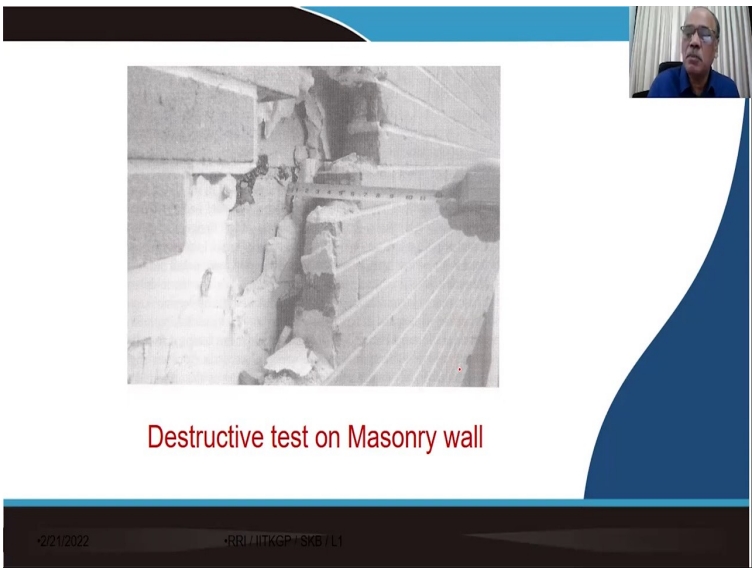


One of the destructive tests that I have shown over here is the, in the masonry wall is by destruction we are trying to find out what is the thickness whether there are any cavity with the wall system or not, and if cavity exists then what type of cavity is. Sometimes we do send a small camera through, which we call as endoscopy test to understand what is there inside in the deeper depth. So that kind of test also we do try to carry out to understand and to gather the data.

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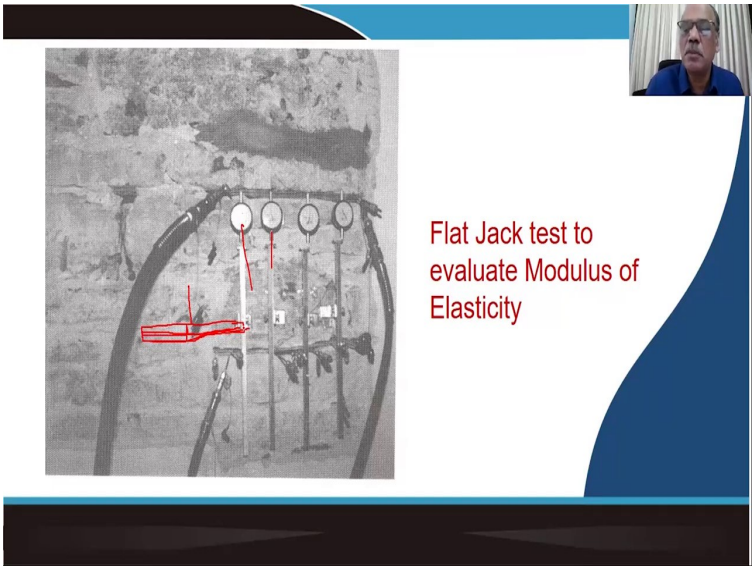

So, having done this test, also as I said that we can find out the modulus of elasticity by applying a particular test which we call as a flat jack test. Now, flat jack test, flat jack is a small instrument which we make use of it. Now, supposing, I cut a slit in a masonry wall, supposing you have a masonry wall and along this you will cut across a slit or you open over an opening.

Now, if you create this kind of opening over here it is expected that because you have the masonry wall onto top of it that will exert some kind of pressure on this opening and because of that pressure this opening will try to get closer. So, what we do is that we insert the flat jack, flat jack is a thin plate kind of a jacking system which can be inserted in this gap. And when, after putting this cut across, we put the dial gauges across this crack as it has been shown over here. These are the dial gauges.

So if you put dial gauges across this then you can find out that how much slit you had opened and how much it is closing down. So, we can measure that gap. Also, by inserting this flat jack across this cut, we try to pressurize the flat jack so that it exerts the pressure on the opening and the wall tries to move up, which had come down because of the load. Now, it moves up because I am applying a pressure on the top.

Now, for each increment of this load which is gradually being applied to bring the wall to its original position, we apply a small increment of the load and then we correspondingly see in the dial gauge that how much movement has taken place. So, we get a load versus displacement point, and we try to plot this load versus displacement or stress versus strain curve from which I can find out that what is the modulus of elasticity of this material.

So, flat jack test is a kind of a destructive test that we normally adopt into the masonry system to get an idea about the modulus of elasticity of the masonry system which we make use in our analysis and analyze the whole system. So, these are some of the destructive or non-destructive tests that we normally adopt to understand a masonry system, and thereby we try to characterize or we try to understand what is the present strength of the existing structure.

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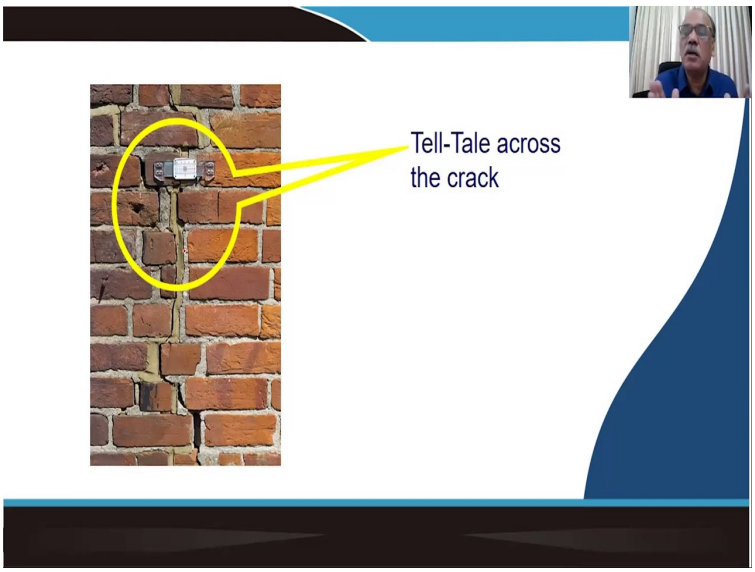


Also, sometimes what happens is if we find some cracks have developed, whether the crack is further widening or the settelment process is on or not, to investigate that we put a glass strip across the crack, which we call as a tell-tale. And this glass strip is monitored. In fact, if cracks, if the crack width is increased then the, it is expected the glass will break because it cannot take in tensile stress. And if there is a small movement, that movement can be recorded on this graphical representation over here.

So, this kind of instrumentations are also being done to understand the movement of the crack or the generation of, or widening of the crack that has developed in service. So, we try to adopt different kinds of tests, different kinds of methodologies to establish that what is happening with the present system, what are the kinds of distresses you have and how these distresses are affecting the present system.

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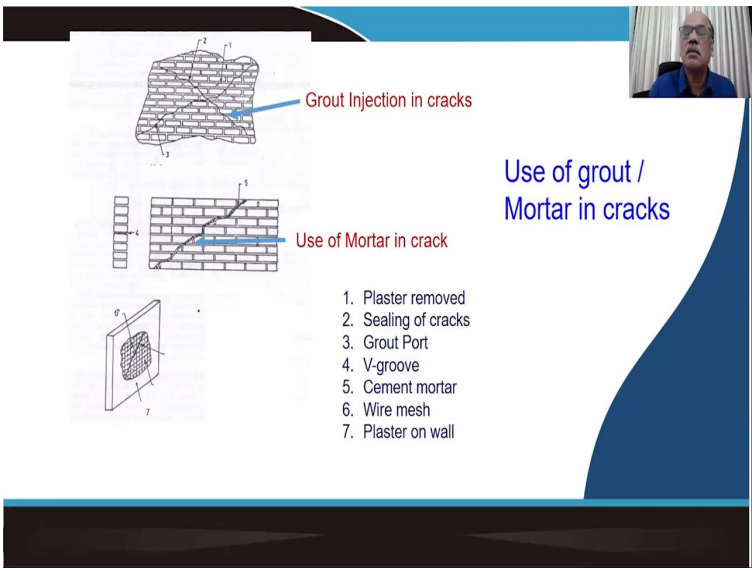


Now, coming to the retrofitting measure, so once you have established, once you have diagnosed that this is the problem, the existing distresses are to be retrofitted. Now, there are certain techniques. One of the techniques is grouting. We can inject cement slurry grouting, and I have spoken about earlier when we spoke about material, we said that we can have cement slurry grouting or we can mix some epoxy into it and modify it, epoxy modified grout can be used, or you can use cements sand mortar, or epoxy modified cement sand mortar if the crack width is long.

So, here it is shown that you have a patch of the wall where the plaster has been removed. Then the cracks which you have seen normally these cracks are sealed with the mortar, and then we put the grouting port at several points through which the cement slurry grout is injected. And we expect that that grout will penetrate through the crack and thereby it will close the crack through this cement slurry grout. So this grouting technique is adopted.

Also, if as I said, if you have a wider crack, normally we try to penetrate the mortar through this crack, so cements sand mortar or epoxy cements sand mortar are inserted with the crack. By making, at the entry point we make a V-groove through which it can be done, and it may be the combinations of the grout and the mortar can be used to seal these cracks.

Then, on to top of this, we normally try to put a kind of a wire mess so that when you will be plastering it, if there are certain movement through these cracks, the wire mesh can take care of that kind of movement and thereby the stresses that will be generated will be taken care of by the wire mesh. And after that, a cover of plaster is provided onto top of these surfaces.

So, this kind of repair technique, let me put these word as, can be adopted in retrofitting a structural system. So, we make use of cement slurry grout, we make use of cements sand mortar, either in that isolated form or modified with the epoxy because where the flexibility in the system, and then we try to repair the system. Mind that these distresses are being repaired using this, alongside that you take care of the root cause of the problem which has caused this kind of distresses and thereby we tackle both the issues together so that the structure is retrofitted in an appropriate manner.

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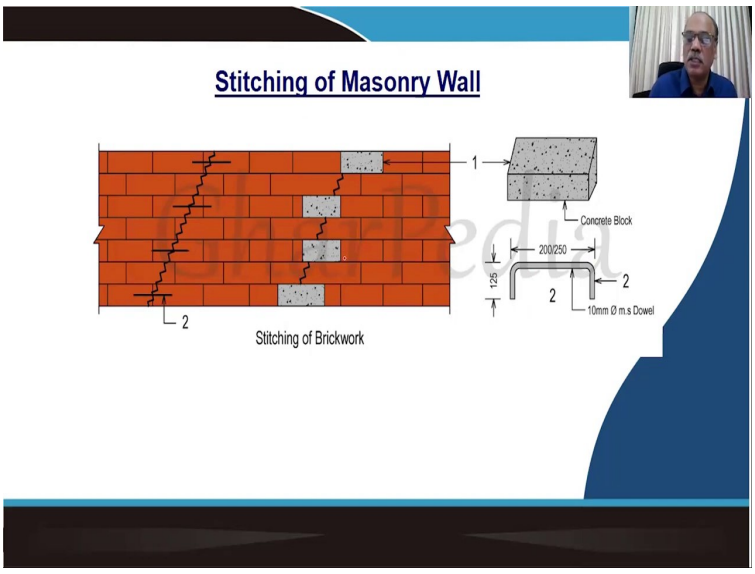


We make use of a technique which we call stitching of the masonry wall. If you have the crack in the wall, across this crack we try to insert an intact element, it could be made out of the concrete, concrete block or even the brick, stronger brick can be inserted so that the crack in the path can get stitched with this.

And also along with this we try to put some kind of iron clamp with a steel rod of 10 or 12 millimeter diameter, we try to put this in the form of a hook which can be placed

across this crack so that the two parts can be kept in position and is not allowed to move further. And this kind of technique we normally call as stitching.

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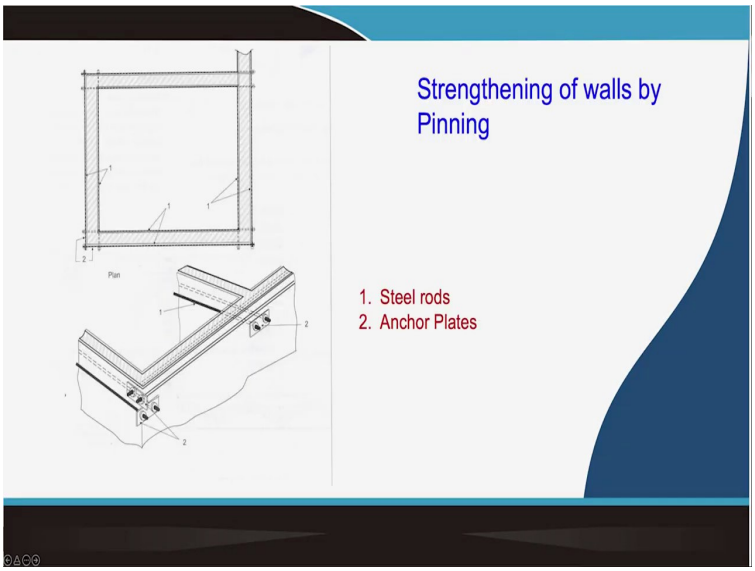


Also we try, many a times we try to strengthen the walls by the action by, of pinning. In this case, the steel rods have been inserted in the wall, and you have, on one side, you have, one, on both sides you have plates, anchor plates, onto top of the anchor plates you have a tightening screw with which you do kind of a pre-stressing in the system. Well, I will talk about more on this particular technique in detail in my next lecture.

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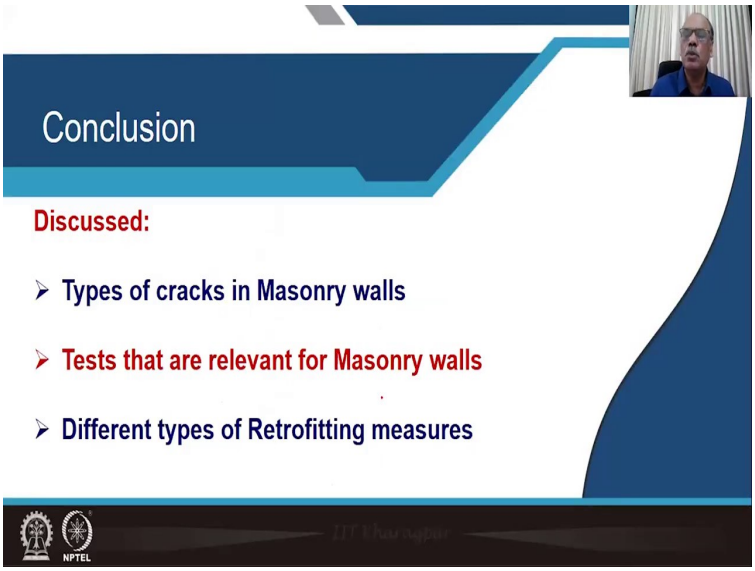

So in this particular lecture, what I wanted to do is that I wanted to show you some kind of cracks which we normally see in case of masonry system, brick masonry walls, and some of the tests which are needed to be carried out to establish certain some of the material properties which are of use to us, and then some of the retrofitting measures that can be adopted so that you get proper retrofitting of the whole structural system.

So, this is what I intended to talk to you. So, we will talk about this, we will continue on this and starting with that meaning of the masonry structural system, and we will see some more techniques that can be adopted so that the masonry structures can be strengthened depending on the kinds of masonry structures that you are treating.

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Well, thank you very much for your attention. So, we will look into it in more greater detail into the next lecture. Thank you. Thank you very much.