Maintenance and Repair of Concrete Structures
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Module No # 03
Lecture No # 14
Strategies and Materials for Surface Repair

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Hi this is the second lecture in the module on strategies and materials for surface repair and in the first lecture we looked at root cause analysis and repair strategies and in this lecture we will be looking at how to select a repair material looking at various type of forces that will act and what are the requirements of a repair material. And then based on those inputs we select the repair material and then in the next lecture we will look at compatibility of the repair material with substrate.

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So, first this selection process itself is very complex because you have to look at various things, what happens during the repair activity? What happens after the repair is done? And so we have to come up with some criteria for selecting the repair materials first thing to look at is what are the requirements set by the owners and engineers or the people who actually build or construct? And then what are the in-service and exposure conditions?

And also what technique you will be adopting to apply the repair material? So, all this have to be looked at and corresponding criteria have to be framed while preparing tender documents for the selection of repair materials. And also we have to look at loading conditions on the repair and substrate materials. If you are talking about a repair material for a bridge as supposed to repair material for a house or building there are 2 different conditions could be very different.

And also for example in the case of bridge you might have an additional feature which is essentially looking at the vibration or the load induced vibrations on the repair and substrate materials. So, all these are very important and then we also have to look at the dimensional changes of repair materials and substrate materials basically looking at the shrinkage, creep and other characteristics and then cured and uncured state how the repair material will behave in the early ages of application or after the application and once the material has cured and then how the moisture condition, temperature, creep, shrinkage etc., or how the material will behave under these various conditions?

Finally, after looking at all this performance requirements and comparing properties of different materials we have to really look at the cost. The cost is also very important and how they perform in the long term not short term but in long term because that is the whole game we have to be good enough to select materials which will actually perform good in long term not just for couple of years after repair. So this is all very important and this is the reason why we think it is actually the selection process itself is very complex.

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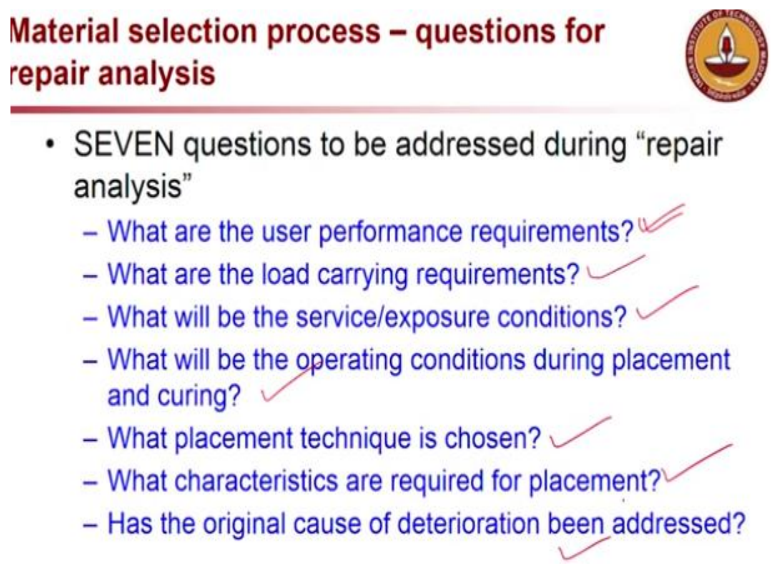

Now how do we streamline this you have to have a set of procedures to come up to simplify this process of material selection? First let us look at some of the questions which you can ask during the analysis of various strategies available. And so far how do you do that? First what are the user performance requirements? and then this are some 7 questions I am going to show you a little bit more details on this questions in the next 3 slides and then what are the load carrying requirements? What will be the exposure conditions or in-service exposure conditions? And what will be the operating condition during placement and curing? That is during the construction.

And what placement technique can be chosen? And what are the characteristics required for placement? And then has the original cost of deterioration being addressed? that is very important to look at because if something went wrong in a structure and you are repairing with the same old materials without really thinking about the root cause and then just doing some repair then the answer to the last question would be no and which is again going to be a problem later on.

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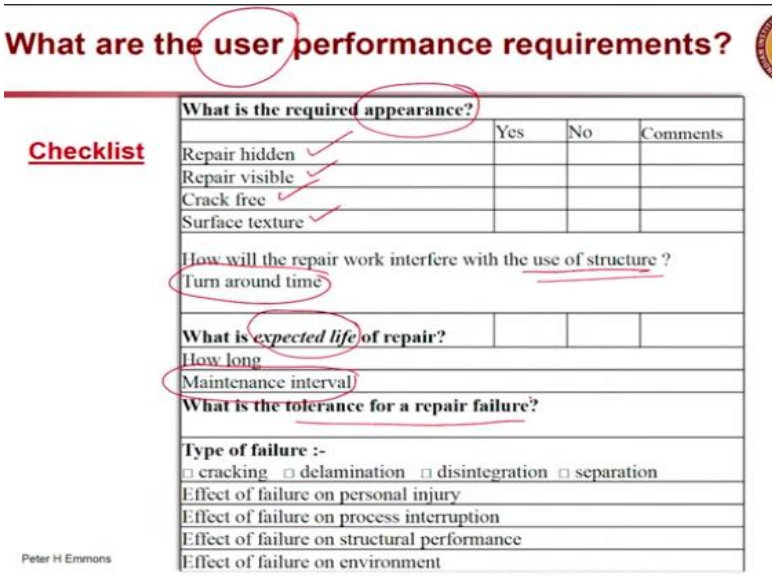

So, let us look at little bit more detail. First question I told in the previous slide was what are the user performance requirements? So look at here, as a user. It is not necessary that user is always a civil engineer. So, there could be anybody so what is the appearance? For example non civil engineers are in particular non material engineer or non-concrete technologist; they would worry about appearance significantly.

So, maybe you will have to make sure that the repair itself is hidden or not visible. Sometimes the people may agree. It is fine to be visible and maybe crack free surface structures. So these are different things which could vary from user to user but when we think about selecting repair materials we should think about putting all these things in perspective so that the end product or the repair at the end is actually meeting the requirement of the user.

So user is the key term here and how will the repair work interfere with the use of the structure? In other words after the repair will the structure be able to; let us say you are talking about a building and where you have a beam and then if you want to repair something, let us say increase the capacity of the beam or something then if you are saying I am going to put a column at the center may be repair will still function but that is not necessary that will actually interfere with the use of the structure.

So that is something which we have to think, the functionality cannot be changed or should not be affected. So again what example I just told was of a structural repair but similar things can be thought also for repair materials. For example if I am talking let us say there is a repair material, if it is releasing toxic gases because why I am saying this is I have been to a building where they used some repair material which was injected into the wall and then people were not able to sit in the room for 2 to 3 months because there are lot of this toxic elements from the repair material was coming into the room and it was not possible to sit in that room.

So you have to think about what are you doing it for and is it going to affect the end user. So that is not a good repair if it is going to affect the end user in an adverse manner. And also you have to look at the turnaround time. How long the repair will take? So you go to a site, do the work and then get out of the site. So what is that? That is what turnaround time is. So how long it takes to complete and transfer the site to the user for using.

Now, what is the expected life in other words durability is it that you want to repair this and then you expect that every 5 years you can actually afford to go and repair again or you want no more repair and one time get it done in a good way at first time itself. So that, we can really say it is a long or durable repair so that means looking at the maintenance interval how frequently you can actually go and maintain? If it is an important structure and then where you do not really want to interfere with the functionality maybe the maintenance interval should be kept as very long.

And what is the tolerance for a repair failure? Means if the repair fails is it really going to affect the structure significantly or the user significantly or some questions like that. So these types of questions should be asked before we select repair materials. So these all information should be there before selecting repair material.

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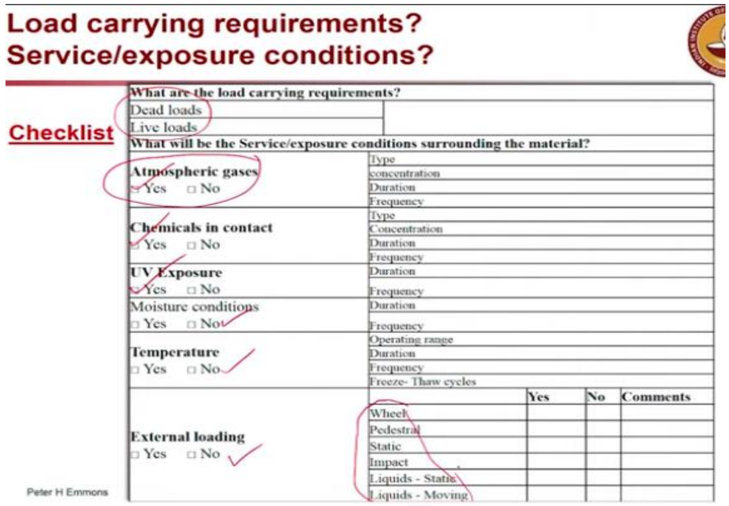

Now, we also have to look at what are the load carrying requirements? In the previous slide we looked at what the user requires. Now here it is more of a structural phenomenon where, what type of loads will come or you need to know what type of loads will be acting on the repair. So we have to look at what is the dead load, live load and that is mechanical load and then also service and exposure condition which is essentially environmental loading.

So, what type of immediate atmosphere is there for the concrete structure? For example if I am talking about a chemical plant then definitely this condition is going to be very important. If we are talking about ammonia plant or any chemical for that matter you have to see what that repair material will be exposed to that is something very important and again chemicals are they going to be in direct contact if we are talking about again a chemical plant where you might spill chemical on floor which is usually the case in food industry or any chemical industry for that matter there will be lot of toxic which will be thrown on to the ground and then you might have some concrete elements also there.

So all these things we have to look at and if you are talking about external exposure; UV exposure is something which is important and what moisture condition and temperature conditions? And if there is any external loading coming then we have to also consider those in particular. This external both mechanical and chemical or environmental loading are included. So this load carrying requirements and basically mechanical and environmental conditions have to be assessed.

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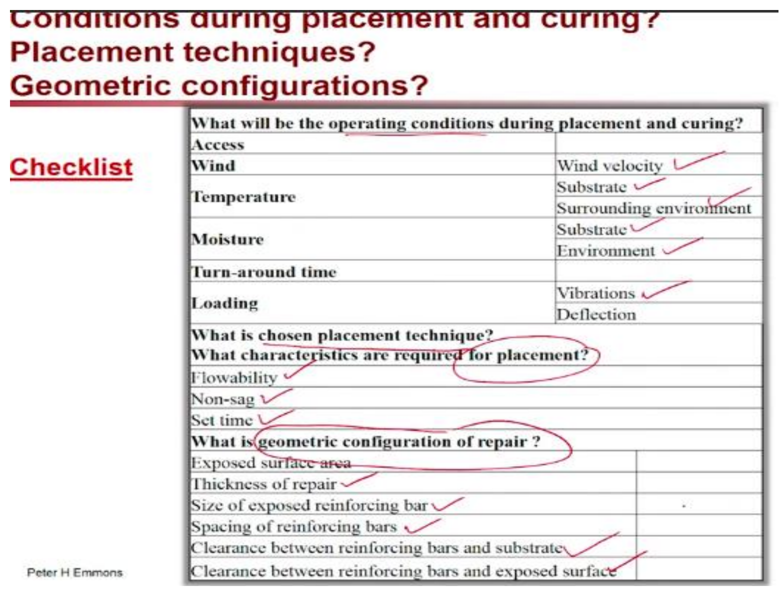

Conditions during placement and curing?
Placement techniques?
Geometric configurations?

Checklist

What will be the operating conditions during placement and curing?	
Access	
Wind	Wind velocity
Temperature	Substrate
	Surrounding environment
Moisture	Substrate
	Environment
Turn-around time	
Loading	Vibrations
	Deflection
What is chosen placement technique?	
What characteristics are required for placement?	
Flowability	
Non-sag	
Set time	
What is geometric configuration of repair ?	
Exposed surface area	
Thickness of repair	
Size of exposed reinforcing bar	
Spacing of reinforcing bars	
Clearance between reinforcing bars and substrate	
Clearance between reinforcing bars and exposed surface	

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And then what about the conditions during placement and curing that means in the early time and then what about the placement techniques? What type of technique should be adopted to place the repair material? And then also looking at geometric configurations, what will be the operating conditions? So for example: access or you know, wind. What is the velocity? Is there any heavy wind conditions?

And then if you are looking at temperature what is that temperature which the concrete substrate is exposed to or experiencing? And what about the immediate environment and is there any significant temperature differential and then if you are talking about moisture again looking at the moisture condition on the substrate and on the ambient air and turnaround time I already discussed in the previous slide and then loading.

If you are talking about a bridge definitely vibration is something which is very important to look at because, you imagine a case where you are actually repairing a bridge structure while the traffic is on, in that case there will be significant vibration and you must sometimes you may not be able to even stop the traffic. So, at least one line will be going on. So, that can induce significant vibration which will dislodge or de-bond the repair material from the substrate.

So, these conditions must be looked at. So what we will have to do in such case maybe a material which will get bonded very fast and in such cases or in other words before the vibratory loads come, you will have to ensure that the bond strength is significantly high. Now, what is the chosen placement technique? So if you have different thing you can place it by hand, you can place it by using a pump. So different techniques we have to look at what is the chosen placement technique?

Now, what characteristics are required for placement? If I am talking about placing repair material, let us say you want to use SCC for placing repair material in a concrete beam which is, let us say you are repairing an auditorium. For example if you have a beam right in the middle of the auditorium which is not easily reachable or even in a girder of a bridge which is also not easy to reach.

So, you will sometimes use concrete pump and if you are using pump, even for repair mortar. If you are using a pump then what are the characteristics of the mortar which is essential to be able to pump that mortar. So, segregation resistance that is very important, you have to be able to handle the viscosity, have a low viscosity. So, all this have to be really thought through different material properties for that particular application.

So for example flowability and it should not sag in first state especially and set time should be reasonable you do not want to wait for too long and another thing is what the geometric configuration of repair is. Exposed surface area, if it is too much or very large surface areas then you have to think about the moisture loss from the repair material or the shrinkage could be high in such cases.

So, all those have to be again thought through. Thickness of the repair, how thick that repair element is, if it is too thin then there may be a high chance of shrinkage and in such cracks. So, how to have sufficient thickness and then or design the material even if it is very thin, design the material in a way that even if it is very thin it will not crack. And size of the exposed reinforcing bar, spacing of the reinforcing bar and clearance between reinforcing bars and substrate that is basically the under cutting which we are talking about and then clearance between reinforcing bars and expose surface that is basically the amount of new repair material which is going to be covering the reinforcement.

So, these different aspects are very important which need to be really thought through before selecting. I just remember one thing, I would like to say that there is a practice now a days that we let the material suppliers to tell us what type of material we should use? I think that is something which is not at all a good thing. As engineers we should be able to think through what the material will experience? What type of stresses? And environmental conditions or exposure conditions the material will be exposed to and we should know in such environmental conditions or such structural loading conditions.

What are the properties that are very crucial for the material to resist damage and deterioration during such cases. And as engineers we should be telling that I want this material and should have these properties and we able to tell measurable parameter. So, set limits with measurable parameters, it is not always good to say something should be high or low and all that. You should be able to come up with a specific range of values for the parameter.

For example, if I am talking shrinkage resistance. I want something which is very good or having high resistance against shrinkage. I should be able to say what is the upper limit and lower limit or in quantitative terms. We cannot just simply say it should be highly resistant against shrinkage; high for me may not be high for somebody else. So you have to be able to give objective specifications in the contracts very clearly when you should say what are the upper and lower limits?

And if you are saying the upper and lower limit, you have to really think through the problem then only you will be able to say. So in that case you will really learn about the subject and then engineers will be able to dictate what is required to the supplier and then they provide that supplier rather than letting the suppliers decide on what is required.

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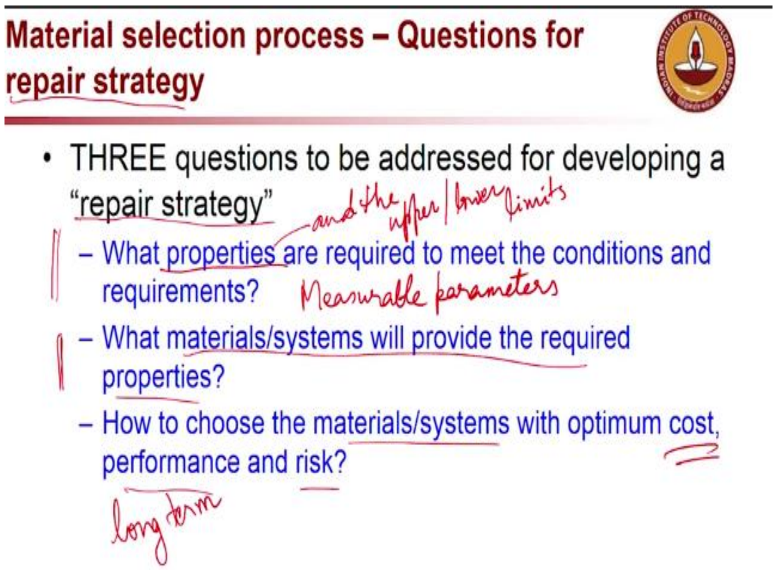

Now, material selection process questions for repair strategy. Three questions main things it is again in similar lines what we already discussed but put it in a slightly different way because here we are talking about the strategy. So what properties are required to meet the conditions and requirements it is exactly what I just mentioned. Engineer should be able to decide on the properties and their magnitude to meet the condition requirement. I am just going to write here and the magnitude or upper and lower limits.

And also another thing which is very important is when we say these properties they should be measureable parameters. Because whatever we say this, when if it is in a lose terms then it is easy for anybody to interpret in different way and then the end result is not always as expected. So when you put things as black and white. I want to measure this property or this parameter and then these are the numbers or the observed results should be in this particular range.

So things are very clear and so when you set a demand to the supplier or the manufacturer they will actually meet the requirements. You know, most of the time we do not tell exactly what we need. So they just try to sell what they have. So this is again, what materials or systems will provide the required. So this is again part of the selection and how to choose materials and systems with optimum cost, performance, risk and especially when I say performance long term performance is something very important.

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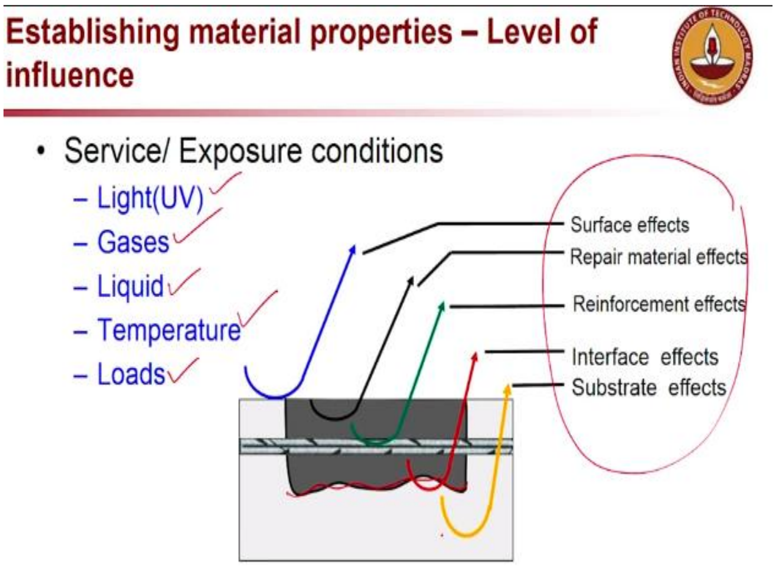

Now, level of influence if you are talking about different service or exposure conditions like I said exposure to the sunlight you can think about UV exposure if it is exposed to chemicals like gases or liquid especially it is very important when we talk about either a pipe line or chemical plant where the concrete elements might get exposed to different gases or a liquid and temperature depending on whether it is an outdoor environment or an indoor environment or if it is a factory where, local temperature conditions are slightly different from the ambient environment conditions.

And then of course, structural loading is also very important. Now, here you can look at the picture here. If surface defects are very important to handle then you can provide surface coating so that let us say level 1 and then the repair material effects. If we are talking about this black arrow here which is again talking about the repair material itself and if you are talking about the reinforcement effects the corrosion of the reinforcement.

Then something can be done at that interface between reinforcement and the steel and also interface between the repair material and the substrate that is the red arrow showing this region here. So that is essentially looking at the bond between the repair material and the substrate and also looking at the effect of a substrate itself whether that is itself is still shrinking or expanding or whatever damage happens to the substrate itself.

So these are the different exposure conditions and different strategies adopted or different systems adopted for repair. So, these are the different systems shown in the sketch.

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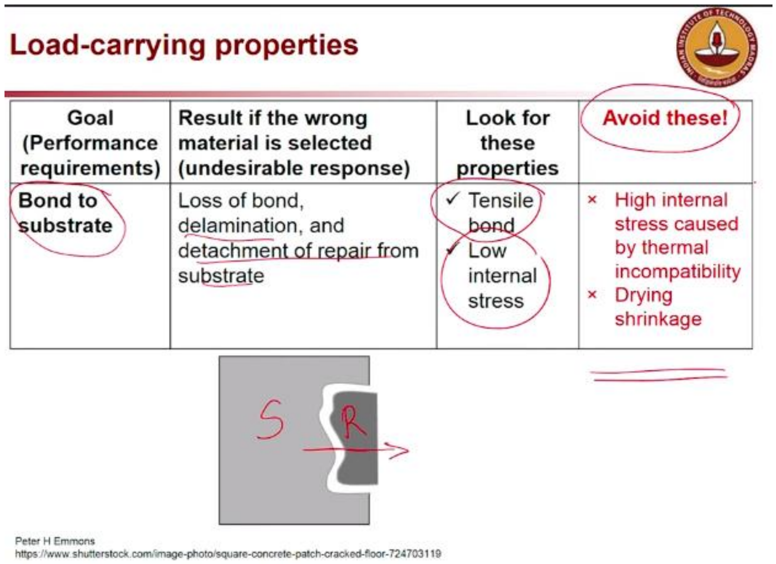

Now for the load carrying properties, bond to substrate seems to be very important as you see in the picture at the bottom, you can see that the substrate here and then repair material here. If the repair material shrinks definitely there is a significant shear stress acting between the substrate and the repair material and it will shrink and then if there is no other mechanical interlocking effect it will just easily come out and flick off from the substrate and it will delaminate.

And detachment of the repair from the substrate so both is same thing. So that is not something which is expected. So, if you want to prevent this type of failure what are the properties you have to look for? Make sure that there is a good tensile bond because if the tensile bond is very good it will not move in this direction; the movement in that direction will not happen and also keep the internal stresses low that means here the internal stresses mainly, let us say one example could be shrinkage.

So, if we can have the repair material which has a very high resistance against the shrinkage then the shrinkage stresses will be very low. So, effectively you will not have this kind of problem. So again the fourth column here, this one it is essentially saying what are the things that we should look to avoid this type of problem? So high internal stress caused by thermal incompatibility should be avoided and drying shrinkage should be avoided. That means this material should have high resistance against the shrinkage and high resistance against the thermal volume changes due to thermal effects.

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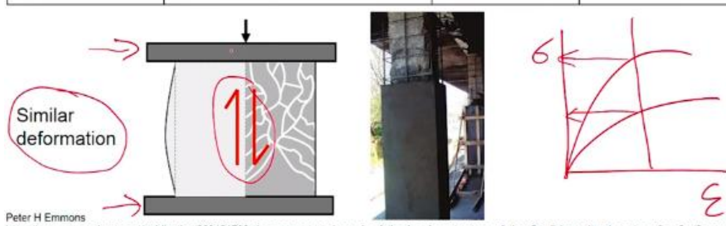
Load-carrying properties (contd.)

Goal (Performance requirements)	Result if the wrong material is selected (undesirable response)	Look for these properties	Avoid these!
Load carrying capacity as intended by engineer	Does not carry load as anticipated, overstressing either substrate or repair material	✓ Equal modulus of elasticity with substrate	× Low or high modulus of elasticity compared to substrate



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https://www.researchgate.net/publication/283121702_Assessment_and_repair_of_the_bearing_structure_of_the_Gradiska_cultural_centre_after_fire/figures?lo=1

Now, same thing continuing load carrying capacity as intended by the engineer and then the question is what will happen if a wrong material is selected? And what happens in this picture as it is shown on the bottom? You can see that there is dissimilar deformation means in this particular case this plate and this is another plate. If the top and bottom if the entire column is deforming to the same level that is what I have marked here as similar deformation then what we can say is that the stress experienced by depending on this stress-strain behavior of the 2 materials.

So, let us say you have 2 materials here stress-strain behavior is something like this. And if they have similar deformation, for example assume that it is something like this, if it is stress-strain graph. If they have similar deformation and of course we are talking about the entire structure here but still for the understanding purpose we can say, when I say similar deformation I am going to assume it as same strain level and then what I can see here is 2 materials will be actually experiencing different stress.

So, that means at the same loading condition 2 materials will experience different stress and one might be still in its elastic region while the other is already started cracking and all that.

So, this is something which we have to think about making sure that either the repair material or the substrate both of them should be kept within the elastic range and so that way we can actually avoid this significant increase in the shear between the materials also.

Anyway point is both repair and substrate should be maintained within that elastic limit the stress applied for both should be within the elastic limit..

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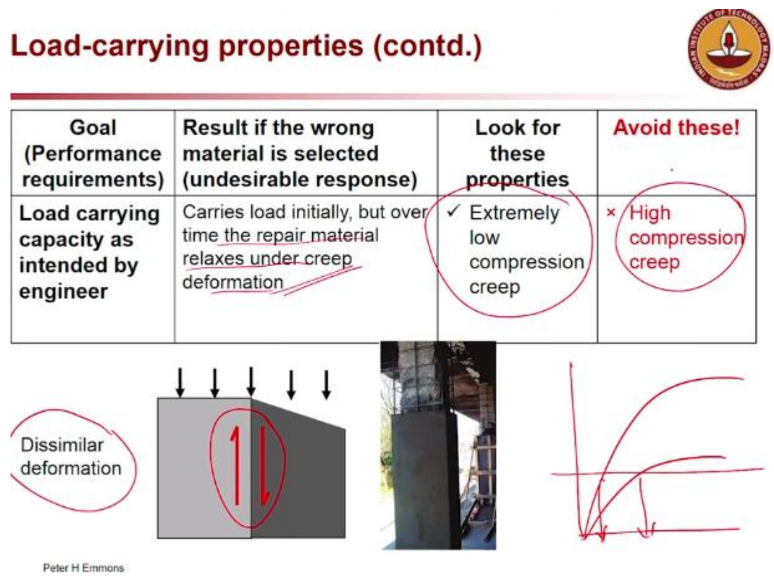

Like in the previous one we showed that there is a stiff plate on the top and bottom. Well in this case if the support or if the top and bottom are not very stiff and then what will happen is, there is dissimilar deformation in the substrate and the repair material or the 2 materials and in such case, if I redraw that graph, let us say you have 2 materials which are having different stress-strain behavior.

So, if it is a dissimilar deformation that means probably at the same load you might have something like this at the same load condition you will have different strains experienced by the 2 different materials system. Now that also might when I say two different strain level that means that there could be some shear stress developed between the 2 materials and which can also create problems and this main reason could be actually due to the creep effects.

And over a period of time the repair material can relax under creep deformation. Now, what should we look for? We should look for extremely low compression creep that means that deformation will be very minimal so that still both the materials will have similar strain. So high compression creep should be avoided we have to get used materials which are very resistance against the creep deformation.

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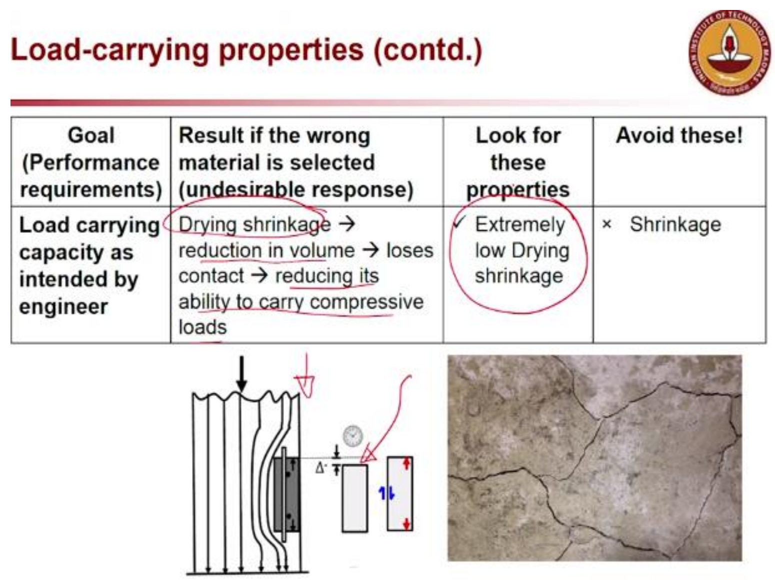

Now, this is an example again we looked at drying shrinkage in the previous slides. If the drying shrinkage is significant eventually that means there is a significant reduction in the volume of the repair material and which will eventually leads to the loss of contact between the repair material and the substrate which essentially reduces the ability to carry compressive load. Imagine this case here where the load is coming from the top down and then if there is a disjoint like this shown here. If the repair material is shrinking then it is not able to transfer the load from top to bottom.

So that is not something which is desirable. So the repair material should be able to transfer the load. So, we can provide a rebar in other words modify the system by introducing a rebar which then will help in transferring the load directly from top to bottom through the repair material region. So, how do we select when we have a problem like this make sure that drying shrinkage is very lows.

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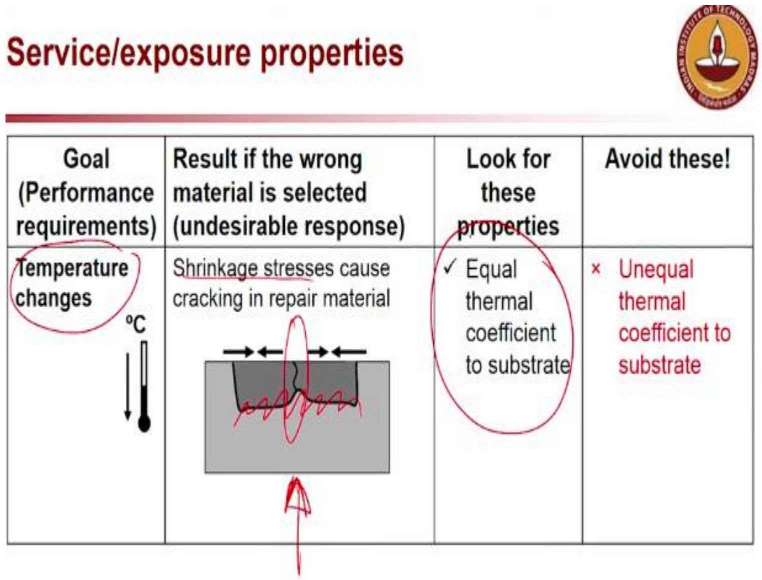

And if you are talking about temperature changes again shrinkage stresses can happen, if there is temperature decrease then it is going to shrink any material in general will shrink and that can lead to cracks like this shown here, the repair material itself cracks. And in the previous picture it was clear here in this bottom right you can see that material is cracking that is mainly because there is shrinkage under restrain.

And here the restrain is provided by this surface here and so half of the material is shrinking to one side and the other half is shrinking to the other side leaving a crack right at the center. Now, how do we prevent, you get materials which are having equal coefficient of thermal expansion as compared to that of the repair material and that of the concrete substrate should be similar then you will not have any issues like this..

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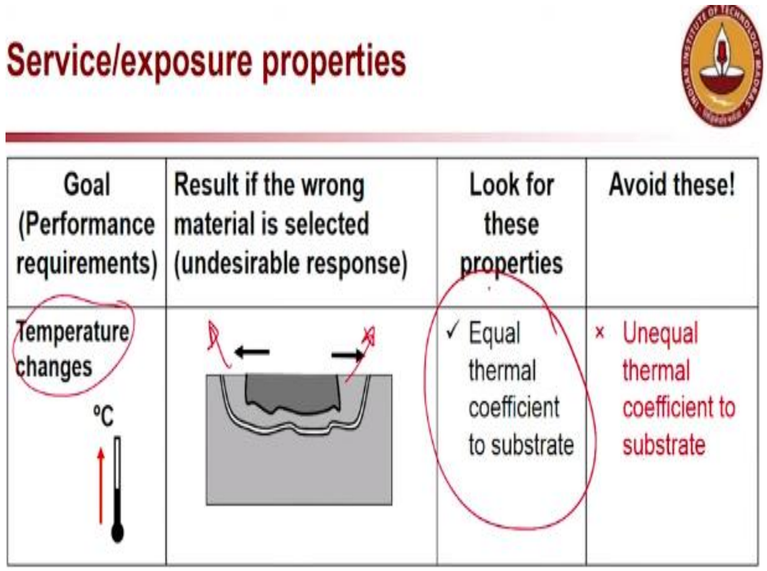

Now, if temperature changes again if we are talking about increase in temperature here in the previous slide we were talking about decrease in temperature. Here when temperature is increasing the repair material might expand and this expansion will induce stresses on to the surrounding substrate. And when it reaches a point where substrate cannot take any more compressive load or compressive stress which is coming from this. So what will happen? It will pop out.

And then the concrete will again get damaged. Now, again same theory can be used that is mainly for a material which has similar coefficient of thermal expansion as compared to the substrate.

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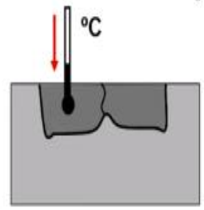
Service/exposure properties (contd.)

Goal (Performance requirements)	Result if the wrong material is selected (undesirable response)	Look for these properties	Avoid these!
Temperature changes in repair material during placement	Shrinkage stresses in repair material causes cracking 	✓ Low exotherm during placement and cure	× High exotherm during placement and cure

Now, here we are talking about temperature changes in repair material during placement. In the previous 2 slides we were talking about after the placement even during placement this can happen if the temperature is decreasing, the material will shrink again how can we handle that because use a low exotherm during placement and curing that means the rate of release of heat should be low and that will help in keeping the material or help in preventing the materials from cracking.

And we have discussed this also in the earlier slides on thermal cracking etc., so, we want the repair material to react or hydrate slowly without releasing much heat in the very beginning. So slow and steady wins the race so this is the idea or strategy here is to use materials which release less heat.

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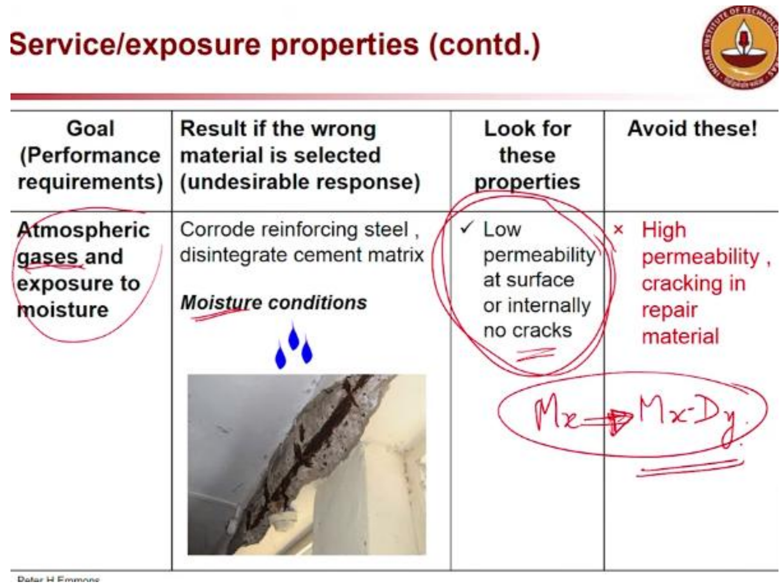

Now, atmospheric gases and exposure to moisture let us say talking about chemical plant or where gases present in the near surface of the concrete could actually lead to corrosion. And also moisture condition if it is very wet for example if we are talking about a power plant where you might have in the cooling tower you use salt water and always the structure is entirely in wet condition.

So, this has to be looked at very important and how we handle such case because we know at the time of construction itself we know that the exposure condition is going to be like this. There will be moisture and salt water is going to be used in the cooling tower. So, we know what the exposure conditions are going to be and we have to prevent those elements like moisture and these chemicals from entering into the concrete.

So, how we have to go for a low permeability concrete especially at the surface you cannot allow the concrete to enter or even there should be no cracks. But main thing is have a concrete which is highly impermeable. It is not the strength always that matters when we talk about durability. We already discussed it but I want to emphasize that we know even today many people when we talk about concrete they talk about M something and what I am thinking is we should start thinking about, M if it is Mx then we should be moving from here to Mx Dy or the D I am thinking this is the strategy which we should have.

Let us forget about just talking about M concrete like M30, M40 that kind of concrete we should start thinking about adding at least one durability parameter when we talk about selecting concrete it is very important if we are talking about structures which are exposed to severe environmental or exposure conditions. I will tell you one example, I know there are cases where cooling towers are made and then this particular example I am talking cooling tower which is made with about 50 Crores of rupees and then within about; I think 6 or 7 years going for a repair which again cost about 30 Crores so that is something insane like too much of money to be spent

And at the time of construction it is not that we did not know about durability and corrosion etc., so it is high time that when we talk about especially large infrastructure projects we must start thinking about enforcing durability parameters or enforcing the use of this concrete which can be really give long lasting performance. So again emphasizing it is time for us to start thinking about MxDy concretes not just concretes specified as.

Because most structural engineers still think about f_{ck} alone and that is not something which is advisable to go for, when we talk about long term performance. We must introduce one of the durability parameters. So which can be then correlated ideally it is diffusion coefficient but we cannot really test diffusion coefficient always so you can get other parameters which can then be correlated to the diffusion coefficient.

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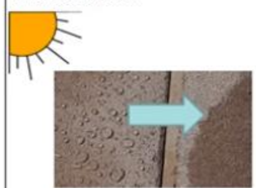
Service/exposure properties (contd.)

Goal (Performance requirements)	Result if the wrong material is selected (undesirable response)	Look for these properties	Avoid these!
UV exposure	Change in mechanical properties of repair material, changes to modulus of elasticity, waterproofing characteristics 	✓ High UV resistance at surface	× Low UV resistance

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Now UV exposure, this is an important consideration when we think about repair materials which include a lot of polymers. For example polymer modified mortar or integral water proofing chemicals, because sometimes this materials if you are talking about water proofing in most cases if you are talking about rain water like water tightness against rain then definitely that element is exposed to the sun light.

And over a period of time if that chemical which is the polymer, which is inside the concrete if that degrades then it will not have the same function as expected. So, when you talk about exterior elements and if you are talking about materials with significant amount of polymers in it. We must check the resistance of that material system against UV exposure. So, avoid materials with low UV resistance or go for materials with high UV resistance.

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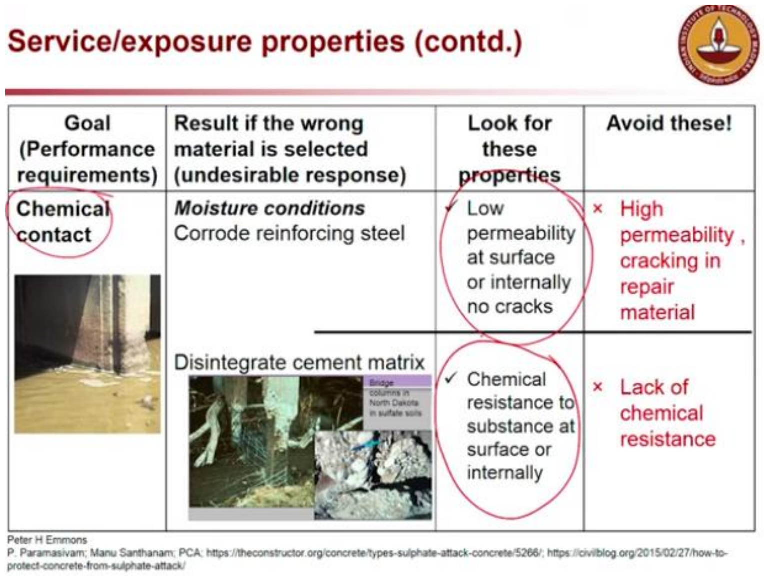

Now, chemical contact in factories or even if you are talking about effluents which are coming from factories so there will be concrete elements which get in direct contact with either the water body or water body which is rich in other chemicals and effluents. And which will eventually damage the concrete cover, remove the concrete cover and then the steel inside just gets exposed and then starts corroding. Again here also the idea is go for low permeability or highly impermeable concrete cover.

And also look at the chemical resistances of the concrete cover which in depth we discussed in the previous slides on sulphate attack and etc., where we were looking at chemical resistance of the concrete.

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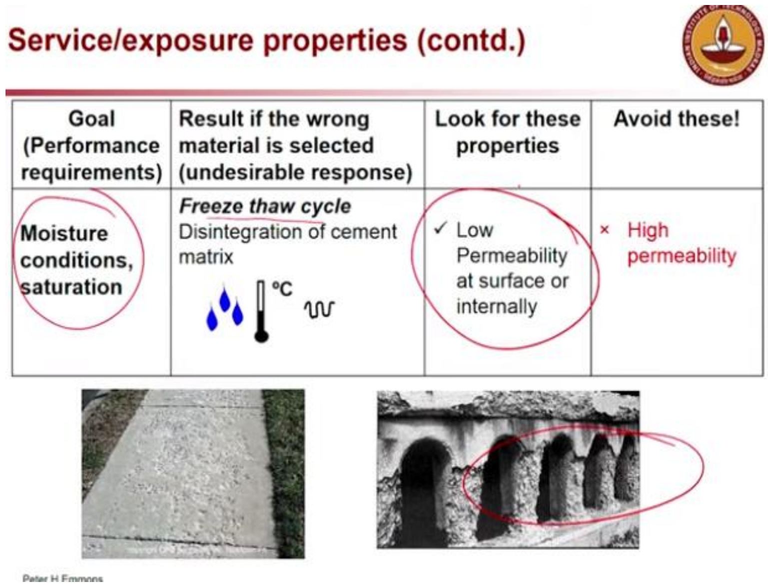

And we also discussed about freeze-thaw and here looking at moisture conditions and saturation and main damage mechanism here is freeze-thaw and that can disintegrate this concrete layer by layer which over a period of time, can remove or degrade significant amount of cover concrete as you see in the photograph here. Again, how to handle this? Go for a low permeability concrete or highly impermeable concrete.

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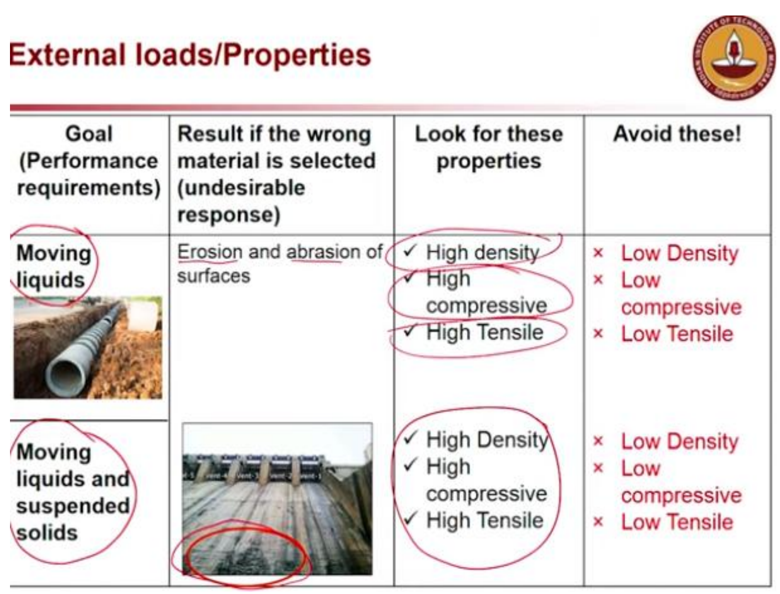

Now let us look at structures or systems where you have moving liquids let us say like, water pipelines or if you have moving liquids and suspended solids like it happens in hydraulic structures or dams as you see in the picture here the top left I have shown a picture of a concrete pipeline and in the bottom right I am showing a picture where the dams spill way where you can see significant erosion at the bottom where there is; let us say you have heavy rain or something and then depending on how much suspended particles are there in the water.

If there is lot of suspended particles then a significant damage can happen to the concrete surfaces especially in hydraulic structures. So, how do we handle this? High density concrete, high compressive strength and high tensile strength so in both these cases that is the strategy. So, here also high density compressive strength and tensile strength. So basically the concrete should be very dense and at the same time this strength properties also should be very good because it is essentially to deal with liquid and suspended particles abrading and eroding surfaces.

And more details on this were covered in the exclusive lecture on this thing which is erosion and abrasion.

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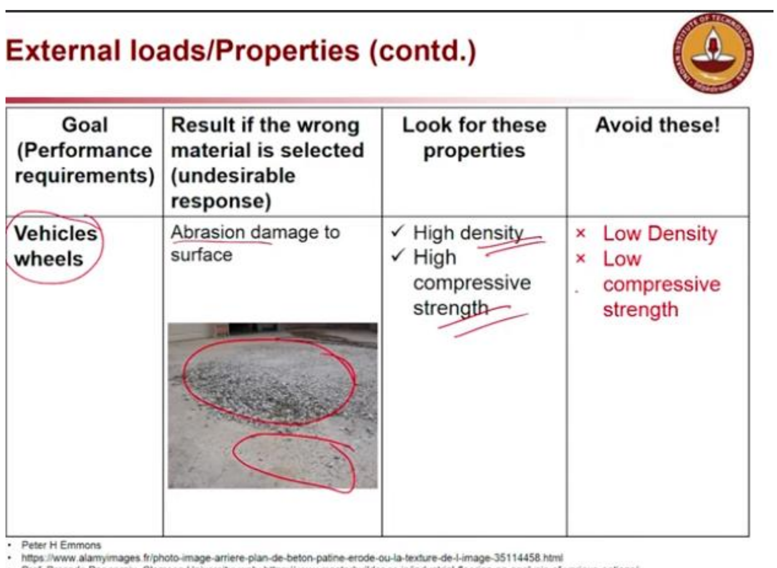

Now, abrasion when we talk about wheels on road structures or even warehouses where you will have heavy equipment movement on the concrete surface and because of the heavy load and traction you can experience significant abrasion damage to the concrete surface. You see here in this picture. You can see this portion is slightly getting damaged and this significant loss in the other portion of the concrete which is shown here.

Again go for high density and high compressive strength. So, density and compressive strength are the key for ensuring this kind of damage does not happen and at the same time we can in detail lecture on this we discussed that there are many other things also which we look at where basically we look at the size of the aggregate and the strength and how much is the paste content different things we looked at and it is possible and also looking at smoothness of the surface especially when you talk about erosion or cavitation.

So, all this have been discussed in detail and I will request you to actually when you look at 1 PPT if there are any connecting images or principles please go back and then look at the other videos also that will help you to really understand the science behind and then to become better engineer.

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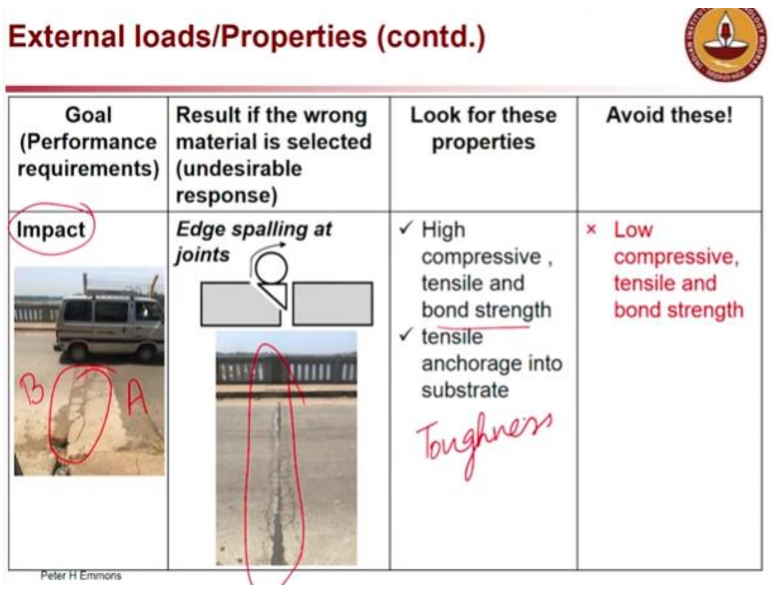

And then if you are talking about impact load, this is an example where you can see very clearly on the right side this bitumen surface is the approach road for a bridge and this is on the left side of the bridge. So this is the approach road and this is the bridge and then you can see very clearly significant cracking at that particular expansion joint there and then this picture also you can see that there is an expansion point and significant cracking along the expansion joint.

Why this is happening? Mainly because the material which is used is very brittle material or in other words the toughness of the material is not very high in this particular case if they were using a fiber reinforced concrete, for example, this much cracking would not have happened. So you have to really look at how much energy the material can absorb or toughness of the material is something very important to look at.

So in the specifications itself when you talk about this expansion joints we should actually start talking about introducing a material at the expansion joint which is not just having high compressive strength but at the same time having high bond strength as mentioned here and at the same time toughness.

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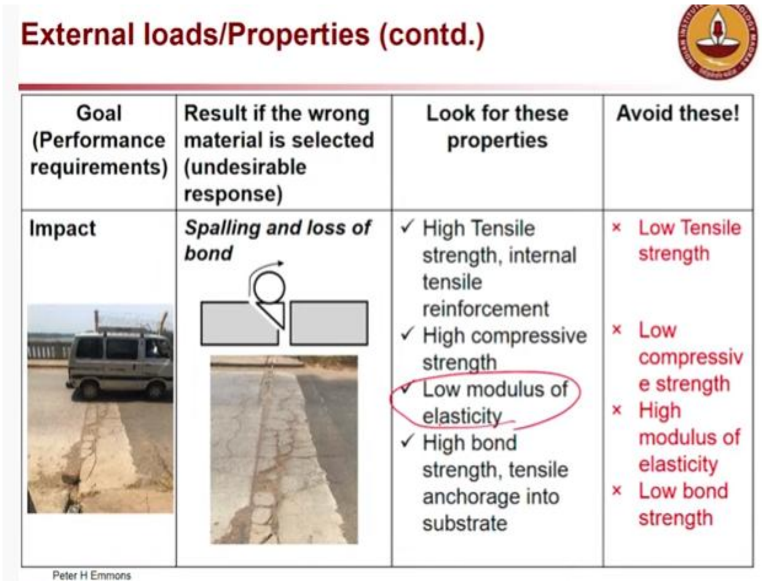

So in the long run the system will perform better without much of cracking. This are similar pictures again here we are talking still impact and then additional parameters we have mentioned here, low modulus of elasticity because you want the material not to develop significant stress even if the deformation is more but within the elastic range.

So, it is very important to consider all these parameters when we talk about. So we have a practice of just looking at only compressive strength when we talk about concrete. It is high time that we change it and we have to really think about what are the specific type of loading which is acting on the concrete material and how do we prevent this kind of cracking or damage. Provide that concrete which will have ability to resist those kind of loads.

In other words here, if we were talking about impact load or fatigue load you have to have a material, concrete should have high resistance against the impact load and fatigue load. So, highly tough concrete must be used.

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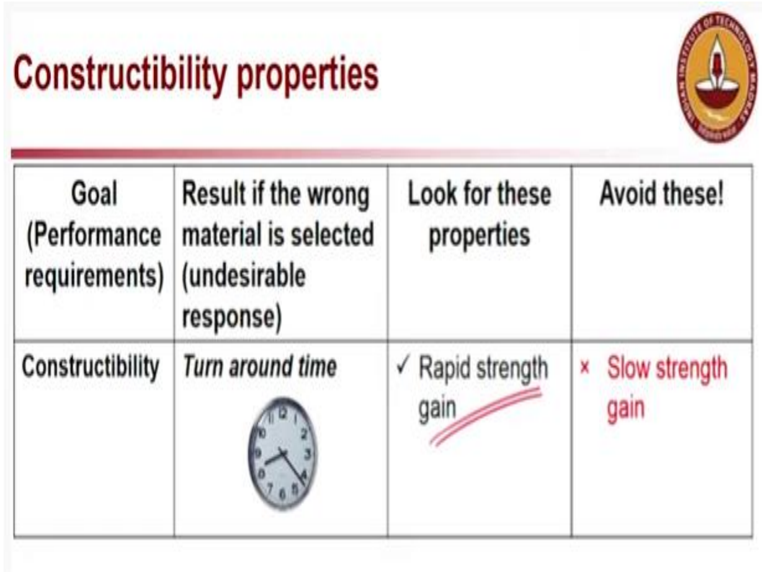

Of course turnaround time is very important especially when we talk about construction at let us say you are talking about construction in a city center and there where you really cannot close the traffic for long period of time. So, if I can get 6 hours of time from mid night till early morning when people are sleeping so we can actually get the construction done and by the time, the traffic is on in the morning the structure already have sufficient strength.

So, rapid strength gain is very important in such cases. So special cement has to be used so that the concrete can really gain strength and even users will not even know that repair where done, that is how good the work should be.

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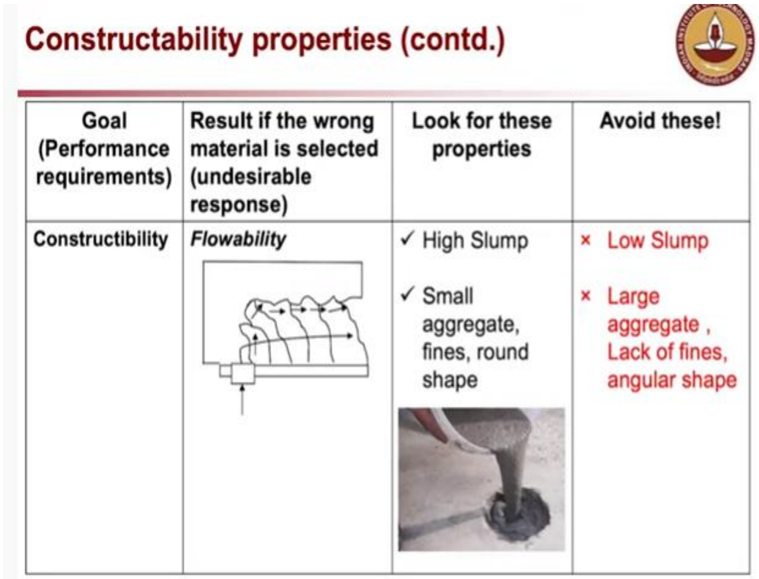

Constructability properties (contd.)

Goal (Performance requirements)	Result if the wrong material is selected (undesirable response)	Look for these properties	Avoid these!
Constructibility	*Flowability*	✓ High Slump ✓ Small aggregate, fines, round shape	× Low Slump × Large aggregate , Lack of fines, angular shape

So let us look at one more property of constructability which is flowability, in this case in the sketch shown here you can see that there is a form work. Imagine this is a case of beam repair, you have a form work here and then you are pumping from the bottom so you pump like this. This is the inlet, you pump like this and then the repair material is supposed to go in and then fill this spaces inside the form work.

Now, this material if it has to really fill it up it has to be flowable material and not I mean depending on the case, sometimes you do not want too much flow. So whatever is the required flow that has to be decided earlier and material should have that required flow properties. How can we achieve? Provide a material which is having high slump.

But also at the same time with low segregation. I am going to write here high slump, low segregation this is also very important parameter and how do we usually achieve this? Use small aggregates, fines and round shaped aggregates so that the material flows very well.

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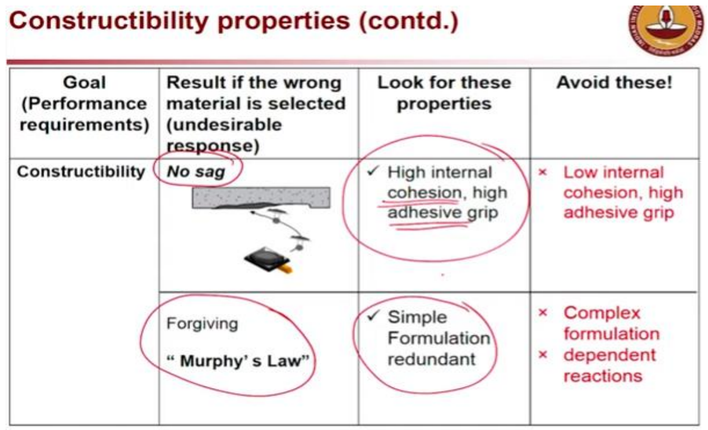

Constructibility properties (contd.)

Goal (Performance requirements)	Result if the wrong material is selected (undesirable response)	Look for these properties	Avoid these!
Constructibility	No sag	✓ High internal cohesion, high adhesive grip	× Low internal cohesion, high adhesive grip
	Forgiving " Murphy' s Law"	✓ Simple Formulation redundant	× Complex formulation × dependent reactions

And another property which is sometimes required is constructability without there should not be significant sag. In other words in such cases we usually go for a material which has high cohesive forces or the cohesion is very high and at the same time, adhesion which is the bond between the repair material and the substrate is also very high. An example of this could be something where imagine a case where you have a roof and then you are actually doing the patch repair in the roof.

So, where you need a material which will actually stick to the roof and work against the gravitational force. So it has to enter that weight of the mortar material itself might be high but it has to actually stick to the existing substrate and so you need actually have a material which has high cohesion and high adhesive bond between the repair material and the substrate.

Now, one more thing I want to mention here is Murphy's Law, "if something can go wrong, it will go wrong" that's what is Murphy's Law and hence it is always better go for a material which is relatively simpler. Simpler formulation is always better where the dependency like something. You know if you are depending on 5 different things for a material to perform, one of them if it goes bad then may be the other 4 will actually help and this have to be thought through.

And you have to think and take, all precautionary measures so that things will not go wrong and your repair will perform good.

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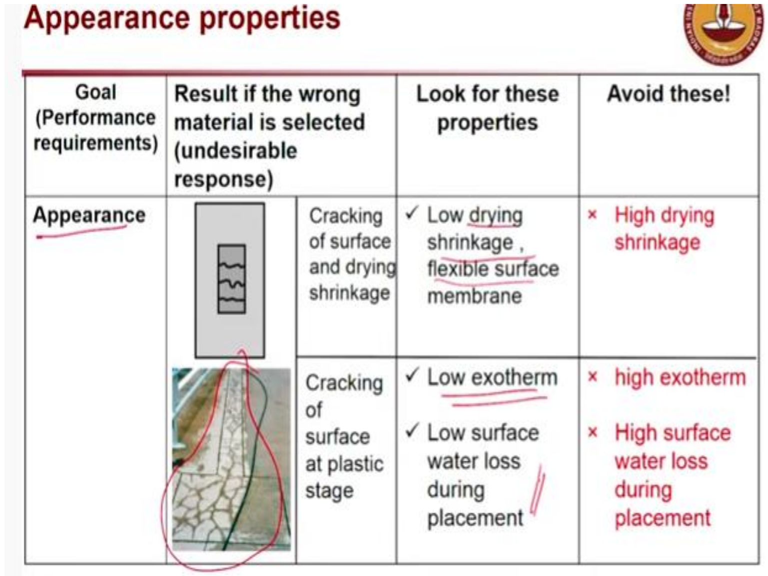

Again lastly appearance is also very important, you see this repair here, this all shrunk and crack like, you can see very clearly map cracking so this particular region is now ready for removal. So, this is something happening just because of the drying shrinkage. If you are replacing you have to go for a material which is highly resistant against drying shrinkage and sufficient flexibility so that it bends but rather than getting cracked.

Or in other words the ductile material would be better than a very brittle material and also low exotherm that means in the early stages, when the repair material has not developed sufficient strength, there should not be significant thermal strains so it is always better to have a material which reacts slowly and releases low heat in the beginning and at the end you get a good product. And water loss during placement basically the evaporation should be prevented or plastic shrinking is what we are talking there.

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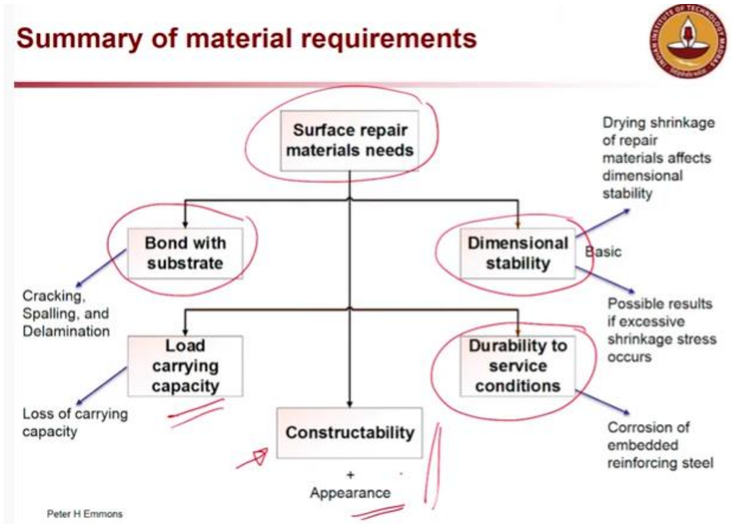

Now summary we have to look at different needs of the surface repair and then how do we select? First we have to look at bond with substrate is very important to consider. And load carrying capacity is very important to consider. What are the different types of loads acting static load, live load and also vibratory type or impact load all these have to be looked at fatigue all this have to looked at and then make sure that the repair material has sufficient ability to resist such loads.

It is not only compressive strength which need to be looked at there are other parameters also should be looked at. Dimensional stability mainly talking about shrinkage either due to the chemical actions themselves or due to the volume change due to thermal effects or due to the loss of moisture or shrinkage. And then also durability conditions is very important because once the concrete or the repair materials starts de-bonding or cracking then definitely the external elements will enter the concrete and then eventually leading to corrosion.

Now constructability and appearance, so let us say you have decided a material which has all these properties and but it is not easy to place that concrete then again it is not a good choice. So we must think about how to place the concrete, so think about the workers at site their knowledge level, the workman ship available all this have to be thought through and then only we should select I mean during the selection process that is something very important to think about constructability. And at the end user want the structure to look good so the repair system should also be able to provide a good appearance for the structure.

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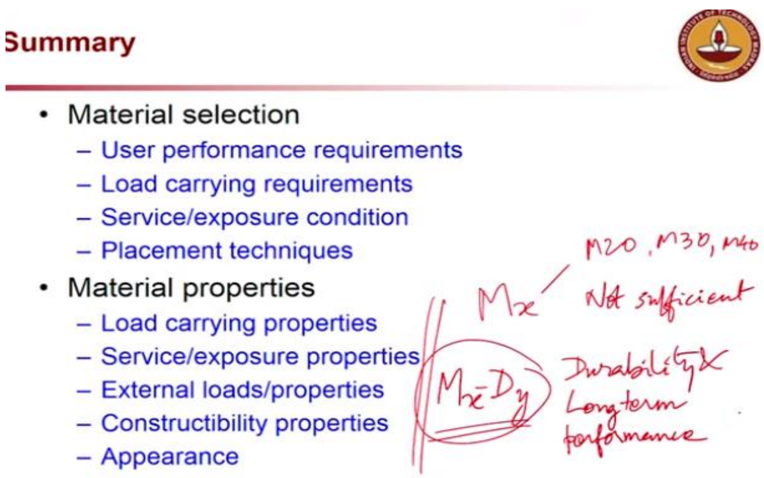

So, we talked about user performance requirement, load carrying requirements and service and exposure conditions and also placement techniques while selecting the materials. Also looked at different properties that are very important for the materials. Again let me emphasize 2 things, it is properties when we talk about it is not only the strength when we talk about only strength we talk about Mx type concrete let us say M20, M30 something like that M20, M30 and M40 something like this.

But this is not sufficient, we have to think about MxDy type concretes and then Dy is basically looking at the durability parameters which will reflect the durability of the concrete and D stands for durability here. So whenever we talk about M something concrete we should also start thinking about MxDy concrete. And introducing a new term here but that is something very interesting and hope this will make us think little bit more deep into or more deep when we think about selecting materials and thinking about various properties of the materials.

And this durability is not just talking about chloride ingress or carbonation. I am saying even fatigue resistance, even toughness all these things which really lead to the long term performance of the structural system that is very important. And so we have to think about this MxDy concrete and D stands for durability and let us say long term performance which sometimes let us shrinkage, long term shrinkage, fatigue all those parameters have to be looked at not just strength. I think that is the key point which I would like to state in this lecture let us start thinking about MxDy concrete.

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These are the references which we used and thank you for listening.