**Basic Construction Materials**
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**Lecture - 20**
**Stone, Brick and Mortar - Part 3**

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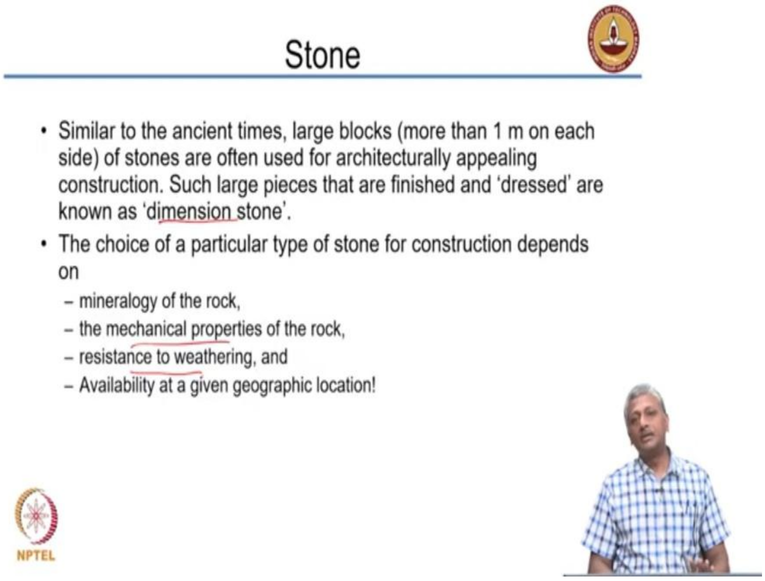


Having talked about basic understanding of structure of bricks and understanding what type of integration processes happen in bricks, let's now look at stone, which we consider to be a more natural material, because bricks anyway you take natural soil and then you mould it and texture it and then dry and burn it. In the case of stone, you extract it and use it as such. You may be dressing it to a certain size or shape. So the stone is quite different as compared to a brick in that perspective.

When we try to use stone in very large blocks, typically of the size one meter or more, a lot of these large scale buildings like for example, if you consider the Old Parliament House that is there in New Delhi and many of the structures that are there in the capital which form the ministries and so on, Rashtrapathi Bhavan for instance, many of these are actually made with very large blocks of stone and these blocks of stone are called dimension stone, 1 meter type size of stone blocks which are used for construction. These are called dimension stone.

Now, of course, people started realising that the productivity has improved a lot more by reducing the size of the blocks. If you think about the oldest structures that you can imagine in stone, like the pyramids of Egypt, the stone blocks that are massive, they are a few meters in size and it must have taken quite a bit of effort from the workers to actually carry this and put this in place. But today, we realized that we can actually bring in a lot more advantages of using smaller blocks and putting them together in different patterns to make the construction possible. Increasingly, we started reducing the sizes of stone blocks, making it easier to handle by workers on the site, so that we can actually impart the same characteristics and at the same time we cut down the size.

Even many of our temples and old forts, you can see that the stone blocks that have been used are very large and those are called dimension stones. Now for that to be possible, you should have a very good source of the stone available, where you can actually extract these stones in such large sizes. However, as the stone quarry has become more and more used or utilized, you cannot really find large chunks of such huge blocks of stone available. So you need to work with smaller blocks and dress them to size before using them in construction.

How do you decide on what type of stone to use? There are various factors that govern the choice of a particular stone for construction. First is the mineralogy of the rock. That is, what is the geological type of the rock? Is it a granite? Is it limestone? Is it a quartzite? Is it a sandstone? Now for obvious reasons, you will also restrict the usage of the stone to what is available in the local area. For example, if you are down in the south, in most cases you will get granite quite easily available. If you are in Andhra Pradesh or in Tamil Nadu, you will see a lot of granite being used for the large monumental structures. If you go to Kerala as I said earlier, laterite is quite popular.

So, the availability is a primary deciding factor for using a particular type of stone. But nevertheless, you also have to be worried about the engineering properties that are made possible by the specific mineralogy of the rock.

The other, mechanical properties and resistance to weathering obviously are performance related aspects. And those are absolutely important to ensure that you are able to build a structure that is going to last for a long time. We call that as strength and durability or in the case of rocks and stones, we call it mechanical properties and resistance to weathering.

For instance, when our forefathers built these large temples and monuments, they wanted the structure to be used for number of generations. They didn't think about the structure only lasting for 50 to 100 years or within their lifetimes, they built these structures to last for hundreds of thousands of years. In such cases, they selected these blocks very carefully and ensured that they got the best possible blocks that are available. Of course, in those days, most of these structures were built at the whims of the king and if the king had sufficient funds or he could bring in material from a nearby kingdom, which had been annexed, they could also use a different type of stone in those days.

But today of course, a lot of the economic considerations require us to be using a lot more of the locally available materials. In fact, if you really look at sustainability also, it's always more sustainable to use what is locally available rather than source the material from outside. Because locally available materials are attuned to the specific environment that you have in a particular area. If you bring in materials from outside, they may not survive to the same extent. The same thing is true with vegetation also. We tried to get all these beautiful plants from all over the country and put it in our gardens, very many of them don't survive and a few of them that actually survived kill off the plants that were local, because they are fighting for the same nutrients from the soil. So one needs to be careful in choosing plants and at the same time, one needs to be careful in choosing materials for construction. Locally available materials are always the best for constructing in a particular region.

But as an engineer, you still need to look at the material properties, mechanical properties, resistance to weathering before deciding whether the material is suitable to be used or not.

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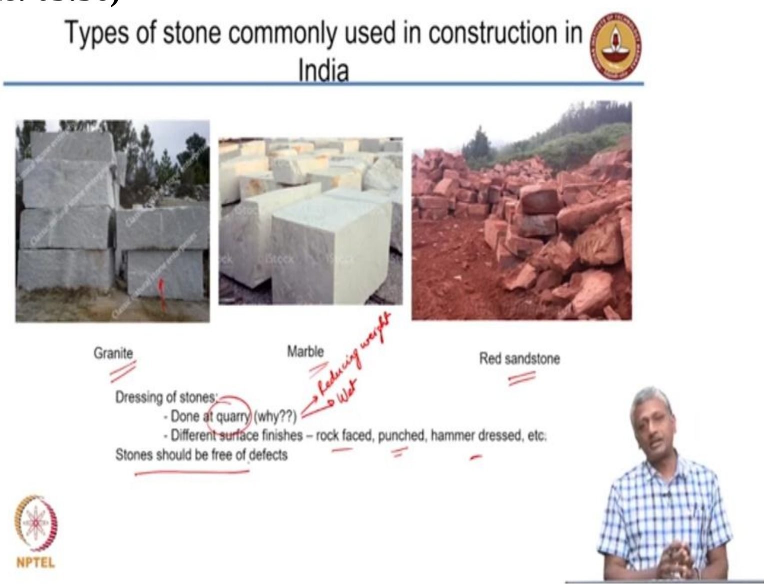

Typically in India, you will see large amount of structures made with granite. Especially in southern India, a lot of structures are made with granite. You also have marble. Again marble is a popular material available in the northern parts of our country, like Rajasthan. We get a lot of marble from Rajasthan and it is popularly used for construction all over the country. Especially again, monumental structures like temples are often built with marble.

Forts and historic monuments, a lot of them are actually made with red sandstone. Again, red sandstone is highly available in the northern parts of the country. A lot of red sandstone is also utilized for making many of these historic moments. Now these stones have to be dressed to the right size. And most often this dressing is done at the quarry itself. Wherever you are extracting the stone, that's where you are dressing it. There are reasons for doing this.

Why would you want to do this? Why don't you simply bring it to the jobsite and then do it? First and foremost, when you start dressing it at the right size, you reduce the weight of the block that you have to carry to the jobsite. So, when you're doing dressing, that means you are cutting and shaping it, you are reducing the weight to be brought to the job site. That's a major advantage. So, one aspect is you are reducing the weight.

The other aspect is that these stones in the quarries, often you will find that they will be wet, the stones are wet. And it's much easier to dress the wet stones than it is to dress dry stones. Why is it wet? Because the soil water or the groundwater would have seeped in through the stone and made it wet. Mostly the stones in the quarry will be wet and you can actually dress the stones a lot more easier as compared to after getting to the job sites when they all become dry.

Depending upon the type of aesthetics that you demand from the stone surface, you can get different types of finishes. Like the rock faced finish, where the outer surface still looks like the rough surface of the rock, even if it is a nice cuboidal block, the outer surface like for example what is shown here, the outer surface still looks like the rough surface of the rock.

You may have a punched or hammered dressed face also. Take a hammer and simply dress the top surface, that means you have some sort of a punched face just to give a different aesthetic appearance and so on.

Again, it is imperative that the stones that you get for construction should be free of defects. Very often marble is something that is prone to a lot of defects. Many metamorphic rocks like marble are prone to defects because they are formed under conditions of high temperature and pressure. And very often in such cases, there is a lot of moisture migration that happens from these materials. So, in such cases, what you end up forming are materials with very large cavities or vesicles. And those can often form defects in your material. Even in marble, many of you may have seen and those of you have marble flooring in your homes would see that some pieces of marble look very nice and uniform in color, whereas in others there are a lot of streaks. These streaks are obviously other minerals that represent the marble. But very often you find that along the streaks you also get cracks in the marble, because of the differential performance of the marble and the material in the streak.

Sometimes you also see very large cavities in the surface of the marble. So you need to be very careful in choosing stone for building applications. They have to be free of defects.

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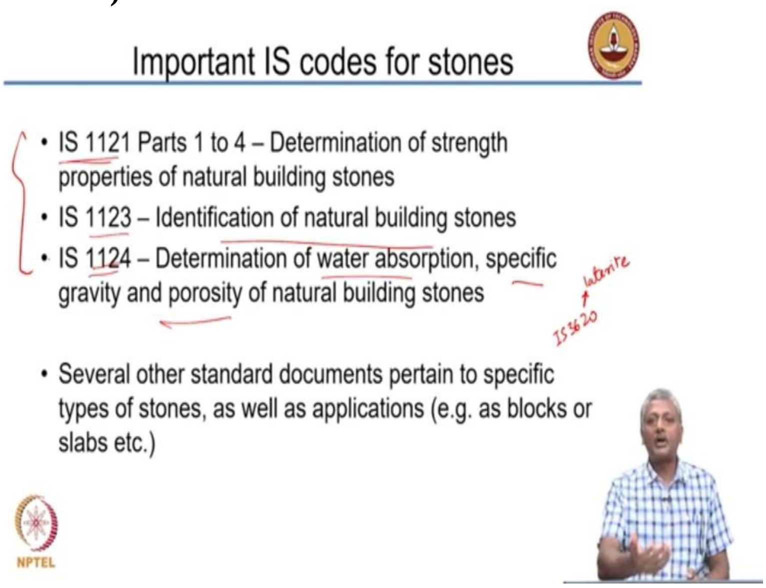


What do we need to identify whether a particular stone is good for construction or not? Once again, the Indian Standard has been devised to help us out in this regard. There are standards within this group of standards in IS 1121, Parts 1 to 4, which talk about determination of strength properties of natural building stones.

For naturally available stones how to determine the strength? What type of size? What type of orientation you need to have for your specimen? should you test it wet or dry? All those conditions are given very clearly in these codes. And of course, not just compressive strength but also tensile strength and shear strength determination are covered in this IS 1121.

Then you have IS 1123, which basically is identification of natural building stones, depending upon the mineralogy, depending upon the mechanical properties and so on. It gives you very clear cut methodologies to identify what type of stone you are actually having for your construction process. And then of course, the other test parameters are water absorption, specific gravity and porosity. Those are also very important from the point of view of engineering applications of the stones. That is covered in IS 1124.

Now apart from these guiding documents, you also have documents covering individual types of stones. For example, sandstone, to make slabs is covered in a very specific standards. There is a standard for laterite specifically. I think laterite standard is IS 3620. That's a laterite standard. You need to refer to these specialized standards to tie in the specific type of stones to the kind of applications that they are intended for, but the general purpose classification of all naturally occurring stones are covered in these 3 standards.

So once again as I said, when you have the time and the resource available, kindly ensure that you go through these standards and the details that are presented in these standards. Now, what is the use of standards? Standards help to regularize the construction practice with a set of materials or processes, so that construction with a given material in one location is exactly the same as the construction with the same given material in another location.

The way that we select the materials, the way that we apply them in practice, all that should be very clear cut and easy to follow and reproducible in different locations. So that's why we do standardization, otherwise everybody would build in their own way. With increasing demands of construction all over the country, we need to have processes that are standardized so that they can be repeated everywhere.

So that's why we do standardization. And standards are not just for materials, they are also for processes. There are standard test methods so that you evaluate the material in the same possible way. You will deal with many of these test methods during your regular bachelors curriculum. You will actually be doing them yourself in the lab and that will give you a lot more learning than any theoretical teaching that we are actually imparting to you through these lectures.

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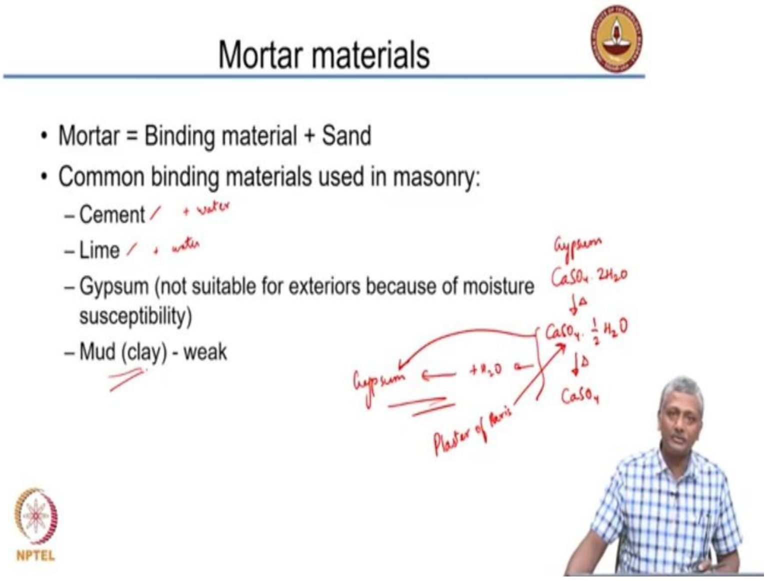


We have talked about brick and stone. Of course, we have not yet talked about masonry, that's a component that I will come upon a little bit later. But before that, I wanted to touch upon the mortar materials that are typically used. Mortar is nothing but a combination of a binding material and sand. What do we mean by binding material? A material that glues the sand particles together is the binding material.

If you use glue, that's also a binding material. A glue with sand will also be a mortar. But in most cases for construction, the mortar binding material typically consists of cement, mixed with water to make it into a binding material and you have lime, again mixed with water and then you have gypsum.

Now gypsum itself is not used in the form of gypsum itself, but it's used in the form of anhydrite or hemihydrate. Because you know, gypsum is calcium sulfate dihydrate, 2 molecules of water attached in the structure of gypsum. When you take this and heat it, you get your hemihydrate that is calcium sulfate half $H_2O$ ($CaSO_4.1/2\ H_2O$), basically which is hemihydrate. When you further heat it, you get dry calcium sulfate (anhydrous calcium sulfate) or anhydrite. When you mix this anhydrite with water, you get back your gypsum. And that’s the process of actually using a gypsum based binding material.

So you have a different form of gypsum which combines with water and hardens to form gypsum. But the problem here is this gypsum also is slowly water soluble. If you use gypsum mortar for binding in an exterior environment, what will happen is because of the moisture, this gypsum will slowly get eroded, it will slowly dissolve away and that will lead to a very low strength of your material. So you will not get proper setting and hardening with gypsum mortars.

Many of you, in your school, you would have done models with plaster of paris. So what is plaster of paris? It is nothing but hemihydrates. Calcium sulfate half $H_2O$ ($CaSO_4.1/2\ H_2O$) is basically a plaster of paris. Mix plaster of paris with water, you get gypsum. Again, it is not suitable for exteriors because of moisture susceptibility.

Another common material that you find in rural areas is simply the mud that defined from the soil or the clay. They mix it, mould it with water, make it into plastic stage and bind the blocks with that. It's efficient and it's also good in sustainability wise, because they are using a locally available material. And it's also got nearly the same characteristics as the blocks that they are using with respect to thermal insulation.

The problem with mud mortar or clay mortar is that it's going to be very weak. And when there is a lot of wetness or moisture because of rains, it will slowly get eroded. So you need to design this mud mortar carefully. But then nevertheless you find several examples of rural structures that are using mud mortars or clay mortars to bind the blocks together.

So these are common masonry materials. Again water is present in everything because water is needed for the reactions to happen. Cement reacts with water, lime reacts with water, gypsum, again, it's used in other forms that need water to reconvert gypsum and hardened, and again, mud needs to be moulded with water. The water simply dries out leaving the moulded mud behind. That's basically the strength of your mud mortar.

One of the materials that is used extensively in India for most of our heritage monuments of the past is lime.

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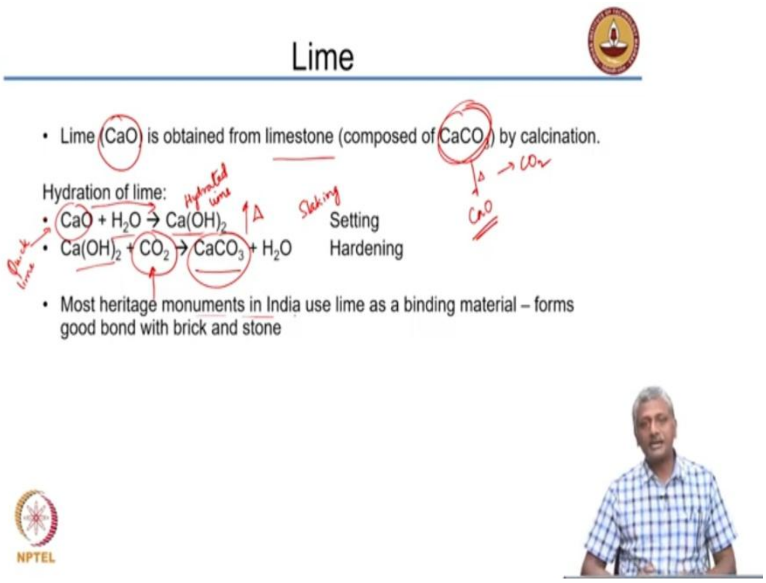


Lime essentially was the material that was being used for thousands of years before we started using cement. Now of course, cement was developed as an alternative to lime with a better engineering characteristic and slightly more controlled design. But lime itself remained for centuries and even today a lot of practice for rural construction still happens with lime mortar.

Traditionally, people have started shifting away to cement mortar for residential construction and for building construction because it is a lot more stronger. But if you have to repair heritage monuments which were originally designed with lime mortar, it is always better to stick to something which is similar to the lime mortar or lime mortar itself for the repair because that is going to be more compatible with the structure.

But what is this lime? Lime basically is calcium oxide and this is obtained from limestone, which is calcium carbonate. When you burn or heat calcium carbonate, you remove $CO_2$ and you get calcium oxide. $CO_2$ is getting removed in this process and you get calcium oxide. Now please remember whenever you burn limestone, you emit carbon dioxide into the atmosphere. So production of lime from limestone is actually a polluting process from that perspective that it gives out $CO_2$.

Same thing you will see later with cement manufacture also, because limestone is still the primary ingredient for cement manufacturing. So you still give out $CO_2$ in cement manufacturing and indeed, most of these building materials because of their processes of burning, leave out a lot of $CO_2$ into the atmosphere. The building industry is actually responsible for nearly a total of 20% of $CO_2$ emissions across the world.

Now, building industry means everything combined together, not just cement and lime. So what does this lime do? This calcium oxide reacts with water and forms calcium hydroxide. This process is called setting. We also know it as slaking. The combination of lime with water will result in formation of hydrated lime. This calcium hydroxide is hydrated lime and this reaction involves a lot of heat, that is, it's an exothermic reaction. A lot of heat is generated in this process.

If the lime has not been properly reacted with water and you use it in a structure, what may happen is, it may absorb some water and start reacting inside the structure and when it does that, the heat that is generated may result in some cracking and related failure in the structure. So you have to convert the lime completely into hydrated lime in the beginning itself before you use this in construction, otherwise you will have a problem.

So hydrated lime is what we need for construction, not pure lime or quick lime. This is called quick lime. You have learned this in your basic school sciences that this calcium oxide is also called quick lime and when you mix it with water, you form hydrated lime. Now this hydrated lime can be used in a mortar. So it's mixed with sand and then it is used for binding these blocks together.

But how does it gain strength? The hydrated lime basically picks up the $CO_2$ from the atmosphere and converts itself to calcium carbonate. Now that's very interesting. We started off from calcium carbonate to form lime and then we hydrated the lime and carbonated it, that means it took up atmospheric carbon dioxide and again converted back to calcium carbonate. That's very interesting. So we started with $CaCO_3$ and we reformed $CaCO_3$. This is the advantage with using lime.

What's happening here? Although we are emitting $CO_2$ while making the lime, we are reabsorbing the $CO_2$ during the process of hardening. That's a very important thing for you to remember. That's why a lot of architects prefer lime, because of this property of almost a net zero carbon dioxide emission from lime. In cement, it's not the case. You will see later that, in cement it is quite different.

So as I said, most heritage monuments in India use lime as a binding material. And it's also seen that it forms an excellent bond with the brick and stone. So heritage monuments more often than not, you are bound to find lime as a binding material or lime mortar as a binding material.

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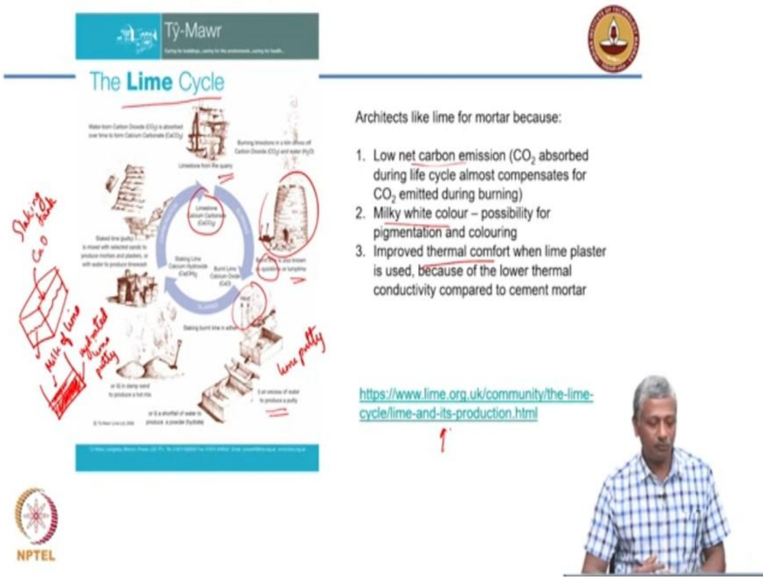


Many people talk about this conversion of $CaCO_3$ to CaO and then back to $CaCO_3$ as the lime cycle. So this is a very interesting picture that is there from UK. So you have your limestone or calcium carbonate, which is extracted in the quarry and is burnt in the kiln and you get quick lime or lump lime. This quick lime is then slaked, heat is produced because of slaking and then you get your lime putty.

What is lime putty? So again, just to tell you a little bit more about this slaking process, in most large lime producing facilities, what you will have is these tanks. You will have rectangular tanks and you will basically fill them up with water and then you dump your quicklime into this water. With time, if you look at what happens here, I will just draw the cross section with time. The bottom most part, you form a nice plastic hydrated lime. All the lime gets hydrated ultimately and you form hydrated lime. But what is in the bottom is called lime putty.

Lime putty has a nice plastic nature about it and you can mix it nicely with mortar, maybe sometimes add some extra water to make your lime mortar. On top of that, you may have thinner layers of lime. You may not really have the nice thick calcium hydroxide that is needed for building construction. And on top of that, you also get what is called the milk of lime. It is almost like a white colored liquid that you get right on top.

The lime water or milk of lime again can be used for your white washing application for instance. There are several different ways in which you can actually utilize the slaked lime. The process of slaking simply is done so that all the lime gets converted to hydrated lime, before the use in mortar. This is very important because the process of slaking ensures that you won't have any remnant calcium oxide left out which will convert to calcium hydroxide later in the structure. That is very dangerous. You want all of it to get converted to hydrated lime in the slaking tank itself. So that's called a slaking tank.

Now interestingly, what has also been found is that, this slaking tank results in or rather the prolonged exposure of this lime inside the slaking tank results in very different qualities of the lime that you get for mortar making. Generally they say for plastering purposes, when you want a very fine texture to be imparted for plastering, the lime that you get has to be slaked for a long time. Nearly 6 months sometimes.

For binding of blocks together, the lime mortar does not need that kind of a texture. So there you can actually slake for 1 to 3 months itself. So again as I said, architects like lime for mortar because of net carbon emission being very low; not zero, it cannot be zero, but it is very low. So the CO 2 that is emitted during burning, most of it gets reabsorbed during the process of hardening. It has a milky white color, lime, pure lime mortar will have a milky white color. That is very good for pigmentation, you can color it in different pigments. So that's why architects like lime mortar that way.

Generally when lime plaster is used, you get improved thermal comfort as opposed to cement plaster, because of the lower thermal conductivity. So again there are websites which are dedicated to the use of lime. Especially with lime being used in heritage monuments, please look at this website and you can learn a lot more about the different Scottish lime kilns that are described here. It's very interesting to read that.

Not all slaking practices are perfectly optimal. In some cases, people just dump the lime on the floor, mix the water into it and continuously mix it for a long time until all the heat dissipates. It depends on how the lime slaking practice is done at the site. So once you mix it up with sand and make the mortar, it has to be in the hydrated lime form.