Characterization of Construction Materials
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Lecture – 50
Image Analysis – Basic Operations – Part 1

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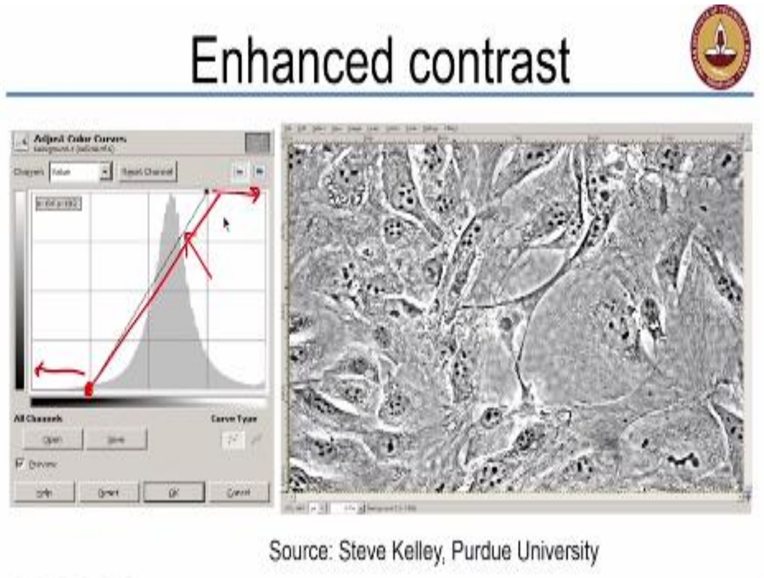

Hello, everybody. In the last lecture we were talking about what kind of operations constitute the process of image analysis. We were first looking at some image processing techniques. One popular technique obviously is the change in contrast and brightness of the image. So, we saw how the gray level histogram of the image is modified to ensure that you can actually exercise some changes in contrast and brightness. So, I gave you the example of this biological material that was being imaged. There is a gray level histogram that is represented by a peak at a certain location, and when you actually want to change the brightness, all you are doing is simply adding fixed grey level to each and every point. So that raises the overall brightness of the entire image. On the other hand, when you are increasing contrast, what you are doing is increasing the difference between the whitest and the blackest phases. So, here what you are trying to do is making the slope of this histogram a lot more steeper and that produces images that have some degree of clarity that you would like to see in your images.

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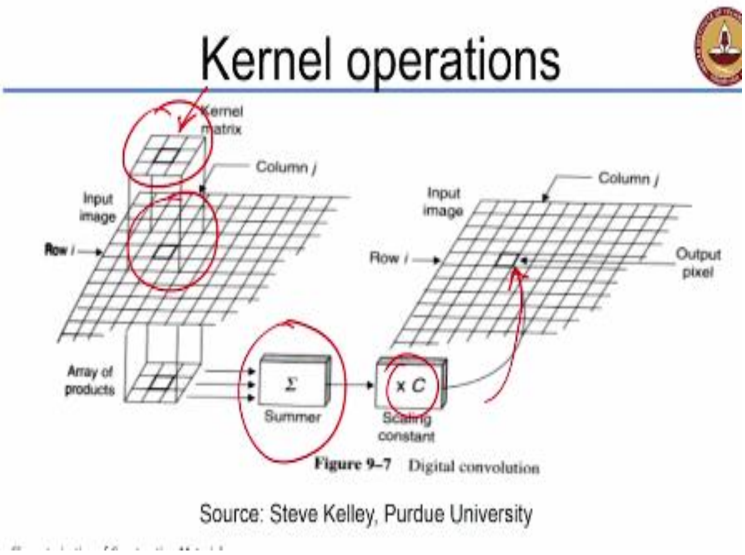

So, having looked at basic image processing operations, now let us take a look at what we can do further to enhance the image in the ways that we want to. One of the common types of operations that we perform on images are called kernel operations. Now kernel is nothing but an operator, even your computer programs, small operations are performed by these small programs called kernels. So, in this case again, the kernel is nothing but a matrix that operates upon a certain region of your image. So, for example, you know that you can add matrices; you know that you can multiply matrices. So in the case of a kernel operation, all you are doing is choosing a smaller matrix to work on the image to change the pixel values of the locations in the image. That means the pixel grey levels can be adjusted by these kernel operations. So what you are trying to do here is using a matrix, a smaller matrix which is called the kernel matrix, to operate upon a certain part of your image, and do some sort of a mathematical operation like summing, for instance, after multiplication and scaling to give the new location a different number. I will show you some examples as to how this can be actually done. So these are called kernel operations, whenever we have an external matrix operating upon the array of points that your pixels actually are representing.

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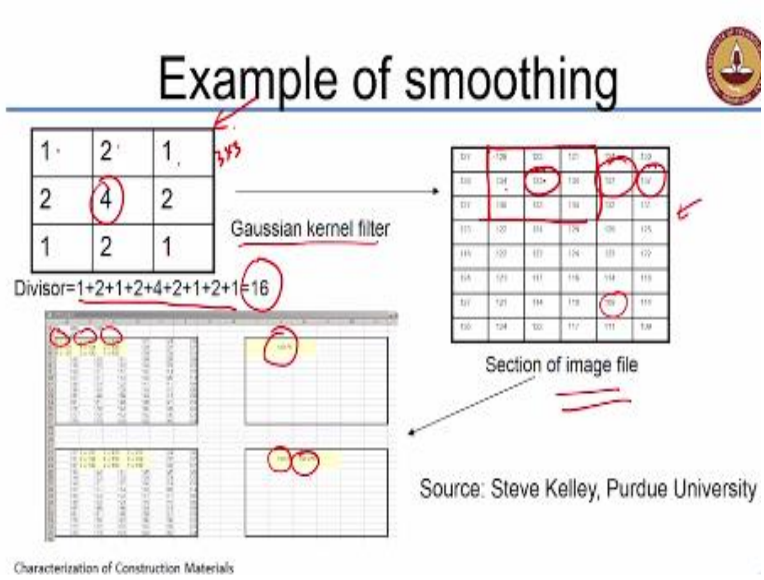

So, to give you an example of smoothing, I told you last time that smoothing needs to be done when we feel that certain features are looking too sharp or too non-uniform as opposed to what is around them. So, we would like to smooth the image because smoothing while it reduces the sharpness of the image, it also reduces the extent of noise that you have in the image.

So, one example of a smoothing filter is this Gaussian kernel filter. It is a 3 x 3 matrix with the numbers 1, 2, 1, 2, 4, 2 and 1, 2, 1. So, the central point is 4, and the four corners are 1 and the other points are all 2. So, this is just a 3 x 3 matrix with those cell entries. Now this is the example of an image file section, part of the image file is given here. What do these numbers represent again in the image file? The grey level at every pixel, for example, here you can see that the grey levels are generally varying between about 109, which is the lowest, and 137, which is the highest. So, here, you have a section of the image that does represent a fair degree of difference in its pixel gray values.

Now, the operation of the smoothing filter will be such that it makes the entire location smooth. What do you mean by that? It will almost give the same grey level to the entire location. So, what we are doing here is taking this 3 x 3 matrix and operating on 3 x 3 segments of the image one at a time. So here for example, what has been done is this matrix has been taken and you have done a matrix multiplication of this number with the first number here, 1 * 127 okay, 2 * 129, 1 * 123 and so on so. So, we have operated the 3 x 3 matrix over a 3 x 3 section of your image file. **(**It is not exactly the same as matrix multiplication, but we are simply taking this to multiply with certain values there.) The resultant summation that you get is divided by this overall divisor, which is the summation of all the values in the cells of the 3 x 3 kernel matrix.

So, what we are trying to do is multiplying and then dividing by this divisor to get a uniform value of 130.75 which is only applied to the central pixel. So this way, in the next step what will happen is this kernel will now move over to the next step, that means over this matrix and then give another value to the central pixel there. So, if you do the same, you end up with 130.75 on this central pixel and 130.875 in the next central pixel. Earlier the values were 134 and 133 which was separated by one grey level, but here the separation is only 0.125. So, what you have done is reduce the extent of grey level separation between adjacent pixels and like this you will be applying it over the entire image to produce a smoothened image.

Now, what do you think will happen when you have a sharpening filter? What about these values in the case of a sharpening filter? For smoothening, we are doing this. In sharpening filter what do you think will be the values inside the cells? There may be some negative values inside the cells. What do you need to do is increase the difference between adjacent pixels, so there may be some negative values also.

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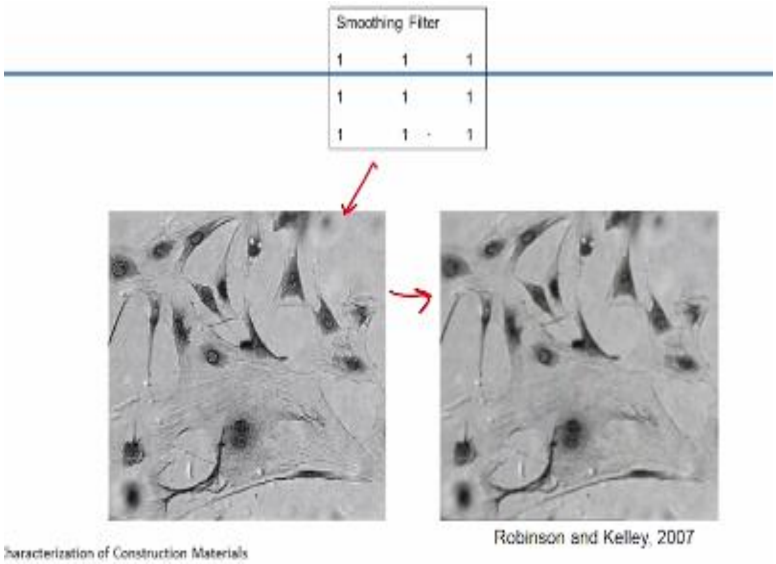

So that is again, just to give you an example of how the smoothing filter actually operates. So you can see that this image is a series of grey level values for its different pixels. The smoothing filter in this case which has been chosen is a unit matrix or 3 x 3 matrix with values of 1 in all the cells and the resultant image that you get after this matrix operates upon this image is a much smoother image. You can actually see that some of the sharpness has been removed from the image.

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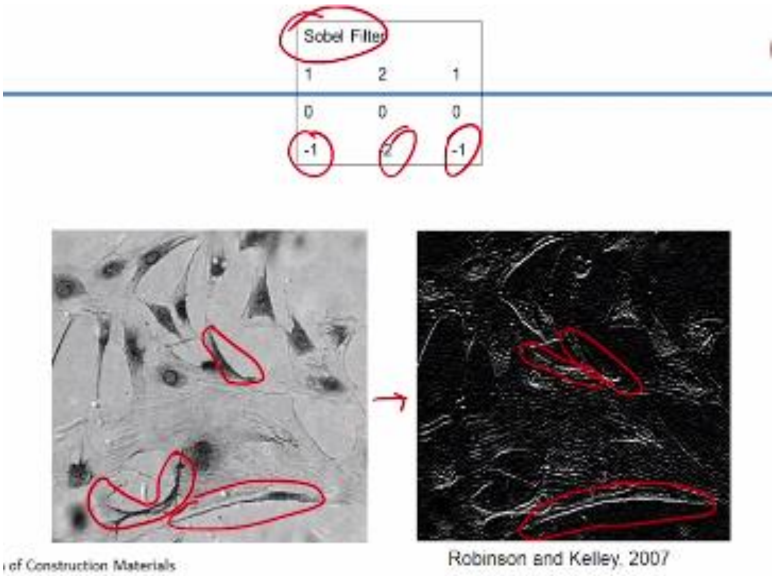

Now, this is a Sobel filter. What do you think is the purpose of using this sort of a filter in this case or this sort of a kernel matrix - what is it doing to the image? What is this image actually showing you? It is actually showing you the boundaries. It is enhancing the boundary effects. That is what it is trying to do. You can see all those locations. The boundaries are all clearly visible in this image. So, it is just enhancing the boundaries between the different features in the image. So, with the choice of mathematical matrices, kernels, you can now modify your image to get the kind of accentuation in different phases that you want.

Another example here, of course of smoothing is given here (in next slide).

So if you remember, I told you that the kernel is a matrix. In this case, we had a 3 x 3 matrix. Now if you have to do a further extent of smoothing, what will you do? You may increase the size of the matrix. So instead of a 3 x 3 can use a 9 x 9 matrix. So in a 9 x 9 matrix, again you are doing the same thing, but you will be operating over a 9 x 9 size of the image, and giving that value to only the central pixel. Here 3 x 3 was operated upon and you got the value, which was multiplied, I mean each value in the cell of the kernel was multiplied by the value in the cell of the image and the total sum was divided by 16 which was the total divisor. In the case of a 9 x 9 matrix, instead of a 3 x 3 the operating kernel will be a 9 x 9 size.

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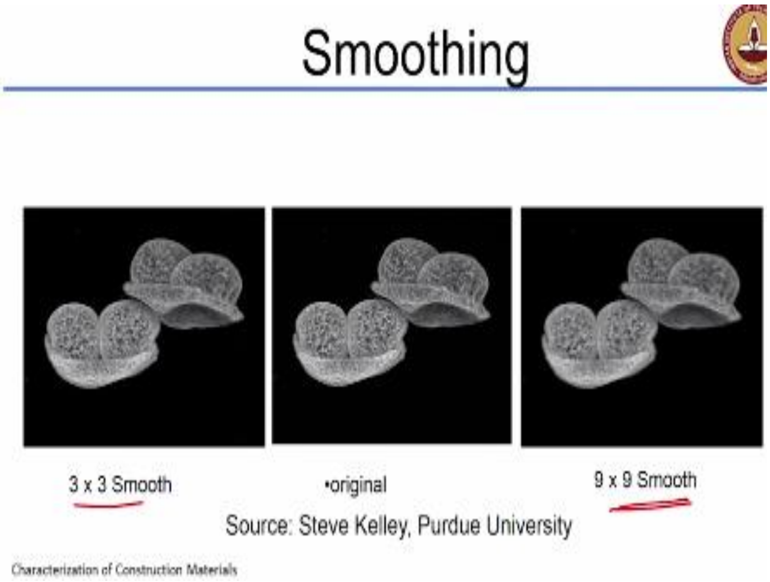

So, what do you think will happen as a result of this? The extent of smoothing that you get is much more than what you get with a 3 x 3 matrix. Now if you have an image in which there is too much noise, an image in which there is a lot of noise, you want to operate upon it with a larger sized matrix. The larger the size of the matrix, the more the reduction in the noise will be.

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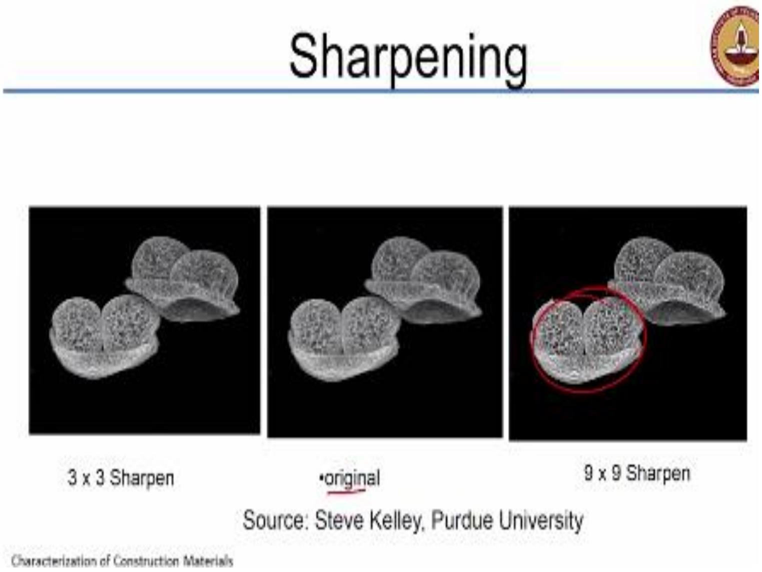

Now in the case of a sharpening filter, see what happens in this case you see that the image, this is the original image (in the centre) and what you can see is the boundaries of these phases are accentuated significantly when you have a 9 x 9 sharpening filter. So, depending upon what you need in your image, what you want to enhance to actually prove your point, you need to operate with the right level of matrices, the right kind of kernel matrices.

If you go to image analysis software, mostly what will happen is, these sorts of kernels will already be pre-defined in the system. It is not like you need to choose your matrix. The kernels are pre-defined in the system and you use those kernels to operate upon your image to get the right level of sharpness or smoothness. So sharpening and smoothing is only one example of a kernel. You can also get the hole filling type of kernels in which the idea would be that if there are any phases in the center that are different from what is surrounding, it takes the value of the surrounding pixels and pushes it to the center. So that is called hole filling sort of an operation. So there are filters designed for that also.

So at each step, you are only giving one operation, but your image analysis may actually involve a sequence of operations. So, you do not always only want to sharpen, you may want to combine the sharpening with hole filling or combine the sharpening with there is also a kernel for what is called erosion and dilation (erosion means you are cutting off some part of the images, dilation means you are expanding certain parts of images). So, all those are also kernels which are operated upon the image file and that produces a different kind of result with an enhanced view of the image that you want to observe. So, at one time, you can only do one operation, but you can combine sequences of operations.

These days of course, in image analysis software, you can set up macros to actually take an image and have those sequence of operations run on the image directly, without having to actually do it manually yourself. If you have, for instance if you have a set of 100 images, you cannot set each and every time the kind of sequence that each image has to go through. So, you can actually create a macro just like in Excel and apply to all the images together at the same time.

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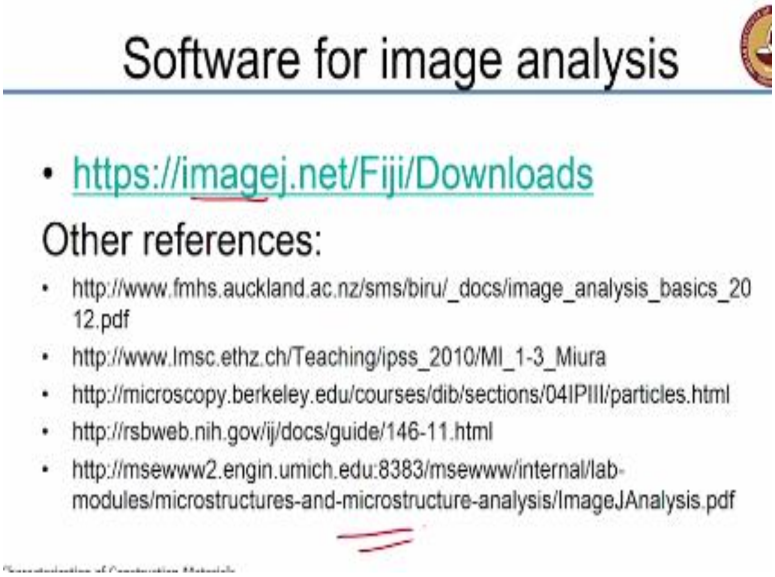

So the software for image analysis is available freely. There are several software available freely. There is one software which is quite popular with our students, it is called ImageJ and you can download it from this website. I suggest that all of you today itself download this software onto your computers and try to play around with images that you already have. It may not be research images; you can play around with images taken on your own cameras for instance. There are several other references, which I think are very important for you to go through which have ideas about how image analysis and stereographic techniques can be applied to gain useful information about images. So, what we will try and do is create a structured assignment in which you can utilize this software to produce the results for a given set of images. I will come back to you with that probably in a couple of classes.

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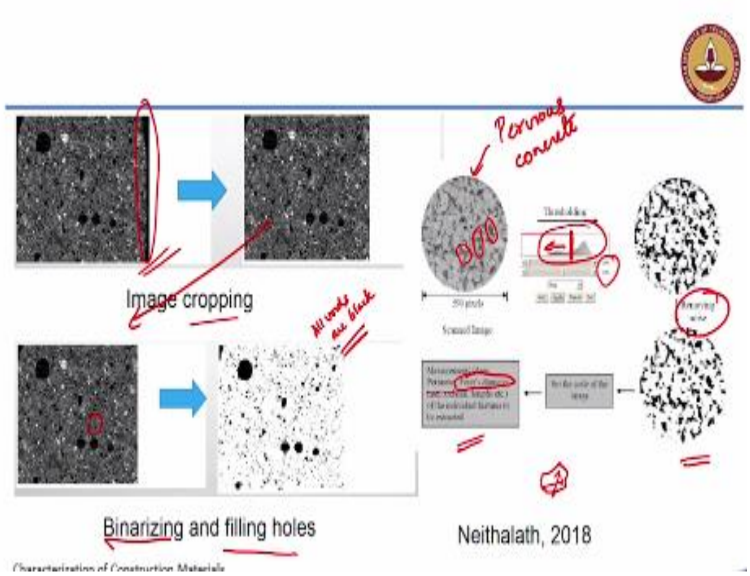

So, just to give you an example, what is happening in this case, are the functions from the software that have been applied to certain parts of the images. For example, here in this image (top-left), you see that there is a large black section at the side which is of no use for our operations. So you can actually do image cropping, which all of you know how to do. Anyway, in most of the photo processing software, you will have image cropping algorithms.

But what is done next is this cropped image is taken and binarized. What is binarizing? You either completely convert things to black or to white, so you are just binarizing and what happens as a result of binarization is you get a complete white for all the non-void phases, all voids in this image are black. Now, hole filling may have to be resorted to in some cases, because some very minute spots here which may be part of your solid phases may start appearing as holes. You want to characterize your voids carefully. So, you need to ensure that you do this hole filling sort of a kernel operation also that ensures that those spots which would otherwise not have been counted in the porosity are removed.

So, again one more example here (on right) is of a pervious concrete sample. In pervious concrete, we do not use any fine aggregate, it is just cement paste with coarse aggregate that leads to large macroporosity being generated in your sample. This is all macroporosity or macrovoids which are generated. So, what is done in this case is the histogram is taken, and the thresholding operation is done to indicate what grey level is the cutoff point for your voids and what grey level is the starting point for your solid phases.

So here for instance, the thresholding gray levels are set manually and you are deciding that this point (denoted in thresholding diagram) is where I want to cutoff for all voids. If I set the threshold here, all the points to the left of the threshold become black and all the points to the right of the threshold are converted to white. That is called binarizing. Again, you can remove noise by smoothing it a little bit and get this image.

And then on this image you can perform several different measurements. What is one measurement you can obviously perform? You can count the number of pixels that are white and black and get the area fraction of the voids immediately. The other aspect is you can get for each void you can get particular parameters like the perimeter of the void. Since the void is irregular, you do not have a diameter of the void, but you need to convert the irregular feature into an equivalent diameter. So for that you need to take measurements across different lengths and you end up with what is called Feret diameter. So again, there are several operations you can actually perform on the binarized image to extract the feature of your interest. So the question is you are looking at a flat image, so it is a 2-dimensional image and you are seeing the area fractions of the voids, but how do you convert that to a volume fraction?

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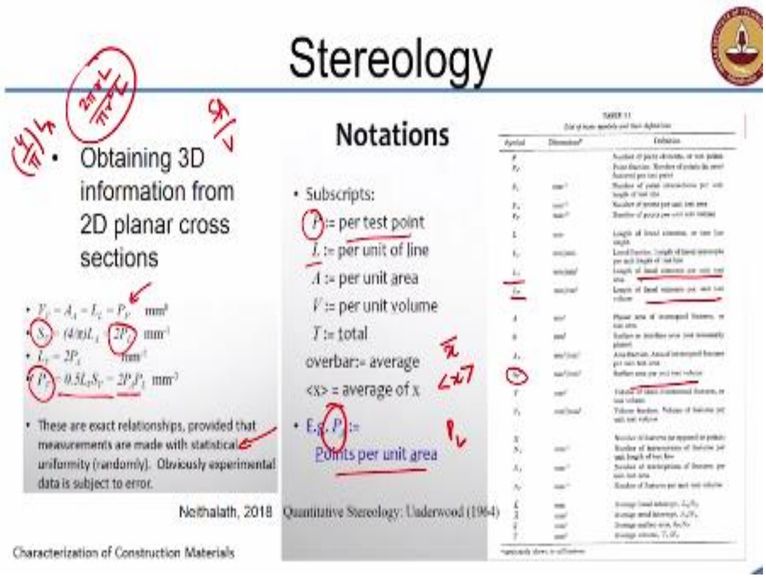

So that is the realm of stereology, so obtaining 3D information from 2D planar cross sections. So now there are assumptions that you need to make but these assumptions also happen to be fairly accurate. So first of all, some notations P is, when you have a subscript of P that means per test point, L means per unit of length, A means per unit area, V is per unit volume, T is total. So, when you put $\bar{x}$, that means it is an average (overbar) or <x> is basically the average of x. So, for example if P_A is given that means points per unit area, P_L means points per unit length.

So you have an image which has several different features. So, let us say I draw a line across that image and wherever it cuts a particular phase, I count that as one point, that is in a line. Supposing I have multiple lines covering the entire image, and I take an average across all the lines. Let us say I have 2 phases. In this case (previous slide), I have the black phase and the white phase. I draw multiple lines across this image and if I count the number of black points per line and take an average of number of black points per line, what will that approximately be equal to. You need to understand this to actually relate this to the volumetric proportions. So what I am doing is I am just taking a line across the image, and let us say whenever my line crosses a black point, I am marking this as 1, 2, 3, 4, 5,… each pixel is actually monitored across that line and number of pixels that are black versus number of pixels that are white on a particular line gives me the number of black pixels per unit length.

So, what happens now, how can I relate that to other parameters? Can I relate that to the area of the black pixels occupied in the entire image if I take that across multiple lines? I can. And similarly I can relate the area to the volume. So that is the principle behind stereology is that volume of the voids or phases per unit volume is equal to the area fraction is equal to the length fraction is equal to the point fraction. Volume fraction is equal area fraction is equal to length fraction equal to point fraction ($V_V=A_A=L_L=P_P$)

So, specific surface area or surface area per unit volume (S_V) is given by:

$$S_V = \frac{4}{\pi} L_A = 2P_L$$

Specific surface area is nothing but surface area per unit volume, assuming that we have spherical or cylindrical phases, you can actually have different sorts of surface area to volume relationships. So, this is obviously for what type of relationship? Here we are assuming that it is an open pore, for instance, $\frac{2\pi r L}{\pi r^2 L}$. So, this gives you (2/r). So what is this now? This specific surface area = (4/π) L_A? So again if you look at the notations here, S_V is surface area per unit test volume. Why did not we get the same surface area in this case, number of black points along the line over a given area that is what is L_A. So, this is not exactly the same as calculating $\frac{2\pi r L}{\pi r^2 L}$. So that is why you are not getting the same idea here from these calculations.

So, these calculations happen to work for a range of phases and range of shapes and sizes. So, these calculations which say that, of course this is what we are saying is an assumption that volumetric fraction is equal to area fraction equal to length fraction equal to point fraction. So, the surface area per unit volume, which works out to be twice the number of points per unit length ($2P_L$) is again something that is valid for a set of images which have been statistically taken. For example, provided that measurements are made with statistical uniformity or you take a particular sample and have multiple images on it, randomly taken multiple images, many number of such images and on that you can prove that these equations hold true. So, what you are simply trying to say is we can now calculate the size of different features based upon these mathematical stereological notations.

So points per unit volume (P_V) is given as $P_V = 0.5*L_V S_V$

where L_V = that is length of linear elements per unit test volume

or PV = 2 * P_A * P_L. Of course, there are a lot of steps in this derivation, we are not going through those steps here, but what I wanted to tell you is from features that we observe in images, we can actually make stereological calculations to relate the 2-dimensional section to an entire 3-dimensional characteristic.

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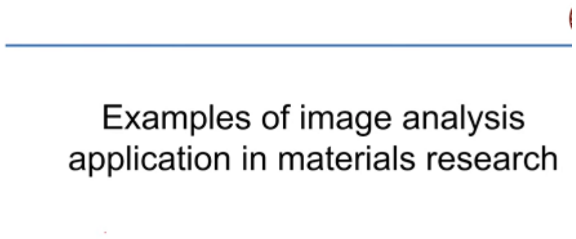

Okay, so now let us try and see how we can interpret images and take data from images to represent the kind of phenomena that we want to observe in construction materials research.

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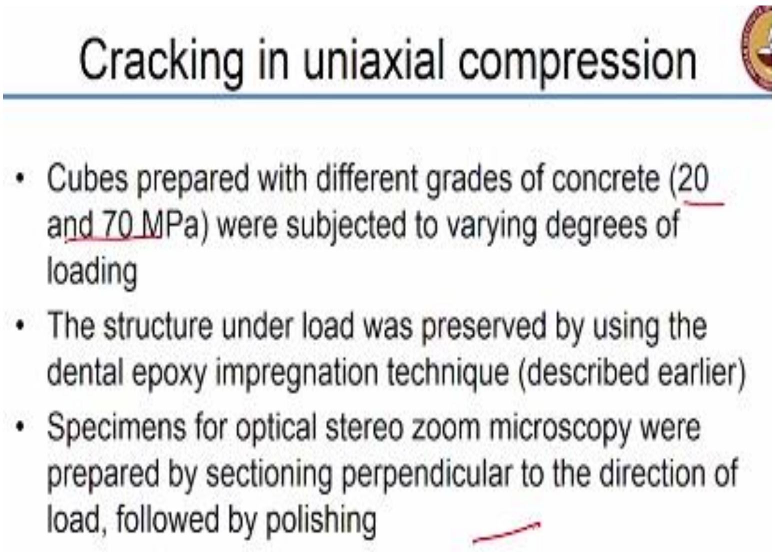

So, here this is a study which I had showed you previously when we talked a little bit about how samples can be prepared for microscopy by encapsulating with an epoxy so that it preserves the cracked state of the material. So here the cracking of concrete in uniaxial compression was being studied of different grades of concrete, one was 20 MPa low grade concrete, one was high strength concrete 70 MPa and these were uniaxially loaded in compression to different levels of the compressive strength. So, loading was done up to 30%, 60% and so on. So, at each stage when the loading was on, encapsulation by epoxy was done to ensure that the cracks will be preserved when unloading happens. So, of course not all of the cracks will be preserved, but at least some part of the cracking should be preserved when unloading happens. And then after unloading, these were then sliced and polished and the projection of the cracks on the horizontal plane was then imaged using an optical stereo zoom microscope, which had limited magnification up to 70 to 100x, not more than that. So, again structure is preserved by epoxy impregnation which we described earlier. Optical stereo zoom microscopy was done on the polished images.

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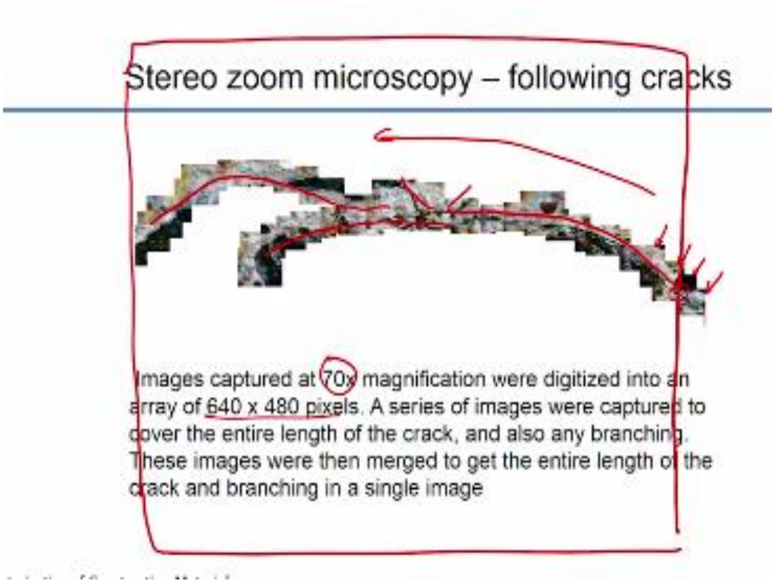

Now, I showed you already when we discussed optical microscopy, that in the 20 MPa concrete, there is a lot of cracking that happens and these cracks have several locations where the cracks branch off and mostly the cracking is around the aggregate. There is expected to be a very large level of energy dissipation because cracking is quite extensive, and it happens around the aggregate and seems to branch off in several directions.

On the other hand in high strength concrete, the cracks were sudden and they appeared to go right through the aggregate. Nevertheless, if you have to extract parameters from this imaging exercise such as the crack length for instance, you cannot just work on one image because each image is taken only over a small area. You need to take it over a very long part of your sample to ensure that you are able to study how these crack lengths are actually developing.

So, in this case, what was done is each image was separately taken and using the image analysis software, these images were then stitched together, you can do image stitching in image analysis software, that is not too difficult. It does not even require specific operations, all you just have to do is drag images into a workspace and then connect them through your visual observation because obviously you need to know where exactly one image is ending and where the next one is starting, so that you can actually connect these cracks or phases which are adjacent to each other carefully when you put the images together. So, images were captured at 70x magnification and were digitized into an array of 640 x 480 pixels. So, this is not a very high-resolution image (640 x 480 is not really high resolution).

So again, this series of images was captured to represent or to track how this crack actually is growing. You can see it goes up to here, and then it seems to branch off in different directions, that is approximately the path taken by the cracks. So, the idea was if you image across so many different locations, you now have an extent of how far this crack is going. Now mind you, this is all part of one large specimen, 50 x 50 mm specimen, we are just taking one particular horizontal section and imaging it in the microscope.