Introduction to Ancient Indian Technology.
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Lecture-37.

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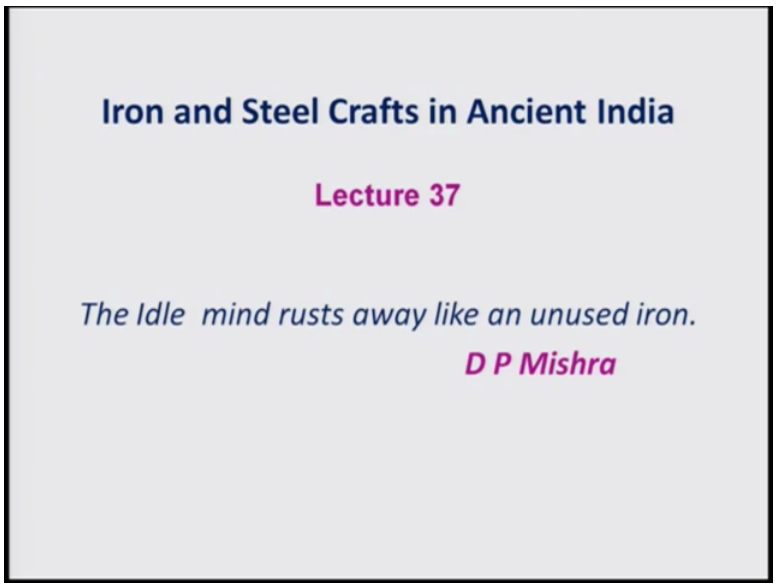

We will start this lecture with a though process, that is the idle mind rust away like an unused iron. If you recall in the last lecture we discussed about various applications and artefacts which were, you know being used earlier days in ancient India. And that shows very clearly that Indians were knowing how to make these products and also we discussed how they were smiting the iron or producing the iron. And I argued that there are several varieties of, or there are several kinds of iron smelting furnaces across the country and people were using their creativity and innovative ideas to implement them and which cannot be done in the modern blast furnace. So today we will be discussing about the iron and steel crafts in ancient India.

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We will have to use basically blacksmithing processes for making a product out of iron. And this process is basically carried out in such a way that metal becomes soft, for this purpose the rot iron is to be heated until the metal becomes very soft enough for shaping with hand tools such as hammer, anvil, chisel etc. of course there are several tools one can use which are I have shown here. These are blacksmith tools like hammers, and of course these hammers can be very small one, can be big one, even people use very big hammers for giving force.

Chisels, punchers, hardy tools and tongs, of course these are tongs I have shown, fullers and flatters. And of course there is a controversy whether the stone anvil was there or iron anvil, but anvil was there in ancient India. And these pictures of course I have taken from the recent one. But there are some figures from ancient excavations which are not good. That is why I have not included it. And by this blacksmithing process, several products namely light fixtures, furnitures, sculptures, tools, agriculture equipments, religious items, cooking utensils and weapons and others were being produced in ancient India.

The blacksmithing techniques can be broadly divided into four categories. One is forging which is also known as sculpting. Welding and earlier days the welding basically forge welding was there in ancient India. And of course the heat treatments, I will be discussing about the heat treatment methods and finishing. So what do you mean my forging? The forging is a process by which the blacksmith shapes the metal to a desired shape and size for making it a useful product and for that purpose.

Of course one has to heat the metal so that it will be soft and then only you can apply the force in a proper way using sometimes die and other things so that it will take the shape whatever you want to have. For that of course the basic forging operations can be divided into various kinds like lengthening.

Basically what you will have to do lengthening means you are increasing the length of the metal when you apply the force in a proper way, in one directional way, such that the length will be increasing, of course it will be thinning down the cross section will be decreasing. And there is another way of shrinking, that means if you compress it, it may decrease its size, length and then it will be shrink then you can bend it that is known as bending and upsetting, and swaging. Swaging is basically, you put into a proper dies and forge it, so that it will take the shape, fuller uses the dies basically.

And of course there is punching mark you want to have then you apply some tool and then apply the force using hammer. And the last but not the lease the forge welding that means you take two metals when they are hot and then you apply the force so that it can be joined together, that is forge welding. So if you look at, these are the things which are were being used in ancient India and ancient indian black smiths, were having considerable knowledge about various thermo mechanical treatments like forging and forge welding heat treatments and others. So we will be discussing about the heat treatment process.

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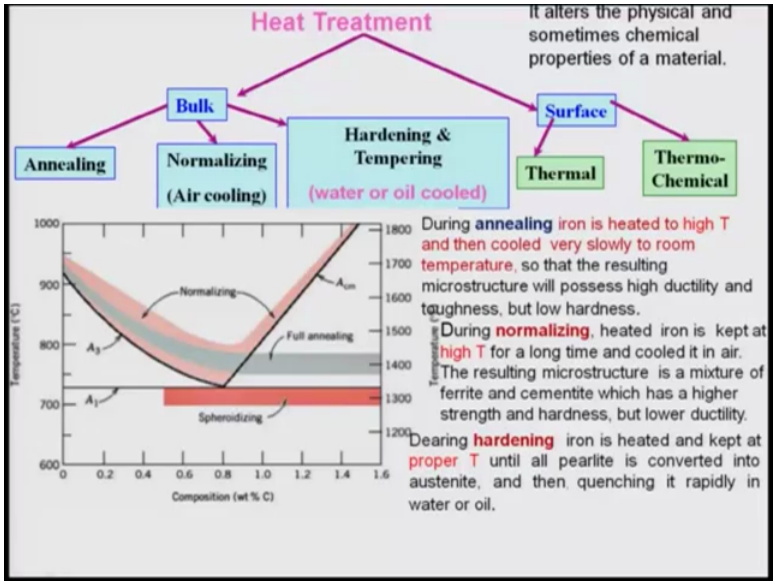

Heat treatment process can be broadly divided into basically, for the bulk material, and also for finishing the surface. So for handling the bulk material so what it can be done, that you

know, one process is being cried out is known as annealing, the other process is normalising. Generally the normalising is carried out by cooling it in the air itself and hardening and tempering, in this process the cooling is cried out using water or oil, and surface finishing is done by the thermal process and thermo chemicals, because you use some chemicals and also apply some what you call heat and then you can get a good surface.

And during this heat treatment process basically the physical and sometimes the chemical properties of material get changed. And so that you need to play with that and get hardness, sometimes you know like malleable and other things, so that you can provide a proper shape to the metal. So this figure I have shown here, is basically temperature and this is the composition and particular indicating the carbon in the iron. If you look at there is a process, of course this is a constant temperature around 700 maybe 27 kind of degree Celsius and the annealing process full annealing occurs at a various temperature for different carbon content, so also the normalising and also the spheroidising.

Let us look at what do you mean by this annealing. For annealing of iron it is to be heated to a high temperature then it is to be cooled very slowly to the room temperature, almost room temperature. As a result this micro structure will possess high ductility and toughness but low hardness and this is has to be done properly so that you will get this thing. And, but whereas for normalising process, the iron is to be heated and it has to be kept at high temperature for a longer period of time. And then of course it will be cooled slowly in the air environment such that the rate of cooling will be lower, or it will be lower as compared to when you are cooling with water or using oil.

So as a result the micro structure will be changed and generally a mixture of ferrite and cementite which will be in a layer by layer, that is known as pearlite and being formed. And as a result there will be you know, increase in higher strength and hardness of the metal but with a lower ductility. So this is basically normalising, during this hardening process iron is heated and kept at a proper temperature until all the pearlite is converted into austenite, and then it will be quenched using the oil and water any one of them so that it will be cooling rapidly.

And then there will be of course the micro structures will be changing and then you will be getting some kind of structures so that it will be what you call, very hard. And during all these three processes the temperature and the heating time, should be maintained properly of course which will be dependent on the percentage of carbon in the iron so that higher level of

austenite can be obtained and the microstructure of the hardened steel consist of ferrite, martensite and cementite also.

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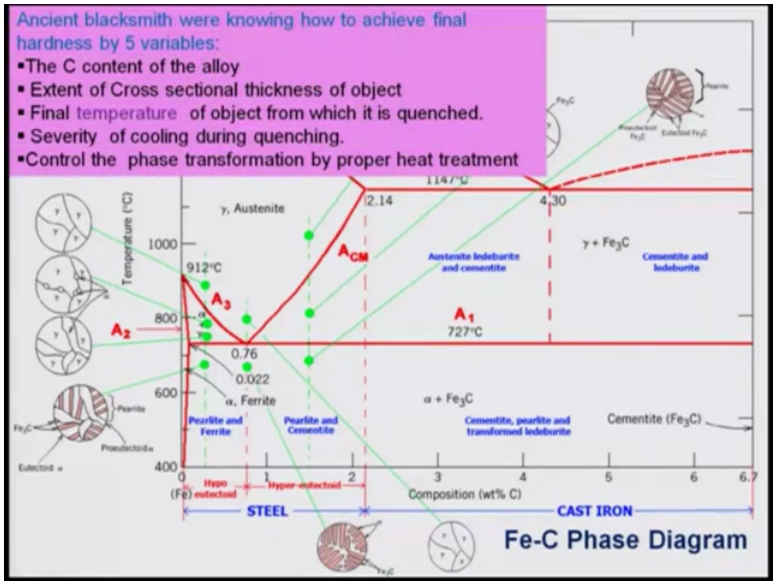

But if you look at it is an art and which has to be done really without getting into the detail of microstructures because you need to have an idea about that what is happening. And of course this comes from the experience and also certain procedures. So I will just talk about, little bit about ferric and carbon phase diagram because we talked about various phases and then various structures, micro structures. If you look at here at a very high temperature it will be liquid and then of course in this zone, there will be some kind of structure, which we do not have much interest in that for so far, heat treatment is concerned.

But heat treatment is basically if you look at in this temperature is shown and in this the percentage of carbon if you look at this, this is the steel is something around 0.02 to 2.17 percentage of carbon is known as steel and then this point, 0.76 percent of carbon or the hypo Eutectoid and beyond this is hyper Eutectoid zone and of course for 2.17 to 6.7 percent is known as cast iron.

If you look at this is corresponds to A1, where here it will be ferrite structure will be there, which is you know like a very soft in nature as compared to other micro structures but as you keep this temperature between something 727 degree and then this region there will be alpha and gama austenite, here will be Gama austenite and in this region of course there will be what you called pearlite and ferite and pearlite and cementite in this region, course this is cementite region.

But what is being done during the hardening is that you know, you put here austenite and then you will be cooling it. And when it is cooling the things you will be getting basically pearlite and ferrite kind of structure and this is occurring during basically annealing process. But whereas as it is cooled very rapidly in case of hardening it will be an austenite but it will be coming suddenly to pearlite and cementite which will be very hard. So if you look at these are the structures which will be you know, we try to maintain because of that there is hardness and softness and ductility all those will be maintained.

And I was talking about pearlites. Pearilite is basically these are lamella statures and this will be ferrite and cementite and particularly when it is hardening this what you call, these will be converted to what you call, more cementite structure kind of things. And the gap between these things will depend on the temperature and the rate of cooling, but if you look at ancient metallurgist particularly in India, they were not aware about all these you know, structures.

What they were knowing is a very know your hands-on experience and they were knowing how to achieve final hardness by varying you know various charactertics, particularly one is carbon content of the iron and extent of cross sectional thickness of the object because if you look at like the rate of cooling will be dependent on the cross section of the object and the also how much time it will be giving for soaking. Generally the rule is that if it is 25 mm you will have to go for at least one hour. But in principle people go for at least 2 hours for soaking at a high temperature.

And final temperature of the object from which it is quenched that also they look at the temperature. At that time there were not any instrument to measure but they will have a visual observation from that they will be trying to guess what will be the temperature and then they will do that. And of course the severity of cooling during the quenching they will go for air cooling or water cooling or for oil cooling kind of thing and control of the phase transform proper heat treatment they were just by guessing they were doing because of hands-on experience.

And even today also you will not see think that I will measure, they will be doing particularly the art, the artist and in the rural area even today they know what is to be done. They may not be knowing all these, what you call FEC phase diagram kind of thing, but they were knowing what is to be done.

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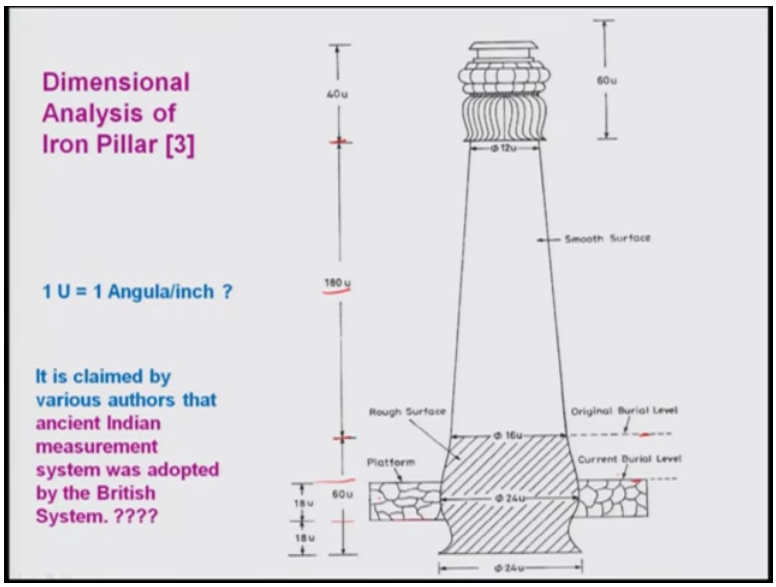

Let us now discuss about iron pillar which is rustless. And if you look at this is the pillar which I have shown here, which is located currently in the Qutub Minar. You can note one thing that this is having an increasing diameter and it is being measured by various researchers and some of them have just put it here and this is having a decorative portion of this rustless iron pillar, this amounts to be 60 units. U is basically related to one Angula or inch. And if you look at it is the diameter of this iron pillar is 12 U here whereas at this zone it is something 16 U and in this portion 24 U and again it comes back to 24, this is below the ground, you know earlier days the original burial level here but now it has been gone to this portion.

And there is a platform below you know which supports this iron pillar. And similarly the length of this what you call, portion which is 40 U what is existing today but people are thinking there was some emblem here above it, and that is why they are thinking of 60 Unit if you put that thing. And from this region, this region it is something 180 U and this is 60 U when it is increasing its diameter and having a very good nice curve to it. And it, if you look at it is like a cantilever, I mean they were knowing this has to be more so that it can support the thing. So 18 U is this one, this portion and this is 18 U these dimensions, right.

And of course it is being claimed by several authors that ancient measurement system was adopted by British system but it is questionable and one has to do more research to find out whether it is true or not or maybe it is just a false claim. So from this you can note that you know dimensionally they were maintaining the object what they were producing. But maintaining a dimensional tolerance is not that easy even today. So let us see how they might

have created this rust less iron pillar which is consider to be one of the wonders in the entire world.

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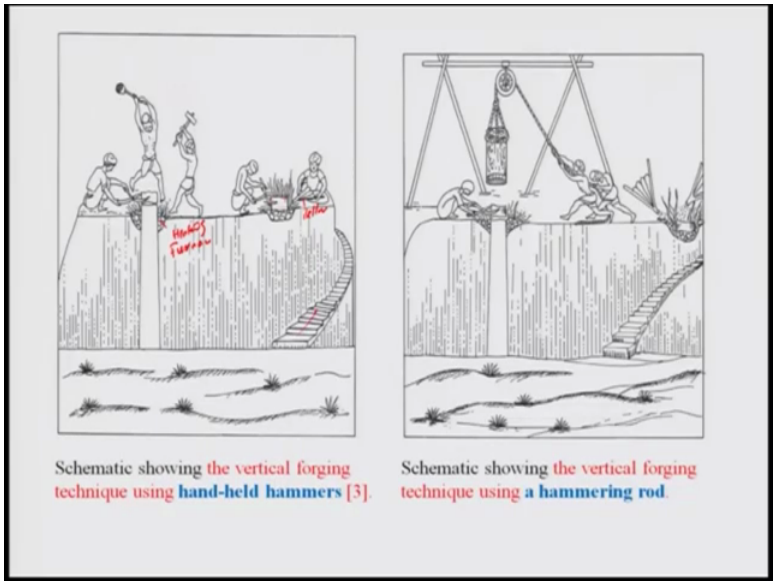

And this is again what I am showing here is basically hypothetical, there is no evidence how they made it. But people are thinking how they might have made this way. This is a pedestal they will be making continuously, of course this is a staircase right through which people will be going to the top and they will be using some iron. This says the iron which is hot iron pieces and they used what you call bellows which is basically bellows and this is a tong which will be, they will be holding this piece of iron they will heat it and take it from here to this region and then place properly and again they will be heating these are all what you call heaters or heating furnace you can say, right.

And they will be applying this force by, with the help of a big hammer in a continuous manner so that it will be forged well with that. This is known as hand held hammers you know, and this is vertical forging technique, this is basically vertical forging technique what people are thinking they might have done. But nobody knows how they did it. So that is even with this people are anticipating instead of what you call hand held hammer which is having limitations, they might be using hammering rod which a pulley and you know rope systems.

And again the some process they will be doing like they will be heating this iron looms and then they will take this and place this and they will go on hammering so that it will be welded. And if you look at, as this height of this pillar goes on increasing there will be increase in this pedestal, it is a very painstaking job if you look at that way.

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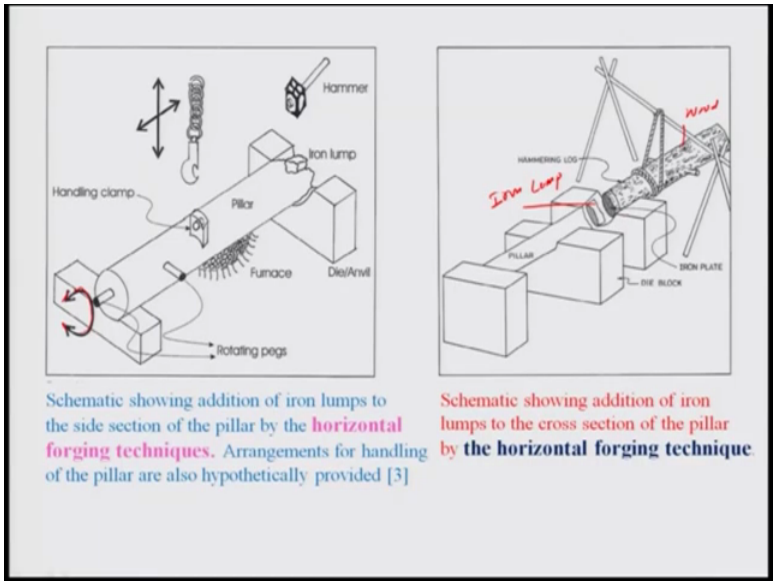

Whether they did in this way or they have used some other way like another way one can think of is horizontal method that is, horizontal forging technique. They will be using a peg here and this is your iron pillar to start with the peg which will that will be easy to rotate they will be rotating this way. And then there is a furnace here and of course handling clap they will be fixing here.

And then what will they will put in a die or an anvil and they will take this iron lump which is heated one, and they go on you know, hammering into the proper size and then they will also rotate this one, this one in what you call a continuous manner and putting this iron lump and so that they could have produced this. And as I told this is a hypothetical because they will have to lift up and then down and rotate it you know this thing, and there is of course similar way.

Instead of using hammer what they will be doing is that they will be using a hammering log, of made of maybe iron with hardness, hardness, iron plate they might have fixed. Of course this can be wood if they are thinking it will be wood, timber and they will be having an iron plate they could have joint it and then hammer it so that it will be making this is basically iron lump. And right, and this die will give this shape because die should be hardened, otherwise die will get you know spoiled in the process. Of course in this case it will be horizontal force which will be acting due to the moment of this log, wood log and also with the iron plate. But they might have made this way. So these are the hypothetically people are thinking that they might have made in this way.

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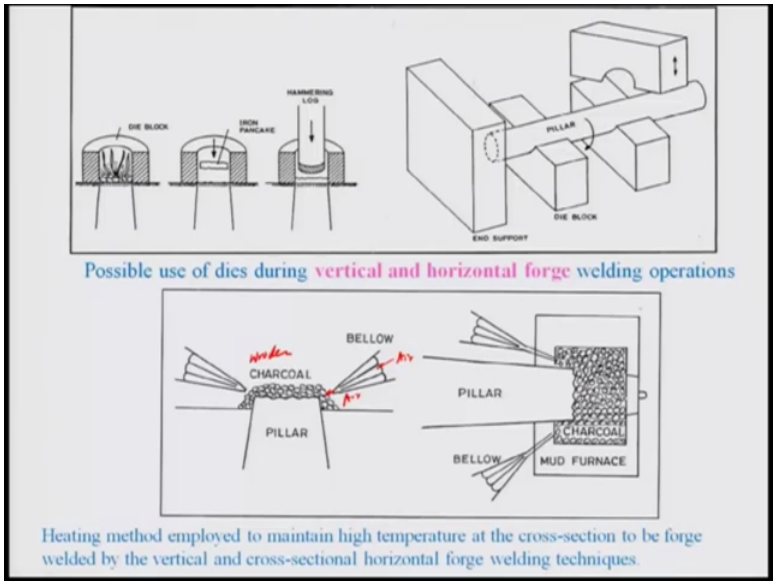

There is a possible use of dies, for example there will be a die block and they will be heating it and then iron pan cake they will put it here and then hammer it by the force or they will be using a hammering log which I had described just now. And there is another way of that you know the similar way that is the pillar and then this is a die block and die block can be put together and they will be rotating it and support it will be and then hammer from this side and so that they will be making the forge welding operation to take place. Of course for these purposes one can use, what you can this is, when it is a vertical pillar making and they will be using the charcoal, this generally the wooden charcoal right. They will be using and bellows for the supplying the air you know, air will be coming out of this and of course this is for the horizontal pillar making process.

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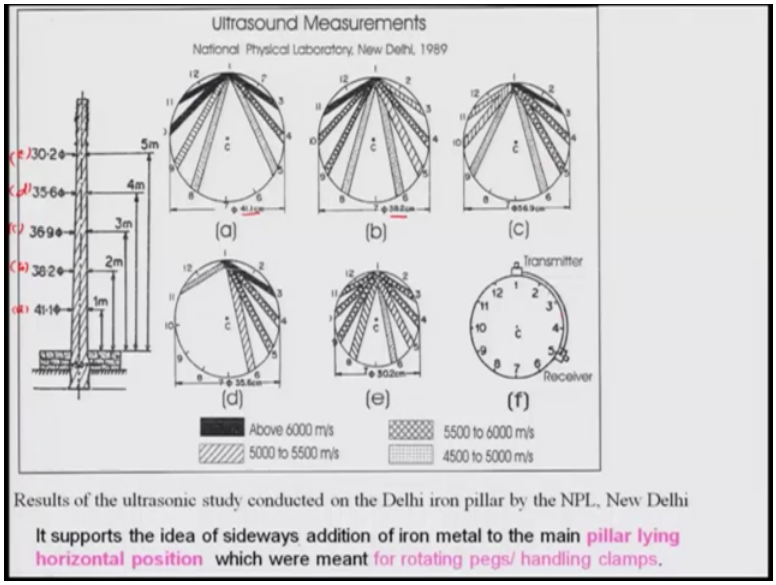

So by this people might have done and one can see that like how it is. Of course lot of other research are going on, I am just showing some of them due to paucity of time. Lot of work has been carried out on this archeo-metallurgy of the iron in India. And this data is corresponding to ultrasound measurements, what they are doing is they are putting a transmitter right and which can produce this ultra sound, and then you will be pouting this receiver at each point and then find out how this intensity going on, what is the speed velocity at which the sound is propagating.

And at different location they have taken they have taken in what you call 41.1 centimetre and then you know like at this diameter this is 1 meter, 2 meter 3 meter 4 meter 5 meter height, corresponding to different diameter which is shown here 41.1 and then 38.2 at different, like this is if you look at this is your A, B and this is your C and D and E, so and these corresponding to the sound and from these they could you know find out that there is a places right.

that side way addition of iron metal in the main pillar lying horizontal position. They are thinking that you know these lumps of thing are being placed in the side as a result what will happen, these velocity is not symmetric right, if is changing. Because of there is obstruction there will be metal surface which will be still lying, there is two metal lumps having a surface so that it will not allow the sound to come, it will be reflecting back.

As a result from this they are saying that in ancient India this iron pillar could have been made in a horizontal position and that is a conclusion they are making because these are

different in some cases, for example here it is very clear this sound is very different than this, where this is 6000 meter per second and this is basically if you look at that is 4500 to 5000 meter per second.

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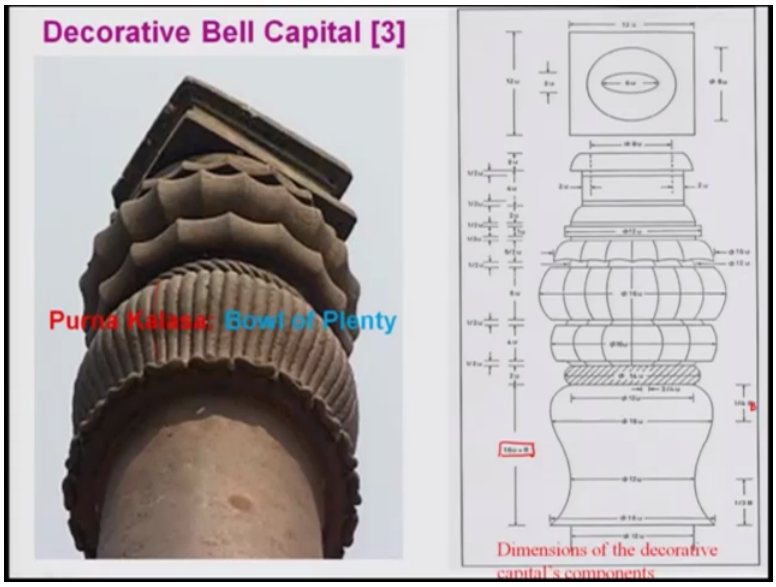

So that is the conclusion they have made from this measurement, and as I told you the decorative bell capital if you look at the dimensions are given in terms of U, you know it has like various complicated looks to very complicated and having this thing. If you look at this bell shape this is like inverted Kalash kind of thing and that is one third B, B is basically corresponding to 16 U and this is also B right one fourth B. And how they are maintaining these curves you know and then what are the, these dimensions, these are the big question which is coming to our mind. And actual figure it shows, these are of course the diagram drawing of this actual figures and it looks too very beautiful.

And a question might be coming to mind, why they have made so you know attractive and decorative in nature. One interpretation is that this is basically a this portion, this portion having a punya Kalash and it is a bowl of plenty. And we know that you know always Indians were very much interested to have the ultimate goal of life of attaining spiritual hood, that is attaining the perfection and what we say is that Punyam idem Punyamadath punyamudachyathe, punyashya, punya mathaya, punya mevamashishate. That means you will have to attain the perfection that is the ultimate objective of life and this is being placed in front of a temple.

So therefore people will be coming and trying to you know look at themselves and then go back and then walk for this attaining the perfection which is the ultimate objective of life so far the Indian philosophy is concerned. And it is not only here, it is all our auspicious occasions there will be a pot which will be filled with water and that also indicates or gives a signal to us that we will have to attain this perfection in as a human being.

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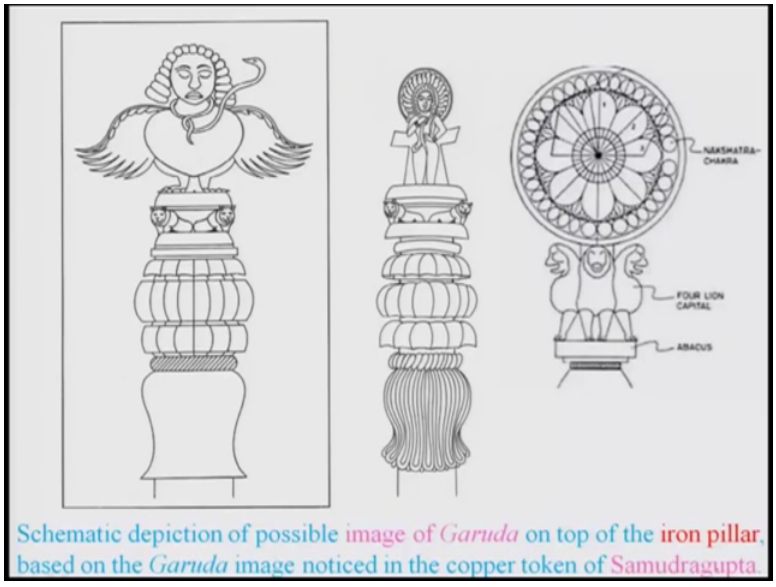

Schematic depiction of possible image of *Garuda* on top of the iron pillar, based on the *Garuda* image noticed in the copper token of Samudragupta

So of course this portion of Garuda which is being shown here is not there and but people are thinking that Garuda shape might be here which has been removed from the original structure and might be again the Vishnu will be there here. And people are also telling that this there might be another one like you know this is nakshatra chakra which was having giving some idea about various nakshatra. And some people are interpreting that there might be sudarshana chakra which is being generally being used by lord Vishnu. And these are being basically made of maybe copper during the Samudragupta period because how they are anticipating it, they are taking this idea, basically from a copper coin which was being invoked during the Samudragupta period that might be the thing, but how they made this thing of course they are thinking that it will be made of not iron but maybe some other bronze or some other metal.

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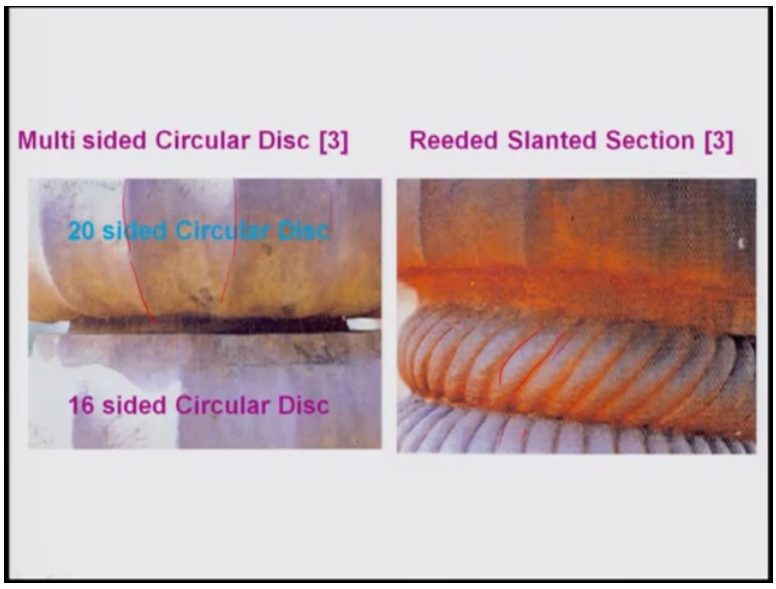

And let us look at this multi sided circular disc which is having 20 disks sided disk in the upper one. If you look at this is one of them right and how they are making this thing that is one thing and of course they are making 16 sided circular disk , why this change one can think of I mean like, these are all mystery one has to research and find out why it is. And this is the reeded slanted section this portion is the slanted section how they have made and there is another section comes the bell shaped inverted Kalash shaped thing how they have made out of this is the one question might be coming into picture.

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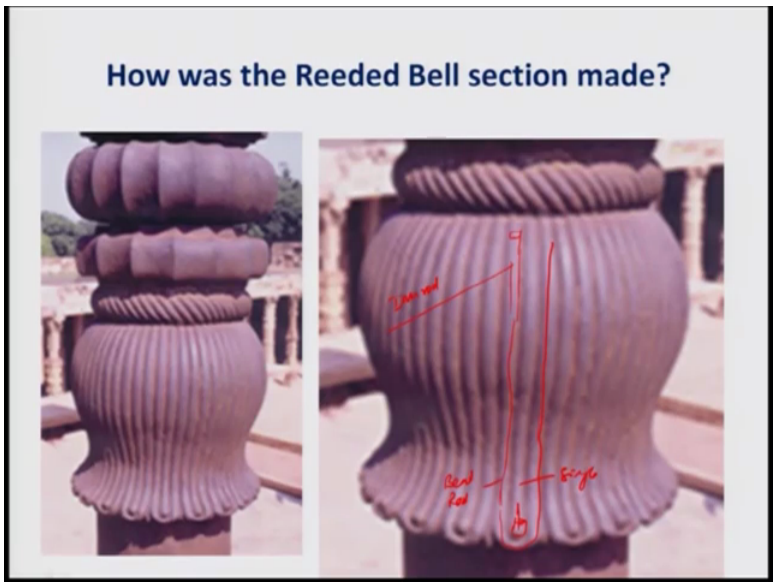

And this is the thing what I was taking about. These are the 20 faces and these are 16 faces and these are slanted one. And this is the your bell shaped what you call inverted Kalash, like

bowl inverted bowl or inverted Kalash you can call. Now how they have manufactured these things, this is one question might be coming to your mind. A lot of hypothesis being made, what I will be discussing is hypothetical because there is no evidence there is nothing written that how they have made about it. So one of them what one can think of that you know these are the shape I have just magnified it here.

If you look at these are rod right, it will be having a rod kind of things, these are all iron rods okay. And they might have tone iron rod here in rod and then bend it and put it here right. If you look at like this is the rod what they have taken and they have also flattened and made this curve little bit. In between there is a one single rod this is the bend rod right and this is the single rod they have made and then forge welded to this portion that might be the one way. But how they were maintaining the tolerance of the rod diameter is one question might be coming and also besides this they were making little flattened.

If you look at this portion you know this portion is little more diameter than inner one and flattened also they make a curved one what shape they will be using how they are maintaining this and managing the shapes is also one question coming to my mind. And these are the things one has to do that, maybe somebody should replicate. And what mind and concentration power and judgement power those people will be having who had made this thing.

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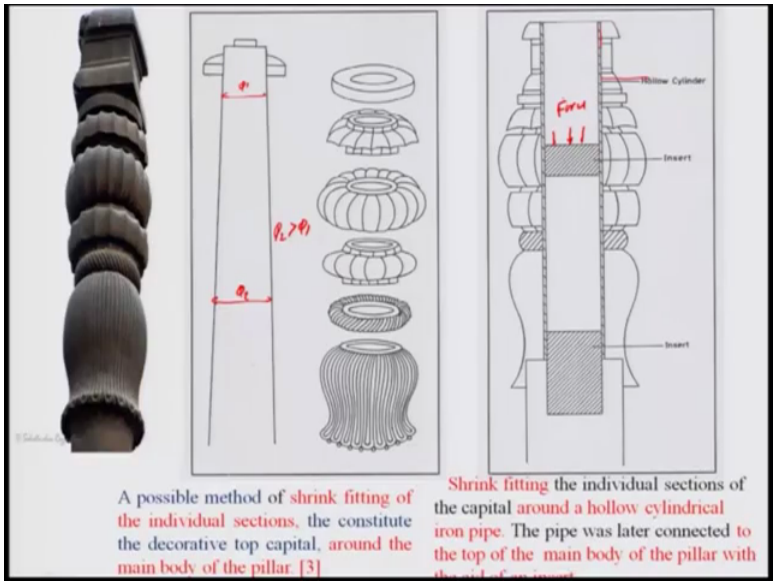

So let us look at how they and there is a thing whether they have made this in a single piece or they have made each pieces and then assembled them together that is one question coming

to mind. But what people are thinking that there might be use some different pieces they might have manufactured and then like this you know this is the inverted Kalash and this is the ring and these are the all ring kind of things and they have fitted.

Now of course there is a decrease in diameter if you look at this is diameter 5 and then 5.1 and then this is 5.2 and 5.2 is greater than 5.1 diameter and then of course you know it will be easier for them to put together. So that is one way of by pressure they will be using it and then you know, but then how they will be matching this diameter so that why it will not go here and there you know like that is one. There is another way of people are anticipating they will be using a hollow cylinder here, this is the hollow cylinder right and they will be putting these individual components on this what you call hollow cylinder with thin wall thickness. And then they will be putting this inside and they will be hammering it using the force. Right, as a result it will be shrink fitting kind of things, that is another way.

But which is the correct one and how they did all those things has to be you know studied and then one can look at. But even if you consider this thing that itself shows that what is the craftsmen they were having and what is the technology that they were having during that, at that time. So therefore it is very important to you now appreciate their skills of making this not only the iron pillar but several of them but I am discussing iron pillar now. And then why, question arises is why is the Iron pillar rustless.

That is the question might be coming of course lot of research has been done on this but there is lot of diverse kind of opinion being made by various researchers. I will be discussing about something which is very simpler being explained by the late professor balasubrahmanyam of IIT Kanpur and I have taken this thing from his book on iron pillar.

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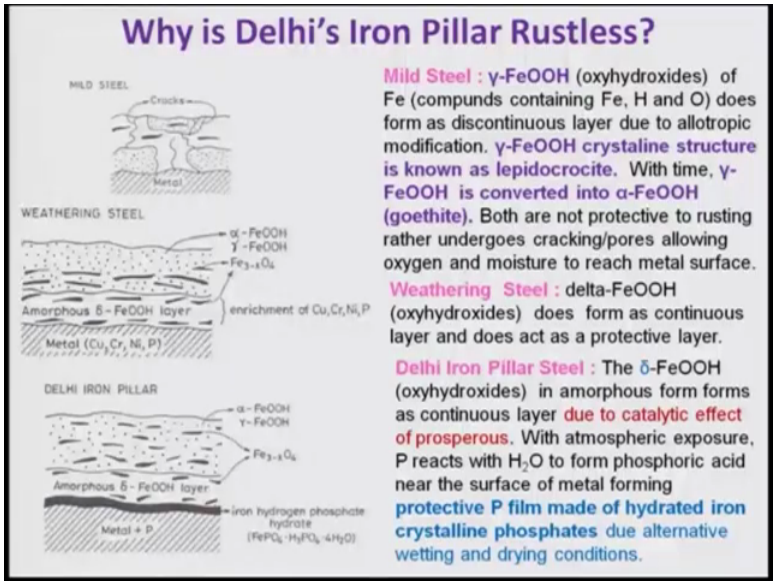

So let us consider a metal, mild steel which will be having of course no other like chromium nickel and other things. As a result what will happen, whenever it will be coming in contact with the atmospheric air oxygen and particularly and also the moisture then what will happen several oxy hydroxides will be forming, like let us say gama FeOOH and because this iron will be containing Fe iron and also the H and O it will be there in this compound. And then these you know creates something like a discontinuous layer near the metal, like if you look at the one layer and this also there is another kind of alpha FeOOH being formed sometimes because with time this gama FeOOH is converted into FeOOH which is known as Geothite.

And this gama FeOOH crystalline structure is known as also lepidocrocite and this being what happen like there will be a crack in between and which will allow this oxygen and the water to come in contact with the metal. As a result the rusting will be occurring because oxide will be formed and then rusting will be occurring and this as a result rusting cannot be prevented by this. But of course in the modern time people do add copper chromium, nickel of course chromium nickel are being used nowadays very much and of course some people have started adding phosphorous in a small quantities.

And this creates a delta oxyhydro oxides layers amorphous, which is amorphous in nature. And this will be acting as a protective layer between the, what you call the atmosphere and the metal, virgin metal. Of course on the top of this delta FeOOH layer there will be alpha FeOOH and Gama FeOOH, there might be crack in between but however they will be amorphous in nature therefore it will not be any crack. And it will act as a protective layer so that we will get rust less iron, like stainless steel iron and other things.

But in ancient times that what people are using in Delhi Iron pillar particularly, they were using the metal containing a lot of phosphorus, certain amount of phosphorus. The good thing about this that it will be reacting with the water and also the oxygen when it is exposed to the atmosphere in the beginning of course there will be some amorphous delta Fe layer will be there, there is might be crack there might be little rusting will be there maybe. But as the time progresses, this layer the protective layer, the iron hydrogen phosphate hydrate layer which will be thickened and then it will be very protective.

With respect to time, you know, time means not hours or days, it will be years together and these became more rust less and that is being occurred due to the alternative wetting and drying condition, because you know in the raining season, it will be, lot of moisture will be there, in the winter season you know moisture will not be there in the air so therefore that will be going on.

And that helps in building this iron hydrogen phosphate hydrate and also its thickness increases, as a result you will get rustless iron with the time, you know. So generally it is other way, if you keep the steel for longer, stainless steel particularly for longer period rusting will be occurring. But in this case that will not occur it is just opposite of that.

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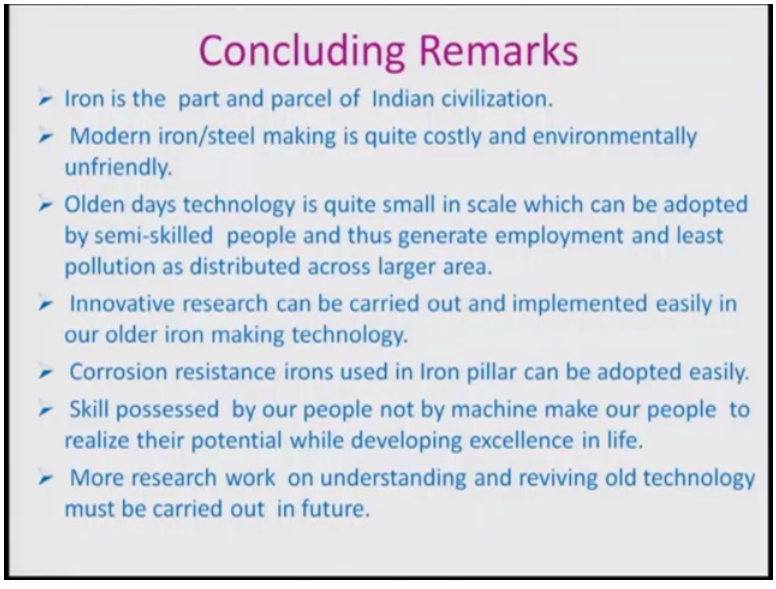

So therefore with this I will conclude that iron is the part and parcel of Indian civilisation and modern iron steel making is quite costing and environmentally unfriendly, as I had discussed in earlier lecture. And olden days technology is quite small in scale which can be adopted by semi-skilled people and thus generate employment and least pollution as distributed across

larger area and people can innovate on it. And because there is a lot of scope for people to carry out you know innovative research and implement very easily in this older iron making furnace.

And corrosion resistant irons used in iron pillars can be adapted easily, skill possessed by the people not by the machine or the what you call very few people, companies make our people to realise their potential while developing excellence in life. So more research work on the understanding and reviving this old technology for making iron must be carried out in future. It is not that only for iron will be you know doing research we will be doing also to revive old technology maybe in a little modern sense so that it can be accepted by the people. Thank you very much.