River Engineering
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Lecture – 14
Physical River Models

Welcome all of you to this last class in river engineering course and today, we will talk about physical river models okay, basically the experimental works what is necessary to do, understand the flow process, sediment process in rivers, so you say scale down models.

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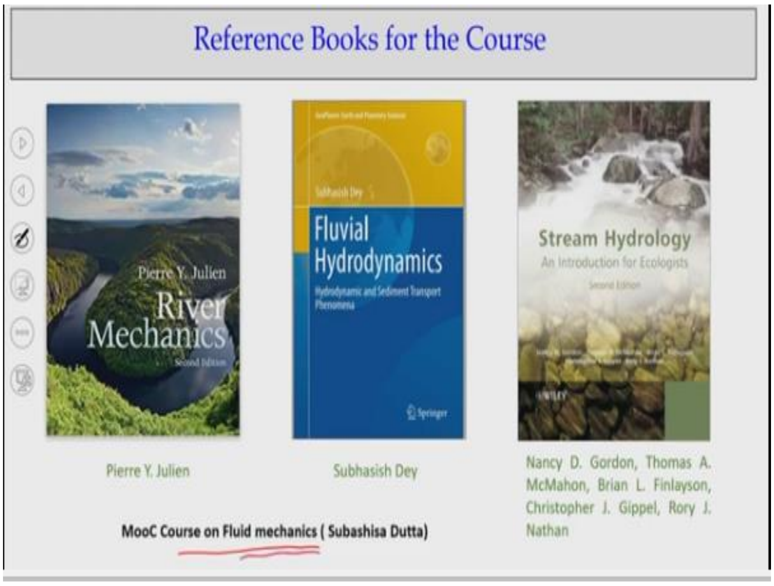

So to start that I will tell it that regarding the physical river models, we should have a knowledge on dimensions and similitudes that is what I have covered in fluid mechanics which is a MOOC course is available. So, please go through that 2 lectures on dimensions and similitudes that some component of that I will cover it here but more details of dimensional analysis and the similitudes, you can follow the MOOC course on the fluid mechanics designed by me.

So, for you can look at that and more or less we are following river mechanics P.Y. Julien book and that is the physical river modelling concept what we will today, we will discuss it.

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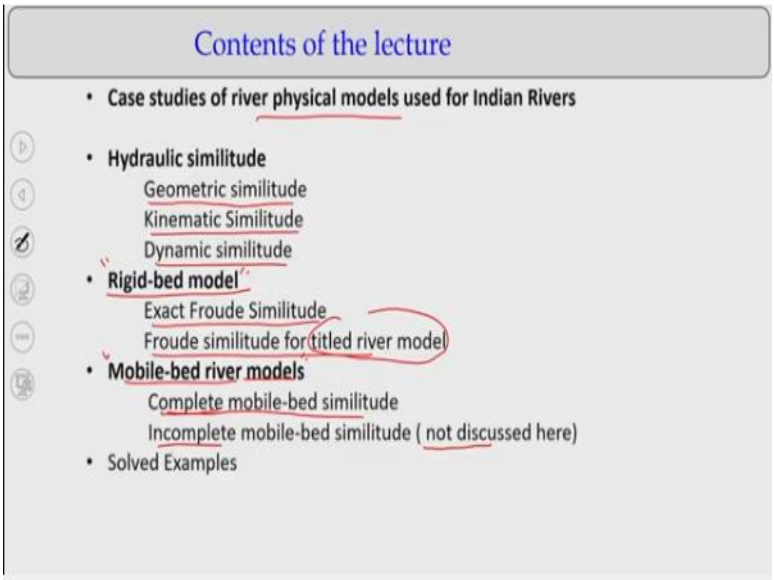

And since it is a last class anyway, I am not going to more details of physical river models but I will try to develop a confidence in you on how to scale physical models for a river or a river reach. So, if you look at that I will show some case study of river physical models used for Indian rivers and then I will talk about the different type of similitudes as you know from basic similitudes like geometric similitudes, kinematic similitudes and the dynamic similitudes.

And here we talk about 2 types of models; rigid bed models, mobile bed river models, so you can understand it, the one case there is sediment transport is dominated, so that is what is the physical river models and we can have a rigid bed models where the sedimentary process is not that dominated, so that case we can use the rigid bed models. So, we can divide into 2 parts, one is exact Froude similitudes, another for the tilted river models.

Similar way the mobile bed river models will be a complete, incomplete models, I am not discussing much details here incomplete models, we will just discuss about complete mobile bed similitudes. Before trying these things to develop a river physical models, we should have an enough knowledge on river engineers, that knowledge will be help us to establish an appropriate river physical models.

And what is our objectives that we should try to understand it engineering point of view, it is also a knowledge, the art of modelling we should follow it to have an appropriate model for a river problems.

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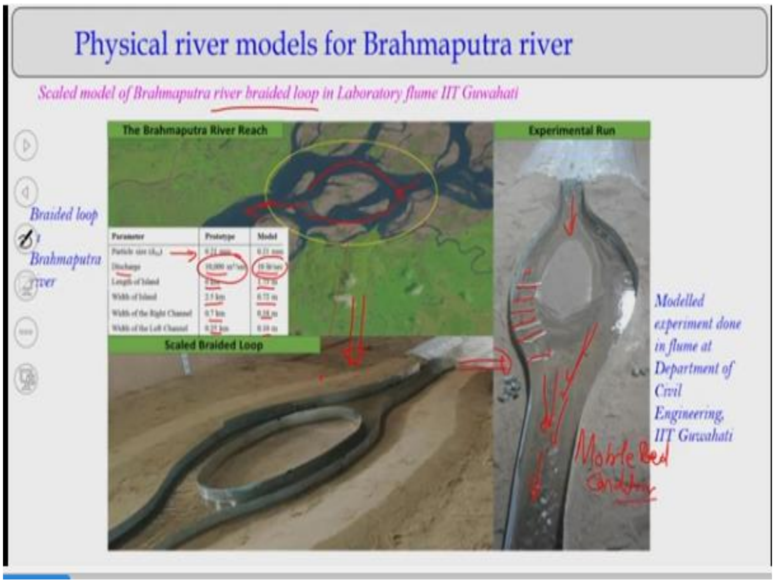

Now, if you look at that very interesting lab setups what we have and there we are trying to set up a small set of river model for Brahmaputra rivers, if you can look at the river Brahmaputra, if you look at this braided loop and the flow is incoming and out goings. The same concept when you talk about if you look at, this is what the prototype level which is showing the satellite imagery and we are developing physical models okay, which in the lab scale is a scale down models.

It is a scale down models and with a training work we can see these, there are geotubes are there which are the training works, before implementing the geotubes, we can know it what is the impact of the geotubes on river morphology that is what we conducted a study and try to locate how the geotubes are effective for arresting the bank erosions. So, if you look at that concepts and what we have done it that particle size of the d50 of the prototypes, this is the prototype, this is the models is the same.

The river discharge is a 10,000 m^3/s, we put a model is 10 lit/s, the river length of the island is 6 kilometres, in the model scale is 1.73 m, width of the island is 2.5 kilometres and the model level is 0.72 m. Now, if you look at the width of the right channels, width of the left channels that is what we have given there, so this is a scale down model.

So, if you look at that geometry scale down models is there as well as the discharge the scale down is there from 10,000 m^3/s to 10 lit/s and it is a mobile bed condition, it is also mobile bed conditions where the sediment, the bed load sediment process are happening it that is what you can see it. So, we always have a scale down models from river to the laboratory scales that is the scale down models. Today, we will discuss it how to develop a scale down models that what we will discuss in more details.

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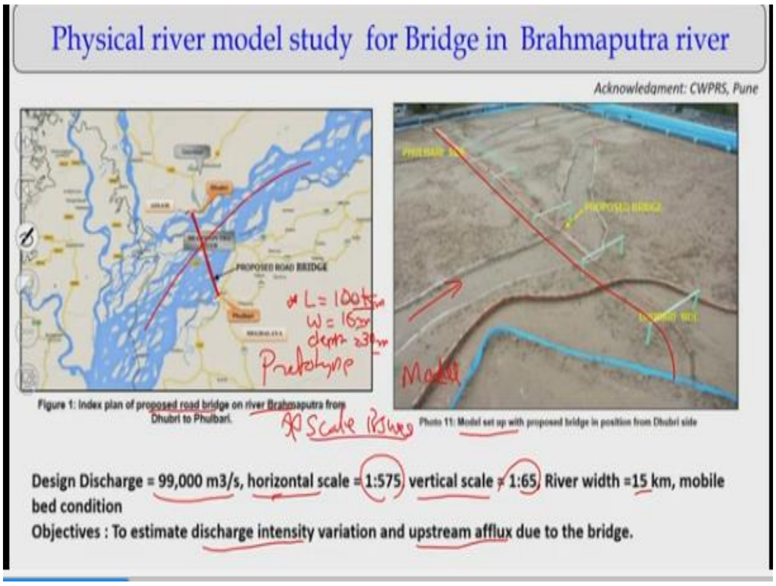

Now, if you look at the similar one examples I will take it that physical river model study for a bridge in a Brahmaputra rivers that means, this is the bridge proposed to be constructed, the same models of the bridge and the piers, you can see it that is what is done it on a physical model setups. So, this is the proposed road bridge on the Brahmaputra rivers, the same things what if you look it, it is implement in physical models.

And these dots are representing bridge piers okay, this is what the main channels and other channel formations are also there. So, this is the prototype, and this is the models. Now, let us look at how about the scale down is happens it; here the design discharge is 99000 m^3/s which is close to 100 year return period flood, horizontal scale is 1:575, the vertical scale is 1: 65, river width 15 kilometres.

The basic idea to know it discharge intensity variations upstream afflux due to the bridge, so if you look at that we before implementing a bridge projects, we do a physical river models to know it how much of discharge intensity variations are there, how much of scour formations will be there at different bridge piers. What could be the upstream afflux will be there because of this construction of this bridge.

So, this type of the prototype to models we do it in the laboratory to know it the flow and sediment transport processes, what is happening in the model scale and that basis we predict it what could be the scenario in real river conditions that is what we do a scale down models. We remember here we have used the horizontal scale and vertical scales are the different that means, is a distorted models, this is what; distorted models were the horizontal scales and vertical scales are the different.

Why we do follow basically the different distorted models for example, if you look at these rivers as you can see that the length of these rivers can be in terms of 100 km, width is 15 km and the depth of the flow maximum will be the 30 m that means, it is a kilometre orders in the plan form dimensions, one is 100 km, another is 15 km but depth when you talk about 30 m.

If it is that the scale we cannot use a geometrical similarity models, exact models because we cannot represent the same scale in the vertical direction and the horizontal direction because of the river dimension that is what many of the times we talk about the scale issues okay, because the scale, the dimensions of the river in terms of length, width and depth that is what is very considerable, so we need to have a distorted models. That means, we will have a vertical scale and the horizontal scales are the different mostly, the vertical scales are the finer scale than the horizontal scales, which will be the coarser scale.

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Now, if you look at 3 dimensional models which is a CWPRS Pune, central water power research stations in Pune. If you look at this Kosi barrage, you can see this Kosi barrage and abutment, all leads are there, so it is try to know it how this flow is varying it that is what is at the physical models levels. The same way if you look at this Kosi rivers where we lot of study has been done for the Kosi barrage like putting the different type of river training works, what is effectiveness of river training works to protect the river banks and this is what the river flowing.

So, if you look at that we conduct a series of physical based models for the Kosi barrage as well as Kosi rivers, same way when we talk about hydraulic structures like Indira Sagar dam, a 3d models we prepare it, exactly a scale down 3d models, Punatsangchhu II 3d models. Similar way this is the port and this is the back water at Poompuhar embankments.

So, if you look it that way always we conduct a physical river models to try to understand it at the structure, how the flow process are happening it, this is a 3 dimensional models, this is 2 dimensional models representing the plan forms, river training, how we have to have a river trainings and you also have a back water for this condition. So, we do the physical river models, central water power research stations Pune is leading in our country to do physical river models.

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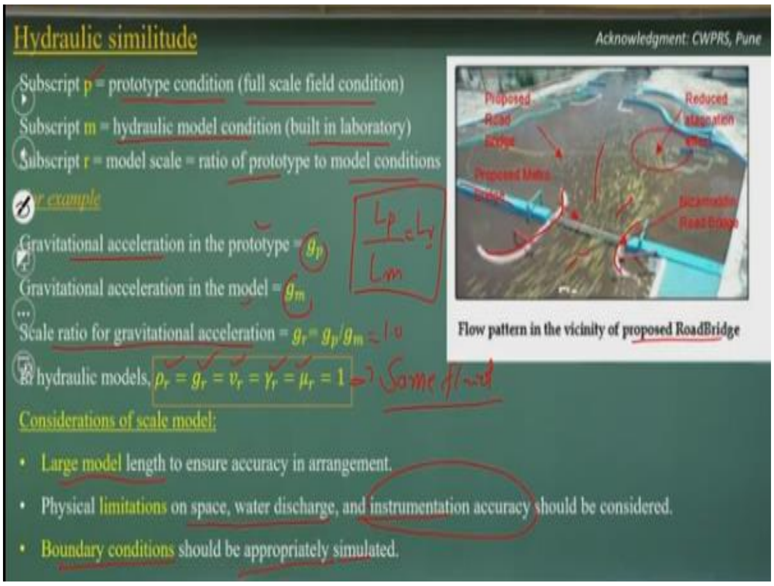

Now, if you look at that what, how you do the hydraulic similitudes, that means we have a prototype, we have the models, we try to do a scale downs that is the reasons, prototypes conditions which we give a subscript of the p is a full scale conditions, field conditions, m is in the hydraulic models conditions built in the laboratory. The the ratio between the model to prototypes.

That means, what we do it if any parameters like a length; length of prototypes by the length of models that what will give length ratio. So, we define in the scale on this, we define this the scale of this by this length of prototype by the length of model. So, if you look at that most of the cases we do the studies in on the earth, so considering that if we first look at the gravitational accelerations of the prototypes and models, the g_p and g_m's they are equals.

That is the reasons the scale ratio for the gravitational acceleration field, it is comes out to be 1, so if you are using the same fluids, same water or same liquid whatever is there, the same liquids you are doing any physical models, so the basic proportions like a density ratio, acceleration due to gravity, ratio of dynamic viscosity, kinematic viscosity, unit weight ratio all becomes 1.

So, the condition is that we are using the same fluid, so you are using the same fluid, so then our model ratios will be the same. The most of the times as I said it we cannot do a total geometric similarity models because we have a lot of constraint like the length, the physical limitations in terms of space, water discharge, instrumentation accuracy, how accurate instruments we have to measure the velocity, measure the flow depth, measure the turbulence properties, measure the sediment.

So, what is accuracy that also matters to design the scale, the scale does not mean it that we can do very, very finer scale unless otherwise you have a highly accurate instrumentations with us. So, similar way we should implement the boundary conditions, upstream and downstreams like these flow models, if you look at the proposed road bridge, this is the bridge structures and this is the guide bunds and you can see that how the flow things will happen.

So, in this case we need to know it what could be the upstream conditions, what it could be the boundary conditions, when you develop the physical models these 2 conditions also should be satisfied.

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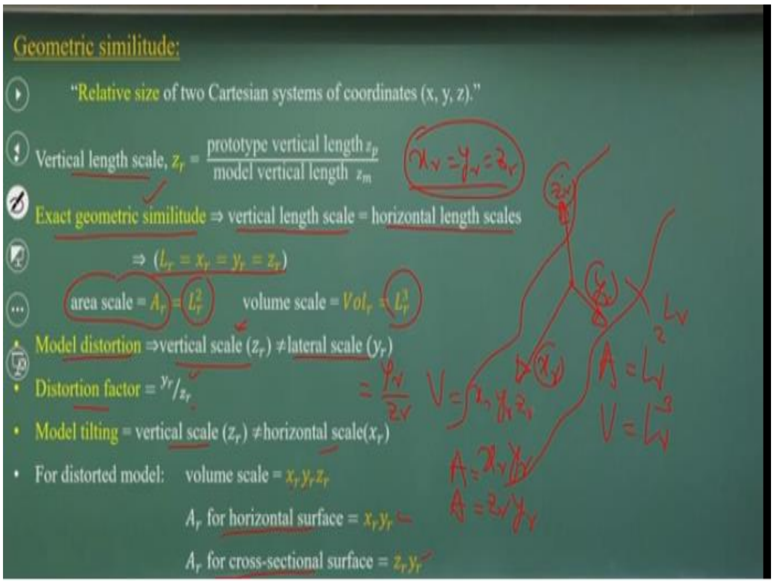

Now, if you look at what you are doing it as I said it, the vertical scales z_r directions, so basically what you have any models you put it okay, in a 3 dimensions, you have a x_r, you have a z_r which is vertical directions and we have the y_r. So, most of the times we try to look it whether you want to do a 3 dimensional models, then you need to locate all these component; z_r, y_r, x_r.

The z is vertical ratio, y is a lateral ratio, x_r is the longitudinal ratio, longitudinal length ratio, ratio of the longitudinal directions. When you do exact geometric similitude, okay that means your vertical length case is equal to the horizontal length scales that means, your x_r is equal to y_r equal to z_r okay which can be done it for a smaller scale, it is exact similitudes, similitudes, that means you are not distorting it.

You are not talking about like a 3d models of a hydraulic structure like a dam structure, we can have all these conditions satisfied okay. So, the ratios can be also satisfy x_r, y_r and z_r and this is the conditions when you have that is the length ratio called geometric similitudes, we call geometric similitudes but many of the times as I said it the vertical scale of the rivers are much lesser, vertical depth of the rivers are much lesser as compared to width or in comparison to the length.

So, we do the vertical scales different than the lateral scales in that case, we have a model distortions will happen that when the vertical scales are not equal to the horizontal scales. The distortions factors y_r/z_r, that length ratio in the y_r directions by z_r is a ratio in vertical directions, so vertical scale is not equal to z scale. In this is the case if you want to estimate the flow area in case of exact geometric similitudes, area will be the square of the lengths okay, the square of the length ratio, the volume will be the cube of the length ratio.

But that is what will be substitute in case of volume, you will have x_r, y_r, z_r product of these, the horizontal surface and the cross section surface will you can interpret, it will be like this. So, basically when you use a distorted models, you use x_r, y_r, z_r's are the different otherwise, if you have exact similitude models, you use the L_r. So for that, area will be the L_r^2 and the volume will be the L_r^3.

But in case of when you are using x_r, y_r, z_r's are the different in a distorted models, then your area will be different depending upon whether is a horizontal surface or the cross sectional surface. In horizontal surface you will have x_r and y_r and in the cross section surface you will have a z_r, y_r.

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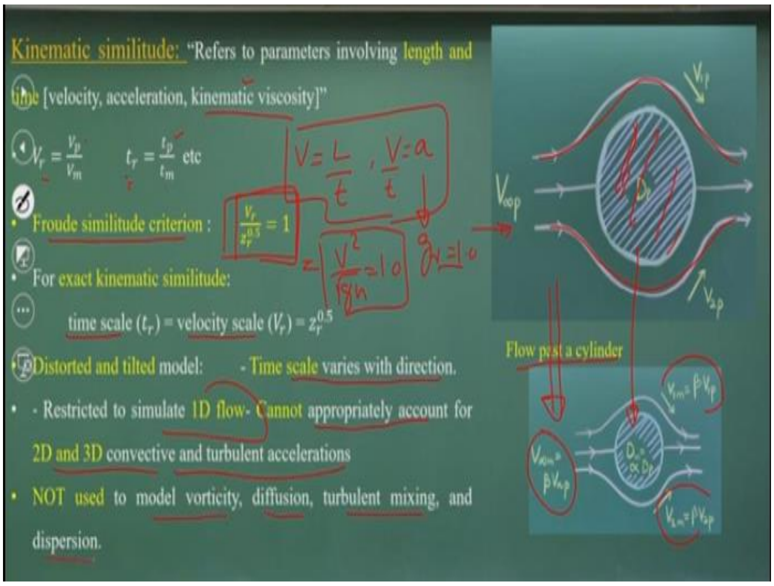

The volume will be x_r, y_r, z_r, so please give a attentions to these which is the ratios and now if you look at basic next similitude is called kinematic similitude, as we discussed in dimensional and similitude analysis and similitude analysis in fluid mechanics, it is the same concept. That means is this is just here we are taking example the flow past a cylinders. This is the original cylinders or you can say is a bridge piers and the flow is coming in which is a cylindrical shape.

This is the prototype levels how the stream lines are happening, how the velocity distributions are happening it. The same geometry kinematic similitude we have to do it, the scale down this the diameter of this bridge piers, which is a cylindrical bridge piers to this shape and then we can have a scale for velocity components. And so that the streamline patterns, the velocity ratio that is what will be maintain it, the length ratio, the time ratio and the velocity space go whatever is there that what can maintain it.

So, if you look at that part that means we are introducing whenever kinematics similitude that the parameter involving length and time that is velocity, accelerations and kinematic viscosity, it is that is also will have the same V_r we given as a V_p/V_m. So, you have a t_r will be the time scales, will be ratio of the time scale will be t_p/t_m, if you look at that and basic properties as you know it, the velocity is equal to length by time and you know it velocity divided by the time will be the accelerations.

So, if you use these 2 terms and try to look at the velocity and the length ratios as we deduct that part and the accelerations as we can consider is a 1 okay. So, in that case we will get it the $V_r/z_r^5 = 1$ which is the flow Froude numbers, $V^2/\rho gh$ is a constant that is what you know it. So, when you do this kinematic similarity, you needs to have the Froude similitudes criteria. So, even if that the that is what is hold good at, that is what is indicating here that you will have that conditions.

So, once this is the conditions is there, the Froude similitude criteria is there, you can compute it time scales as well as the velocity scales. Now, we can go for the distorted models where the time scales varies along the directions, the restricted to simulations 1D flow it cannot account for the 2 dimensional, 3 dimensional convective and turbulence accelerations. When you do the distorted model or tilted model, so it is not used to model the vorticity, diffusion, turbulent mixings and the dispersions process. This distorted model you can use it and most of the times when you talk about the river scales we have to use distorted models.

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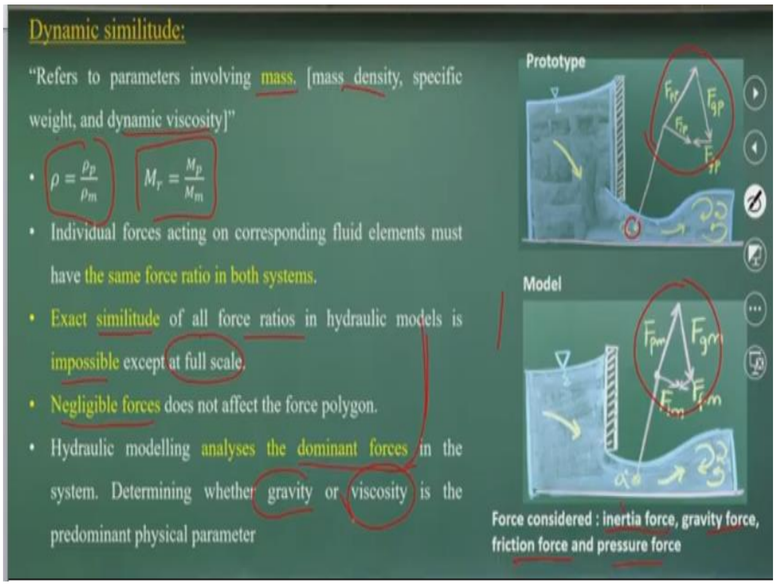

Now, if you look at the dynamic similitudes that means, we are talking about as if you look at the prototype of models okay, it is a scale down models. So, all the gates are also scale down, flow properties are scale down such a way that if I take, a points which is having the force because of inertia, the gravity force, friction force and the pressure force and force diagrams like this. The force diagrams will be more like the same, the force diagrams will be the more or less is same but only the magnitudes will be difference.

When you attain that then we call dynamic similitudes, then we call the dynamic similitudes at that what each conditions happens it, that means it is a involving with a mass, that means mass density, specific weight, dynamic viscosity when we try to have the ratio between the model and prototypes, so that is what is the ratio of the densities and these mass ratios what is there.

So, individual force acting on corresponding fluid element must have the same force ratio in both the systems they have the same force ratio, exact similitudes of all force in hydraulic structure is impossible, only at the full scales. So, when you look it to have an exact similitudes, that means that geometric similitudes should be satisfied, kinematic similitudes should be satisfied and the dynamic similitudes should be satisfied.

If these 3 condition is satisfied, looking all these equations we can know it, it is only possible when you have a full conditions, which you cannot implement, the river the scale model you can; cannot implement the full scale model for a rivers, it is impossible. So, we go for distorting forces, how do we get it? We look at which are the forces negligible like whether the friction force is dominated, whether the inertia force is dominate, the gravity force or the pressure force.

So, based on that we try to look at which is a dominated forces like most of the open channel flow, the gravity plays the major roles. So, we try to look at the gravity is more impact when you have an open channel flow or you look it where the viscosity or flow resistance play the major roles that is way we try to look at which component of force we can use for the prototype models which will be so the dominating forces, other in not a negligible forces like other components always we can neglect it that is the strategy being followed for river physical models.

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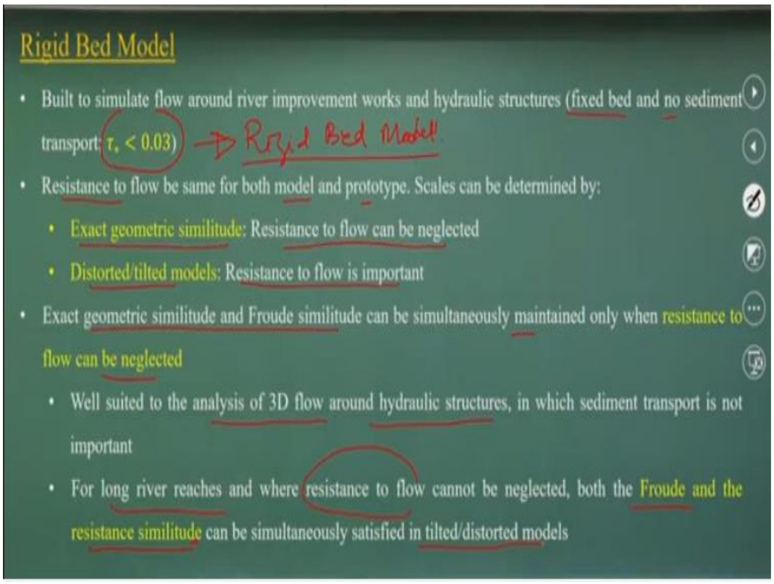

Now, let us coming to the rigid bed models when you consider it like you have a hydraulic structures, spillway, you have a fish ladder passage, where the sediment transport is not that significant or you are not considering the sediment part that extensively, we are looking more towards the flow structures. We try to move towards to understanding how the turbulence behaviours are happening not considering the sediment part.

So, we can go for rigid bed models which is the fixed bed, as name implies the no sediment transport that is what we consider it where the silt parameters is less than 0.03. So, you can see a river flow where you have the shield parameter is lesser than 0.03, then you can consider it is rigid bed model. So, basically what we try to look at resistance to flow should be the same for model as well as the prototypes.

So, it needs to have an exact geometric similitudes that means resistance of flow can be neglected or you can have a distorted tilted models where a resistance to flow is important that is what you have to consider. Exact geometric similitudes and Froude number similitudes can be simultaneously maintain it when the resistance to flow can be neglected. So, you have a geometric similitudes, you have the Froude number similitudes that is what we can maintain it, it is possible to do it, only if the resistance to the flow can be neglected.

So, the basically it is well suited for the 3D, 3 dimensional flow around the flow structures where the sediment is not river but when the long river reaches like Brahmaputra or river where flow resistance play the major force components, we cannot neglect it. In that times we should do Froude number similitudes as well as resistance similitudes which basically the manning's equations or stricklers manning's equations we can use it to satisfy for tilted and distorted models.

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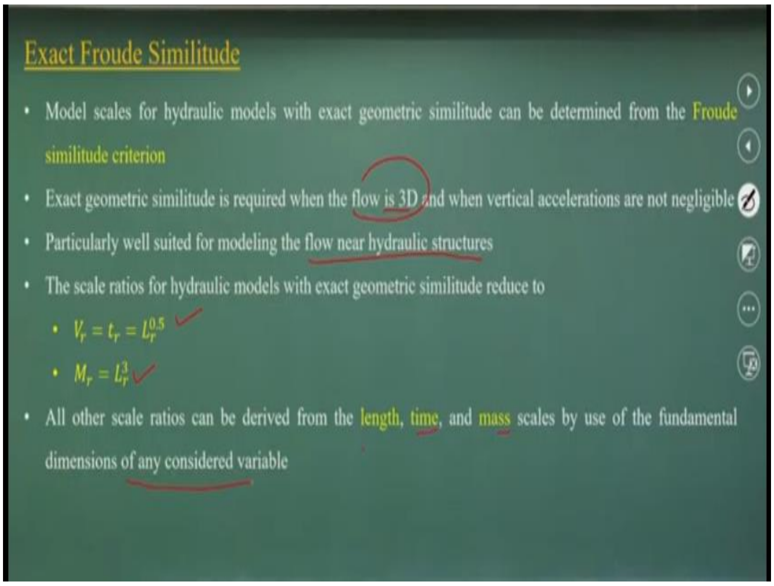

Now, if you look at that exact Froude number similitudes as already you have discussed is that we try to look it first the exact geometric similitudes should be there for the Froude number criteria and which is what 3 dimensions. If the vertical accelerations are not negligible that is what you need to have 2 dimensional models and these are the particular well suited model for flow near the hydraulic structures, as I said that spillway structures or sluices structures, so all these.

And you can have the length scale and the mass scales like this, you have a length, the time and the mass scales using the fundamental dimensions we can consider it and we can derive it, I do encourage you to follow dimensional analysis or similitudes to any fluid mechanics courses to know it how to get it the mass ratio is a function of the length ratio or the that is what you have to do it by considering this dimensions of the variables.

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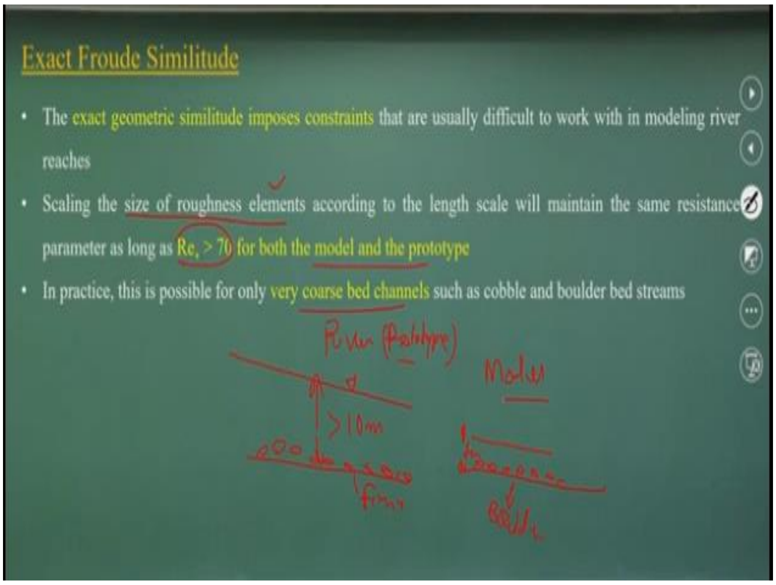

Now, if you look it there is a 2 conditions again is coming it that exact similitude imposes constraint that usually difficult to work for modelling of the rivers, scaling the size of roughness also its matters it. So, when you do a river models, what is the size of roughness you will get it, this is a river which is the your prototype, and you have a scale models which will be the few centimeters and you have in terms of meter, 10 m.

So you need to try to look at the resistance what you are saying it, are same orders okay, so if you look it that way, the size of roughness elements according to length scale will maintain the same resistance parameter as long as the Reynolds numbers, the grain Reynolds number is greater than the 70 for both the models and the prototypes. This is the possible only very coarse bed materials are put it on the bed streams.

The basically, here you can have a fine sand to represent that here put it either the boulders to obtain, this is the model to obtain the same resistance. So, you try to know it how to do the scaling, when we try to locate the similitudes of this part.

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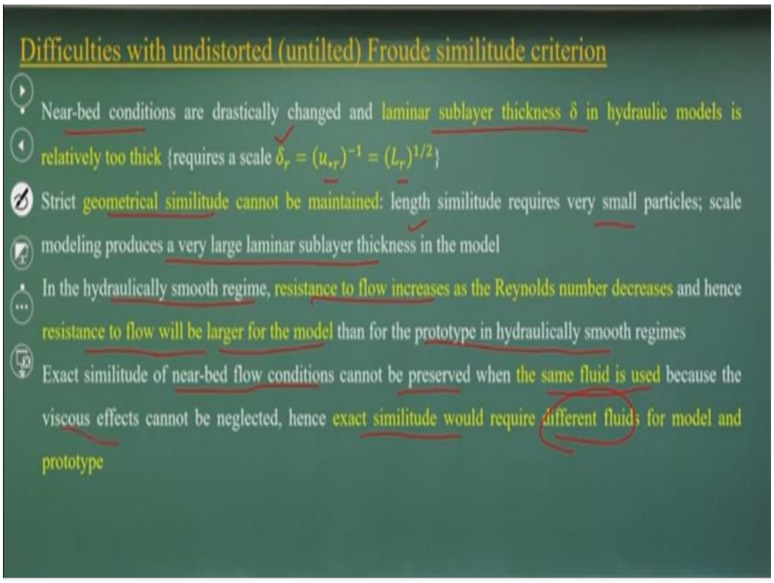

Now, if you look at how you need to do it, as I said it we need to look at, as we discussed earlier, near bed conditions will be drastically change because laminar sub layer thickness in the hydraulic models is relatively too thick, in the hydraulic models is a relatively too thick that is the reasons you require to scale down the laminar sub layer thickness ratios in terms of shear velocity ratio, then the length ratio.

So, I just to repeat it that when you try to make it the flow behaviour, what is happening at the river level, the same thing conditions you want to talk about near bed conditions at the what is happening at the flume level at the laboratory scales, what we need to look at, what is the thickness of laminar sub layers. The laminar sub layer thickness in a laboratory scales is much thicker than the case of the laminar sub layers in a river.

So, we need to do a scale down of laminar sub layer thickness, so if you look at that way we need to have, we cannot maintain exactly geometric similitudes, the length similitudes require very small particles, the scale modelling produce very large laminar sub layer thickness in the model. What I am trying to do it because I have been completing this course of these lectures, physical river models it needs to have to have a lot of knowledge on the near bed conditions what it happens in the river.

The same conditions whether you can prevail or you can maintain with a ratio at the flume scale that is the very challenging task like the same concept like hydraulic smooth regimes, resistance to flow increase as Reynolds numbers decreases, the resistance to flow will be larger for the model than the prototype in case of hydraulic smooth regimes. So, we try to;

river knowledge, mechanics knowledge what we have if you try to correlate it, you can see that when you do a scale down models, there is an issue on change of the laminar sub layers as well as the flow resistance.

The exact similitudes of near bed flow conditions cannot be preserved when the same fluid is used, you just try to understand it, the viscous effect cannot be neglected, exact similitudes would require different fluid for the models and the prototypes. That means, the river may have the waters but you can do other materials where you can satisfy this the flow resistance similitudes, that same ratio we can maintain it at the model levels and the compared to the prototype levels.

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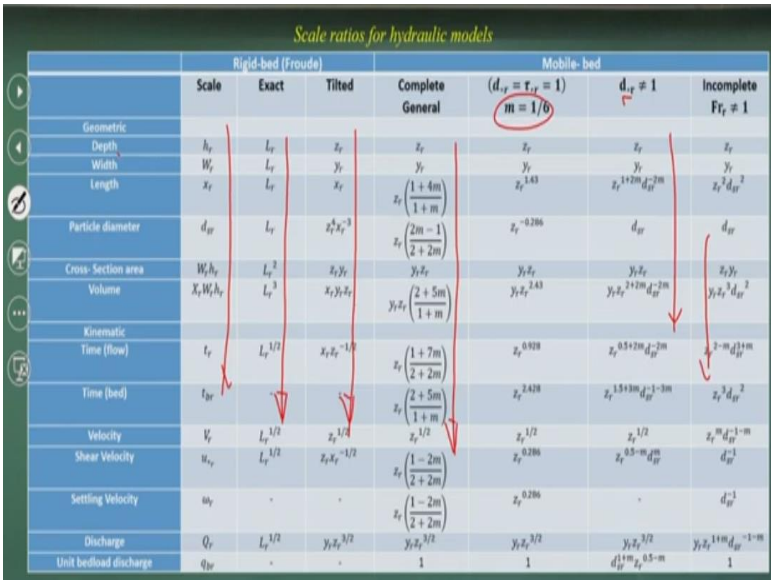
Scale ratios for hydraulic models

	Rigid-bed (Froude)			Mobile-bed			
	Scale	Exact	Tilted	Complete General	$(d_{*r} = \tau_{*r} = 1)$ $m = 1/6$	$d_{*r} \neq 1$	Incomplete $Fr_r \neq 1$
Geometric							
Depth	h_r	L_r	z_r	z_r	z_r	z_r	z_r
Width	W_r	L_r	y_r	y_r	y_r	y_r	y_r
Length	x_r	L_r	x_r	$z_r\left(\frac{1+4m}{1+m}\right)$	$z_r^{1.43}$	$z_r^{1+2m}d_{sr}^{-2m}$	$z_r^2 d_{sr}^2$
Particle diameter	d_{sr}	L_r	$z_r^4 x_r^{-3}$	$z_r\left(\frac{2m-1}{2+2m}\right)$	$z_r^{-0.286}$	d_{sr}	d_{sr}
Cross-Section area	$W_r h_r$	L_r^2	$z_r y_r$	$y_r z_r$	$y_r z_r$	$y_r z_r$	$z_r y_r$
Volume	$X_r W_r h_r$	L_r^3	$x_r y_r z_r$	$y_r z_r\left(\frac{2+5m}{1+m}\right)$	$y_r z_r^{2.43}$	$y_r z_r^{2+2m} d_{sr}^{-2m}$	$y_r z_r^3 d_{sr}^2$
Kinematic							
Time (flow)	t_r	$L_r^{1/2}$	$x_r z_r^{-1/2}$	$z_r\left(\frac{1+7m}{2+2m}\right)$	$z_r^{0.928}$	$z_r^{0.5+2m} d_{sr}^{-2m}$	$z_r^{2-m} d_{sr}^{1+m}$
Time (bed)	t_{br}			$z_r\left(\frac{2+5m}{1+m}\right)$	$z_r^{2.428}$	$z_r^{1.5+3m} d_{sr}^{-1-3m}$	$z_r^3 d_{sr}^2$
Velocity	V_r	$L_r^{1/2}$	$z_r^{1/2}$	$z_r^{1/2}$	$z_r^{1/2}$	$z_r^{1/2}$	$z_r^m d_{sr}^{-1-m}$
Shear Velocity	u_{*r}	$L_r^{1/2}$	$z_r x_r^{-1/2}$	$z_r\left(\frac{1-2m}{2+2m}\right)$	$z_r^{0.286}$	$z_r^{0.5-m} d_{sr}^m$	d_{sr}^{-1}
Settling Velocity	ω_r	-	-	$z_r\left(\frac{1-2m}{2+2m}\right)$	$z_r^{0.286}$	-	d_{sr}^{-1}
Discharge	Q_r	$L_r^{1/2}$	$y_r z_r^{3/2}$	$y_r z_r^{3/2}$	$y_r z_r^{3/2}$	$y_r z_r^{3/2}$	$y_r z_r^{1+m} d_{sr}^{-1-m}$
Unit bedload discharge	q_{br}	-	-	1	1	$d_{sr}^{1+m} z_r^{0.5-m}$	1

Now, if you look at we can develop the length resource, considering the basic definitions of the fluid properties, flow properties that is what is we can do it. If you look at this rigid bed okay, exact one, tilted one and complete general ones okay, there is a 3 conditions. For a mobile bed you can have a, m equal to i.e. sticklers coefficient m equal to 1/6 and you have, when you have a grain particle size ratio that what is not equal to 1, you will have and you have incomplete.

So, if you look at this tables, which clearly indicates that I can compute the geometric particle diameters, the cross sections areas, the volume kinematic properties like a time, the flow and the bed velocity, shear velocity, settling velocity, discharge unit bed loads okay, q_{br} stands for unit bed loads which is we consider for the mobile bed.

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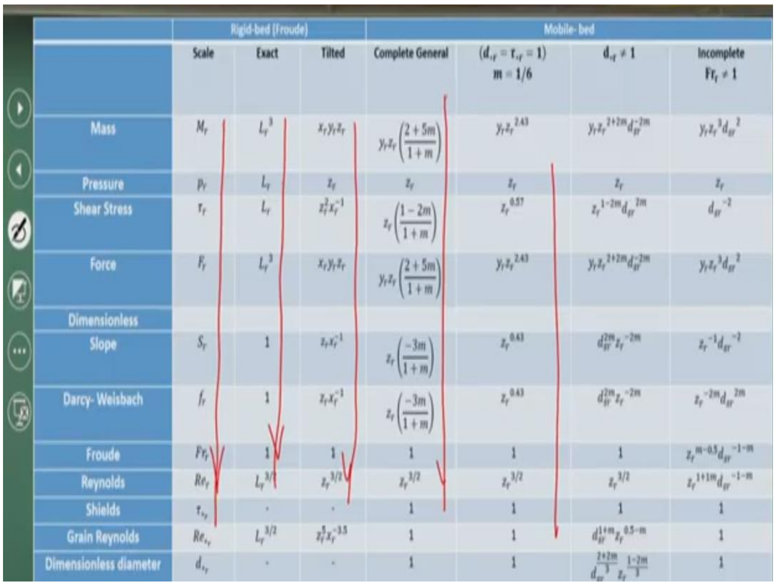

	Rigid-bed (Froude)			Mobile- bed			
	Scale	Exact	Tilted	Complete General	$(d_{*r} = \tau_{*r} = 1)$ m = 1/6	$d_{*r} \neq 1$	Incomplete $Fr_r \neq 1$
Mass	M_r	L_r^3	$x_r y_r z_r$	$y_r z_r\left(\frac{2+5m}{1+m}\right)$	$y_r z_r^{2.43}$	$y_r z_r^{2+2m} d_{sr}^{-2m}$	$y_r z_r^3 d_{sr}^2$
Pressure	p_r	L_r	z_r	z_r	z_r	z_r	z_r
Shear Stress	τ_r	L_r	$z_r^2 x_r^{-1}$	$z_r\left(\frac{1-2m}{1+m}\right)$	$z_r^{0.57}$	$z_r^{1-2m} d_{sr}^{2m}$	d_{sr}^{-2}
Force	F_r	L_r^3	$x_r y_r z_r$	$y_r z_r\left(\frac{2+5m}{1+m}\right)$	$y_r z_r^{2.43}$	$y_r z_r^{2+2m} d_{sr}^{-2m}$	$y_r z_r^3 d_{sr}^2$
Dimensionless							
Slope	S_r	1	$z_r x_r^{-1}$	$z_r\left(\frac{-3m}{1+m}\right)$	$z_r^{0.43}$	$d_{sr}^{2m} z_r^{-2m}$	$z_r^{-1} d_{sr}^{-2}$
Darcy- Weisbach	f_r	1	$z_r x_r^{-1}$	$z_r\left(\frac{-3m}{1+m}\right)$	$z_r^{0.43}$	$d_{sr}^{2m} z_r^{-2m}$	$z_r^{-2m} d_{sr}^{2m}$
Froude	Fr_r	1	1	1	1	1	$z_r^{m-0.5} d_{sr}^{-1-m}$
Reynolds	Re_r	$L_r^{3/2}$	$z_r^{3/2}$	$z_r^{3/2}$	$z_r^{3/2}$	$z_r^{3/2}$	$z_r^{1+1m} d_{sr}^{-1-m}$
Shields	τ_{*r}	-	-	1	1	1	1
Grain Reynolds	Re_{*r}	$L_r^{3/2}$	$z_r^{5} x_r^{-3.5}$	1	1	$d_{sr}^{1+m} z_r^{0.5-m}$	1
Dimensionless diameter	d_{*r}	-	-	1	1	$d_{sr}^{\frac{2+2m}{3}} z_r^{\frac{1-2m}{3}}$	1

And if you look at next ones; the mass, the pressure, the shear stress, force and the dimensionless number like slope, Darcy Weisbach, Fr values, flow Froudes, Reynolds number, shield numbers, Grain Reynolds numbers, dimensionless diameters, this is these states is a dimensional and the sediment densities. If you look at that I just encourage you have the self-readings on these chapters to know it what is the scales and the exact and the tilted case.

In case of the mobile bed we have a general, we have a different conditions of dimensionless diameters and the incomplete part which we are not discussing here. So, if you try to look at these things we can derive it and that is the modelling part.

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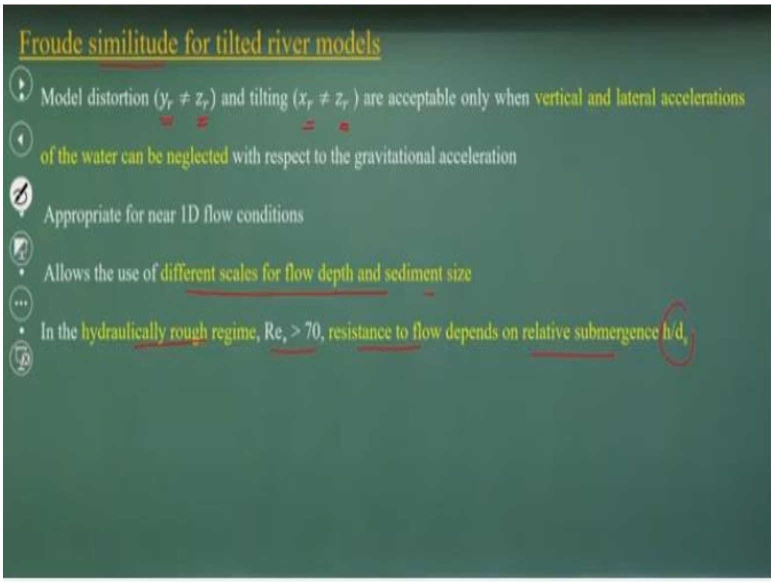

Now, I will be not going more details but I will just put it as an empirical nature but you try to derive it, when you do the Froude similitudes for tilted river models, so we make a tilted river models y_r, length the vertical ratio and the lateral ratios are not equals, in case of the tiltings you will have a case of x_r the longitudinal directions ratio and the vertical directions that not acceptable.

So, when vertical and lateral accelerations of water can be neglected with respect to gravitation, so the basically it allows the different scale for flow depth and the sediment size, again you can look it when you have a the grain Reynolds numbers is greater than 70s the resistance to flow depends upon relative submergence that is what we discuss when you talking about the resistance.

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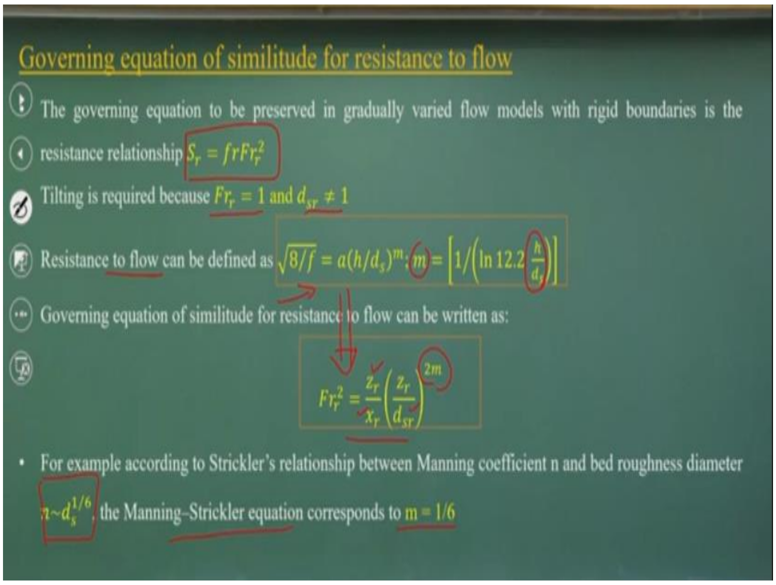

That way if you look at how you have to have a 2 equations to satisfy here, this is a flow Froude numbers as well as the flow resistance equations. To satisfy both we are writing the resistance equations in terms of flow Froude numbers here, as a flow Froude numbers is equal to 1 and you have a d_{sr} is not equal to 1, from the resistance to flow which is Darcy Weisbach formulas we can establish exponent component is a functions of h/d_s, the submerged ratio.

And if you put in that equations, you will get it the flow Froude ratios are, is a function of z_r, x_r and d_{sr} and exponent of 2m, this m when you talk about manning stricklers equations, this m is equal to 1/6 that is what if you remember the manning stricklers equations, we define the m is a function of dx to the power 1/6 that is the power exponent point which m equal to the 1/6 that the instead of we can use m equal to 1/6.

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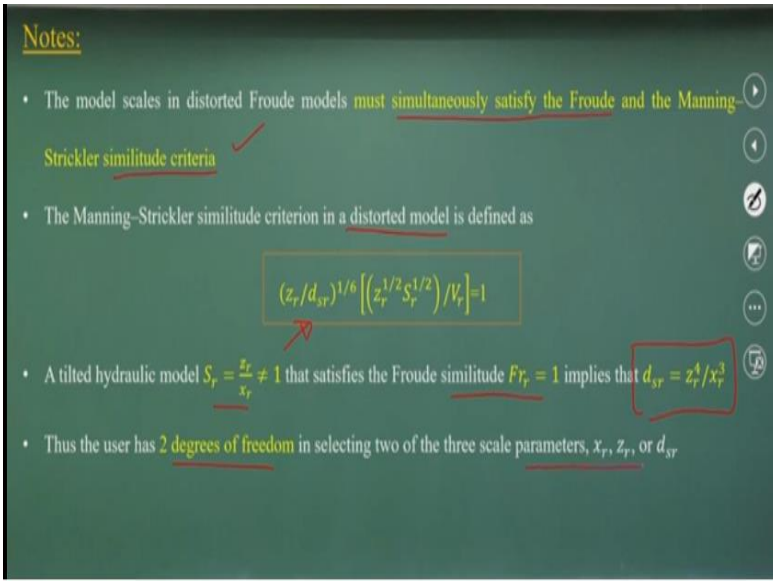

So, in that case you will have the 3 criteria, just try to understand, so you have a 3 criteria's that means it will be mostly satisfy the Froude numbers, Mannings stricklers similitude criteria. If you use all these equations, then you will get it in a distorted models you will have a relationship like this. A tilted models you will have a not equal to that, satisfy the flow Froude numbers, you will have a d_{sr} relations.

Now, if you look at for these equations we have a 2 degree of freedoms, selecting from 3 parameters x_r, z_r and d_{sr} we can consider that and change that value still, the model and prototypes should satisfy these 2 conditions, as it follow these conditions we can have a say that it is having the Froude and Manning stricklers similitude criteria.

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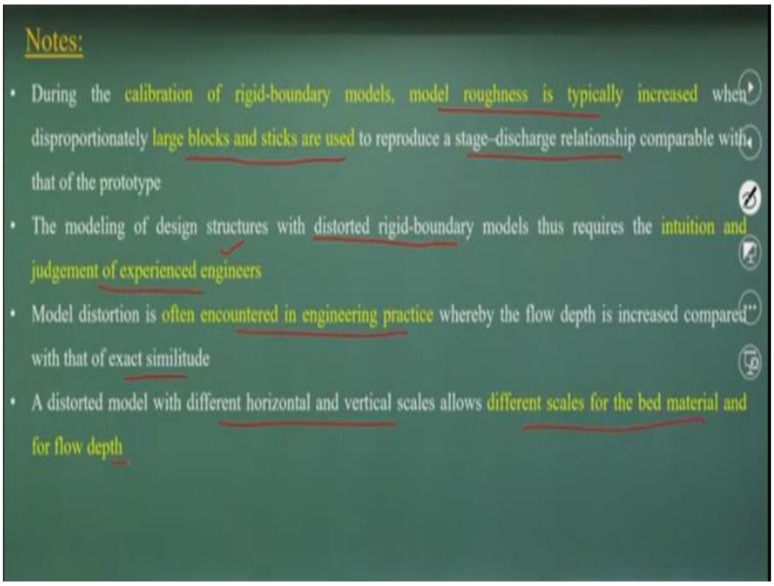

Now, if you look at this is what the notes is there for when you do the rigid boundary models, we have to look at that when you have a roughness is typically increase with a disproportionate large block of sticks are used to produce the stage discharge relationship which are comparable to the prototypes okay that is we have to do it and most of the times as it says that when you work with a distorted rigid boundary models you need to have intuitions and judgment of experience okay of engineers that how it is matter is.

Often encounter by engineering practice where the flow depth is increases and that what is exact similitudes, so a distorted model with a different horizontal, allows the different scales for the bed materials and the flow depth. So that is the point I can show for the rigid bed river models.

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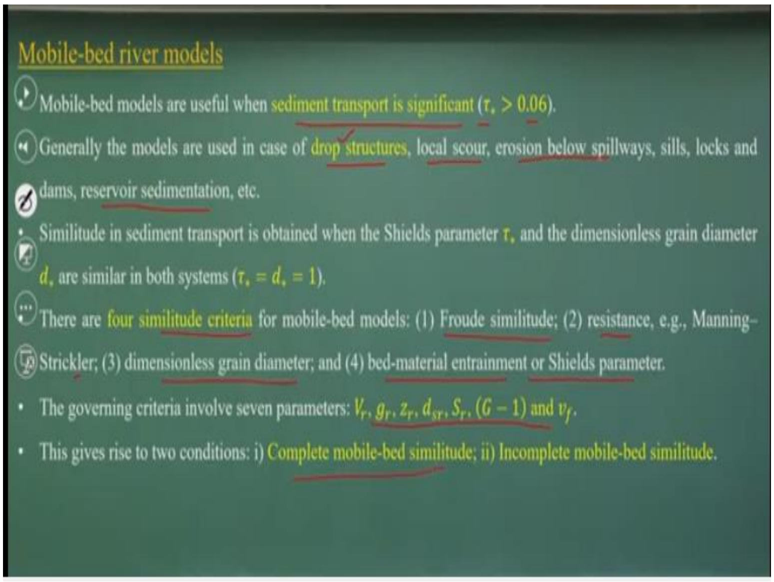

In case of mobile bed river models, I just want to you to go in depth because the course is already is a 24 hour lecture which is over, so I am not going more detail about mobile bed models how we are develop it but in a short, I will tell you that this type of models are necessary when you have a sediment transport is a significant. That means shield parameters greater than 0.06 that is the conditions which you see that.

That is what is necessary for the local scour, erosion below the spillway, locks, dams, reservoir sedimentations, for those studies we should go for mobile bed because that what will be safe. When you do these ones, what is there the similitude criteria is that Froude similitudes, resistance similitudes that is Manning strickler formulas, dimensional grain diameters, bed material entrainment and shield parameters.

So, if you look at that the 4 equations we have to satisfied it, the Froude similitudes, if the resistance that is what is Manning strickler formulas, dimensionless grain diameters, bed material entrainment or the shield parameter, so we need to satisfy all these 4 conditions we have a the different ratios if you look at that velocity ratio, acceleration ratio, flow depth ratios and all, to make a complete mobile bed similitudes.

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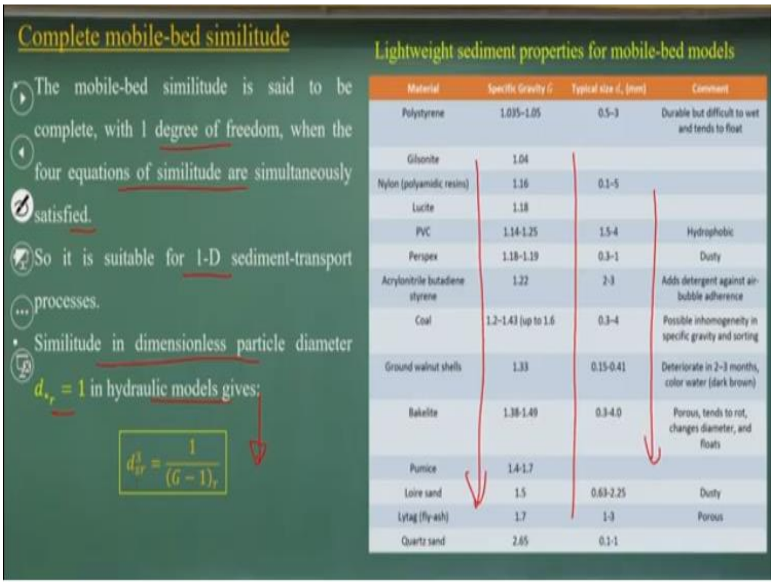

I am not going to more detailed derivations, I will say it we need to do for a 1 degree of freedoms, 4 equation similitudes are simultaneously to be satisfied. So, then if you look at the similitude dimensionless parameter of diameters and the models is gives like this, so many of the times we go for different bed materials like we to satisfy these conditions, we cannot use the same bed materials, we go for different bed materials of a different specific gravity and the typical size that will be the different values will come it.

And you will have a comment over these that means how the size variability is there and the specific because then it can satisfy all these 4 criteria which will be giving a particle diameters, the ratios in terms of specific gravity. So, we can choose a specific gravity, so such that this what can be satisfied it with a difficult process. So that is the reasons it is many of the mobile bed models we use the different bed materials not the sand or not the gravels based on these studies what we do it.

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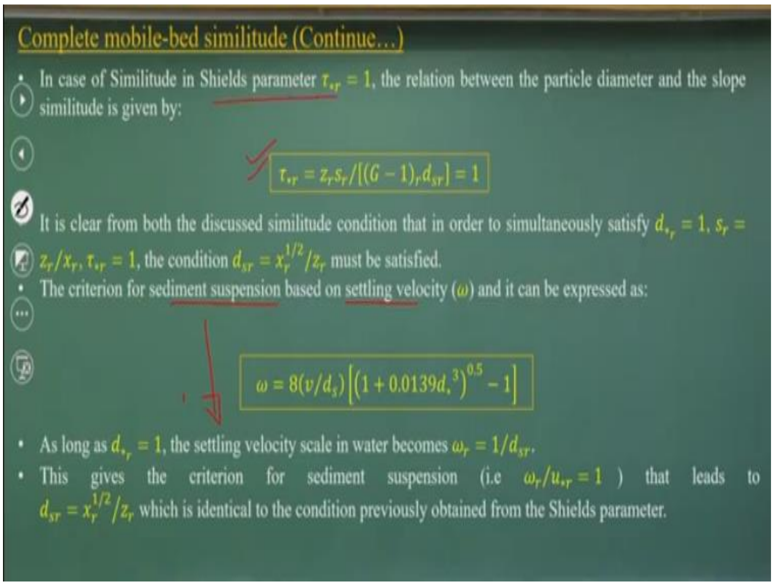

So, now if you look it, I am not going more details but I will tell you that always it has to look at that what you are looking at, like for examples you are looking at sediment suspension based on the settling velocities for a suspended load, you should look at the settling velocity component. If you are looking at shield parameters ratios, you can look at how you are to making this ratio equal to 1.

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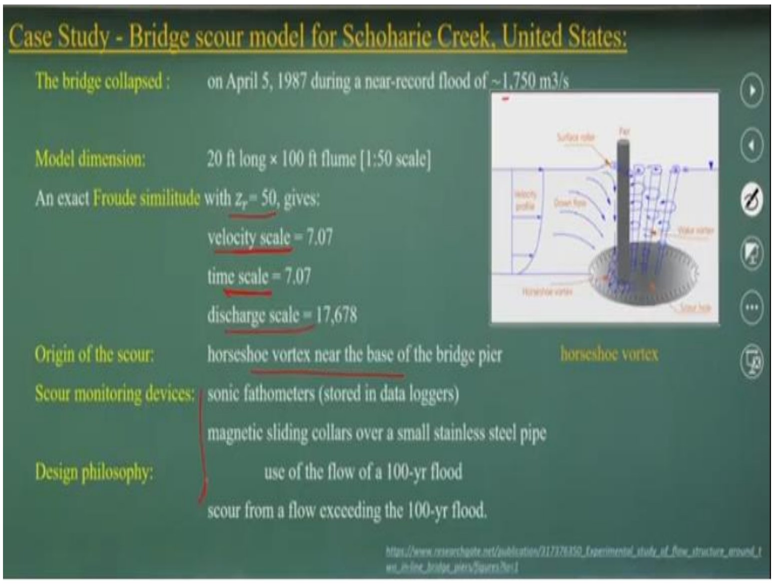

So, those things what I am suggesting is that you can have a self-readings and this is one of the bridge models is considered way back in United States that which is where collapsed in 87 with a distance of these, this is what z_r ratios, velocity scale, the time scales, the discharge scales and try to look at the horseshoe vortex near the base bridge piers and that is what is instrumentations happen it.

So, as we discussed earlier much details about this, so that is what is done it to know it why the bridge is collapsed on this state and that what is gives us design guidelines are for constructing a pier in a rivers that is the points is there.

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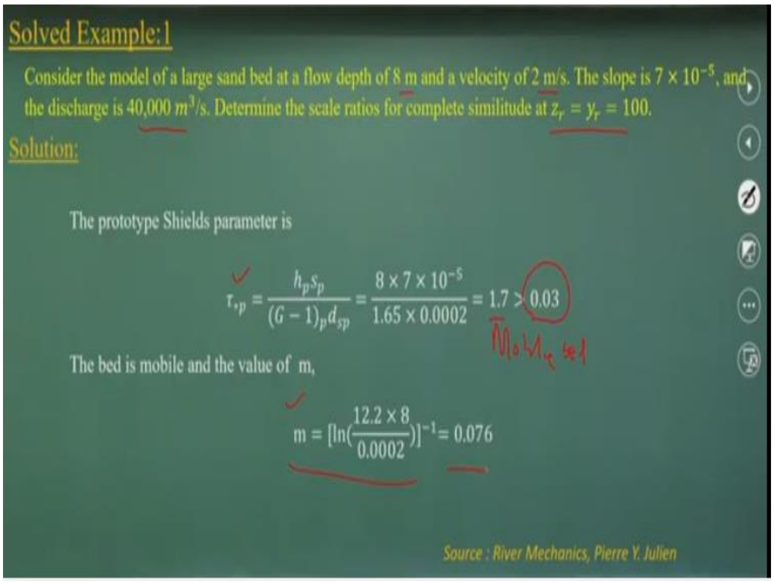

Now, if you look at just one examples, I will show it here that other examples you can have self-studies, so if you look at that consider model of large sand which is flow depth of 8 meters, velocity 2 m/s, slope is there, y_r and z_r ratio is there, then discharge is there. So, first you have to compute the shield parameters; as the shield parameter is more than 1.7 then we need to know consider is mobile bed.

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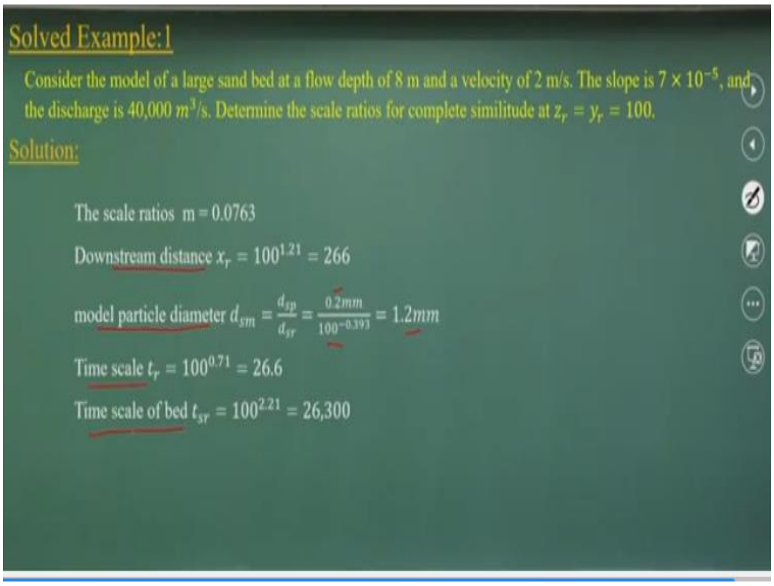

Then we need to compute the m value okay, we can compute this m value and based on that tables what I showed it to you, we can compute it the ratio in downstream distance, model particle diameters we can; because we know the prototypes, 0.2 mm is there and you can compute it what will be the model particle diameters, the time scale, the time scale of bed that is what you can compute it for a time scale for bed and time scale for this component you can compute it.

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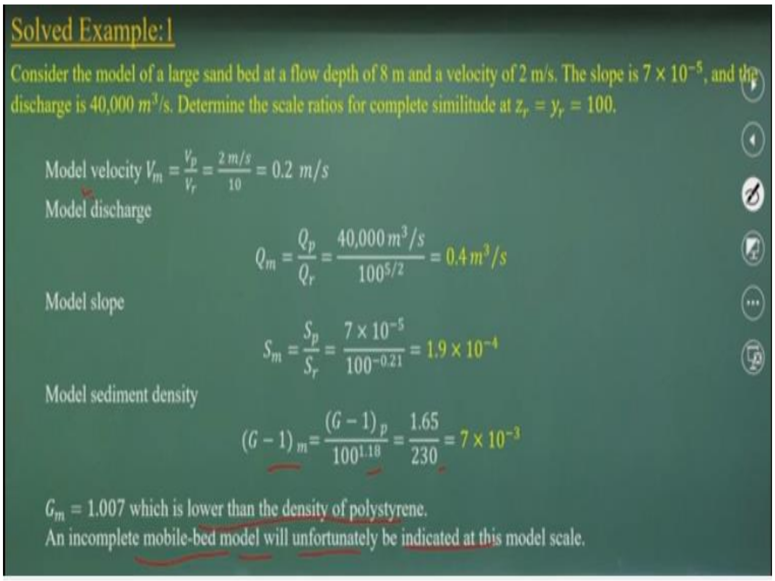

And once you compute this part then you can go for velocity ratio okay, from the velocity ratio as we can compute it what will be the model velocities the, we know the q_r values, we can get the model discharge, we can get the model slope, we can get the model density, sediment densities functions we can get it, and which is coming about to be G equal to one point which is lower than the density of polystyrenes, so incomplete model will be unfortunately be indicated by this model scales.

So, if you look at that when you get this model sediment density, it is clearly saying to us that we cannot use these present materials bed materials, alternative bed materials, to do it we have to go for incomplete mobile bed models.

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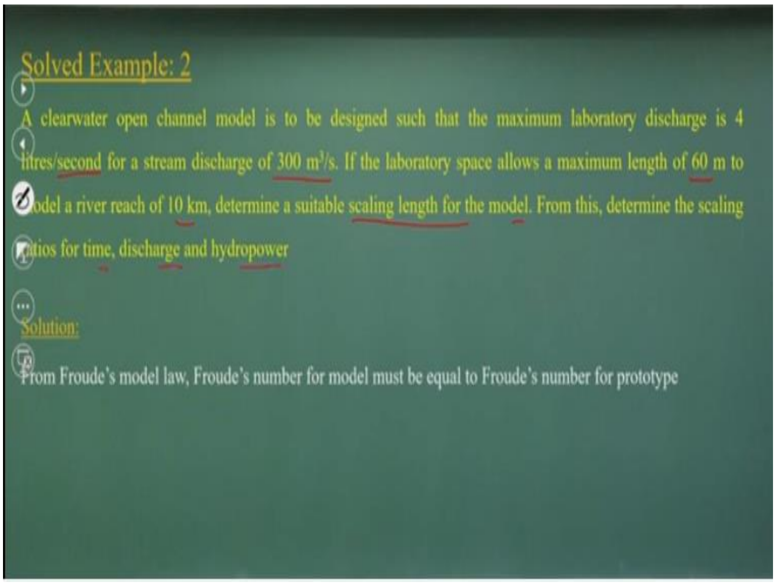

The second example is quite interesting examples like that is a clear water open channel model, the maximum laboratory discharge is given to us, the maximum laboratory discharge is given to us which is a 4 lit/s. The stream discharge is 300 m^3/s, the laboratory allow the maximum length of 60 m to model the river of the 10 km.

Determine the suitable scaling length for model, determine the scaling ratio for the time discharge and the hydropowers. So, if you look at these models, so that means we have to have a Froude numbers similitudes, so we need to make the Froude numbers of the models is equal to the prime Froude numbers of prototypes.

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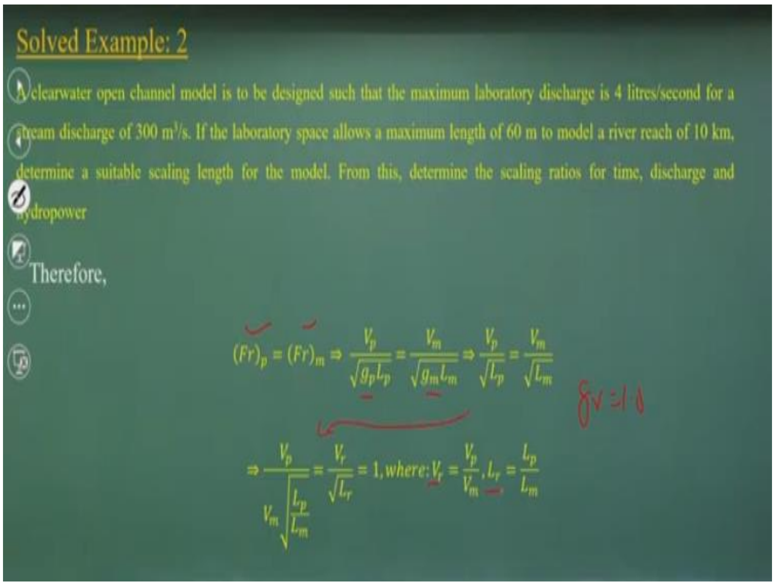

So, if that is the conditions that is what we are substituting here, since g_r equal to 1, g_r equal to the accelerations; ratio of the accelerations is equal to 1, so we can rewrite it and you can rewrite in terms of velocity ratio and the length ratios.

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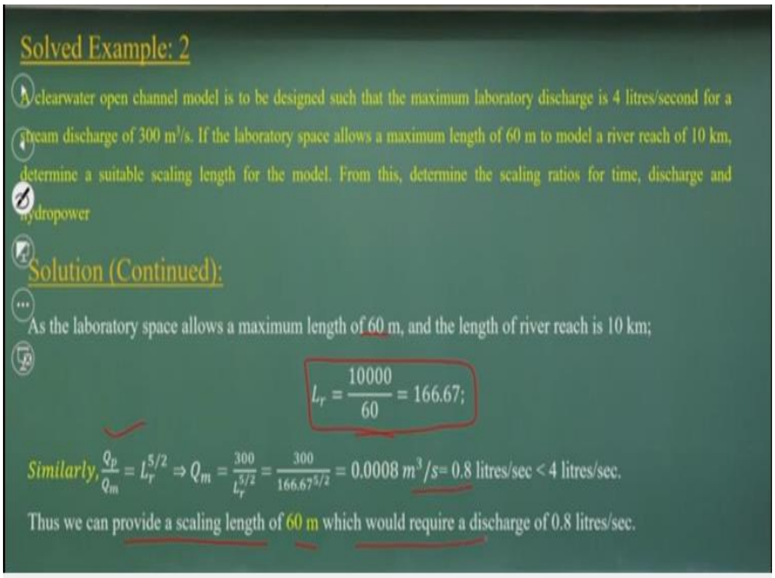

And if you look at next component is that because there is a constraint only 60 me we can use for the 10 km, we have the length ratio that is a fixed for us, so we can compute the discharge ratio to have how much of water is necessary for that is 0.8 lit/s which is much lesser than 4 litres. So that means we can provide a scaling length of 60 meter which could require discharge of 0.8 lit/s.

So, this is what the design of a physical models we do it based on the conditions what we have in our flume and what is the prototype size, the flow variabilities range and what we are trying to do it that is whether the mobile bed, whether the rigid bed are only flow Froude similitudes or we are looking for the resistance similitudes.

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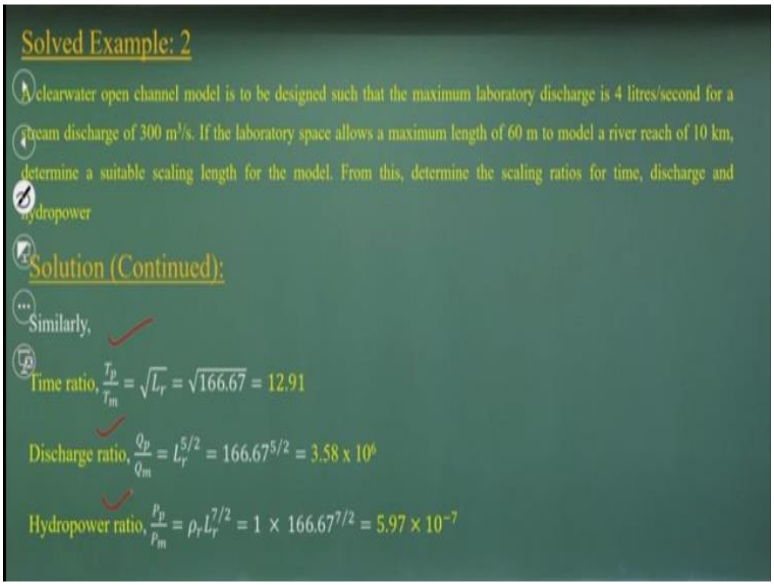

So, with this I need to look at that again you can have a time ratios, discharge ratios and this hydropower research part you can put it to get it what will be the values what you are getting it.

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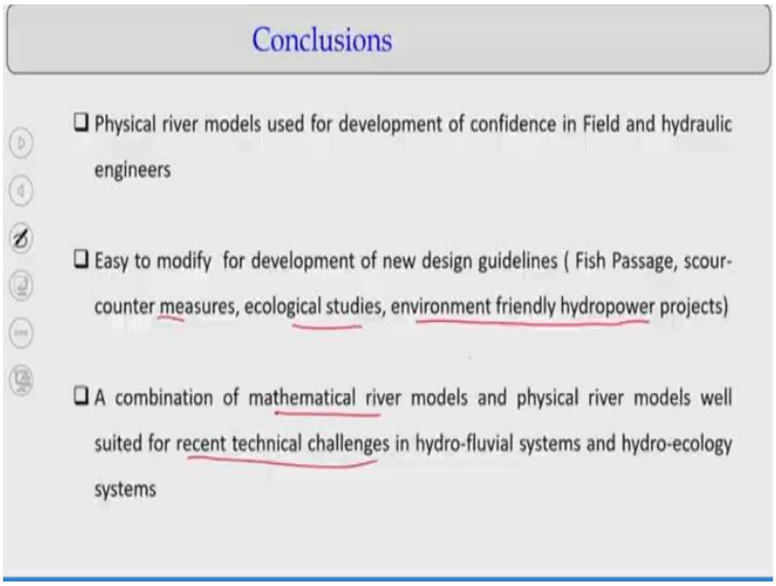

Now, let me I complete this course as well as this class looking at that physical river models actually gives a confidence to a field in engineers before implementing any mega projects because as you know it, most of the river projects are very, very costly, so it is not easy to modify it, if you do a mistakes. That is a reasons it gives a lot of confidence to the field or the hydraulic engineers before implementing the project.

So, most of the big projects as I said it the Kosi barrage project or what are the project implement in our country we always do a physical river models in central water power research stations in Pune or other places. So, physical river models are the major components, any mega projects when you implement it because when you try to make a guidelines for river training works or river infrastructures, we should have the physical models which will be like a scour counter measures, the ecological study.

Today, we are talking about environment friendly hydropower projects, all these projects you want to look at that we cannot do it only mathematical models which cannot give a feel good confidence levels for hydraulic engineers or these technocrats to implement those projects. So, we need to have these physical model setups to give a confidence and it can be a complimentary with a mathematical river models.

Well we have a recent technical challenge for the fluvial systems and the eco; river ecology systems river health, all are bigger issues, the combinations of mathematical models and the physical models can give us a set of the solutions which we can implemented.

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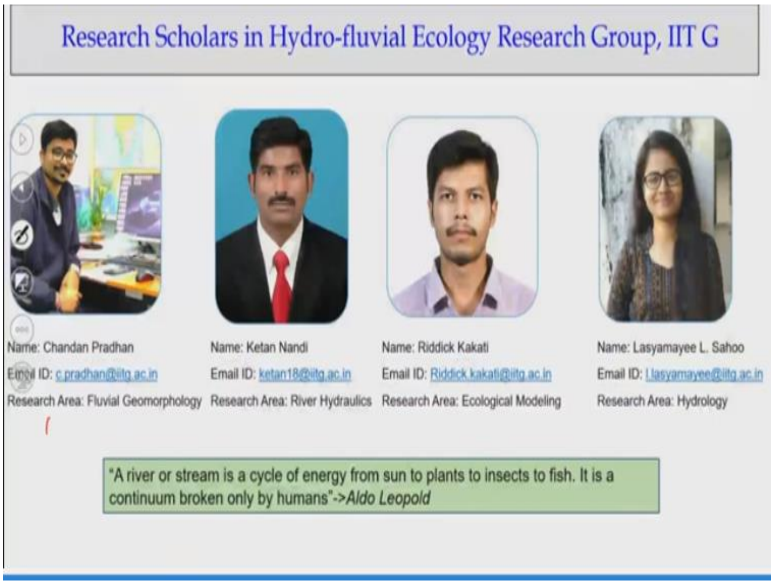

So, with this note let me I finish this lectures by thanking my all my research scholars who has done, who has put a lot of effort for you to prepare a good photographs from Chandan Pradhan, Ketan Nandi, Riddick Kakati, Lasyamayee L.Sahoo, so all they put in a lot of effort for you this PPT's to prepare in that. End of the day, let me I put it river or streams is a cycle of energy from sun to plants to insects to fish. It is a continuum broken only by humans, Aldo Leopold, so with this let I, let me complete these lectures, thank you.