Principles of Engineering System Design
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Lecture - 27
System Modelling and Simulation

Dear friends, welcome back to one more lecture on Engineering System Design. In the last few classes we have been discussing about the modeling techniques employed for engineering system design, what kind of engineering methods can be used at various stages of system design. We discussed about the data modeling, process modeling and behavior modeling and today we will talk more about modeling of physical systems especially the dynamics of physical systems.

Whenever we make some product or whenever we design a product we need to look at the performance of the product even before we really make it. So, in order to make sure that whatever the product we are designing should work as per the requirement; we need to create some models and then test it and ensure that it actually performs the way we want in some cases it may be a simple just to check the shape and it is wait and other features, but in some other cases it may be the performance parameters like the acceleration time or the desolation time or the time to reach a particular state or what will be the maximum attainable parameter we can achieve.

So, these are the things which we need to analyze using models. So, the modeling and simulation basically the system modeling and simulation looks at the possibility of developing models for the physical systems and testing them through simulations to study their behavior we can actually use various kinds of modeling techniques you can use the physical modeling or iconic model where you actually we make some small prototypes. And then text them or we can actually do some experiments simple experiments and then study the behavior, or we can actually create some mathematical models and apply some non mathematical techniques to simulate it and study the behavior.

So, there are various ways of doing this modeling and simulation. We will look at some of these methods and then see how this can be applied for system engineering of course, the focus of this course is not to go into the details of these modeling techniques, but basically to tell you that these are the modeling techniques existing and what are the basic principles applied for such modeling methods.

So, we will be briefly going through these methods, but not into the details or in depth study will not be carried out, if you want to know more about those methods you can always refer to some other courses which are readily available or methods available on the web or there are some video courses also available. So, you can use any of these resources and learn more about these methods.

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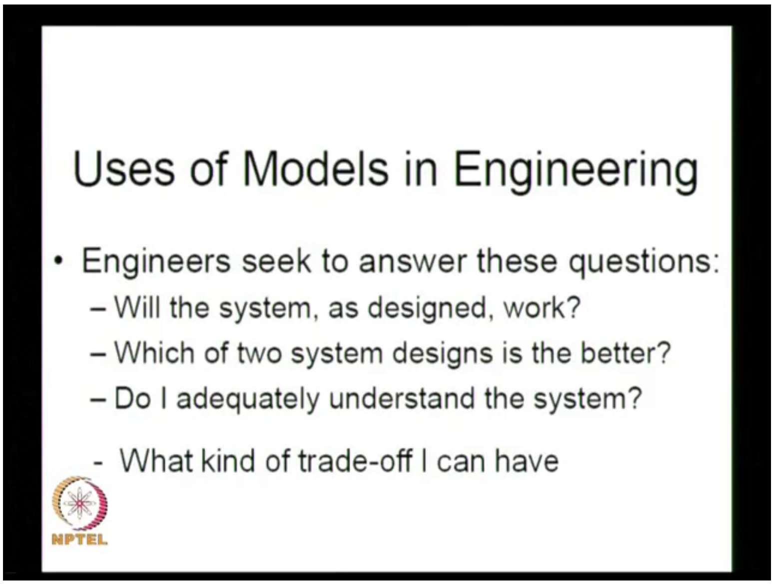

So, let us look at the methods existing or you need to see why we actually we need the models and what kind of models can be used.

So, here the uses of models in engineering are basically to seek answers to some of the questions. Will the system as designed will work. So, we are designing some system and we need to see whether it will really work or not and which of the two system designs is the better suppose you have many designs or alternatives are existing. So, which one will really work and do I adequately understand the system, and as well as what kind of trade off I can have. So, these are the basic purposes of making the model. So, we need to check whether the system will work or whether the understood the system completely or whether we can have a choice between two models or whether we can have a trade off in some of the aspects.

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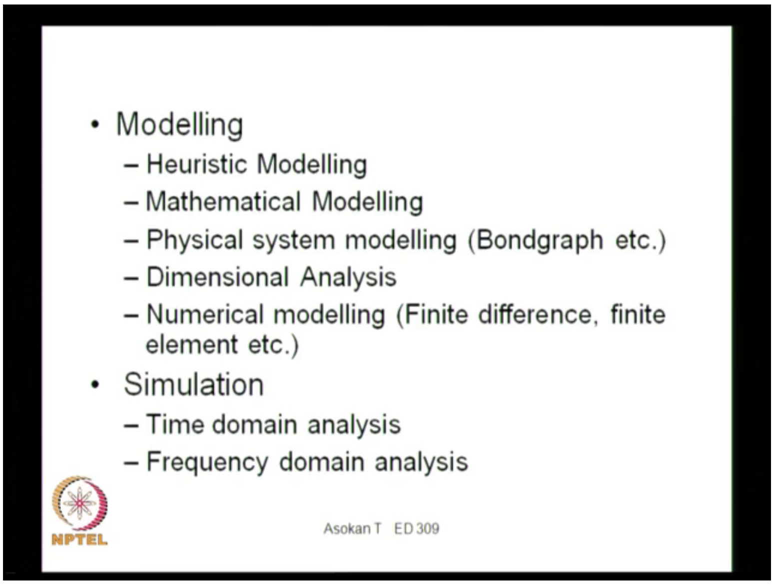

So, this can be studied using engineering models. And coming to the methods of modeling we have various methods of modeling the system or the physical systems. So, you can go for a heuristic modeling basically depending on our on heuristics and our own intuition, and imagination we can actually create the models and then test them to see the behavior. And the other one is known as the mathematical modeling in mathematical modeling we can actually write down the mathematical equations corresponding to the physical model and then study the behavior.

Another method is known as physical system modeling or bond graph modeling. So, we can see the physical system modeling method is bond graph is one of the methods of physical system modeling, and then this bond graph method we normally what do is look at the physical system and develop the corresponding model which actually have a one to one correspondence with the model and that is easy to understand. And this method is used for multi domain systems when you have a system with various disciplines like a mechanical engineering, electronics communication software.

So, for such systems we can use the physical system based modeling what bond graph is one of the methods. Then there are other methods like dimensional analysis the numerical modeling you might a heard about finite difference and finite element methods and these are the modeling techniques we can employee for modeling of the system, and then once you have a model whether it is a mathematical model or a physical system based model, we can actually use it for simulation and we can carry out the time domain analysis as well as frequency domain analysis to find out the behavior.

So, the model is basically converted to a simulation model the physical system model or the mathematical model will be converted to a simulation model and using the simulation model we can predict the performance in time domain or in frequency domain and then see what kind of parameters we need to modify in order to get the desired performance. So, that is the use of modeling and simulation in system engineering. So, this is normally used when we go for the actual design of the system. So, initial design stages like a functional decomposition, and the design of architecture we do not go for this kind of analysis, but when we really make this design the components and the sub systems we need to check the performance of these components and sub systems and we go for this modeling and simulation and then analyze the performance.

Let us go through one or two modeling methods to show how this can be used for our application.

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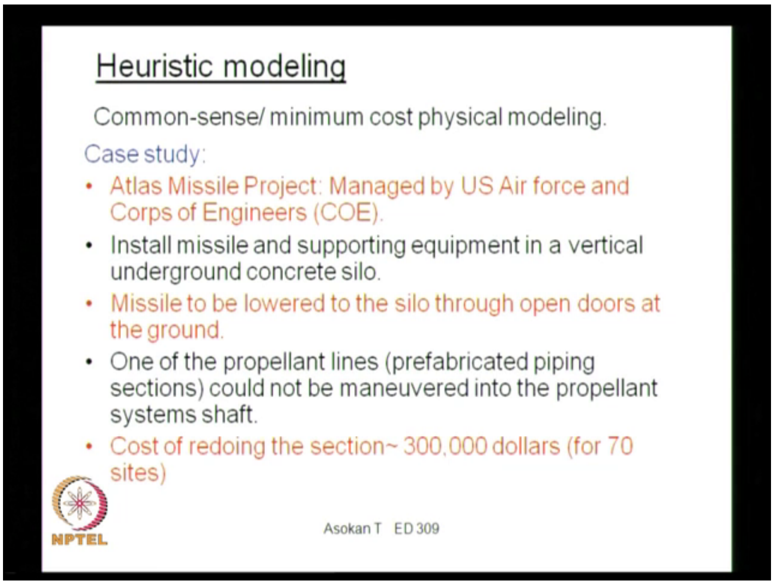

Heuristic modeling as I mentioned it is a common sense or minimum cost physical modeling. So, here we do not go for any detailed modeling of the system we apply some common sense or make some simple models using minimum cost as a criterion and then develop the model. So, that is heuristic modeling common sense or minimum cost modeling.

Just tell you a case study where this kind of minimum cost physical modeling can be used this was a real situation or a real project where actually some common sense modeling was applied to get the work done without going for a detailed analysis we mentioned about the atlas missile project in one of the lectures. So, this was a project managed by us air force and corps of engineers for developing a series of family of missiles for us air force. So, this missiles need to have some installation support; so the install missile and supporting equipment in a vertical underground concrete silo.

So, the supporting equipment need to be inserted or to be placed on a underground concrete silo missile to be lowered to the silo through open doors at the ground. So, once you have a concrete silo we need to lower the missile to the concrete silo through a open door at the ground one of the propellant lines that is prefabricated piping sections could not be maneuvered into the propellant systems shaft. So, there was a propellant system shaft which actually should carry the propellant lines, but they were not able to maneuver this propellant system shaft through the silo or to the ground silo they created.

So, they tried many ways to do this, but they could not bring this propellant system shaft into the silo because the propellant lines were actually obstructing the moment of the system shaft, but they want to do the complete section then it would I mean cost around 3001000 us dollars for 70 sites. So, that was the problem if they could not do this to they could not maneuver this particular shaft into the silo then there were to redo the complete section and for all the sites it may cost around the 3001000 dollars.

So, they could not do it for many days and they were trying what to do with this particular problem and then this heuristic modeling method came to their help they created a very simple model of the pipeline as well as the shaft and then tried on the ground many ways of inserting this into the silo. So, they maneuvered this shaft under various orientations and various positions, and they would find that there is one position where actually they can bring this into the shaft or the shaft can be brought inside the silo.

So, this was tested using very simple prototype very low cost model and they found out the method to insert it and then they simply applied the same principle and then they could maneuver this shaft in to the silo and could solve the problem. So, this kind of modeling basically comes from the common sense of the users the designers think about the all possibilities and then make some simple models and then create a scenario work actually they want to solve the problem and get a solution. So, that kind of modeling is known as the heuristic modeling.

For example if you have a large cupboard to be moved out of the room and you have a small door to be there to take it out then we need to look at how do you actually take this cupboard out of the room, may not be possible to simply take it as it is. So, you may have to tilt it some site or you need to make some particular angle and somebody has to move forward and then take a turn and then the other person has to come and take a turn and then tilt the table or the cupboard in a particular direction to take it out.

So, those kinds of things cannot be modelled or simulated using mathematical methods we need to apply some common sense technique and do this. So, the same principle applies for system engineering also. We can actually do some common sense modeling and sold many of the problems which we really faced on the ground when really implementing the system. So, there kind of methods are known as heuristic modeling.

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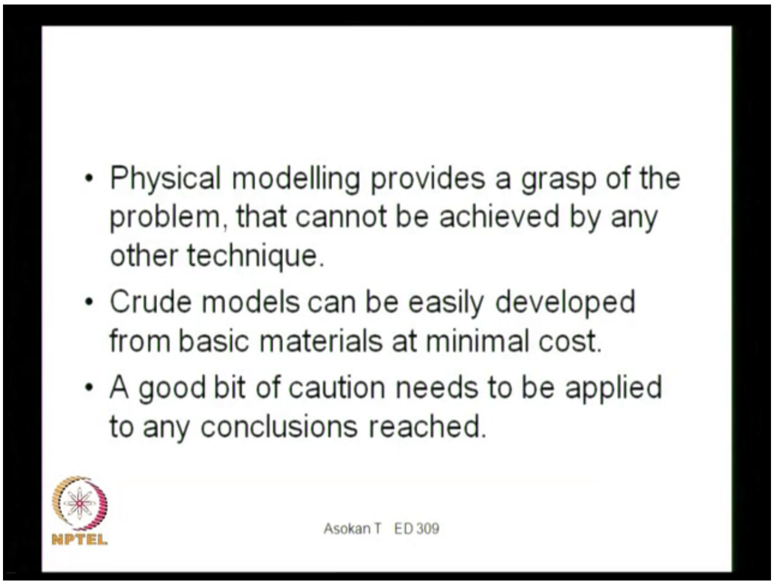

So, this kind of modeling the physical modeling provides a grasp of the problem that cannot be achieved by any other techniques. So, if you apply this common sense methods or the heuristic modeling technique we can actually get the grasp of the problem were other methods cannot be applied. And crude models can be easily develop from basic materials at minimum cost. So, in order to do this we can actually create some crude models and using basic materials and very low cost and a good bit of caution needs to be applied to any conclusions reached.

So, whenever we do this kind of heuristic model you cannot make any generalized conclusions that particular solution may be applicable only to that situation. So, bit of cost is needed when we do the this kind of modeling and make some conclusions out of this. So, that is the first method of heuristic modeling.

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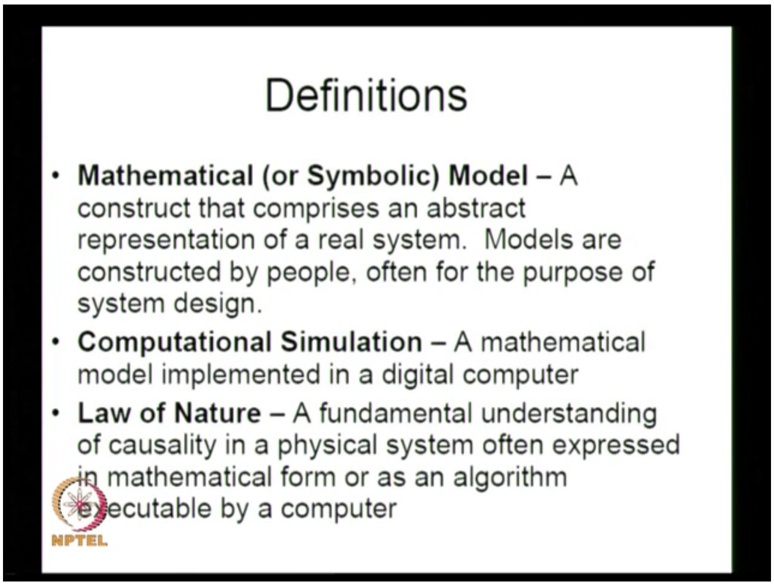

Then we can actually do different types of mathematical modeling also. So, a mathematical model can be defined as a construct that comprises an abstract representation of a real system, models are constructed by people of10 for the purpose of system design. So, mathematical models are abstractions of the physical systems when you have a physical system we try to abstract into a model using mathematical methods and their constructed by people often for the purpose of system design and then computational simulation a mathematical model implemented in a digital computer.

So, once you have a mathematical model we can implement in a digital computer and get the simulations done. So, the computational simulation is basically a mathematical model converted to use in a computer and whether you can actually get the output. Of course the law of nature a fundamental understanding of causality in a physical system often expressed in mathematical form or as an algorithm executable by a computer. So, whenever we make the model we need to follow the fundamental understanding of the causality in physical systems. So, what causes the a particular system to behave in a particular way. So, that actually comes from the physics behind the dynamics or the system behavior.

So, we need to look at those fundamental issues and then only create the mathematical model and use them.

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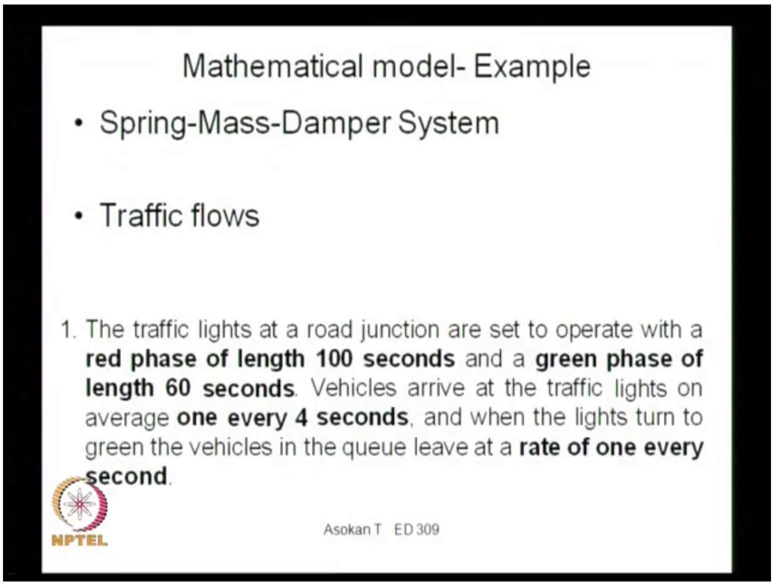

So, let us see how the mathematical model can be used in engineering system design. So, most of you may be knowing how to create mathematical models. So, we take a an existing system or a mechanical system and then find out the abstract nature of that system and then create a mathematical model and then see how to write the mathematical equations corresponding to the various performance parameters of the system, and then write down the equations and later on you convert the those equations into a form were the it can be accepted in a digital computer and simulations can be done.

So, we will just take one simple example a spring mass damper system and I will show you how to model this system using the mathematical methods. So, let us take a very simple case of a spring mass damper system.

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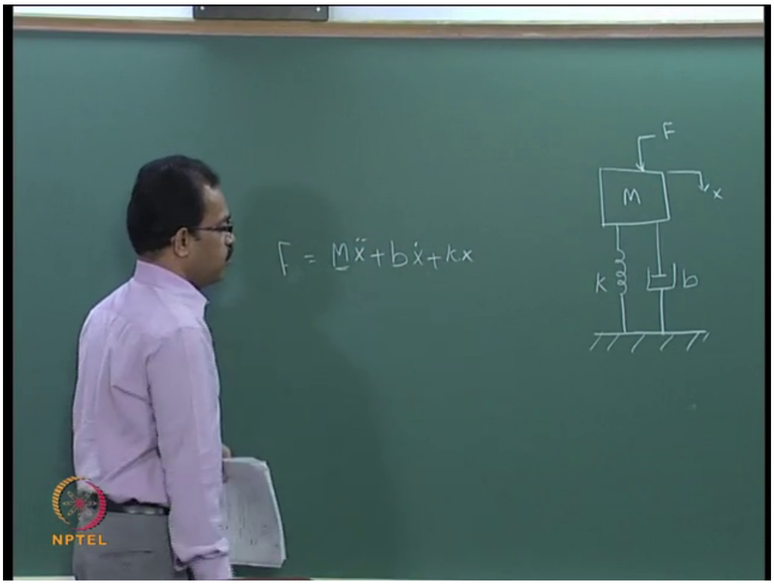

So, we will have a spring and a damper. So, this can be representation of any mechanical system. So, if you have a spring mass damper system like this and a force is applied here, a force of f is applied and if this is the stiffness parameter of the spring and this is the damping parameter of the dashboards.

You can actually represent the displacement of this by parameter x. So, if you want to find out the displacement of the mass and you apply a force and what will be the dynamic nature of the response we can actually model this using mathematical relationships and then convert that into a simulation model now if you want to know this relationship then we can write down the equations of motion in terms of the force balance. So, you have F first force F is equal to M x double dot plus b x dot plus k x.

Where x is the displacement of mass and M is the mass of the body and b is the damping parameter and k is the stiffness, this is the time domain relationship. So, this is x double dot stand for the acceleration x dot stands for the velocity and x displa for the displacement; in order to sold this and to find out the relationship for x.

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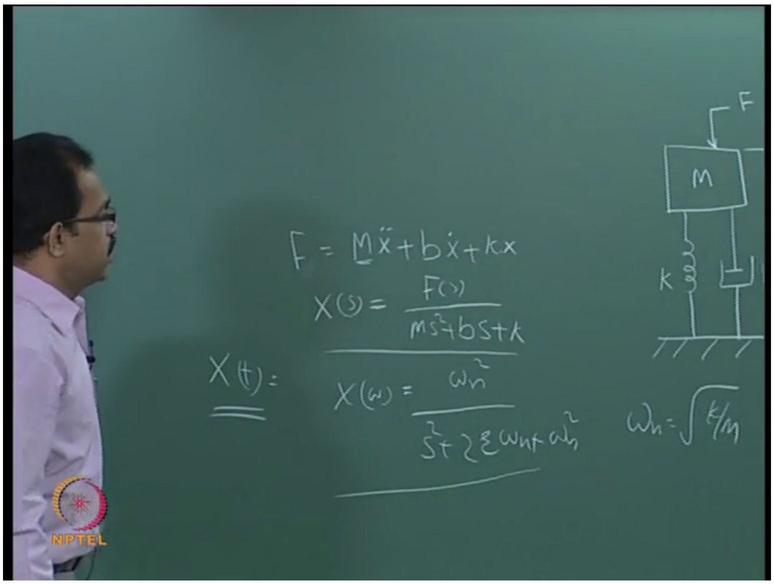

So, we want to find out the displacement x in terms of time domain. So, x t need to be found out we can actually change this to the Laplace domain to solve it. So, if you do this then he will be getting it as X s that is the Laplace domain s F s over m s square plus b s plus k. So, the s stands for in the Laplace domain. So, F of s is the force in the Laplace domain M is the mass and b and k.

Now, we can actually solve this for using standard mathematical formulas or you can actually put this in the X omega is equal to in the frequency domain omega n square divided by s square plus 2 it zeta omega n plus omega n square where omega n is given as the natural frequencies given as square root of root k by M. So, we can actually get this as in, this can actually be converted into a time domain and then you can actually you can solve this and then converted into time domain. We can actually use any standard simulation softwares to simulate this behavior this equation can be easily solved I can actually simulate it.

Similarly, in the time frequency domain also we can get the output using this relationship. So, now, for any applied force F, we can find out the response of this system the displacement of the system displacement velocity and acceleration can be easily obtained from here.

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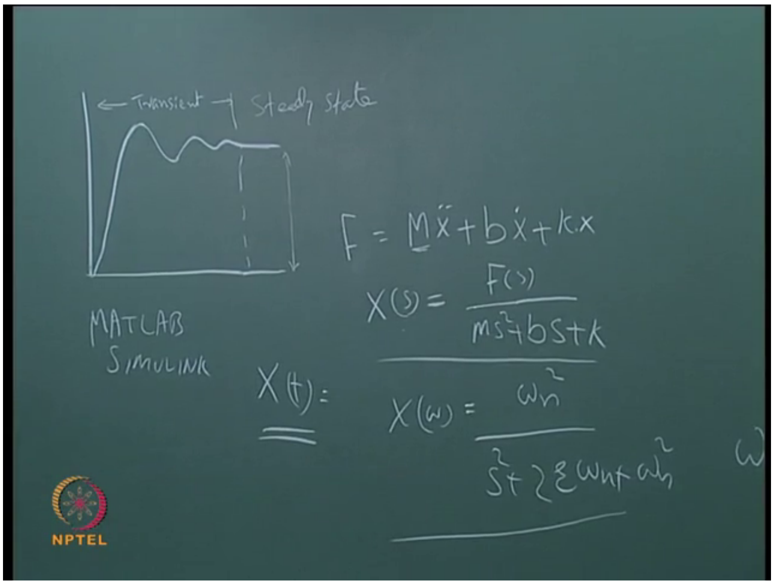

So, if you simulate this in the response can be something like this the time response can be obtained like this depending on the parameter values we will be getting various performance parameter is like raise time, then the settling time, if all those can be plotted for a given force you will be getting a constant displacement here.

So, this is the transient period. So, you can find out what is the time taken for the transient to died on. So, transient period and then you have a steady state period. So, using this equations you can actually simulate it you can use the software like MATLAB or a Simulink. MATLAB or simulink can be used for simulating the behavior of this particular system. So, that is very simple system and we are showing how the mathematical model can be generated for that kind of systems.

When you have a complex system we need to do is to take the abstract that complex system to a mathematical model and write down the equations of motion for the system and then simulate it and get the behavior. So, when I complex system can be model using this kind of methods mathematical modeling techniques. If you have a robotic system or you want to find out the behavior of a machine tool any of these even if you have a simple motor you want to find out the performance characteristics what you design. And then you want to see what kind of response time it has how much time it will take to reach a particular value of acceleration all those things can be modelled and then simulated will get the output using this kind of methods.

So, that is one way of doing mathematical modeling not only this we can actually do many other things also using mathematical methods. So, I will show you another one were actually we can model and simulate the traffic flow doing the peak time at a traffic junction. So, that also can be modelled using mathematical methods, or you can if you want to find out the deflection of a beam we can actually do that if you have a beam like this a cantilever beam.

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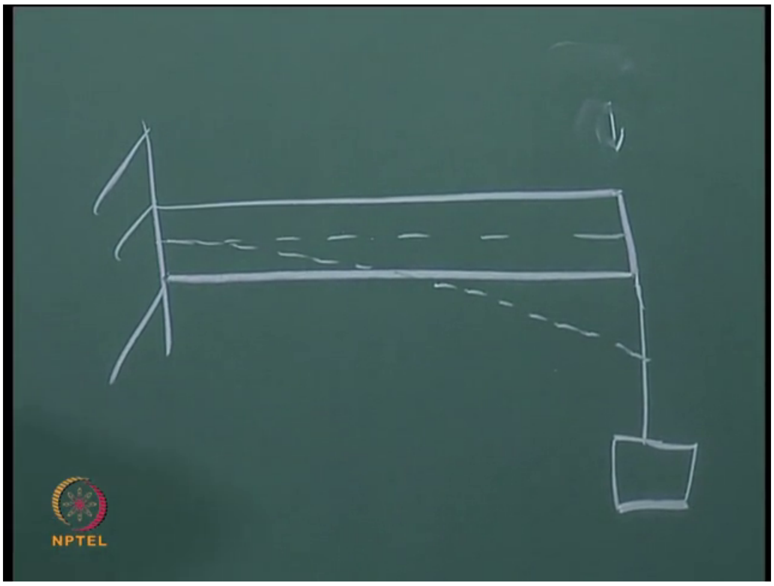

And you want to find out the deflection suppose you apply a force over here or you hang a mass over here.

You want to find out what will be the deflection of this beam again we can we have standard equations for representing the deflection. So, we can actually find out what will be the deflection under various situations depending on the type of load you can find out the deflection as well as the bending moment bending stress all those things can be modelled and then simulated to get the output. There are different methods mathematical modeling is one of the methods to get the outputs

Now, coming to a traffic problem we will see how that this kind of traffic problems also can be model using mathematical method. So, this is the problem given the traffic lights at road junction are set to operate with a red phase of length hundred seconds. So, you have a red phase of hundred seconds. So, we can put it as r g as hundred seconds sorry red phase r.

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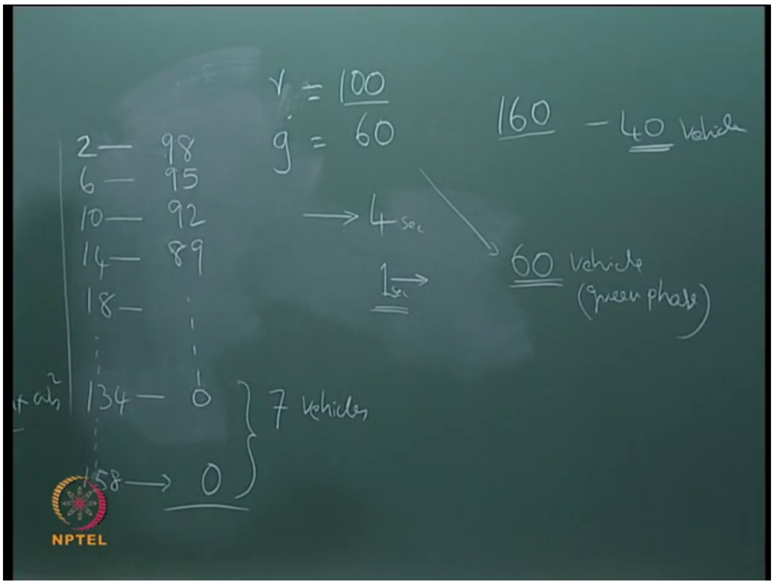

And then green as 60 seconds. So, you have a traffic signal which actually there is a red signal for 100 seconds and green phase of for the 60 seconds and vehicle arrive at the traffic lights on average 1 every 4 second.

So, every 4 seconds 1 vehicle is arriving. So, every 4 second 1 vehicle is arriving and when the lights turn to green the vehicles in the queue leave at a rate of 1 every second. So, this is the arrival every 4 second 1 vehicle will be coming and when it is green every 1 second 1 vehicle will be going. So, we need to model how long the green signal should be there or if you want to find out how much delay will be there for the vehicle to go from the signal or whether there will be any pile up of the vehicle at the signal we can actually model it using mathematical methods or we can actually use simple methods to model it and then predict what will be the waiting time for a vehicle or when the signal is about to change or how long the vehicle will wait at the signal or what will be the average waiting period can be model using mathematical methods.

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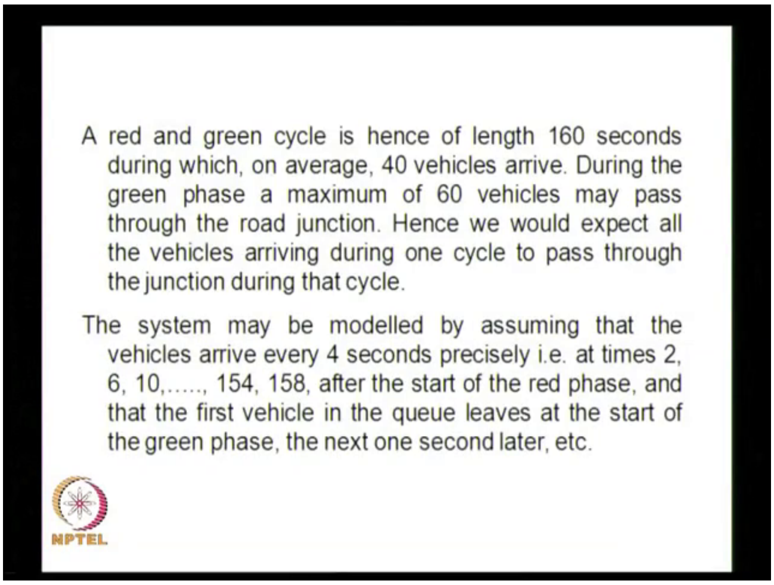

So, we will see how this can actually be done. So, now, we know that a red and green cycle will actually have 160 seconds. So, we have 160 seconds for a red and green phase. So, when it change to green there will be 60 seconds when it changes to red it will be 100 seconds. So, during the green phase a maximum of 60 vehicles may pass through the road junction since it can actually go through 1 second is needed for 1 vehicle to go. So, we can actually have only 60 vehicle passing through during the green phase.

So, 60 vehicles during green phase whenever the signal changes to green you can have 60 vehicle passing through now 40 vehicles will arrive. So, during the 100 seconds; so 160 seconds. So, totally we have 160 seconds. So, we can actually except 40 vehicles to arrive during this phase. So, it will be having 40 vehicles arriving during this phase.

It should we can have 60 vehicle passing through the green phase so; that means, there will not be any pileup of the vehicle. So, during 1 green phase all the vehicle can actually pass through the green phase because 60 can pass through and we have only 40 vehicles arriving and this can actually be model either by because it is a simple system and it is only for 1 case we can actually model it just by writing down the table and then see how many vehicles will pass without any waiting or what will be the average waiting time for each vehicle that can actually be model by writing down the table.

So, we if we assume that 2 seconds after that is signal changes to red 1 vehicle is coming then 6 second then 10 seconds then 14 second 18 seconds. So, 1 vehicle will be coming at 2 second another will be coming at 6 10 14 18 this vehicle which is coming over here it has to wait till the signal changes to green. So, it has to wait for around 98 seconds. So, the vehicle coming at 2 seconds after that is signal changes to red it has to wait for 98 second. So, that is the delay time for the first vehicle and for the second vehicle it will be 95 because 1 second will be for the passing of the vehicle and then will be having 92 seconds waiting then will be having 89 and so on.

So, we will be having in the total delayed periods, where the vehicle is coming at 134 seconds you can see if you write down the table you will see that 134 second this has turn to green and all the vehicle have pass. So, this vehicle will be having a 0 seconds delay similarly till 158 in the last vehicle also pass without waiting at the signal; so this many vehicles. So, we will be having about 7 vehicles passing through the signal without have any delay, those 0 delay will be there and if you take the average delay we can actually find out the average delay of the vehicle and you can calculate the average delay from this one.

So, that is one way of doing it, but this again it is writing about making the table and then calculating it now how do we actually convert that into a mathematical equation and then do it or generalize it for any kind of traffic problem. So, here we are assuming that 4 is fixed and 1 is fixed, but if it is not fixed then how do we model it you can actually use the mathematical equations and then model this particular delay.

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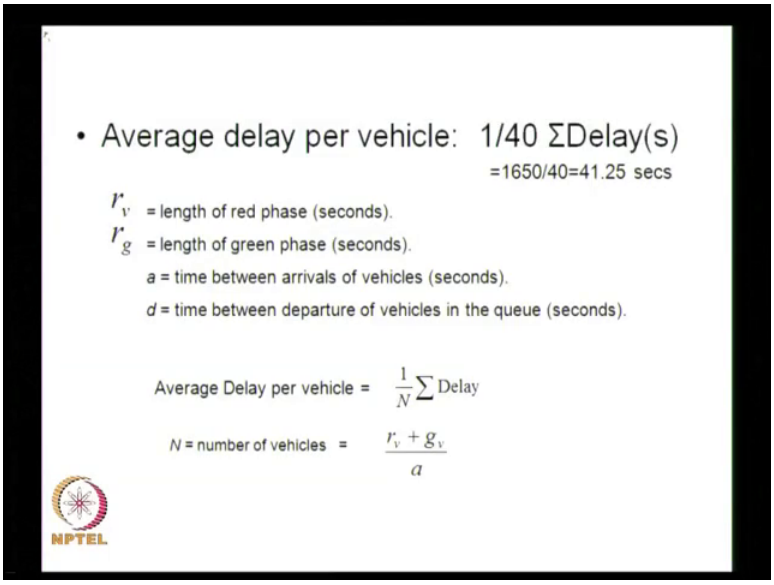

So, we need to find out the average delay in this case the average delay will be total delay. So, we have the total delay of the vehicle divided by 40 vehicle.

So, we have 40 vehicles coming during the phase. So, there will be sigma delay by 40. So, that will be the delay. So, in this case you can see that the delay will be around 41.25 seconds; that it is the average delay of the vehicle. Now if you want to model this using mathematical equations we can actually (Refer Time: 25:42) the parameters and then create a mathematical model for it and then use that one for simulation of the system under various situations.

So, whenever they r g or r v changes. So, we can actually model it easily without creating a table like this.

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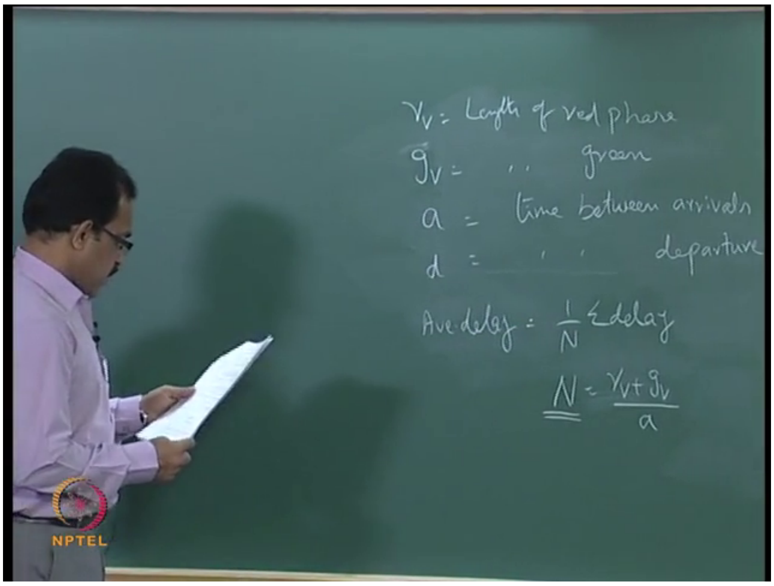

So, in this case you can actually see that r v is the phase o red phase. So, length of red phase, and similarly g v is the length of green phase and then a is the time between arrivals, and d is the time between departure, the same as what we saw there r v was 100 and g v was 60 and a was 4 and d was 1.

Now, if you want to find out the average delay average delay is 1 over n sigma delay that is the total delay divided by n, where n is the number of vehicles number of vehicles will be equal to r v plus g v divided by a. So, this is r v r v plus g v divided by a will give you the number of vehicles and the sigma delay over n will give you the average delay.

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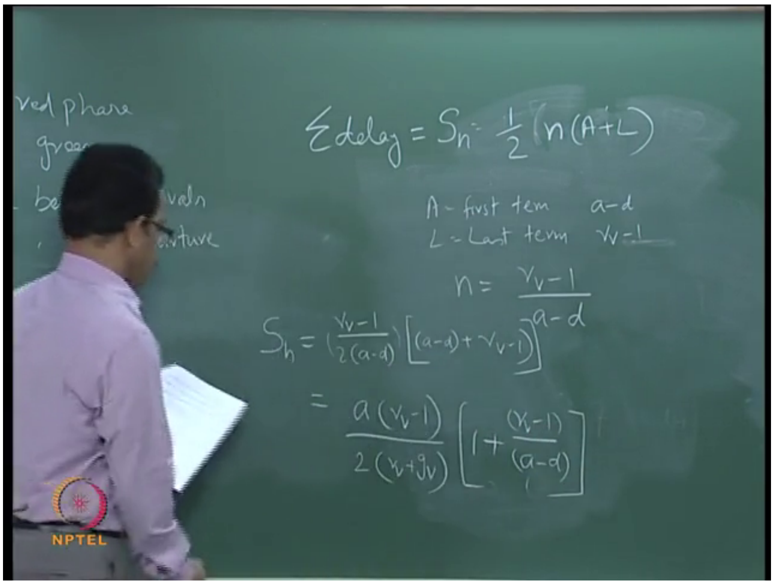

Now, if you want to find out the sigma delay the sigma delay can be calculated, S n is equal to 1 over 2 n A plus L

So, this is it will be the relationship for average delay where A is the first term in this that table what we saw in the previous case that is a minus d and L will be the last term which is r v minus 1. Now n can be obtained as r v minus 1 divided by a minus d. So, using this relationship we can write s n as r v minus 1 divided by 2 a minus d multiplied by. So, this stands for the n and then a minus d plus r v minus 1.

That is the delay and if you simplify these you will be getting the S n as equal to a multiplied by r v minus 1 divided by 2 r v plus g v multiplied by 1 plus r v minus 1 divided by a minus d. So, this actually shows that any scenario any dynamic scenario can be easily model using mathematical relationships and that can be used for modeling that particular scenario and predicting the behavior and depending on the requirement we can actually modify the parameter or we can think of changing the system parameters in order to suit the requirements.

So, that is the advantage of using mathematical model for this kind of applications. So, in the system design, we will see many scenarios like this where we need to find out the behavior the dynamic behavior of that system at a particular situations and then we need to modify the system designs. So, mathematical tools will be really helpful for such situations.

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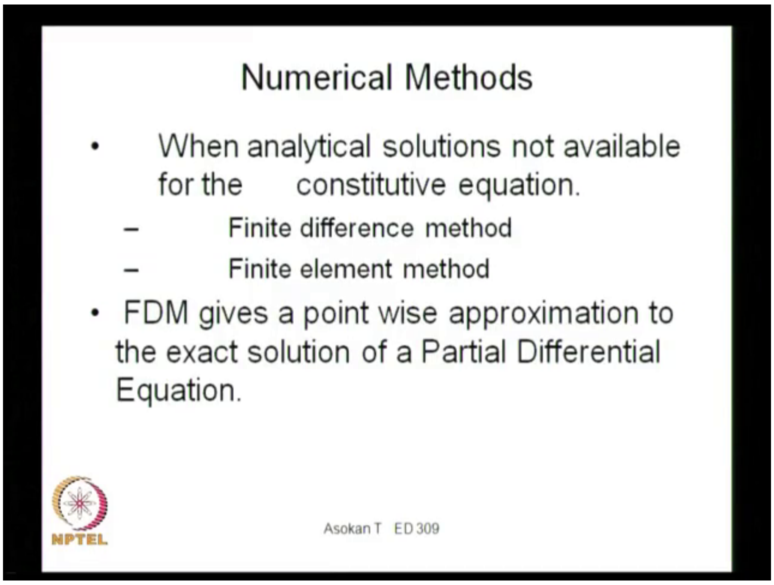

Let us see some other methods also. So, we have few other methods also for modeling. So, when analytical solutions are not available we go for a method called a finite difference method or finite element methods. So, finite different method gives a point wise approximation to the exact solution of a partial differential equation.

Again these are the two methods which can be easily use for analysis of the structures especially when you want to find out the load acting and then the stress levels or you want to find out the temperature distribution. So, this kind of application there are wide application for this kind methods like finite element method and finite difference methods. I am not going to the details of these methods, because you can find many resources for learning about these methods, but just want to tell you that these methods can be easily employed for system design and whenever the requirement is there we can apply these methods to do the analysis.

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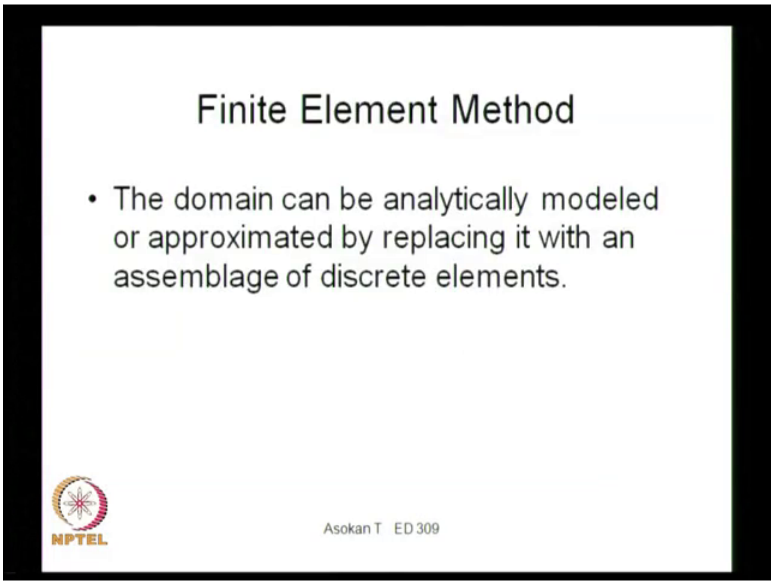

Just to show you how it works in the finite element methods the domain can be analytically model or approximated by replacing it with an assemblage of discrete elements. So, that is what we have an assemblage of discrete elements to represent the system.

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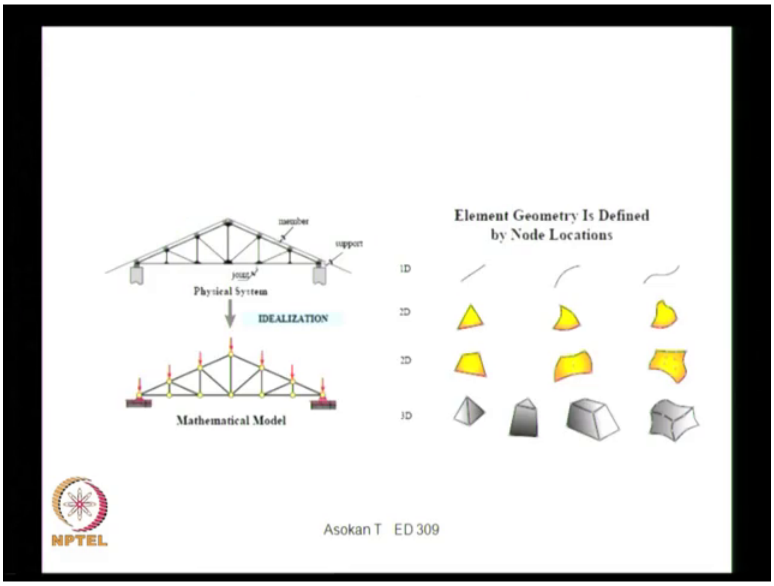

This has some examples or methods if you have a structure like this physical system you can actually create a mathematical model by idealization and then use different kinds of elements. So, in finite element method we use various elements one d one dimensional element, two dimensional elements or three d elements can be used for modeling there are various softwares available for doing this. So, we can actually conversion of the physical system to a mathematical model is the first task once you have this then actually you can use standard software for simulating it and finding out the behavior.

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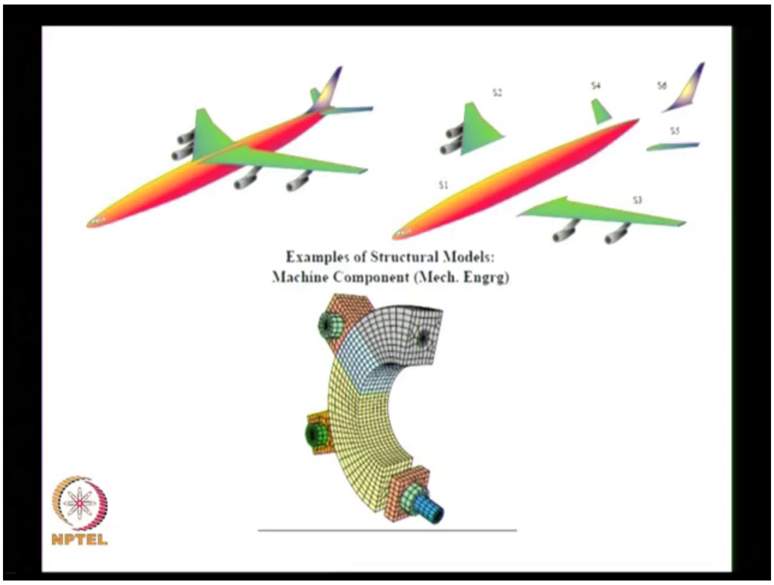

These are some other examples this finite element methods are widely used in design activities; so for the in especially in the case of aircraft design missiles and all. So, basically when you do the machine you will be getting a structure like this you will be having different elements. And we can find out the stress or temperature or any other parameter using from this elements and then you can plot it to find out how it will be affected by various parameters.

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So, this is a finite element model of an aircraft.

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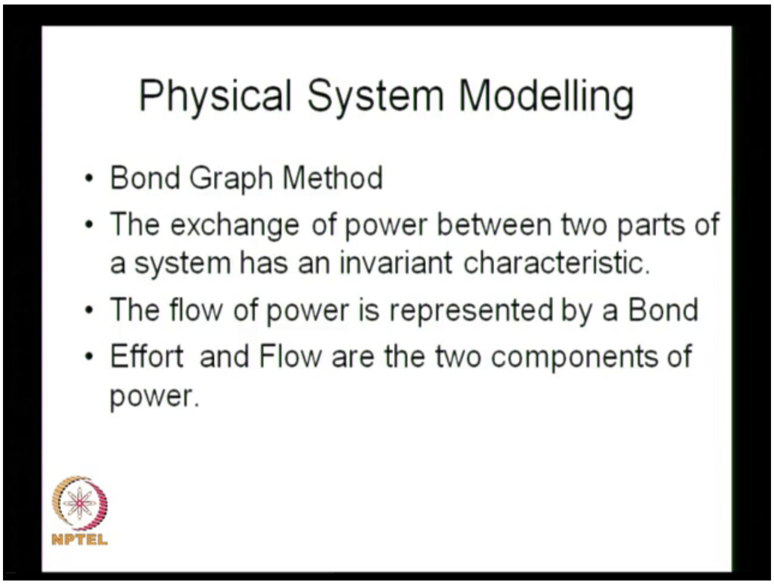

And the last system I would like to discuss is the bond graph methods, as I told you bond graph is a physical system based modeling technique. So, here we will look at the physical system we do not convert that into a direct mathematical equation, what we do is we will try to create a graphical representation of the physical model and then using a method called bond graph we can actually a represent the physical system directly and then can be simulated.

So, this was developed by a person called painter long ago and it is widely used by professionals and there are few softwares available for using this method to simulate the particular system when we model the system using bond graph. So, here in bond graph method the exchange of power between two parts of a system has been considered. So, we always assume that whenever there is a system there will be some exchange of power. So, the power interaction between the elements is considered here and that is why sometimes it is known as power bond graph method also the flow of power is represented by a bond. So, whenever you have a an exchange of power he represent that by a bond an effort and flow are the two components of power.

So, there are two parameters we need to define to get the power that is the effort and flow.

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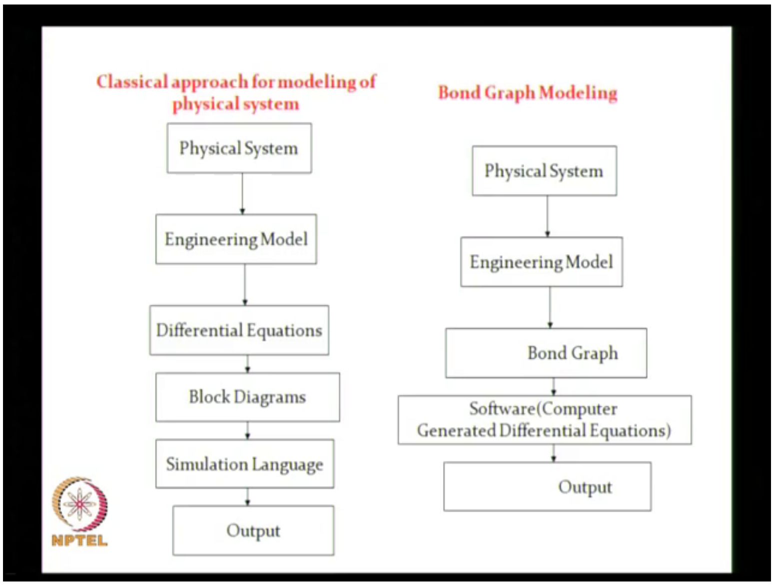

The main difference between the classical approach for modeling a physical system and the bond graph modeling is shown here in this diagram, as you can see here in the classical approach for modeling, we start with the physical system and then we create an engineering model using some mathematical methods or we convert that into a simplified an abstract model and that is the engineering model and then we write down the differential equations to corresponding to that model. And then we use some standard methods like block diagrams and then simulation language to simulate it and get the output.

But in the case of bond graph modeling, we do not go through this stages we keep some of this stages we have this physical system then we create an engineering model using converting of the physical system by taking abstracting that we an engineering model and then we create a bond graph. So, we actually we do not write down the differential equations or go for the block diagrams we convert the engineering model to a bond graph and then this bond graph will be used in the computer through some software and simulated and will get the output.

So, that is the difference here in bond graph modeling. We do not need to know the differential equations corresponding to the particular model or we do not really need to worry about what kind of equation to be used how to solve this equations. So, all this are done using the bond graph method. The only difficulty is that we need to know how to create the bond graph for this engineering model, no direct equations here only the graphical representation. So, we will create the bond graph from the engineering model and it will be used for generating the differential equation through the software. So, the software can actually do the job of creating the differential equations and then simulating it.

So, we do not really going to this part of this modeling in the bond graph method. So, that is the advantage of using bond graph modeling ok.

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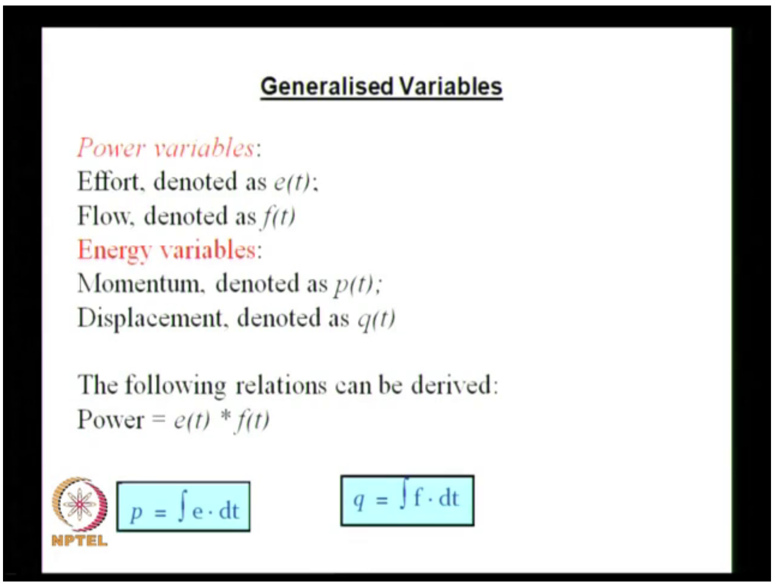

So, the methods used an bond graph we need to learn some of the basic elements used in bond graph in order to understand how the bond graph modeling can be used for system simulation or how the engineering systems can be simulated using bond graph. There are some basic elements as I told you there is a parameter called effort and flow and apart from this we have many other generalize parameters.

What we do today is to look at those generalize parameters and then we will stop after seeing the parameters and then we will see how to use these parameters in the system modeling in the next class. So, I will just explain you about the generalized variables as I told you initially the power variables are effort and flow. So, you have a effort variable and the flow variable effort is represented by e and the flow is represented by f. So, this is the effort representation e and flow is denoted as f.

Then we have two other parameters known as energy variables the energy variables are the momentum and displacement. So, the momentum is represented using p and displacement is denoted by q and there is a relationship between this p q and e and f, the power flow in the system is given as power is a effort multiplied by flow. So, whenever there is a power flow taking place that is actually a product of the effort and the flow. So, what whatever maybe the effort and flow the power actually can be calculated by taking the product of this effort and flow.

And this momentum is basically a integral of the effort. So, p is obtained by integral e d t and similarly q is obtained by integral f d t, that is the integral of flow gives the displacement and integral of effort gives the momentum. So, integral of effort gives the momentum as you can see here this is if you take the variables you can represent them in various domains as I mentioned earlier bond graph is basically used for multi domain systems and you have mechanical systems, electrical system, hydraulic system and their combined we need to have a common language to use for modeling.

So, here the effort and flow are common in all the domains. So, whatever maybe the domain whether it is mechanical, hydraulic or electrical we can use the same variables effort flow momentum and displacement.

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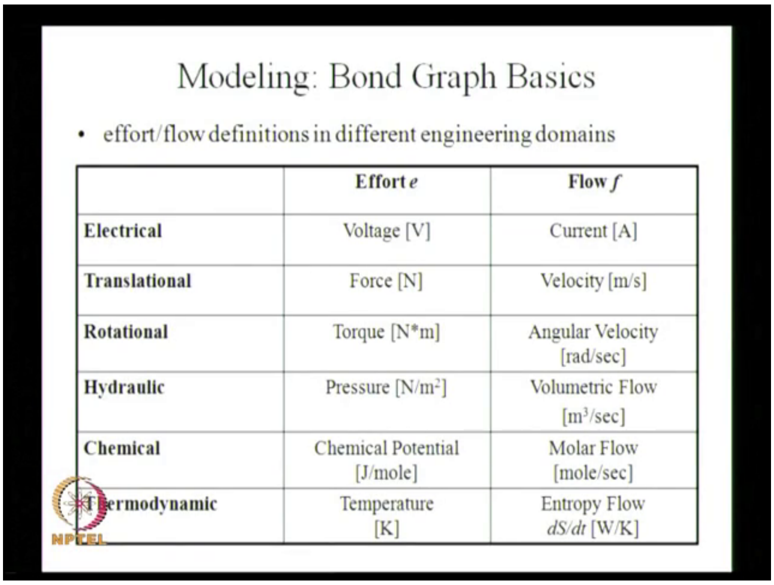

	Effort e	Flow f
Electrical	Voltage [V]	Current [A]
Translational	Force [N]	Velocity [m/s]
Rotational	Torque [N*m]	Angular Velocity [rad/sec]
Hydraulic	Pressure [N/m^2]	Volumetric Flow [m^3/sec]
Chemical	Chemical Potential [J/mole]	Molar Flow [mole/sec]
Thermodynamic	Temperature [K]	Entropy Flow dS/dt [W/K]

This chart shows the variables effort and flow and different domains. So, we can see the electrical domain the effort is voltage and flow is current and voltage into current will give you the power. So, multiplication of the effort and flow will give you the power and then translational the force is in the translational motion the force is the effort and velocity is the flow and rotational motion torque is the effort and angular velocity is the flow and in hydraulic pressure is the effort and the volumetric flow is the flow.

Similarly, for chemical potential and molar flow, thermodynamics, temperature and entropy; so as we can see here whatever maybe the domain you can still represent the effort and flow and that actually helps us to have the a common modeling language for multi domains.

So, I would like to stop here today we will see the methods by which how do we actually use the bond graph for modeling, the engineering system and what are the basic modeling elements used in bond graph. We will see all these details in the next class. So, till then goodbye to all of you.