Engineering Mechanics
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Module - 01
Statics
Lecture - 01
Introduction to Engineering Mechanics - I

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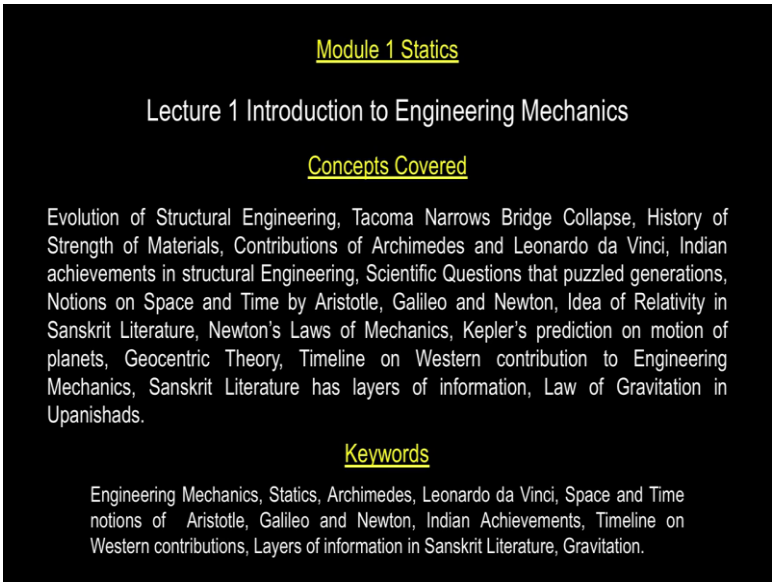
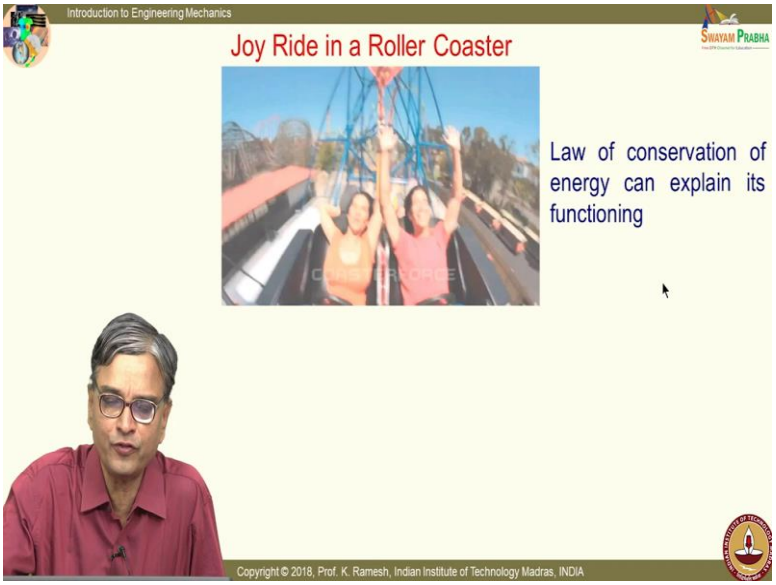


So, welcome to the course on Engineering Mechanics. It is desirable that when you learned a new course that you get to know the history and the human struggle to arrive at that body of knowledge. In these set of slides, you see a variety of structures dating from 2500 B. C. This is the Parthenon in 438 B.C and this is the famous Eiffel tower in 1889, and this is the bridge under construction at Dubai.

And what you see in these slides is complexity of the design has phenomenally increased from just stones standing in one place to a beautiful construction of depicting a human smile on the bridge. And another aspect is you also find a change in the materials that they have used. You find steel is used in the Eiffel tower and the modern construction they have used concrete and also steel and variety of other aspects. And you know it is desirable when you have a course it is like a roller coaster; you have ups and downs and also you have sense of joy in the mind of these people.



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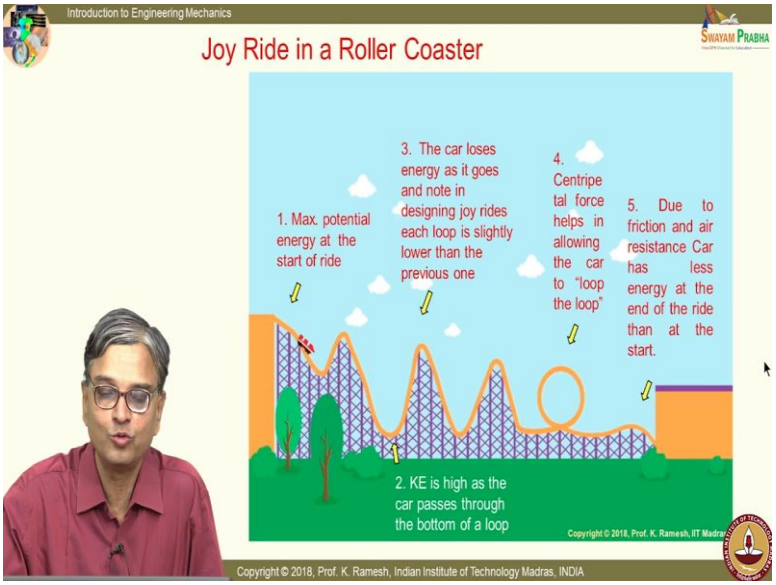
And I would like you to have this sense of joy as we learn the course. Because I believe learning is a pleasure. And what you see in the roller coaster you can easily explain by the law of conservation of energy.



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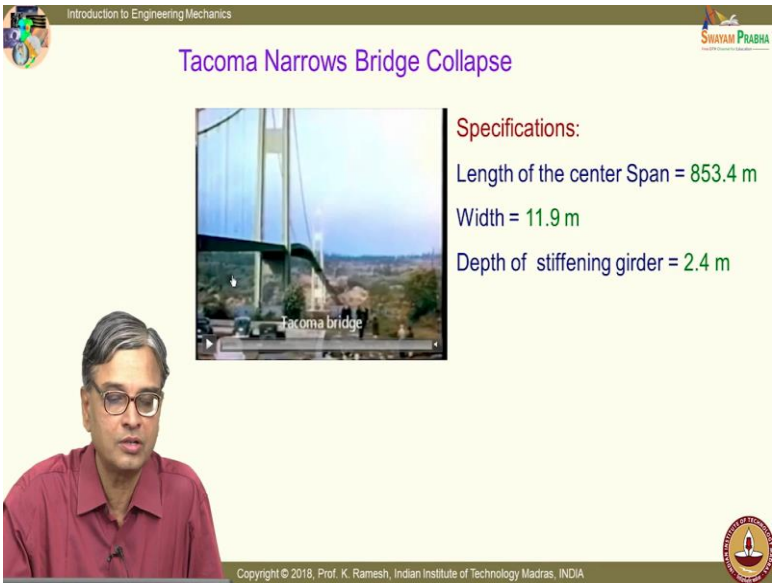
And many of you know this in your earlier training and from an engineering perspective you should view this simplified model of the roller coaster. Can you see something very interesting and striking in this? If you look at the peaks they are cleverly put at different levels and it is mainly because you start with the maximum potential energy at the beginning of the ride. And you select the height in such a way that the car is able to loop the loop and all this you can comfortably explain by initially neglecting friction. That is the way we do the modeling and make our life simple.



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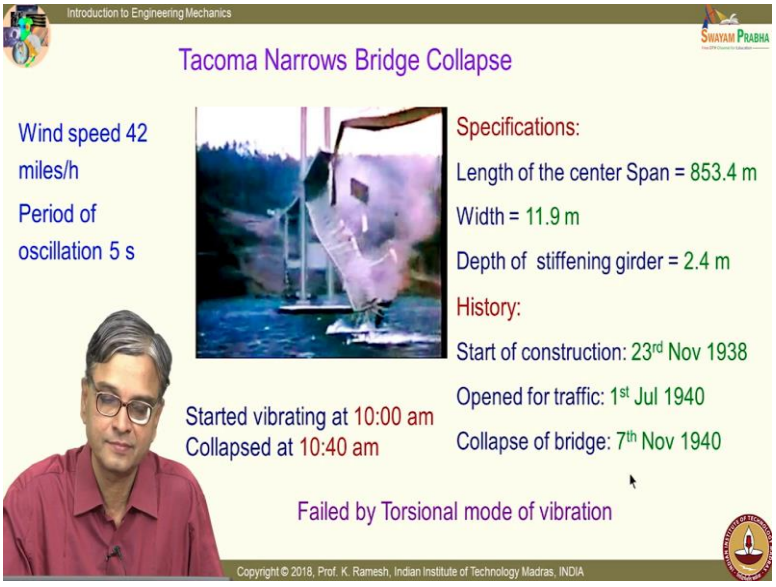
And you should also know that there have been spectacular failures. Look at the concrete bridge. This concrete bridge is going through an oscillation and if you can watch carefully there is a person who is coming along the central line of this that is the nodal point of this. The story goes that there was a car, there was a car here and there was a dog inside the car he was trying to rescue that car and he is a professor of vibration. So, he knew how to navigate this vibrating structure and look at the concrete bridge. Can you ever imagine it can twist like this?



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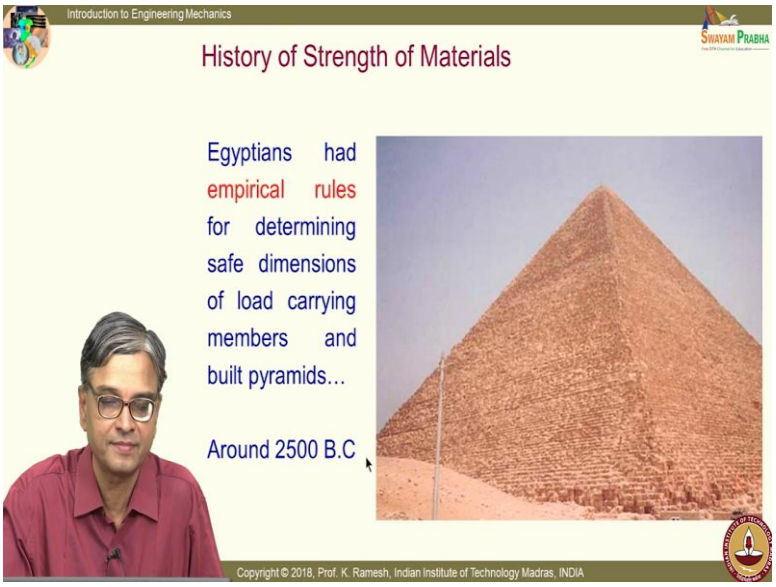
And all of this happen without a warning; see the human civilization learnt many things from failures than success. And this was the bridge constructed in 1940s and the wind speed at that time was 42 miles per hour and the period of oscillation was about 5 seconds. It was started in 1938, opened to traffic in 1940 in the month of July and it collapsed in the month of November just 4 months of operation.

It really sent shock waves to the designers what is it that they have not noticed while designing this bridge. And the interesting story is it started vibrated at 10 o' clock in the morning continued for about 40 minutes. There was a video store at the end of the bridge

and he saw something happening and he started recording it, you might think that the video quality is not good. But you should also associate with time in 1940 that is the quality that they had and that is a real learning experience for many to see and this failed by torsional mode of vibration. And the bridge completely collapsed into the water body.



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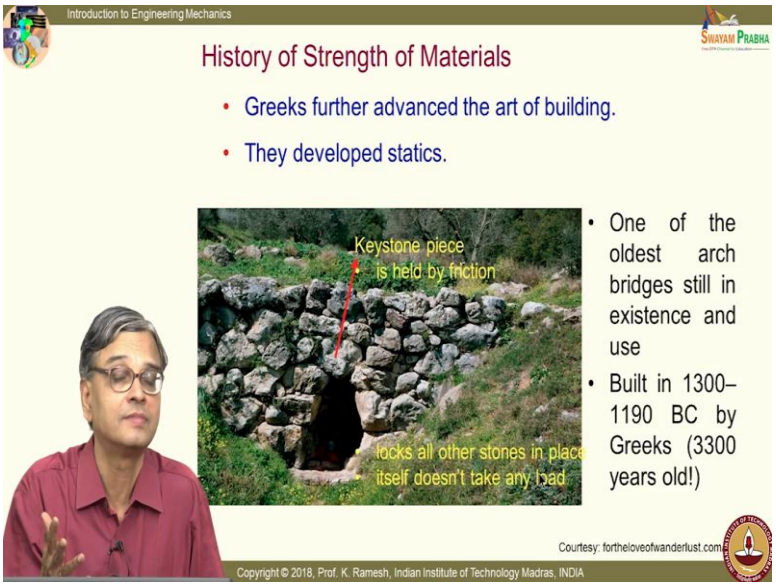
And if you look at history; Egyptians had empirical rules for determining safe dimensions and they built huge pyramids. This was dating back to 2500 B. C.



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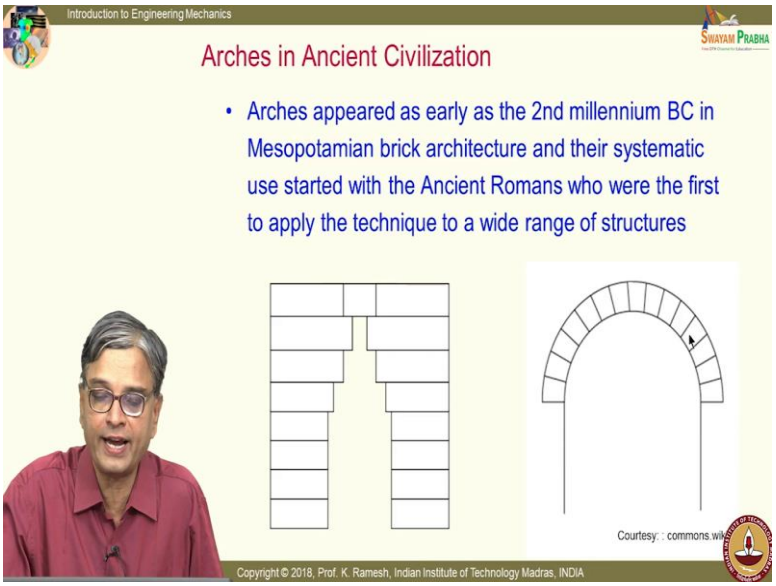
Then what you find Greeks further advanced the art of building. They had built an arch bridge this is still surviving what you will have to look at is, this looks very trivial at this point in time. But this bridge is in use for 3300 years. And now we know what is the mechanics behind the arch bridge you have a keystone piece. This is held by friction locks all other stones in place; all these understanding now we have at that point in what kind of understanding they had we have no clue.



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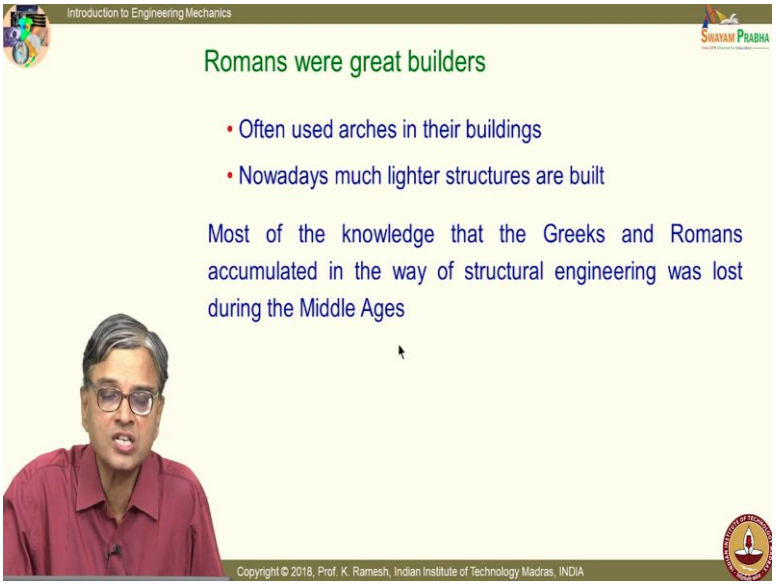
And what you find is Romans were great builders and we also had arches in ancient civilization. Starting from 2nd millennium BC, Mesopotamian brick work is like this, and this is the one you saw in many of the structures that Romans have built extensively used arches in their buildings.



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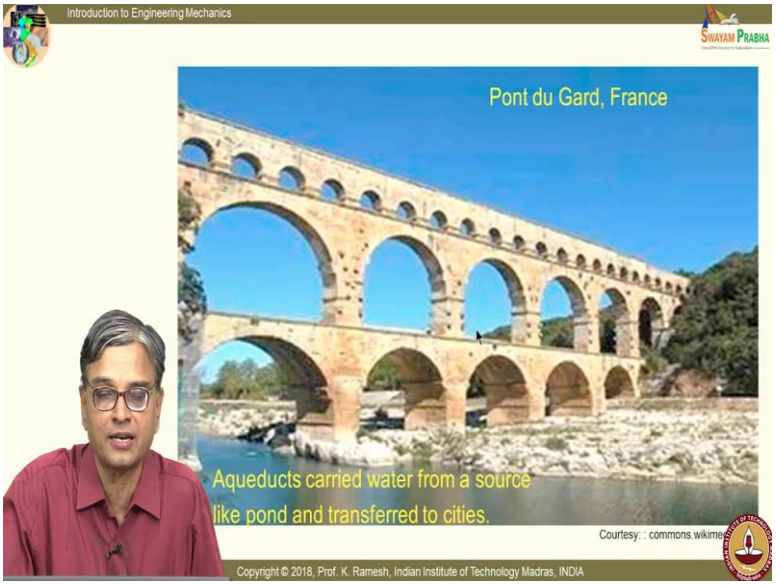
And you should know nowadays much lighter structures are built. You have to conserve material and people have looked at engineering as advanced. Nevertheless, you should compliment people when they had problem; they had a solution that solution may not be optimal that is a different issue. But they had a solution when they were forced to get certain things done. And most of the knowledge that the Greeks and Romans accumulated was lost during the Middle Ages; that is the saddest part of it.



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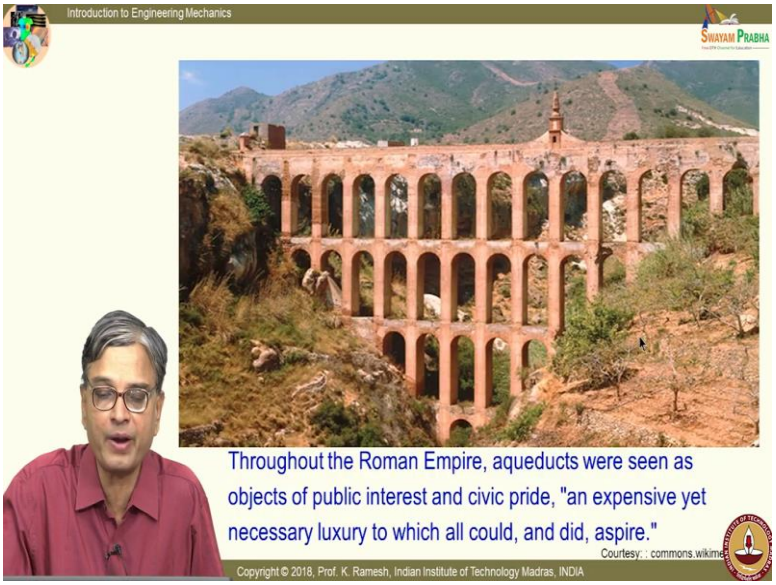
And you can see here the use of arches and this for the transporting water these are called aqueducts.



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And it was a sense of pride and this is a hilly terrain, so you have a ravine here and they have built similar arches multiple layers. So, they were able to solve the problem of water requirement by having these kinds of structures.

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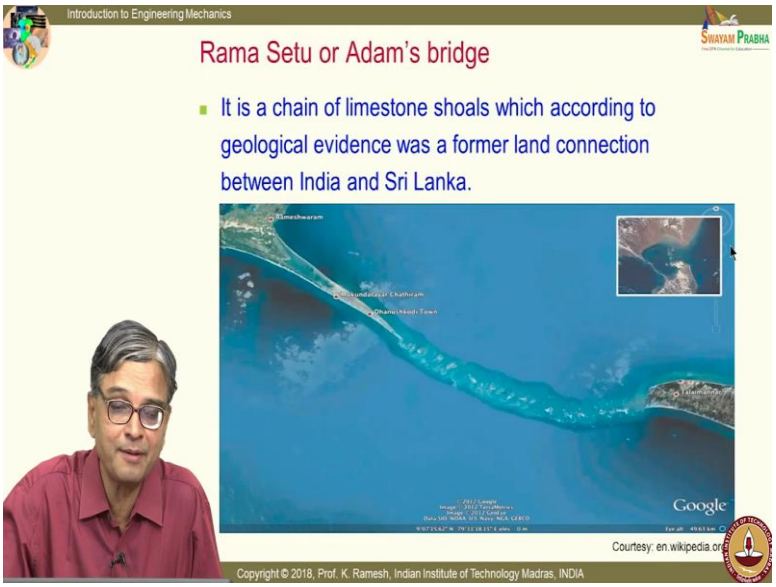
And it is also surprising to see the Romans were also the ones to use concrete in their bridges. And it appears they have built not one bridge; 931 bridges about 2000 years ago. So,

that is something creditable. See normally when we learn anything, we have learnt so much about western civilization how it has come about. We have never looked at as Indians what we have been doing it; we saw a bridge in Roman Empire that they have built it 3300 years old.



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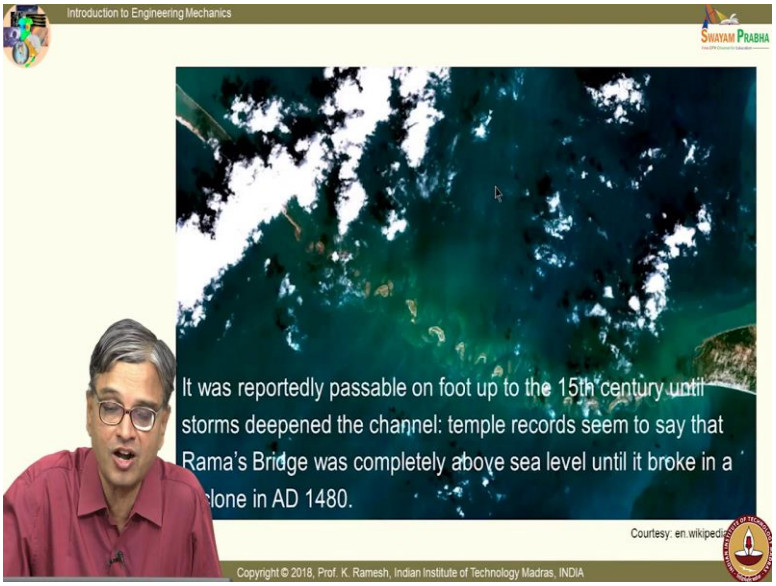
We also had parallel examples and dating back to Ramayana and you have a bridge on sea. And I said that they have cleverly used a material which will float on the sea they are limestone shoals.



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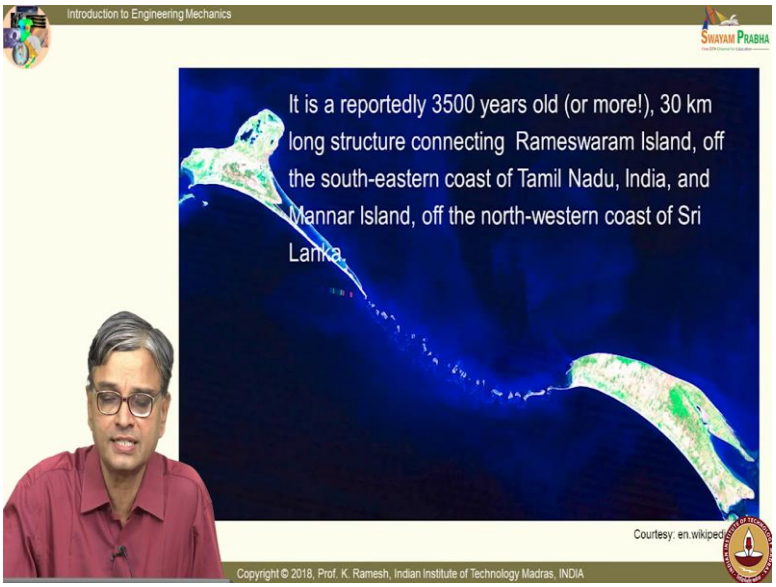
And this is not a short bridge it is a bridge covering 30 kilometers and this bridge was in good shape until there was a storm in the 15th century and it broke only in the cyclone of 1480 until then people were able to go for several 1000 years this bridge was existence so that is something very interesting to see off.



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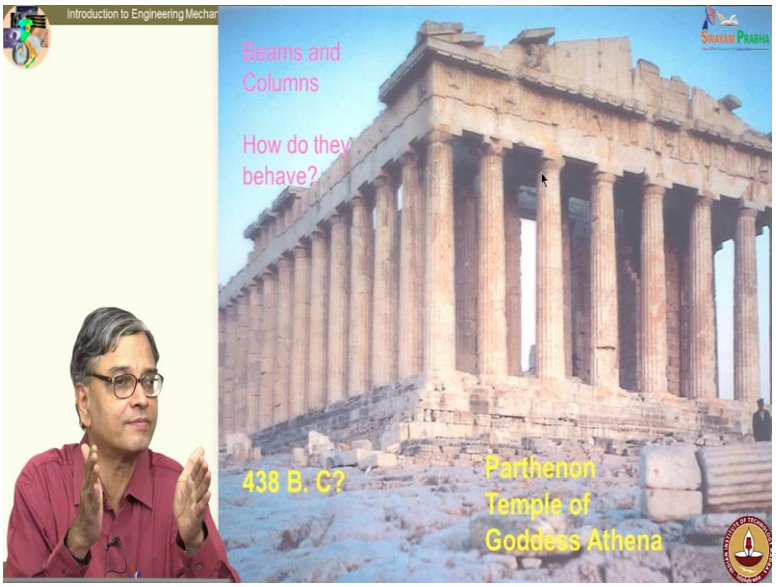

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And when you look at the Parthenon you have a nice building with a roof; this is consisting of vertical members which are called as columns which you will learn in this course. And the horizontal member which support transverse loading are called beams. So, they had an idea that you want to build a structure you can have beams and columns.

The one striking difference is you look at the distance between the columns it is very narrow. Whereas the room in which you are sitting you are having a beam; in this room the beam is like this, the span is very large we have understood the mechanics. So, we are able to exploit it better. Nevertheless, you should compliment when it was 438 B.C, they had the idea of building structures like this.

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And we also had several temples having 1000 pillared Mantapas. So, the span is different span is the one which is different.

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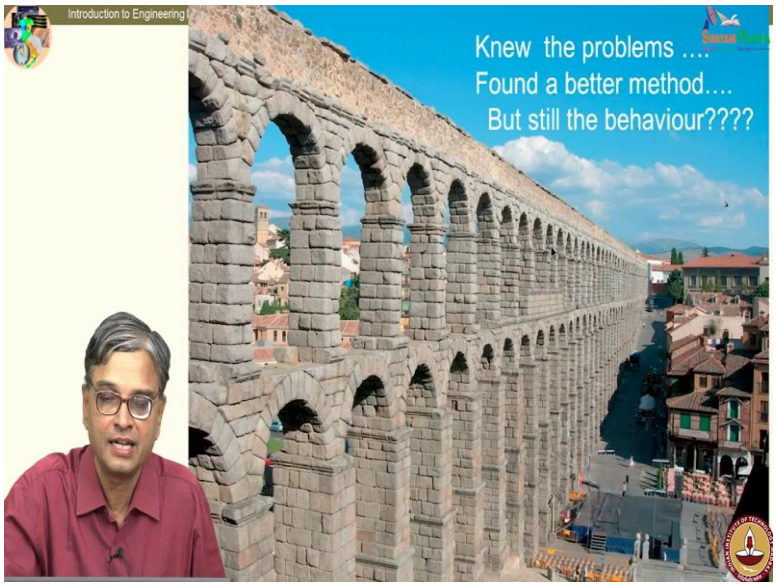
So, if you look at the earlier civilization, they knew the problems; they had solved it by some method. But still the behavior have they understood the behavior completely for them to extrapolate or teach the next generation what to do.



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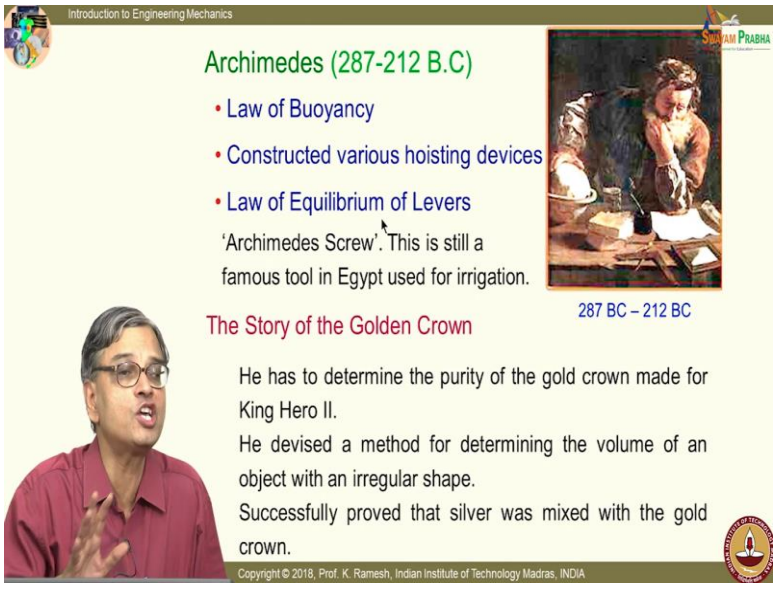
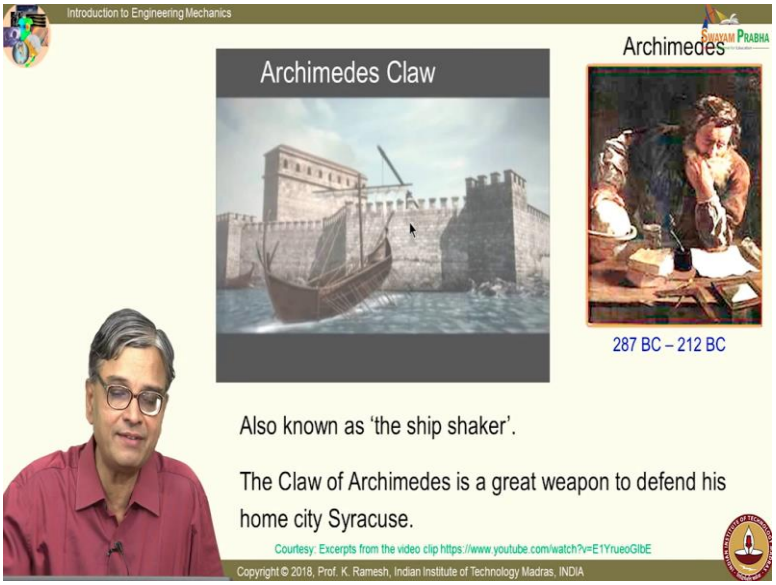
And if you go back to history you know you have this Archimedes; I would like you to look at these historical figures with their associated time. You should recognize that this was in before Christian era and all of you know the law of buoyancy that is the eureka moment. What precipitated this? He was given a problem by the



king; he got a golden crown and he wanted to know whether it is done properly even at that point in time people were cheating ok. He wanted to find out whether it is made of pure gold or not. So, he had to find out a way to find out the density and he solved the problem.

So, in those eras you had a king, he had a court, he will have a bunch of scholars who would solve king's problem. It is not that the general mass had an idea or clue how to solve the problem if they are faced with. And you also have very nice construction of hoisting devices this is still used in Egypt for irrigation. And Archimedes is also very well known for equilibrium of levers. In this course we would exploit and analyze levers to find out many gadgets that are of use in today ok.



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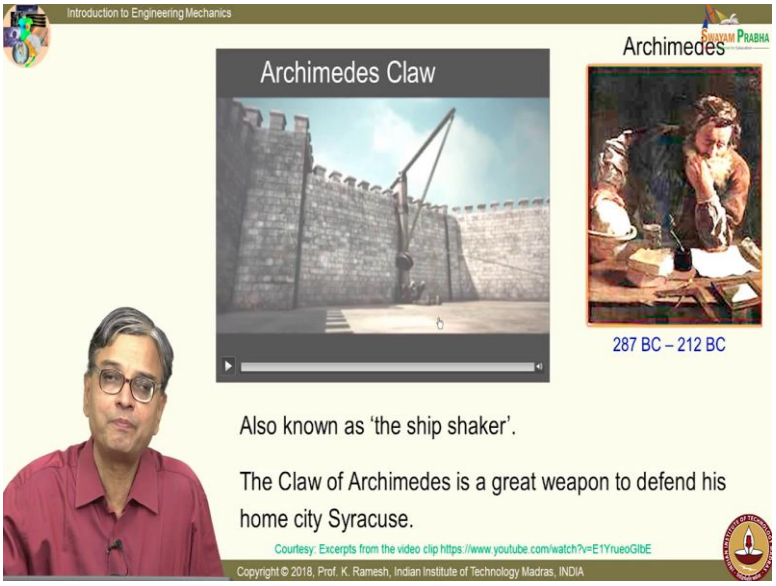

But if you look at what prompted him to develop these levers, the story is different; he had to defend his country. So, he devised a lever which will lift the boat and sink it in one shot that is what you saw it in the animation. And on the other side this animation shows how the ship is snapped very fast.

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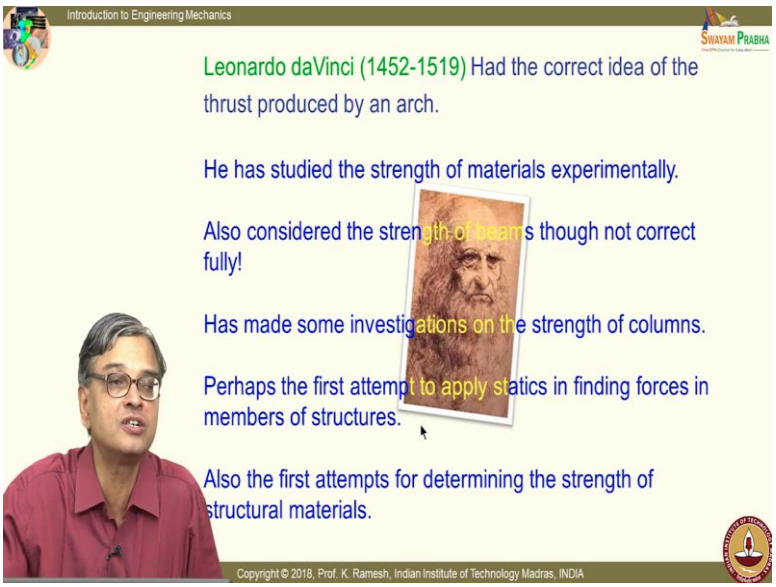

So, the idea what I am trying to convey is unfortunately many of the key scientific developments whether it was in the olden days or currently it is all precipitated by military considerations. First people develop it for military to kill each other. Then they find a technology it can be used for maybe making your heart valve titanium alloys are used for heart valve; it percolated from that kind of technology. So, that you will have to keep in mind it is not that science always focuses on human betterment.

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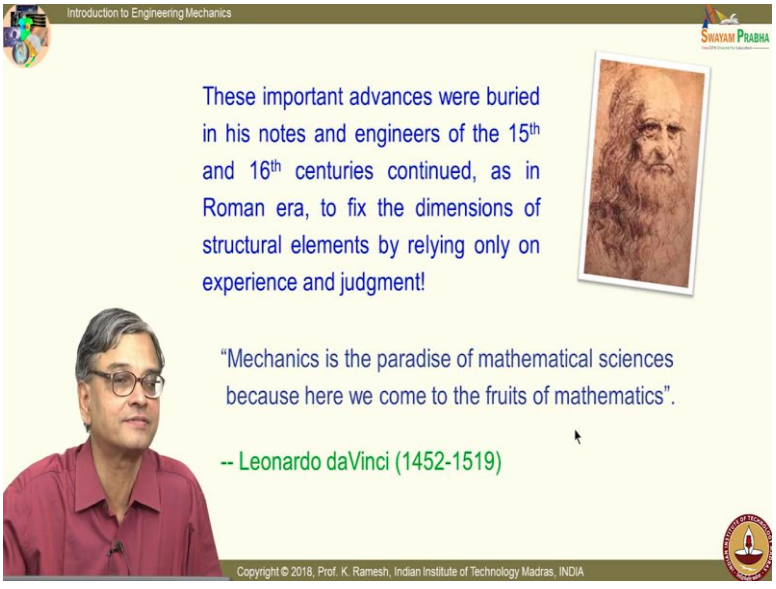
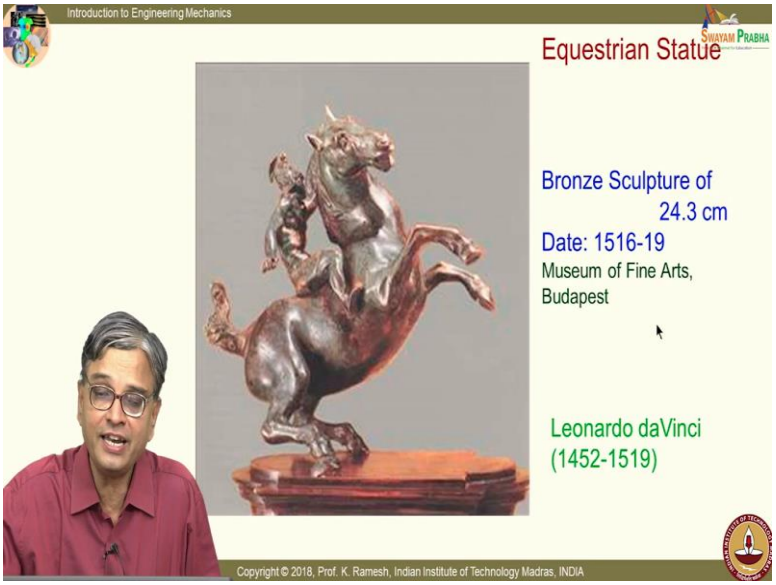


Funding is available only for military that is another aspect that you have to keep in mind. And if you go back to history Leonardo daVinci had the correct idea of the thrust produced by an arch which I have already given hint of what it is. He has studied strength of materials experimentally until then people have not done it. Also considered the strength of beams though not correct fully and you will be surprised analysis of beams development of a proper theory took 400 years of human effort very bright minds have contributed to it is not a child's play.

We may teach theory of beams in 15 minutes in a class, but if you look at the history it was a great struggle; daVinci also made some investigations on the strength of columns. Perhaps the first attempt to apply statics in finding forces in members of structures. Whatever the important advances made by daVinci buried in his notes.



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As in Roman era to fix the dimensions of structural elements the engineers relied only by experience and judgment that is a very vague word unless whatever the understanding is brought into mathematical equations, it cannot become a science. So, daVinci really realized mechanics is the paradise of mathematical sciences because here we come to the fruits of mathematics; so, the very important statement.

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And he was also a great artist and he was acclaimed for a very nice piece of bronze statue. And if you see here it stands on two hind legs unless you understand the distribution of weight and statics properly you will not be able to make this statue. And this statue is only above foot in height and when was it done; it was done in 1516 to 1519 ok the horse was standing on two legs.

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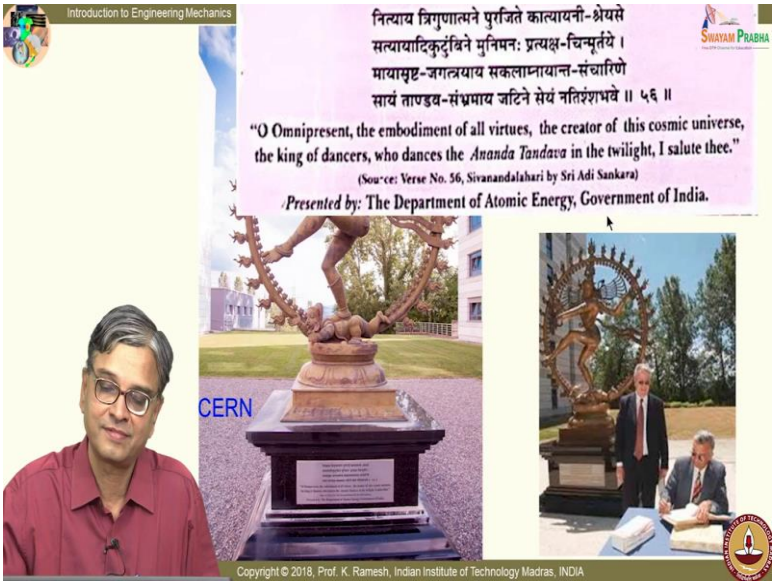
But in Indian achievement we had statue of Nataraja standing on one leg; don't you feel that it is much more creditable? And when was it done? You had excavations revealed right from 6th century onwards we have Nataraja and whatever the idol I am showing here is the 10th century Chola statue standing on one leg that is amazing. And you look at this; this has a depth very complex dynamical structure. It cannot be done unless they had some understanding of mechanics.



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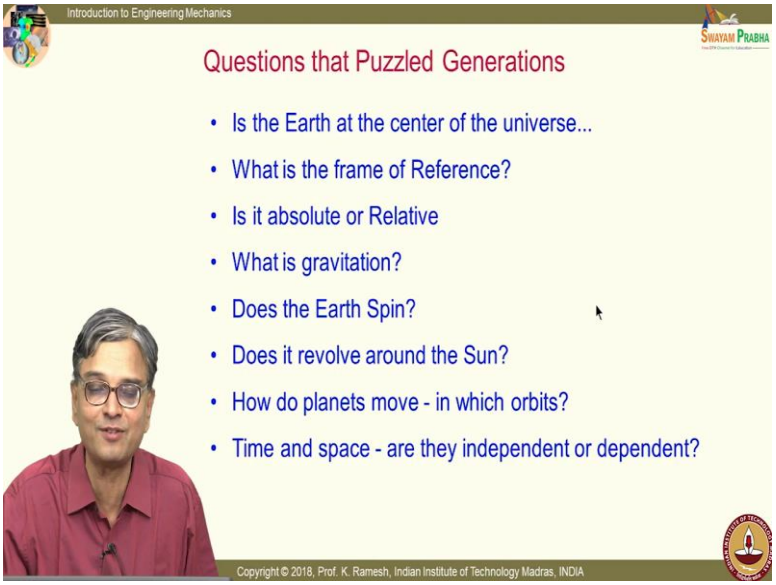
We had this knowledge 1000 years ago before daVinci could build his equestrian statue and this is all embodied in Silpasasthra and you will also be surprised the statue of Nataraja has been given as a presentation to the CERN which is the particle accelerator at Switzerland by the Department of Atomic Energy, Government of India.



Because whatever the subatomic particle which they were trying to reveal they had inspiration from the dance of Nataraja.

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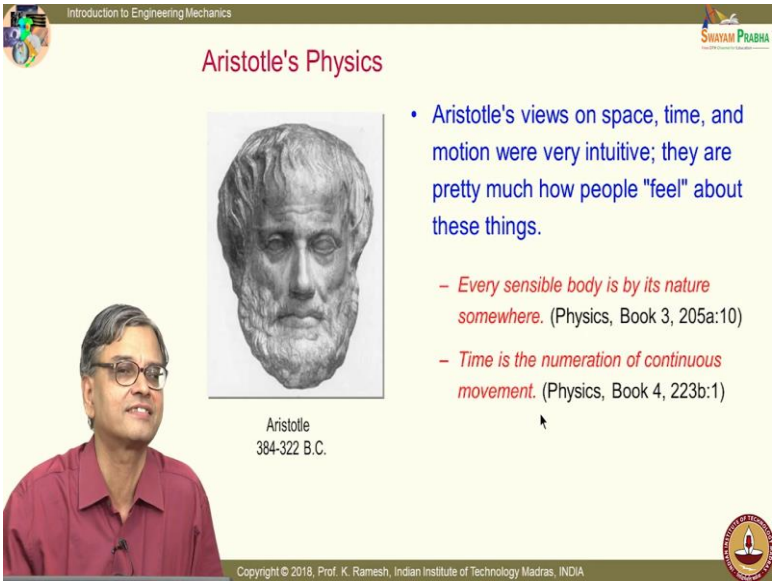
And the questions that puzzled the generations they are very important. Is the earth at the centre of universe; If you suppose you start thinking you want to find out reason behind

everything then you are confronted with these basic questions. What is the frame of reference? Is it absolute or relative? What is gravitation; because gravitation was a very puzzling aspect because you have forces being exerted when bodies are not in contact.

People could understand when the bodies are in contact, they exert each other force that was reasonably understood. So, gravitation as such was a very puzzling in the human evolution to understand and does the earth spin? Does it revolve around the sun? How do planets move? In which orbits; time and space are they independent or dependent? You are all very well taught in your physics courses in your schools you would say Kepler's laws that say planets travel in elliptical orbits. You will proudly come and say now we will go back and say what Indians have done earlier fine.



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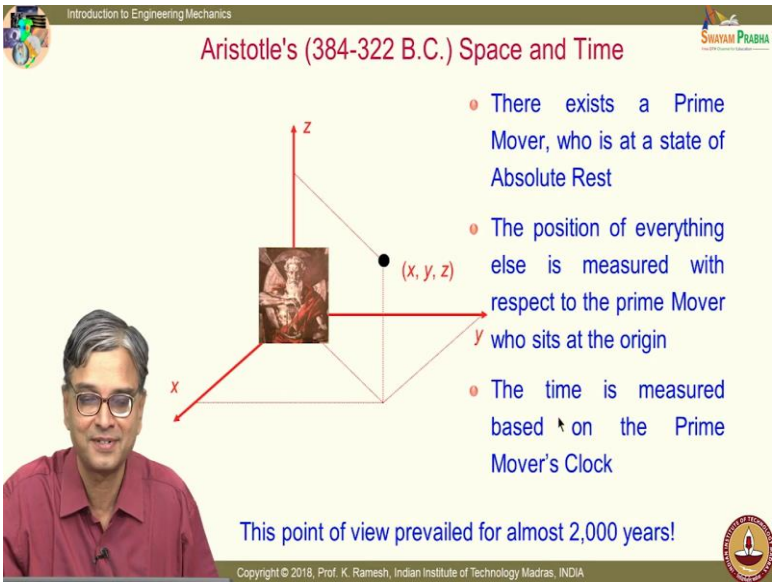

And let us get back to the very root of scientific thinking you had Aristotle's physics this started in 350 B. C or so. So, the Aristotle's views on space, time and motion were very intuitive; that means, everybody will agree with what he says. And these are the statement that he has made that. They are very abstract in nature. Every sensible body is

by its nature somewhere. Time is a numeration of continuous movement; very abstract ok.

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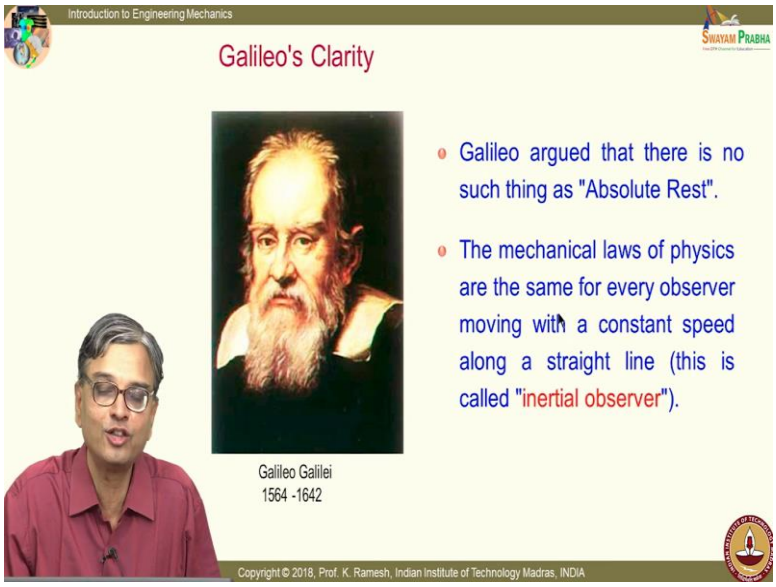
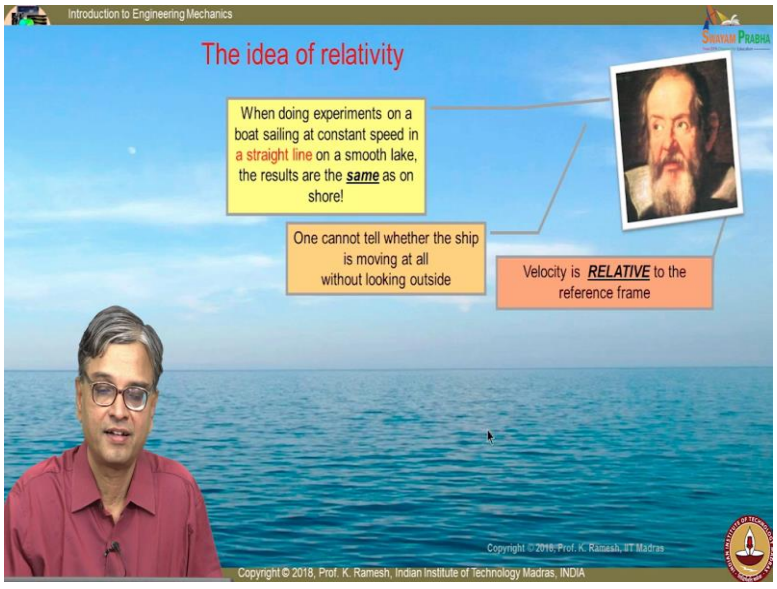


What did he say about frame of reference? There exists a prime mover which is at a state of absolute rest and with respect to this state of absolute rest you have to measure whatever the coordinate system that you have. And the prime mover also had a clock you see this old clock that he has; the time is measured based on the prime mover's clock; a very convenient to get started when you get started.



Can you imagine for how many years these views were unchallenged? Can you make a guess when somebody makes a statement to understand what happens around him and formulate? Certain basic ideas you will be surprised this took 2,000 years to change not 1 or 2 years. So, when you get a doubt after a class; do not be annoyed fine human civilization was like that if you are getting a doubt you may be getting that original doubt they had asked at that point in time.

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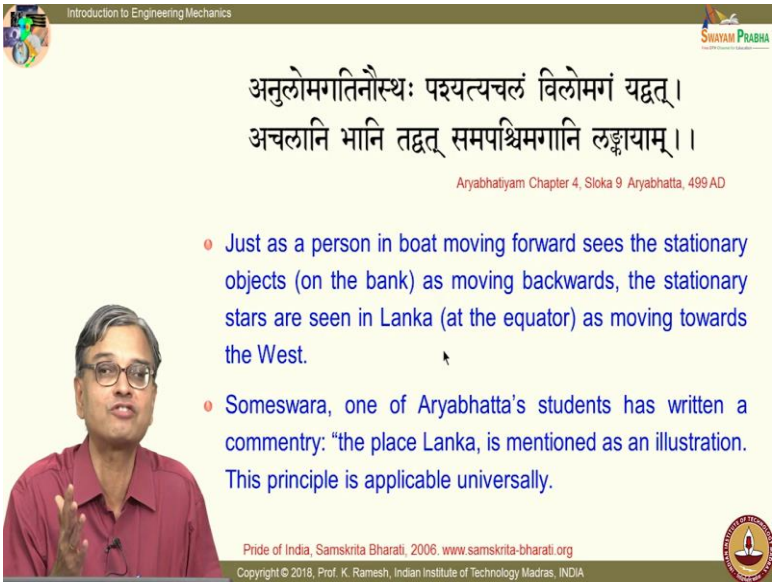

And Galileo came into the picture; he came 1500 years or 2000 years later. He argued that there is no such thing as absolute rest. The mechanical laws of physics are the same for every observer moving with a constant speed along a straight line; this is called inertial observer.

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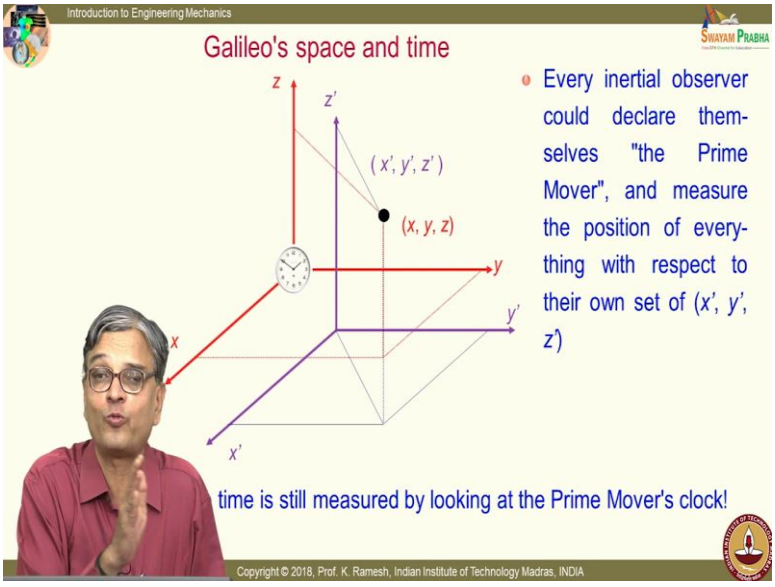
And in those days for locomotion what do you had? You had only these boats ok. So, he said when doing experiments on a boat sailing at constant speed in a straight line that is very important. On a smooth lake the results are the same as on shore. One cannot tell whether the ship is moving at all without looking outside, it was a great understanding ok.



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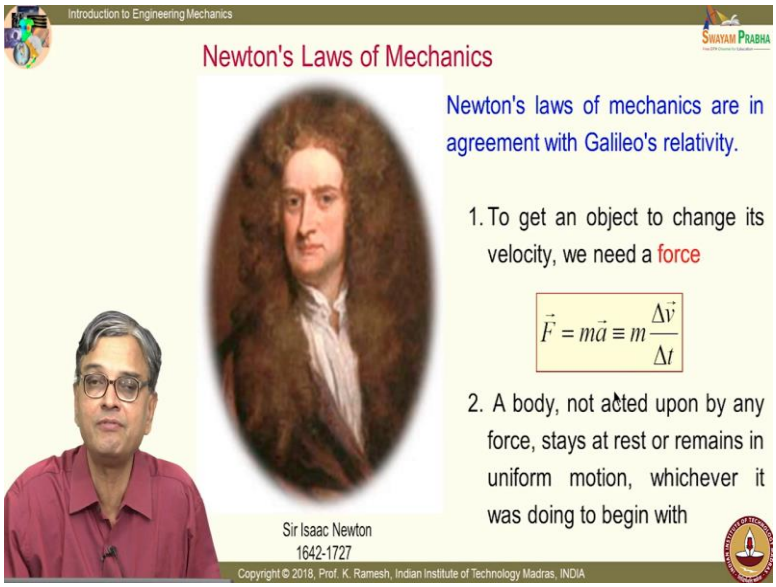
And if you say that what Galileo has said if we go back to our literature you have a sloka which says "Anuloma gathinaustha…" the sloka reads like this. This is from Aryabhatiyam this is in 499 AD. At least 1000 years before Galileo was thinking about relativity; the meaning of this is; just as a person in boat moving forward sees the stationary objects on

the bank as moving backwards, the stationary stars are seen in Lanka as moving towards the West; very important. Concept of relativity was not simple. Indian scientists had this vision 1000 years earlier than this you have such records ok.



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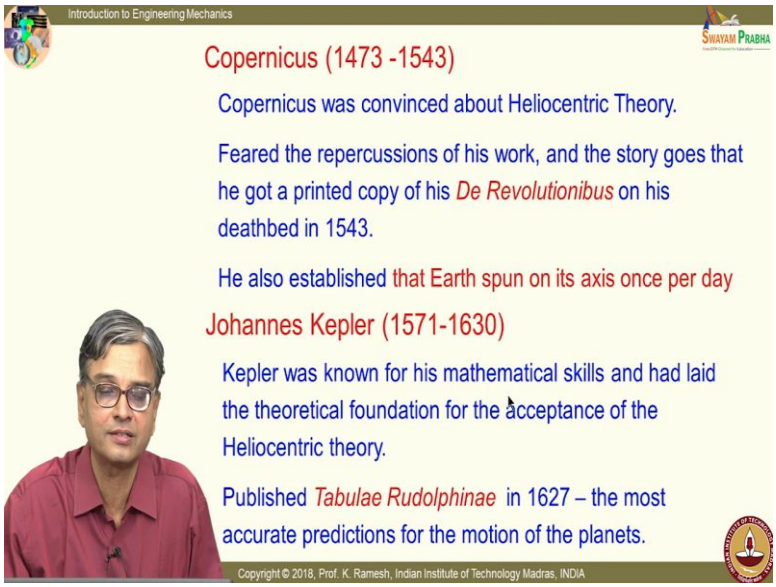
And what was Galileo's space and time; he also had a reference frame like this and he did not say that it is absolute ok. So, what he said was every inertial observer could declare themselves as "the Prime Mover" and measure the position of everything with respect to their own set of coordinates x prime, y prime and z prime. The only restriction is it should travel in a straight line with a constant velocity, it could be in one direction, it could be on another direction, or it could be in a very generic direction.



So, he had relaxed what should be the frame of reference, but what did he do about time? He still measured the time from the prime mover's clock; that was not changed. This is a story after 2,000 years.

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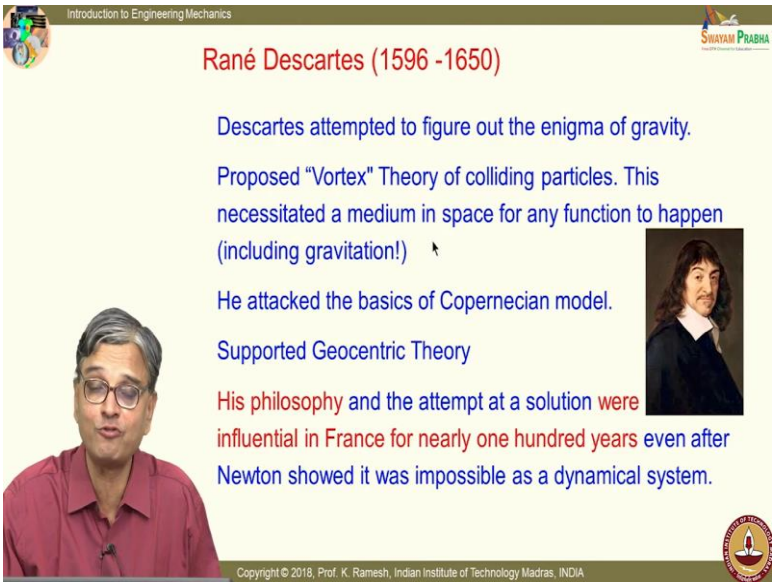
So, where Galileo left; Newton Started and if you look at Galileo's life ends in 1642 and in 1642 Isaac Newton is born. And he says Newton's laws of mechanics are in agreement with Galileo's relativity. And we all know reasonably well what is Newton laws to get an object to

change its velocity we need a force. The other statement is a body not acted upon by any force stays at rest or remains in uniform motion whichever it was doing to begin with; very important statements in the development of mechanics.



It took 2,000 years to do that; we will again and again see in this lecture various ways of looking at Newton laws of mechanics ok so that you get the idea central idea how difficult it was to comprehend this and you have the famous law

$$\vec{F} = m\vec{a} \equiv m\frac{\Delta\vec{v}}{\Delta t}$$

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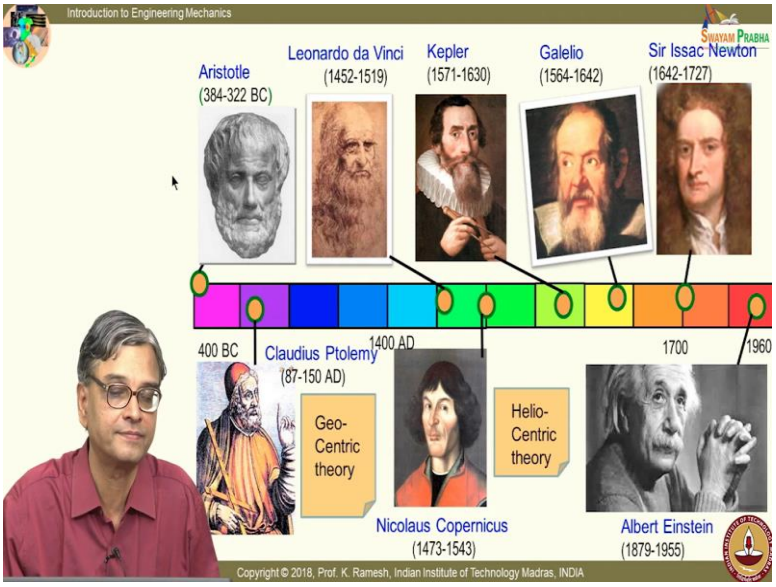

And there was also Copernicus between 1473 and 1543. We asked the question whether earth is at the centre of the universe. For 2,000 years people believed the earth is at the centre of the universe. So, there was an uproar against it. One of the scientists which brought this about was Copernicus. He was convinced about the heliocentric theory, but very afraid of repercussions of his work.

And the story goes that he got a printed copy of his De Revolutionibus on his death bed in 1543. And he also established that earth spun on it is axis once per day; until then people did not have that idea ok. Then you had Johannes Kepler 1571 to 1630. He published Tabulae of Rudolphinae in 1627- the most accurate predictions for the motion of the planets and all of you know he said Kepler's laws of motion and you know the planets travel in elliptical orbits. All these happened when; in 1570, 1630 and so on ok.

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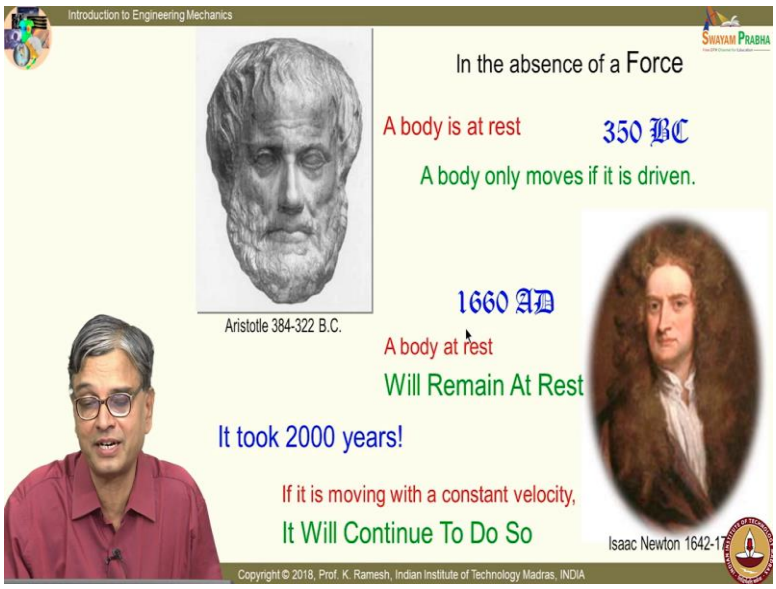
And you had Rane Descartes between 1596 and 1650. He attempted to figure out enigma of gravity because this is a force without contact. So, he devised he was accustomed to only with contact. So, he proposed the vortex theory of colliding particles. So, that is required a medium in space which is not possible and he attacked the basics of Copernican model which questioned the geocentric theory.



Because people were for geocentric theory, they stuck on to Descartes for 100 years. Even when Newton showed it was impossible as a dynamical system whatever Descartes was saying about the vortex theory. Because people are very difficult to change, they do not want to change their opinions so easily. Scientists have to struggle to convince that.

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And this is a time line and the time scale is not linear; you had Aristotle and you have Ptolemy they were proponents of geocentric theory; very comfortable for civilization to think that they are very important in the creation of God. And Leonardo daVinci was

between 1452 and 1519. Then you had the Copernicus who talked about the heliocentric theory, then you had Kepler talked about the planetary motion.

Then you had Galileo established the idea of relativity and Newton followed Galileo's relativity and much later you had Albert Einstein who questioned the concept of time. From Aristotle to Newton they still had the prime mover having a clock from that only you measured the time that took 2,000 years. From Newton to Einstein it took 200 years to change those views and he had also come out with special theory of relativity.

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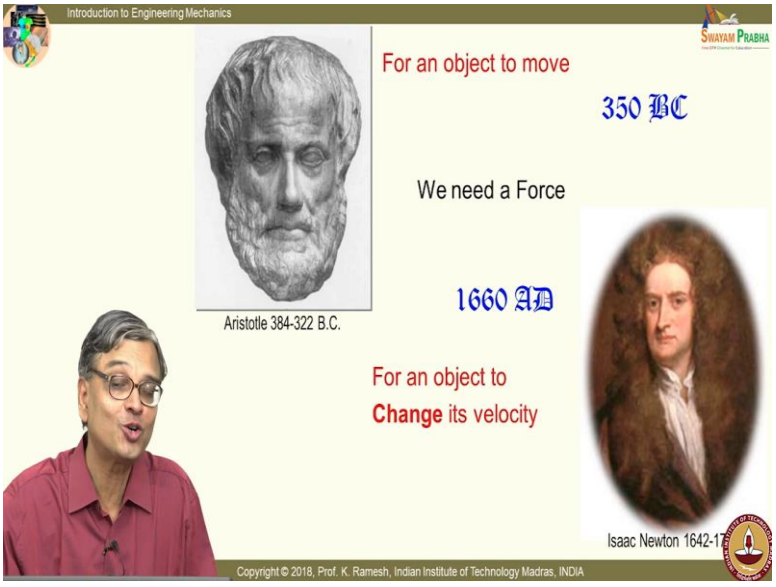
And let us look at what was Aristotle's contribution. In the absence of a force what happens? A body is at rest; that looks plausible, very nice and so on and so forth. And what did Newton say in 1660 AD, he also agreed a body is at rest; will remain at rest. There was no contradiction there. He made one more statement, which looks very simple now. If it is moving with a constant velocity it will continue to do so; very simple statement, but it took 2,000 years to get that. It is a very significant development and achievement.



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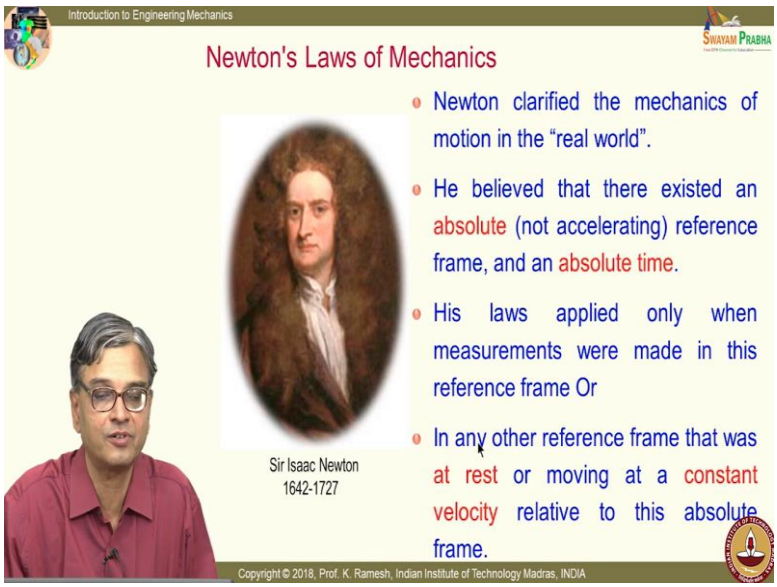
And look at it from other perspective; we need a force for what? We need a force for an object to move; that is also people can comprehend. What Newton said? For an object to change its velocity, the difference is very subtle. To penetrate this fact, it took 2,000 years. Now, you follow Newton's law and then you make mistakes; that is different, but the laws are said and it is repeatedly proved that the laws are correct. And this is the time when they were making laws, when it was not available very clearly for anybody to use it.



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Newton clarified the mechanics of motion in the real world. He also believed that there existed an absolute reference frame and an absolute time. His laws applied only when measurements were made in this reference frame or in any other reference frame that was at rest or moving at a constant velocity relative to this absolute frame; they are called initial frames of reference ok.

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And he is also associated with the famous story of apples falling and it and made him to write the book Principia Mathematica. So, the apple falling has also dislodged whatever the thought process Aristotle had about the universe, space, time so on and so forth ok. Because the gravitation was so difficult to comprehend and that precipitated these developments. Now let us look back what is there in Sanskrit literature.

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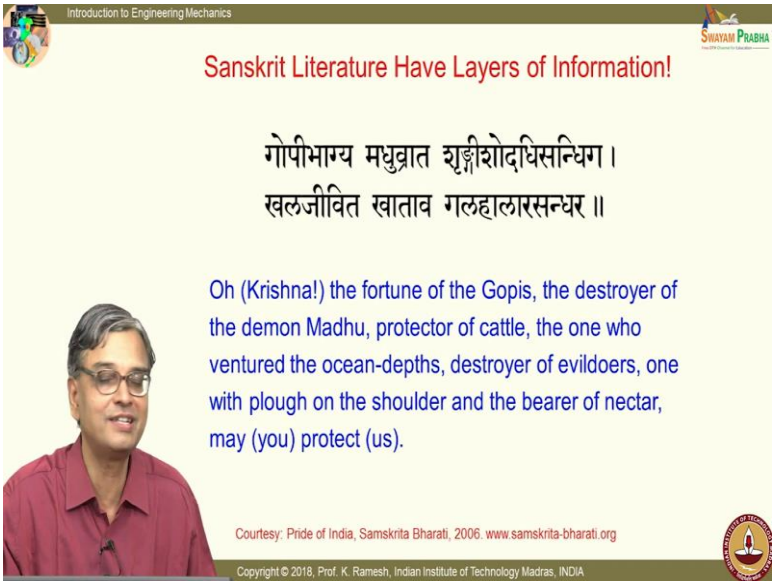

I will read a simple shloka like this "Gopi bhagya madhu vrata…". The shloka goes like this; on the face of it if you read it extols the activities of Krishna. Oh, Krishna the fortune of the Gopis, the destroyer of the demon Madhu, the story goes like this, but what is interesting in Sanskrit literature is it contains layers of information.

See now you are in a different era you have terabyte as your hard disk; you can store any amount of information you want. They had to transmit knowledge from one generation to another generation by wrote memory and they also want to have this knowledge transmitted to right kind of people you have cryptology now. So, they had packed all the information in Sanskrit and they were also made that cryptic. So, only people who have trained can unravel this information. Now I am going to show you a very interesting information this simple shloka says; we will see that.

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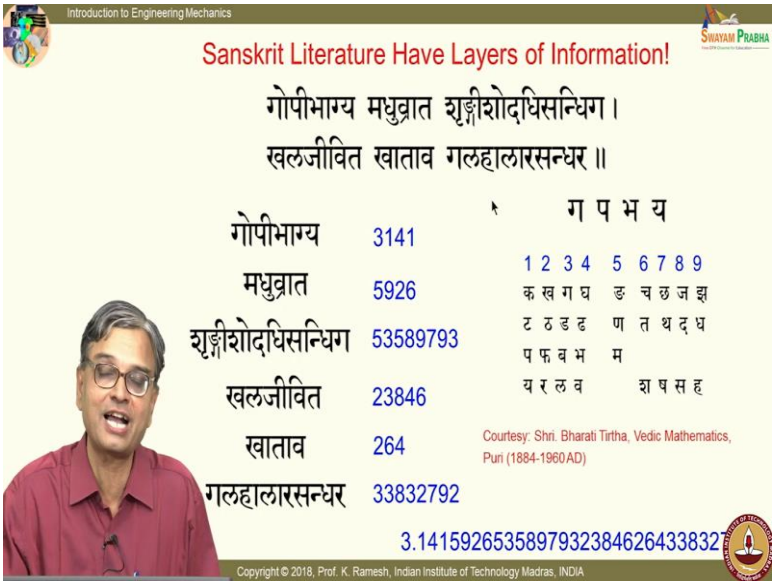
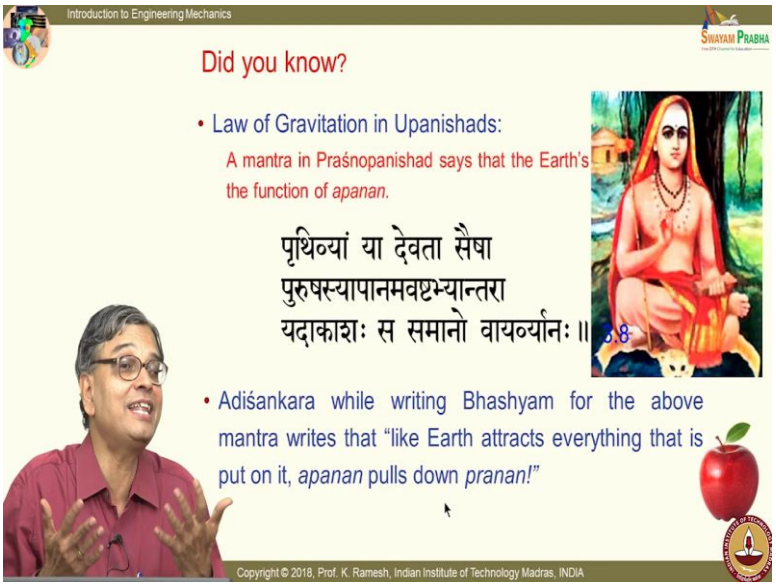


There is something called Katapayathi in Sanskrit literature. When I say Gopi bhagya I can see that as the letters Ga Pa Ba Ya. And these are the numbers given to that and if you look at these numbers, I get 3141. And what is Madhuvrata; in a similar

way you can find out what is Madhuvrata it is 5926. "Shringi shodadhi sandhiga…" that has a very long digit. Can some of you guess where I am going towards too? Ok; that is good.



So, "Khalajeevita.." and you have Ka Tha Va and you are able to get all these numbers and this shloka tells the value of pi accurately to 32 digits. Unless somebody comes and tells us that the shloka has this that goes to the credit of Shri Bharathitheertha of Vedic mathematics. And the story also goes we saw that this extols the activities of Krishna; there is another interpretation it also extols Shiva. So, the Sanskrit literature is so complex unless you have a right interpreter you will miss what it communicates that is the background that you have to keep in mind.

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And now we have said that the gravitation was so difficult to understand ok. Because it is a force acting at a distance; law of gravitation is in Upanishads. How many of you have ever heard of this kind of point of view? A mantra in Prasnopanishad says that the Earth's Devata is activating the function of apanan. And you will have a shloka like this and I said shloka alone is not sufficient; you need a right interpreter to do it.

So, "Prithivyam ya devata…" the shloka goes like this. When Adisankara wanted to explain the meaning he had said while writing Bhashyam for the above mantra Adisankara writes "like Earth attracts everything that is put on it, apanan pulls down pranan!" And this was when? This was again in B.C; Before Christ. We all have to be very proud that our Indian tradition had many of these concepts on mechanics from time immemorial. When I grew nobody told me, when I have learnt over the years, I thought

it is essential for me to communicate, we also had this kind of knowledge much earlier than what the western scientists have got it.

Nevertheless, you have to give them the credit they have put it in a mathematical form which everybody can use it. Unless you have great Sanskrit scholars with background in modern science they can go back and unravel the mysteries of Indian civilization. In fact, many such works are currently underway; people are working on it; people are having a relook at it.

So, in this lecture we had a bird's eye view of what is the history behind strength of materials some tit-bits we have seen. You have to appreciate the human struggle what you learned and take it for granted has not come about in a single day. People have to struggle and people hold on to the views, it is very difficult to change something which is comfortable.

If you ask all the 1000 questions to one person; he will only collapse. These are very mind-boggling questions. So, in the next class we will continue the discussion. We would also see a very surprising information on planetary motion very correctly said as elliptical motion in our literature. Nobody has told us we have to resurrect and then take pride in the civilization that we have grown in. Thank you.