Dynamic Behaviour of Materials
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Lecture No 4
Quasi-Static Vs Dynamic Deformation: Atomic Perspective

Hello everyone, so today, we will be discussing the difference of quasi-static and dynamic deformation from the atomic perspective. So, although we will be explaining our wave propagation problem with continuum approach in the rest of courses, but it is important to understand how the deformation happens in atomic level. So, now we will see both the quasi static and dynamic deformation from the atomic structure perspective.

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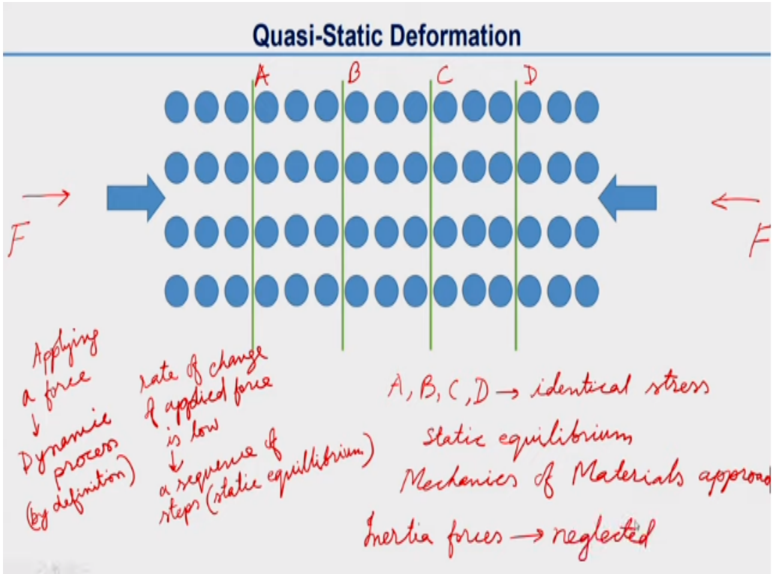

So this is an area of atom, so we can imagine as a long bar so we are having 4 sections. Let us write as, section A, section B, section C, and section D. So, this is a bar, in two-dimension we are seeing. So, we will have 2 forces here, the same forces on the left side and right side that is compressive in nature. So, we need to be careful here. So, although we are showing the deformation of the body with some atomic movement here, this may not represent the exact atomic movements, because we will have crystallographic constraints during this atomic movements.

Applying a force in solid body is a dynamic process by definition. Why? Because the force is being applied and the material will deform continuously. So, that is why it is by definition dynamic process. But if the rate of change of applied, is low, then we can consider the process as a sequence of steps in which the body's in static equilibrium.

We will demonstrate the two processes; both quasi-static and dynamic process with atomic movement now. So, this animation is not perfect, so we will see how the atoms will deform it just to give you an rough idea about the atomic movements. Sorry, this actually, the A, B, C, D is now going away from the section, but anyways, we can write it again.

So, we will see you see this once again. So, you are applying the forces from both the end and now what is happening here is, the inter-atomic distance is reducing, that is reducing uniformly in the entire bar A, B or C and D in all the sections if you can see that the inter-atomic distances are same and all the sections A, B, C, D experiences identical stresses, identical stresses at every stage of deformation.

And this will as we discussed, at every stage of this deformation, can be considered as a static equilibrium we can consider every step as a static equilibrium and we can solve this problem using mechanics of materials approach, which is cannot be possible using for dynamic deformation and also the inertia forces are neglected here in case of quasi-static deformation. So, now, we will see the dynamic deformation case.

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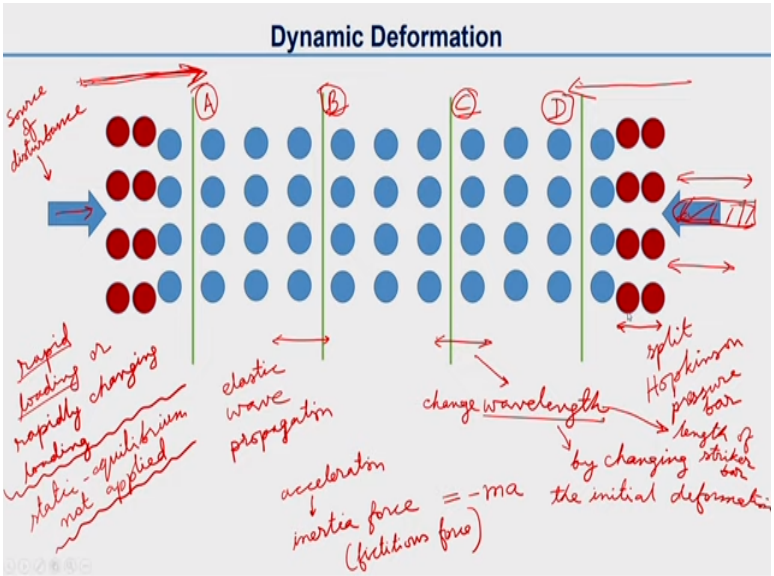

Here we will be taking the same bar in two-dimension and we will give the same kind of loading, that is in comparison from both ends. So, we have, again we are having four sections just to explain the problem and here we have rapid loading or it can be rapidly changing loading. So, if it is rapid loading, the internal stresses are not instantaneously transmitted throughout the body. So, these stresses from these point of disturbances, it does not transfer instantaneously.

So, this is our source of disturbance we can call where the point of application of the force. So, from the source of disturbance, the disturbance should go this way and similarly from the other side, right hand side, the disturbances will come this way and as we know our loading is rapid loading or rapidly changing loading, the disturbances are not instantaneously transferred to the transmitted to the other part of the body and we cannot assume static equilibrium like our quasi-static case, no static equilibrium, so static equilibrium not applied here.

So, in the dynamic case, in the figure, the inter-atomic distances will be reduced when you run the animation. So, the intermediate distances will be reduced and a group of atom, we can see the red atoms will be compressed at first and this disturbances will propagate. So, now, in this case as we were exerting the load from both the sides, we can see the disturbances are moving both from left and right towards the center.

So, now, if you see in any intermediate position, let us say in this position, we have the section A here, section B here, C here and D here. So, in that position, so what will happen is Section A and D will experience the stress, but at the time Section B and C will not experience the stress. But after some time, so, we can see Section B and C we now experience the stress now A and B the stress will be reduced or it may vanish.

So, whatever we are discussing, this propagation of the disturbance is nothing but wave propagation and this is actually elastic wave propagation, the deformation is elastic, later we will get et some other types of wave like plastic waves. So, this is elastic wave propagation and in this case the atoms are experiencing considerable acceleration and these acceleration will give the inertia force which is a fictitious force and that is equal to negative of mass into acceleration that acts in opposite direction.

So, in the quasi-static case, we ignored the exploration and we can neglect the inertia force, but in this case, we cannot ignore the inertia force or inertia effect. Let us know think about this. So, I am running this animation again. So, we were deforming from both left side and right hand side. So, what is happening here is this group of atoms are moving towards each other. So, now, how can you determine that how many rows of vertical rows of atoms that means, here in this case we have only 2 rows.

So, how many rows of atoms will be grouped together and these atoms will move towards the other side of the body. So, that is actually the group of compressed at atoms gives us the wavelength. So, that is related to wavelength of this elastic wave and these wavelength can we changed that can be changed, we can change the wavelength, by changing the initial deformation that means, here in this case that whatever displacement we are giving here.

This is the first step now, and this is the second step. Again, this is the first step when we are just having the force, and then the second step we are having the deformation, and running it again and again. So, that deformation or actually initial the displacement that displacement will decide what will be the wavelength. So, higher the that initial displacement higher will be the wavelength and later in case of Split-Hopkinson pressure bar that Split-Hopkinson pressure bar is an experiment we discussed earlier so, in case of Split-Hopkinson pressure bar, we will see that this wavelength is related to length of the striker bar.

So, basically we will see that, that is probably twice the length of the striker bar wavelength of the elastic wave in a Split-Hopkinson pressure bar experiment is twice the length of the striker bar, striker bar is the projectile suppose in this case, we have a bar like this on the right hand side so this is the bar, which is hitting the material and so, what is the length of the striker bar, that will decide the initial displacement and that will decide the wavelength, wavelength we can write Lambda.

Sorry, this is not exactly the wavelength, the wavelength is not exactly the dimension of the compressed region of atoms, it is more than that, it can be probably twice of that, we talked that compressed region of atoms. So, that is what we discussed about dynamic deformation.

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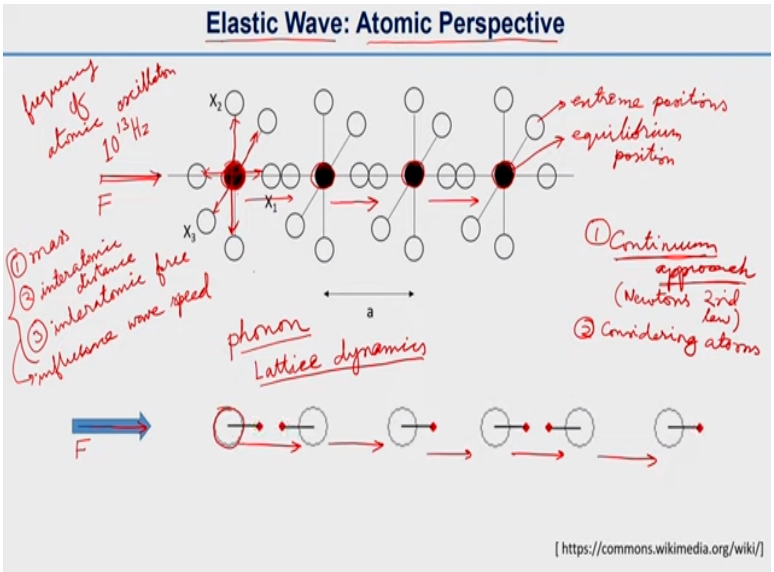

So, we will go to the next part of it, we will discuss about the elastic wave with atomic perspective here. So, what we discussed in the previous slides is, we were assuming a very idealized atomic structure without considering any crystallography constraint. In this case also, whatever we have shown in this slide, so, this is also kind of an idealized linear area of atoms, that may not be the exact case in reality.

But here whatever we are seeing is this solid circles are the equilibrium positions of the storm and we know this atoms actually oscillates, this atoms will oscillate at a very high frequency, very, very high frequency**,** and these oscillations can be broken down into 3 directions, that is what we are doing, x1, x2, and x3. That frequency of atomic oscillation is very high is 10 to the power 13 per second or we can write Hertz.

So, in a second, it will oscillate 10 to the power 13 times s**o,** and we have broken down this into x1, x2, x3 direction and we will now see how we can determine the elastic wave velocity, an approximate determination of elastic wave velocity from these atomic perspective. So, we are giving a force from left side, we do not have a force from right side this time, so, we have a force from this side. So, if we can accelerate the atoms to a certain velocity, the atom, this atom, the first atom on the left side will transfer its momentum to the second atom.

And similarly, the second atom after some time will transfer its momentum to the third album and similarly, it will go on to the subsequent atoms. So, basically the wave speed how these disturbances will propagate throughout this material depend 3 things; the first one is mass, mass of these atoms and second is inter atomic distance and third is inter-atomic force, whatever attractive or repulsive force in between these atoms.

So, these factors influence wave speed. So, these dark circles are, these are equilibrium positions of atoms and these are extreme positions. So, I have got this some animation and I modified it from the from the internet with the medium and then I modified it a little bit to just show you a rough idea to give you a rough idea of the atomic oscillations.

Let us assume that the circle is the original portion of atom and then it is oscillating right to left. So now, these oscillation is not exactly independent of each other, that means one atom oscillation is not independent of the oscillations of other atoms and this collective excitation of the lattice is known as phonon, so the, you know, collective excitation of the entire lattice is called phonon and the field of study is called lattice dynamics, we will not discuss these things, but just for your reference you can probably, if you are interested, you can study about these.

So, now, when we are exerting a force from, let us say, left side, we are giving some disturbances F so what will happen is, the first atom will transfer the disturbances to the second atom and then second atom will transfer to the third atom, so it will go on. There are two approaches by the way to study these elastic wave velocity, the first one is the continuum approach that is what we will be discussing in this course.

So, that means, continuum means, the mass is uniformly distributed and we are not considering any discrete atoms or molecules. So, we can use Newton's second law to derive our wave propagation equation. And the other one is, the second one is considering the atoms. We will not be discussing on this much but we will be mostly we will be focused on continuum approach in rest of our course.

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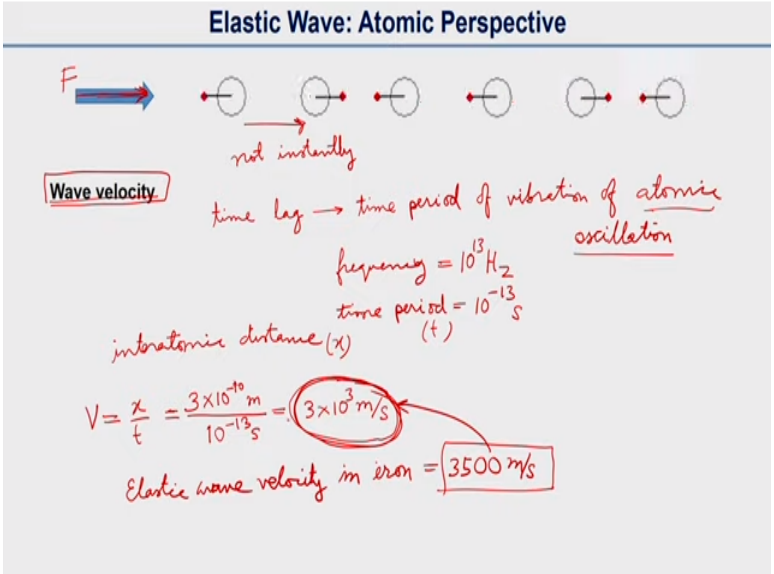

So, basically what we want to show you here is how we can determine an approximate value of wave velocity. So, when the force is applied on the left side, as you can see when force is applied on the left side, the disturbances we not be transmitted to the other atoms instantly. It is not instantly, it will take time, very little time, but still it will need some time.

So, that time difference, what will be the time difference that is equal to the time difference or time lag for transferring the disturbance from the atom one to the atom two is the time period of vibration of atomic oscillation. And we know the time period of vibration, as I told you, the frequency is 10 to the power 13 Hertz, that means, the time period is 10 to the power -13 seconds.

So, then how to calculate the velocity wave velocity, so we need to know the inter-atomic distance. So, inter-atomic distance we need to know as we know that wave velocity V is equal to X, let us say inter-atomic distance is X and then the time period is T, so inter-atomic distance, let us say, for iron is 3 angstrom, is close to 3 angstrom, 10 to the power -10 meter and divided by your time period, that is 10 to the power -13 seconds, and this will give you value 3 to the power, 3000 actually, 3000 meter per second.

So, if you see the elastic wave velocity in iron is, I think, around 3500 meter per second, so which is close to this value. So, our calculations, which is a very simplistic calculation is actually giving us a very close estimation, this estimation is very close to what is found from experiments that wave velocity in iron is 3500 meter per second.

What we did here is, we are discussing just how this disturbances that the force or the internal stresses will transfer from one atom to other atom so that is, it is taking a time of 10 to the power -13 second, which is the time period of atomic oscillation and we know the inter-atomic distance, we are considering iron as our material and that is giving us 3 into 10 to the power 3 meter per second wave velocity.

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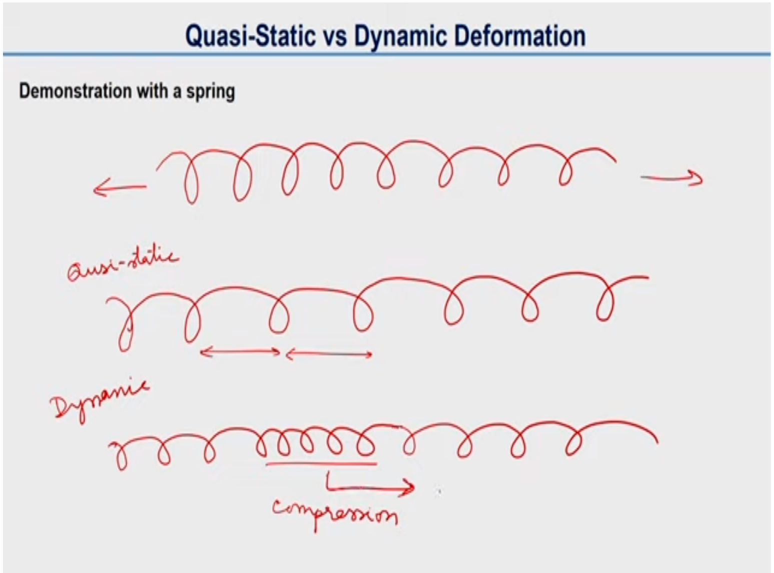

So, we will demonstrate this quasi-static and dynamic deformation with the help of a spring. So, this will be our spring. We will demonstrate that in a while. So, this will be our spring and we will see that if we consider a quasi-static case and if we try to give it a tensile load then what we will see that coils of the spring will have identical extension. But in the dynamic case, we will try to have a genitive wave and that will give us that we will get a wave, which will be, let us say, compression here and compression and rarefaction.

So, that compression, this portion, we propagate. So, this compression part, whatever we saw in the earlier slides with respect to from atomic perspective. So we will see in a while, with spring that compression will propagate and this is actually a longitudinal wave in a spring.

(Video Starts: 29:52) Now, we will see how a quasi-static deformation happens. If we stretch the spring very slowly, if we can see that the distance between these is uniformly elongated and we can say that a static equilibrium exists in the entire spring. So now we will see how the dynamic deformation happens, we can see a wave propagation, longitudinal wave propagation and wave goes and reflects back from the other end **(Video Ends: 30:45)**.

That is all for today, we will continue in next lecture.