Advanced Design of Steel Structures
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Lecture - 56
Ice loads

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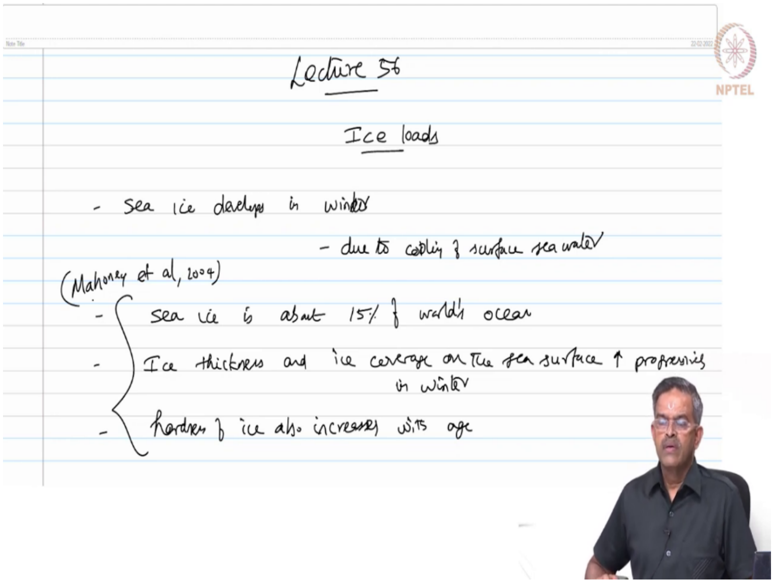

Friends, welcome to the-56th lecture on Advanced Steel Design. In this lecture, we are going to learn more about Ice Loads. Generally, sea surface or sea ice develops in winter this is essentially due to the cooling of surface seawater if you look at a simple statistics sea ice is about 15% of worlds ocean.

There is another fact which is bothering as a designer to us is the ice thickness and ice coverage on the sea surface increases progressively in winter which is basically a fact which all of us know. Further to that hardness of ice also increases with age. these are studies interestingly made by Mahoney et al., 2004 which will be helpful for additional reading for you.

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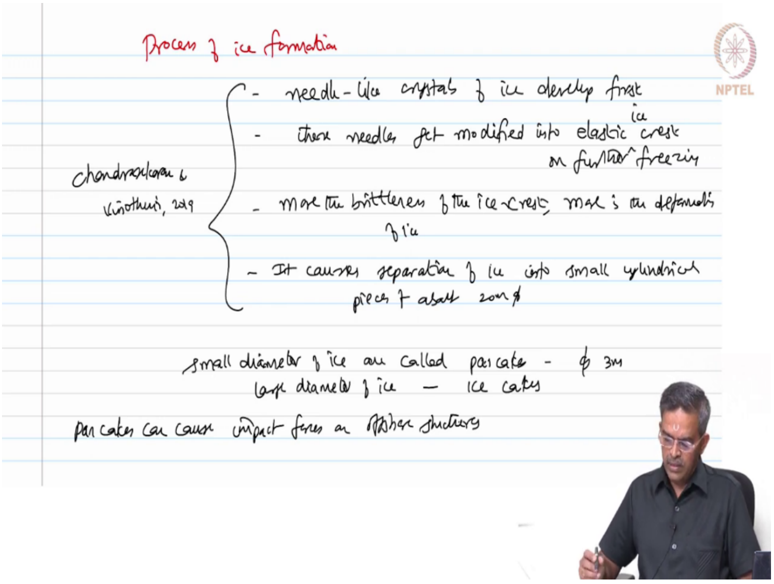

Friends, during ice formation needle-like crystals of ice develop first. Let us look into the process of ice formation needle-like crystals of ice first develop they get modified in elastic ice crest from further freezing. Elastic you can say ice crest on further freezing. Ice deforms more with the brittleness of the ice crest, more the brittleness of the ice crest more is the deformation of ice. It causes separation of ice into small cylindrical pieces of about 20 meter in diameter.

More details of this progress of ice can be seen in one of my publications 2019. Small diameters of ice are called pancakes. They will be of diameter 3 meter. Large diameter of ice is called ice cakes pancakes can cause impact forces on offshore structures.

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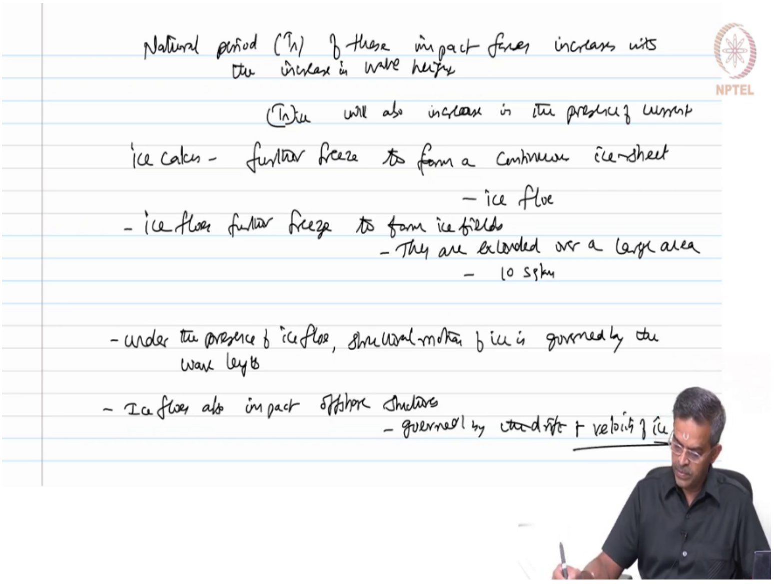

The natural period of these impact forces increases with the increase in wave height period of this will also increase in the presence of current. Now, Ice cakes which of larger diameter, further freezes to form a continuous ice sheet. They are also called as ice floe.

Ice floes further freeze to form ice fields. They are extended over a large area which will be about 10 square kilometres. Under the presence of in ice floe structural motion of ice is governed by the wavelength. Ice floes also impact offshore structures they are governed by the drift of velocity of ice.

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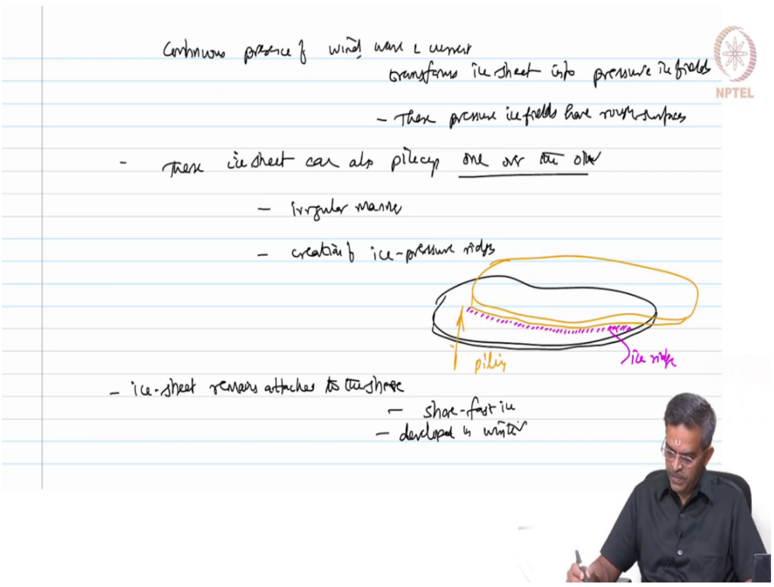

Continuous action of wind wave and current transforms this ice sheet into pressure ice fields. These pressure ice fields have rough surfaces. These ice sheets can also pile up one over the other. You have an ice sheet of certain thickness; there can be another ice sheet of another thickness they can get piled up. This is what we call as piling.

They generally pile one over the other in an irregular manner and that will result in creation of ice pressure ridges. For example, this intersection of this piece with the bottom one is a classical example of ice ridge and so on. Further, friends, ice sheet remains attached to the shore such ice sheets are called shore fast ice. They are usually developed in winter.

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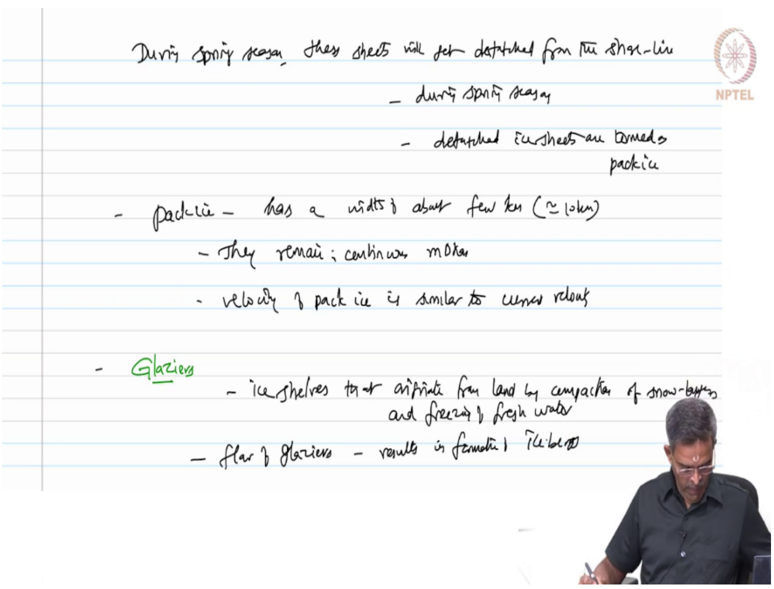

This sheet will get detached from the shore line during spring season from the shore line, this happen generally during spring season. Once they are detached, they are called pack ice. Pack ice usually has a width about 10 kilometres. They remain continuous motion. The velocity of pack ice is similar to the current velocity.

Now, let us talk about water glaziers. Now, glaziers are essentially ice shelves which actually originate from land by this island by compaction of snow leaves and freezing of freshwater. They result in glaziers. Flow of glazier's results in formation of ice bergs.

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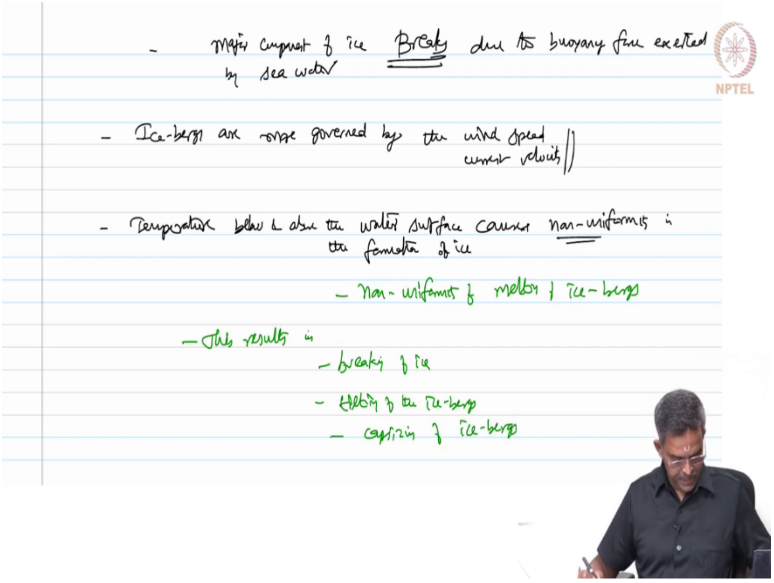

The chunk of ice breaks due to buoyancy of seawater. Further friends, icebergs are more governed by the wind speed current velocity and so. Temperature below and above the water surface causes non-uniformity in the formation of ice where is the non-uniformity occurring? The non-uniformity comes from non-uniformity in the melting of icebergs.

This therefore, results in breaking of ice unless otherwise it is not broken it will remain as a continuous sheet. It also results in tilting of the ice bergs. It can also cause capsizing of ice bergs.

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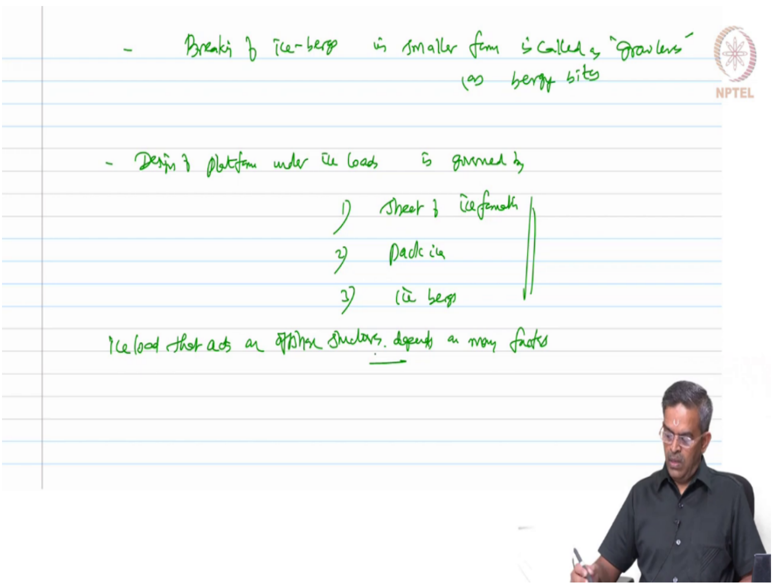

Now, friends breaking of icebergs is in smaller form is called as growlers. They are also others called as bergy bits. Therefore friends, structural design of platforms under ice loads is governed by 1 – sheet of ice; 2 – pack ice and 3 – ice bergs. So, these are the three structural form of ice which can cause worries the design of the platform under ice loads. Ice loads acting on offshore structure depends on many factors.

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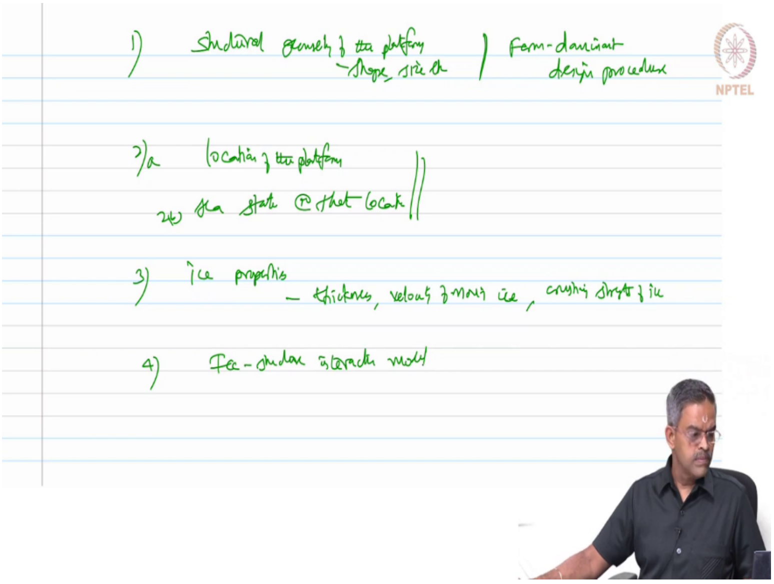

Let us see what are they. The first and foremost factor is the structural geometry of the platform depends upon the shape of the platform, size of the platform etcetera. So, friends this is also reminding us that design of structures and rise load is a form dominant design procedure. 2 – it also depends on location of the platform. It also depends on sea state at that location. So, both are location factors. I will say this is 2 (a), this is 2 (b).

The 3rd factor that governs ice load calculation is the ice properties itself. For example, thickness of ice, velocity with which ice is moving crushing strength of ice and lastly, the ice structure interaction. So, ice load calculation depends on many such factors.

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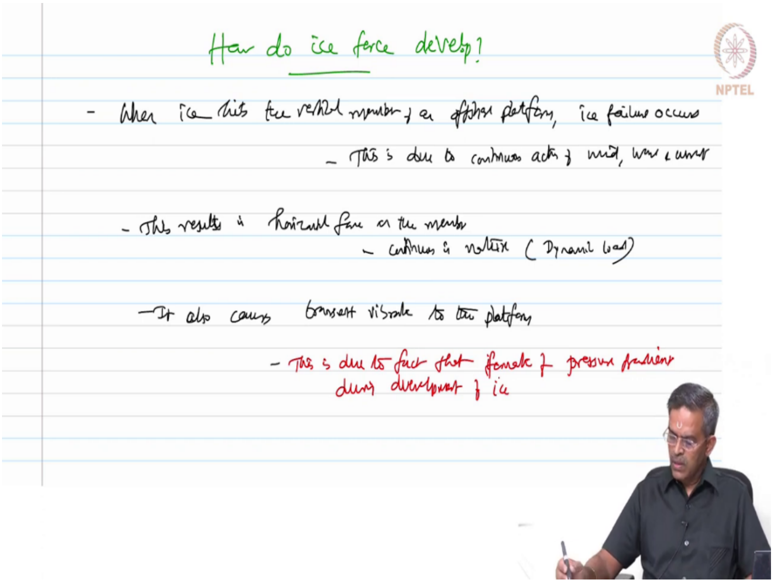

Having said this, let us ask a question. How does ice force develop? What is the analogy behind this development? Friends, please listen when ice hits the vertical member of an offshore platform, ice failure occurs. This failure is attributed to continuous action of wind wave and current.

Now, this results in horizontal force of the member. This is continuous in nature and hence is a dynamic load. Secondly, it also causes transient vibration to the platform. Why this is developed? This is due to the fact that formation of pressure gradient during development of ice.

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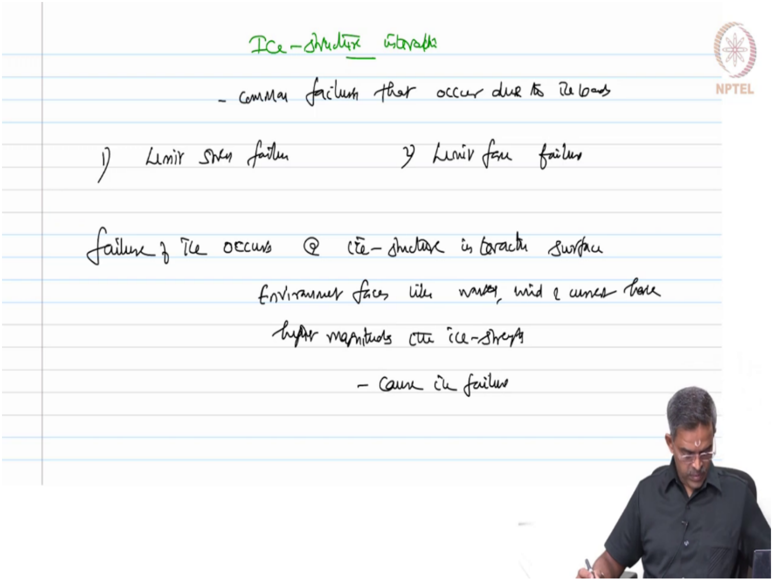

Let us talk something about ice-structure interaction. To understand the ice-structure interaction, let us talk about the common failures that occur due to ice loads. 1 – limit stress failure. 2 – limit force failure. Now, failure of ice occurs and the ice interaction surface.

When the environmental forces act on the ice like wave, wind and current, their magnitude increases and the magnitude very higher than the ice strength and therefore, ice face like waves, wind and current have higher magnitudes then the ice-strength which causes ice failure.

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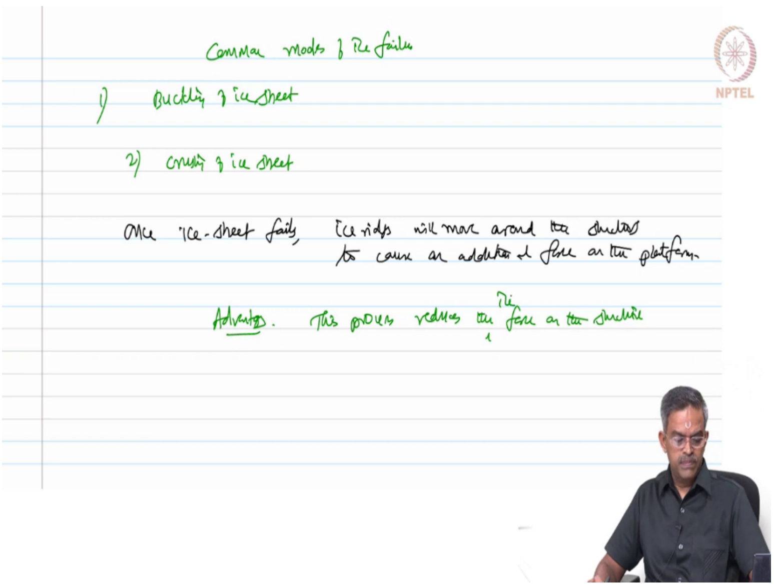

Let us see what are the common modes of ice failure. Ice can fail by buckling of ice sheet. 2 – it can also fail due to crushing of ice sheet. Once the ice sheet fails ice structure interaction surface causes movement of ice ridges around the structure.

Ice ridges will move around the structure to cause an additional impact force on the platform. Interestingly friends, this motion of ice which is relatively important, but to the motion of the structure reduces the force structure. So, the advantage is this process reduces the force on the structure; to be very specific, the ice force on the structure.

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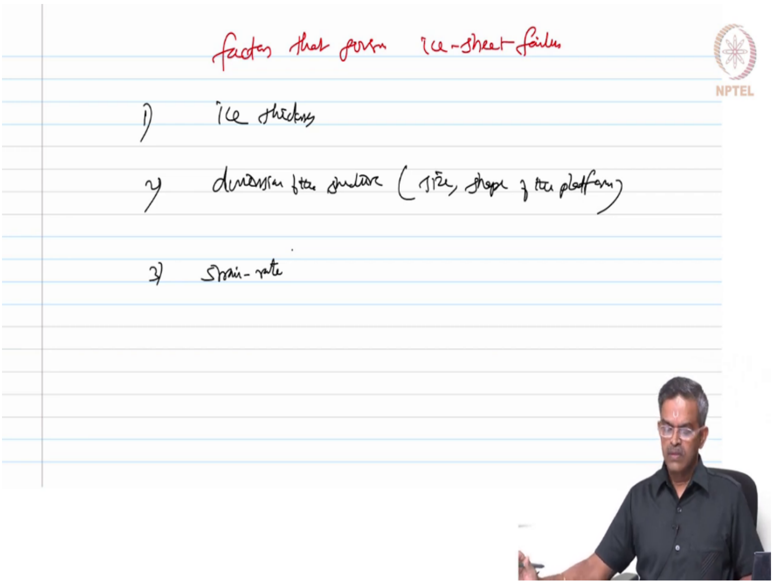

So, let us ask a question what are the factors that govern ice sheet failure. Ice sheet failure depends on ice thickness. It also depends on the dimension of the structure to which ice impact is considered. Dimension moment I say is size; shape of the platform. The third one is a strain rate which is very important.

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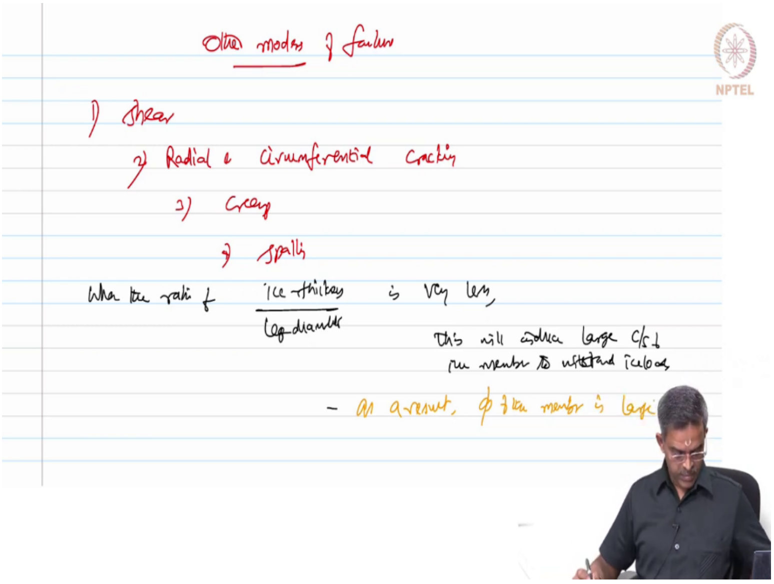

There are other modes of failure; 1 is they failed by shear, 2 radial and circumferential cracking, 3 – it can also be due to creep, 4 – the failure can also be due to spalling. Now, interestingly friends, when the ratio of ice thickness to leg diameter of the structure is very less that is thickness size is very more compared to the leg diameter of the member diameter. If this ratio ice thickness by member diameter is very less and this will induce larger cross-section of the member to withstand ice force.

So, as a result the diameter of the member is very large. Encountering ice force is very large.

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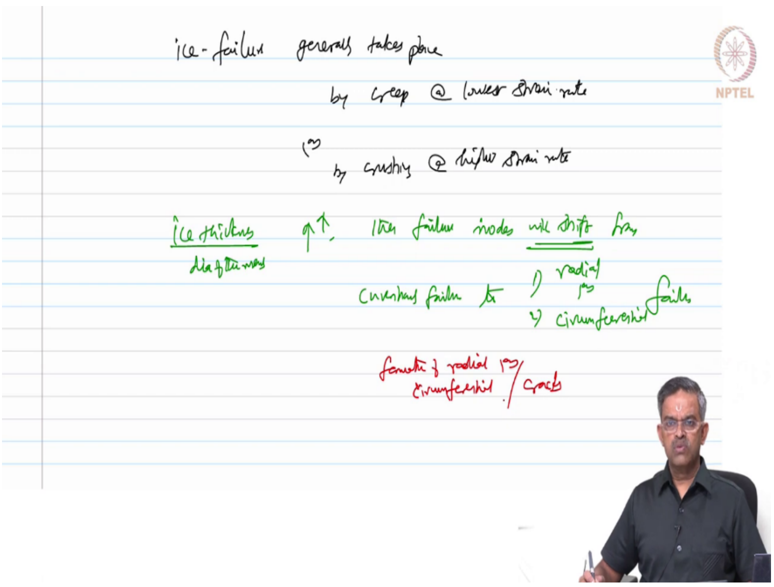

Having said this, ice failure generally takes place by creep at lowest strain rate or by crushing at highest strain rate. So, friends, the ratio of ice thickness to the diameter of the member – if it is increasing then the failure modes will shift from conventional failure to radial or circumferential failure. So, the failure modes will get shifted from the conventional modes of failure to formation of radial or circular cracks.

Having said this, one should use carefully the suitable empirical relationship to estimate ice force on offshore structures.

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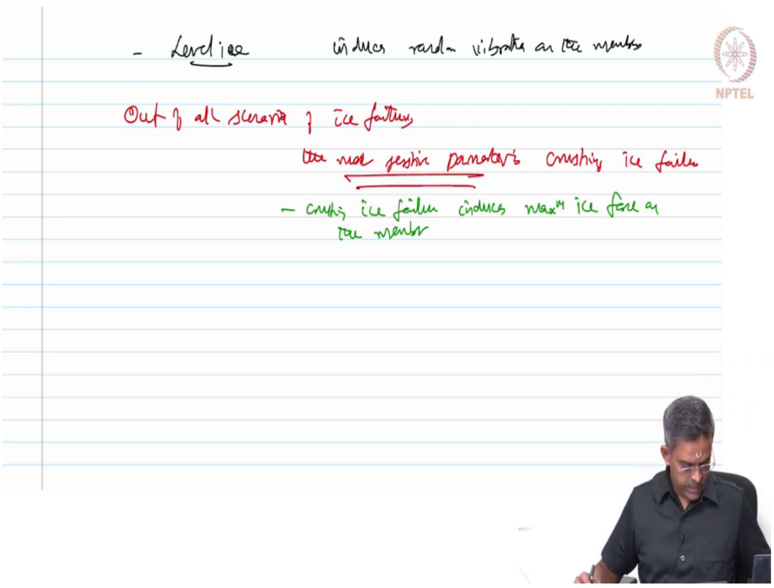

In the literature if you look at the ice loads there is a term called level ice. Level ice actually induces random vibration on the members of the structure. Out of all the scenarios of failure, the most sensitive parameter is crushing ice failure. Crushing ice failure is considered as a worst scenario because crushing ice failure induces maximum ice force on the member.

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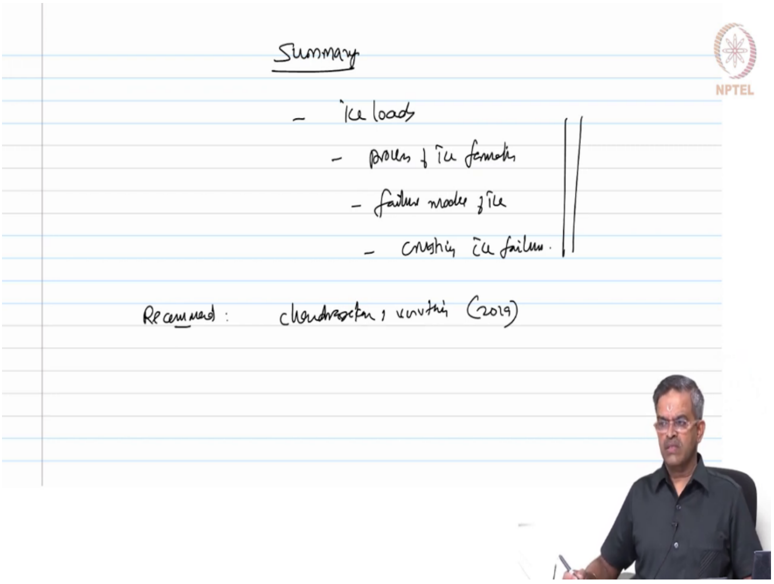

So, friends as a summary, in this lecture we started learning more about ice loads; we learnt also about the process of ice formation; we also learnt about the failure modes of ice; we also learnt about the crushing ice failure which is a very important phenomena of failure because this induces maximum ice force on the member.

Have a thorough reading, I can recommend a textbook and Vinodhini 2019 which is talking about analysis and design of offshore complaint triceratops platforms, where the theory about formation of ice in the process of formation and the factors governing the ice load are clearly illustrated in the textbook.

Thank you very much and have a good day.