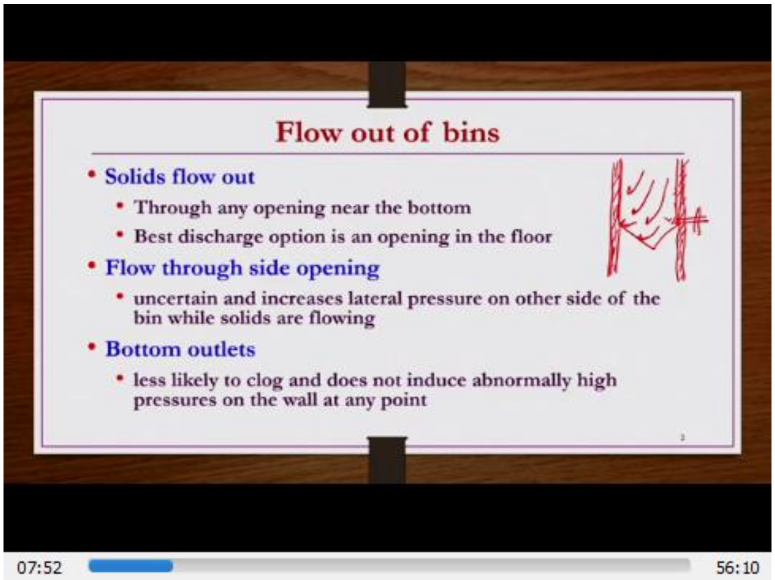
Mechanical Unit Operations
Professor Nanda Kishore
Department of Chemical Engineering
Indian Institute of Technology Guwahati
Lecture 12
Solids Flow Out and their Flow Patterns

Welcome to the MOOCs course Mechanical Unit Operations. The title of this lecture is solids flow out and their flow patterns. So particularly what we are going to discuss in this lecture is, let us say we have a solid storage container vessel from which the solids are flowing out, so what kind of flow patterns may be developed inside the, inside those storage vessels, etc. And then how the stresses or pressure distribution varies from location to location those kind of details we are going to see in this particular lecture.

(Refer Slide Time: 1:03)



So let us say, if you wanted to have a flow out of bins for the solids, if you wanted to have the solids flow out of bins. So, what kind of options in general you think of? You think of having solids flow out through an opening near the bottom usually preferably and then best discharge option is an opening in the floor like we know to have the kind of storage vessel really like silo or hopper or something like this.

So let us say you have a silo like this and this one, you will you have a kind of this solids which you wanted to take out as per your requirement. So there is a opening, there may be a kind of valve here. When you open this one, so then how the flow pattern will change that is what you see.

So actually in general, this is a kind of this hoppers are, a kind of symmetric, or axisymmetric or non-symmetric plane geometries they may have or we have already seen we are going to see those geometries once again in this lecture. So these are in general supported with a kind of supporting thing and then supporting stands like pillars kind of a things are available. So these pillars are deep rooted on to the in to the earth.

So whatever the material that you want you take here in a kind of a container and then you whatever the material that you get here, you may take it into the tractors or elevators something so that you can take to the next unit operations wherever they are required. So the floor is in general mentioned by these kind of slanted or inclined surfaces or hopper surfaces that we are having. So you can have a kind of opening anywhere from the sides also from the bottom.

Anywhere from this area, you can have a kind of solids, but it is always best to have a kind of a opening in the floor something like that this so that you can have a kind of best discharge possible. So this is a symmetrical hopper we have drawn here. If you have a kind of a non-symmetric plane hopper something like that, so then it not necessarily be at the bottom, it may be somewhere else and then those things one has to see as per the kind of a, of this requirements.

Flow through side opening is also possible but it is always gives a kind of a uncertain flow rate. You may not have a kind of certain certainty in the mass flow rate of the solids that you wanted to get and then that may always increase the lateral pressure on the other side of the bin while solids are flowing actually. Once again we draw the same thing here. So whatever the bins are there so most of the pressure, the load is bin taken by the floor. Some like pillars kind of things in general.

So what happens when you have a kind of opening not at the bottom, but somewhere in the side? Something like this? That can also possible depending on the type of the solids that you are handling. So this is also possible but what happens. When you do this one, some of the stress, goes on to the valves of this container. On this container valves, the stress will be increasing. So that is not going to be helpful in general because these are the kind of things are designed once in a while.

You do not change every often as per the change of the operating conditions, etc. You cannot change as and, as and when you required or you feel like. They are designed once in a while for a kind of, or at the beginning of the designing of the chemical plants. So you will be having difficulty in changing these orientations, etc, very often. So it is better to decide at the beginning of the design itself.

So let us say when you are filling this is again, we are going to discuss again in the stress distributions. So when you are filling the solids kind of vertical stress distributions are possible in this section and slightly vertical inclined kind of the pressure distribution is possible inside the bins.

But when you are opening from the sides like this, what happens, kind of a kind of, lateral contraction of the solids may take place and then distributions may be something like this, something like this. So that distribution may not be helpful especially with respect to the valves of the container. So that is an another side of the bin, definitely it is going to have a more pressure.

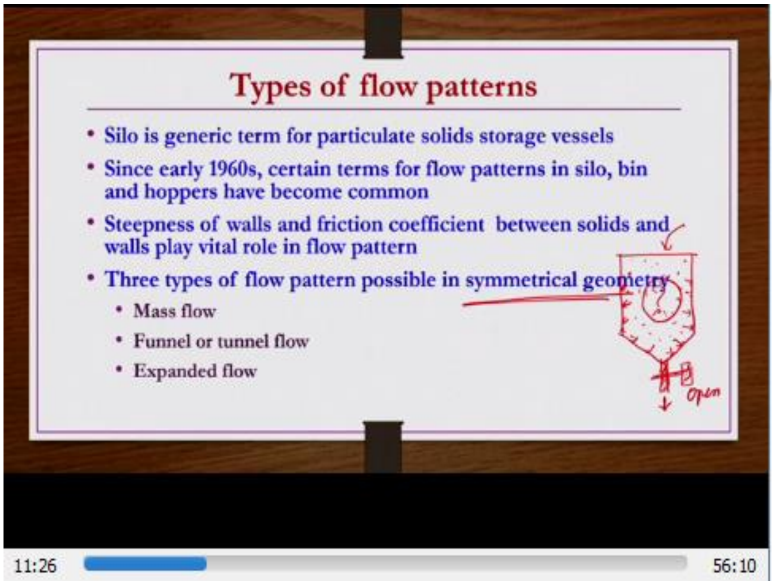
So that is not going to be useful anyway. So that is the reason; though it is possible to have a kind of openings in the sides, but it is not preferable because of these two reasons. One is the you will not be certain about the flow rates and another one is that the lateral pressure may be increasing on the other side of the bin while the material is flowing out. So these details of this pressure distribution change stress distribution, etc, we are going to see very soon now. But however, this is one of the reason that you do not prefer to have a kind of side opening.

Bottom outlets are going to be better options because of the reasons that they are less likely to clog and does not induce abnormally high pressure on the valve at any point. So here like if you have side opening so then the pressure may be low here at this on this particular valve, but on the other valves the pressure may be very high. So because of that one so a kind of abnormality of the pressure you can see from one point to other point.

But if you have a kind of bottom outlet, so such kind of abnormality of the pressure you may not expect, you may not be having. Even if you are having, it may be having only for very specified reason that will also be discussed anyway, when we discuss about the stress distributions. So because of these two reasons, it is better to have bottom outlets because they are less likely to clog and then there will not be any abnormally high pressure at any locations on the valves of the bins at any point.

So now let us say when you have a kind of particular flow out of bins; the solids flow out of bins and then having the outlet at the bottom what kind of flow patterns you may expect. That is what we are going to see.

(Refer Slide Time: 08:03)



So depending on the steepness of the hopper and then depending on the friction between the solids and then wall of the bins, different types of flow patterns are possible. So those flow patterns we are going to see.

However before going to the flow patterns in general, the silo is a generic term for particular solid storage vessels. So ever since 1960s there have been, since early 1960's, there have been several terms for a flow patterns in silo, bin and hoppers have become very common. So we are going to see some of them now. So as I mentioned steepness of walls and then friction coefficient between solids and then the wall of the container or the bins is going to have a kind of a very important role in the type of flow pattern that is going to be developed while the solids are being, flowing out.

So when you have this hoppers, initially maybe they are compact packed properly. Let us say when you open this valve. Let us not call it valve probably. Valve is specifically for the kind of, in general used for the liquids. So you have a kind of feeder. Whatever this opening through which the material goes out, that is known as the feeder with respect to the this storage and conveying of the solids. Feeder is not something that is coming in here from the top that, that we do not call a kind of feeder.

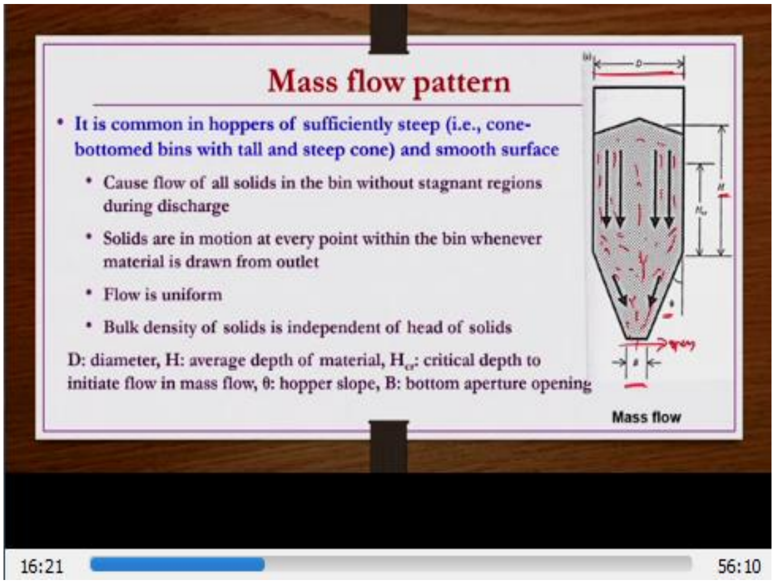
So the gate at the bottom that is opening whatever we have at the bottom that we call it as a kind of feeder. So initially the pressure maybe laterally I mean, pressure may be vertically aligned in a direction. The solids are contracting in a vertical direction. So when you open the channel at the bottom the flow may be taking place. So because of that one the because of that one the pressure variations, etc will be there.

So and then when the flow is going on depending on the solids as well as the friction between the solids and then these walls. Whatever the solids that you have, so that solids and then the interaction, the friction between the solids and then container wall whatever is there, so that one is one of the important factor along with the steepness of the walls. So how steep are the walls. So that is also going to have a kind of role.

What kind of pattern that is going to be developed inside this storage vessel. So those different possible, possibilities of flow patterns we are going to see now. So in general three types of flow patterns are possible in symmetrical geometry. We are discussing it in general to symmetrical geometry. When you have the non-symmetric plane geometries, the same things may be different because of the locations of the outlet, etc and the non-symmetrical nature.

So we are not discussing; so in general we are discussing here in this particular lecture about the symmetrical geometry. So in symmetrical geometry three types of flow patterns are possible. One is the mass flow. Another one is the funnel or tunnel flow. And the third one is the expanded flow. Now, we are going to see details of each and every type of this flow patterns. Let us start with the mass flow patterns

(Refer Slide Time: 11:32)



Mass flow pattern, it is common in hopper of sufficiently steep that is cone bottom bins with tall and steep cone and smooth surfaces wherever we have a kind of a the steep cone like this. Conical section, not only this one but this section also, not only cylindrical but the conical section is also steep one. Then what happens we have a kind of a mass flow pattern may be possible in general. So, this is the opening and then in addition to that one the surfaces of this wall surfaces a wall surface should be smooth.

Should be smooth in the sense that - that should not be offering more friction to the solids. If the friction is more, so then whatever the layers are the particles are there close to the solid walls, they are very difficult to flow and they may not be flowing comfortably. So that is the reason it is beneficial to have a smooth surface. So if you have a hopper sufficiently steep, that is, cone bottom bins with tall and steep cone and smooth surfaces. You may expect to have a kind of mass flow pattern for a free flowing material in general.

So the schematic of such kind of geometry is shown here - mass flow pattern mass flow bins are shown here. So this is what we have here. The diameter of this silo is the height of the material; the head of the solids is H. H_{CR} is the critical height, critical depth up to which, the which is sufficient which is necessary to start the kind of a mass flow. So theta is the cone angle that we are having B is the size of the opening that we have the bottom. So in this kind of, mass flow bins we have a mass flow pattern what happens here.

Moment you open the opening here open it, so then what you have you expected to have the material, all the material smoothly coming out without any kind of problem. As a kind of any kind of restrictions is not going to occur and then there will not be any kind of obstruction in the flow and then flow the kind of smooth you can have. You can have a kind of smooth flow without any kind of stagnation; stagnation in the sense, sometimes what happens, some material may be sticking to some wall and then a kind of bridging kind of things may also take place.

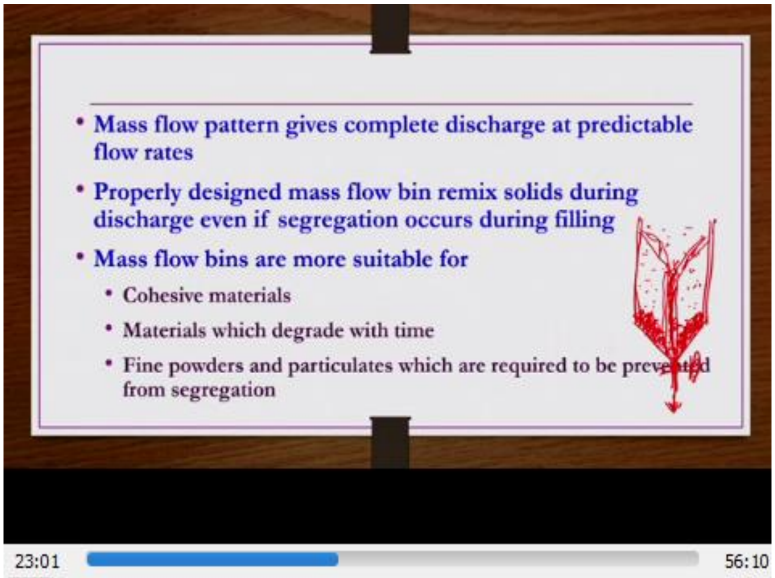
Those kind of problems are there so in some other geometries but when you have the mass flow pattern those kind of things are not going to occur. So that is because the flow of all solids in the bin without stagnant regions during the discharge. When you start opening the flow would be initiated each moment the very first layer at the bottom comes out a kind of disturbance created and then that will be transferring to the entire area, the solids occupied area.

And then the entire material will be under a kind of certain kind of flow condition. Solids are in motion at every point within the bin whenever the material is drawn from outlet. So that is what such a kind of free flow kind of, I know flow pattern is possible during this kind of mass flow. Flow is further uniform. You can expect a kind of uniform flow rate you may not expect to have a kind of varying flow rate, those kinds of things in general what you happen.

You if you do not have the for complete mass flow rate, then you may not have a kind of a uniform flow rate at different intervals. Whereas in the mass flow pattern bins, if the in these kind of bins if the mass flow pattern is developed then flow would be uniform, irrespective of the time, except the initial time that is required to develop the steady state. Mostly the flow would be a kind of a uniform nature and then in general the bulk density of solids is dependent on the head of the solids in general.

But if you have a kind of a, mass flow pattern in the bins then it is possible that the bulk density may be independent of the head of the solids. Head of the solids is like any kind of whatever the H that is the head of the solids. So if you have a mass flow pattern the bulk density might not be depending on this H. So in this picture, D is the diameter of the silo, H is the average depth of the material, H_{CR} is critical depth to initiate flow in mass flow pattern. Theta is the hopper angle whatever the hopper slope and then beta and B is bottom aperture opening. So other details of the mass flow patterns if you see.

(Refer Slide Time: 16:30)



Mass flow pattern gives complete discharge at predictable flow rates. You are not going to have any kind of a stagnation in general if you have a mass flow pattern. So there is not going, no material is going to be retained in the container. So if you have sometimes, very cohesive materials and then flow is not mass flow and flow is not the free flow kind of thing.

Then it is possible that when even in the valve is fully open there may be some material sticking to the wall or some material may be at the stagnant region, etc. So but if you have the mass flow pattern it is possible to have that the entire material, the complete discharge is possible entire material can be taken out comfortably. Because once you start the material drawing out what happens, a motion would be developed in the entire solid material that is retained inside the silo. So the motion is there everywhere in the in the container.

So that will ensure the material to flow out completely, without staying inside the container inside the, this thing. Properly designed mass flow bin remix solids during discharge even if segregation occurs during the filling. Sometimes when you fill this containers are is in their having two parts you have to fill and then store something; you may not be taking them drawing them immediately. You may be storing for some day, sometime, some week something like that depending on the nature of the material and nature of the operation that is being to carried out subsequently, and then nature of the solids that have been stored.

So the duration may be a few days to a few weeks few months also, it is possible. So sometimes while filling a kind of, segregation may take place. But if these mass flow bins are properly if they are properly designed a kind of remix of solids will take place this during the discharge. So that will ensure there will not be any kind of material retained inside the container when they, when you are aiming to have a kind of complete discharge. That is you can get the complete discharge.

Mass flow bins are more suitable in general for cohesive materials because cohesive material in general very difficult to flow. If you have a hoppers or mass flow bins are such a design such a way that that can ensure you a kind of a mass flow pattern. So then it is always better to use such kind of material - cohesive material such kind of bin should be used for cohesive material because cohesive materials what happen they coagulate amongst themselves and then form a kind of bigger lumps or something like that.

So then it is always better to have a mass flow bins for such kind of materials. Otherwise, what happens in general? Let us say, we have a kind of bins like this. Even if you have a bottom opening something like this in the bottom. So if your material is a kind of a cohesive material if your material is a kind of cohesive material sometimes what happens, when you open the gate or the when you operate the feeder to take the material outside. Then what happens whatever the material in this region is there that may be drawn out.

But beyond this one they may be forming a kind of bridge kind of thing - something like this; bridge kind of thing they form. So that is the material whatever the material here in this bottom portion is there though that has been taken away, has been gone out of the container. So the because of the sticky nature of the material the kind of bridging of the material will take place and then those bridges bridging is so strong that they can uplift the weight of the material that is resting on those bridges.

So that is that is kind of a big problem in this cohesive material. So if you have a kind of bins where mass flow can be ensured, so then such kind of cohesive sticky material may be taken inside those bins, so that we can avoid this kind of bridging effect and then one can have a kind of a unrestricted, undisturbed flow of the solids to the subsequent operations.

They are also good for materials which degrade with time. We are going to see in the other kind of, materials flow patterns what happens sometimes some flow patterns, these materials though you have a material completely like; initially when you not drawing it is filled like this, but when you are started drawing out the material – do lid sort of it, what happens, a kind of a these kind of rat holes are formed.

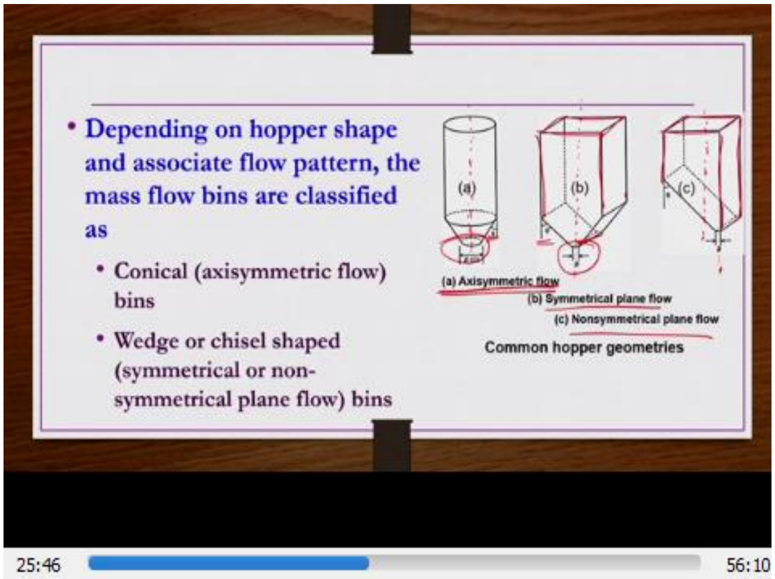
Actually what happens, the material just above the opening, whatever is there, that passes out and then it is, it forms a kind of a vertical column like this, all the material is comes out through columns like this. So that is the top layer material comes out and goes through this column only. Whereas the material bottom that which has reached first while filling that goes very last.

So this kind of problems are there. So this so such kind of, so that is in a kind of stagnation kind of things occurs in here like. So this material the material here at the center through column that is flowing; but the material which at the surfaces they stagnate they are stagnant so they are not going to leave in general, though the material above may be passing out.

So if the material is degrading and then this flow if you are doing for a kind of week or something like that or after a week you are doing; so that material whatever the stagnant region. Whatever the material captured in the stagnant region is there, so that may be degrading. You do not want degrading of the material. If some portion of the material is degrading it is always going to be affecting the subsequent operations or it is going to degrade the remaining solid materials as well.

So that is the reason you if you have a kind of material which may degrade with respect to time if you store for a longer time, so if that is going to be degrade under such conditions. It is always better to have a kind of a mass flow bins so that the material can easily, conveniently come out of the bins. Then fine powders and particulates which are required to be prevented from segregation. If you do not wish for your operation is such a way that you do not prefer to have a kind of segregation of the material, so then it is also preferred to have a kind of mass flow bins.

(Refer Slide Time: 23:09)



So depending on the hopper shape and associated flow pattern, the mass flow bins are classified as a conical bins and wedge or chisel shaped bins. These conical bins are also known as the axisymmetric flow or the axisymmetric hoppers that we have already seen here. So where we have a kind of a cylindrical section and then conical hopper is there. Cylindrical steep bin is that to which kind of conical bottom section is there.

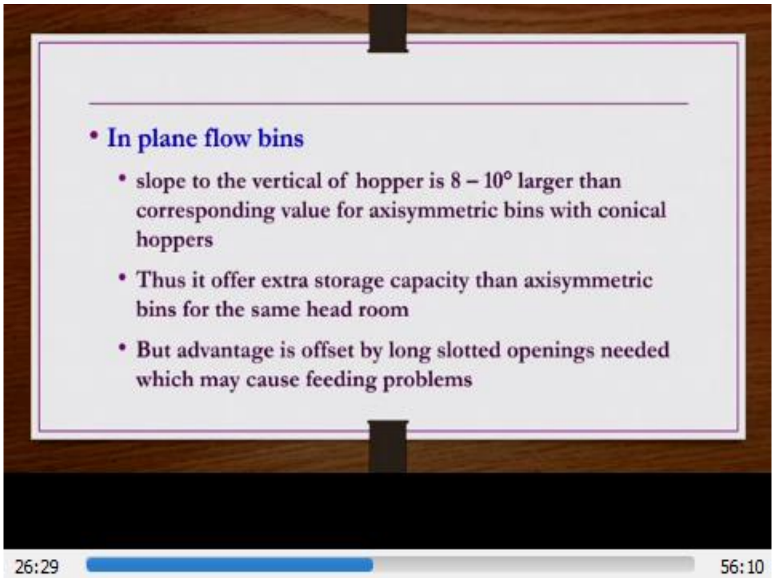
So such kind of things are known as the axisymmetric flow. Where the center axis of opening as well as the container are aligning to the same vertical line like this. So the plane flows are you may not be having a kind of a cylindrical column, but you may be having a column like this sections are shown here like this. So that way, you can make sure here also, the center of the opening and then center line of the these top section are again aligning into the same vertical line.

So then that is a reason they are known as the symmetrical plane flow, but you may have a kind of other designs. So like, not a regular shape something like this as shown here in the picture C. So where, you are not expected to have the center line of the opening and centre line of the this container aligning to the same line. They are not aligning to the same line. They are different.

So that is the reason they are non-symmetrical plane flows. Further from the pictures also we can understand that, this theta here this theta here, that is the hopper, or the cone angle that we have in general. So now the pictorially also we can see that the theta in the B, B section or the B figure the symmetrical plane flow, is slightly higher than the theta in axisymmetric flow.

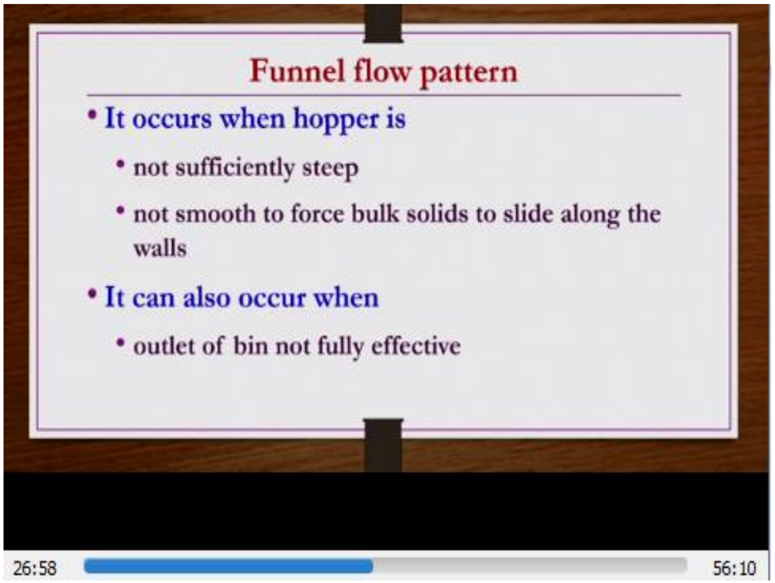
So this additional theta what it does, it provides additional storage capacity for the material but however in this kind of plane flow geometry, you can have you need to have a kind of long slanted kind of feeders like shown here, which is not required here in the case of axisymmetric flow. So this is going to be kind of a disadvantage. So whatever the advantage of having the additional storage capacity because of this, higher theta value in the case of a symmetric plane flow, that is going to be offset because of the slanted long feeder design. So this we have already seen.

(Refer Slide Time: 26:03)



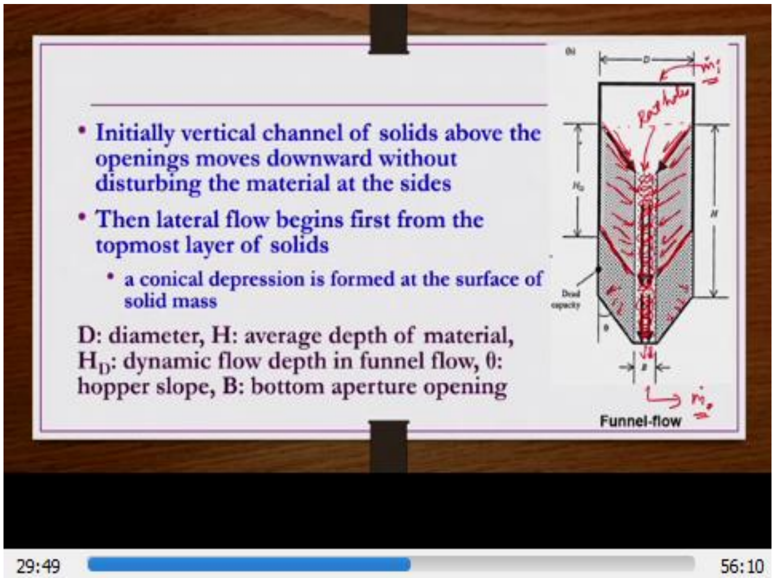
But however, we once again seeing them. As I mentioned in plane flow bins, slope to the vertical of hopper is 8 to 10 degrees larger than the corresponding value for axisymmetric bins with conical hoppers. So it offer extra storage capacity than axisymmetric bins for the same head room. But this advantage is offset by long slotted openings needed which may cause feeding problems in plane symmetric flow bins.

(Refer Slide Time: 26:39)



Then next one is the funnel flow pattern. It occurs when the hopper is not sufficiently steep or the surface the wall surface of this container is not smooth to force bulk solids to slide along the walls. It can also occur in other conditions where the outlet of bin is not fully effective, maybe because of poor design of the feeder or outlet. So it maybe not effectively fully effective then also the outlet is not fully effective than also it is possible that you may have the funnel flow pattern.

(Refer Slide Time: 27:15)



So what is funnel flow pattern? So initially vertical channel of solids above the openings moves downward without disturbing the material at the sides. So like shown here. Now what happens at the opening; whatever the material that material just above the opening or the just above the feeder, whatever that material is there that falls out as a kind of , vertical column vertical channel like this.

Almost vertical it may not be exactly vertical but almost vertical like this without disturbing this material, whatever the material here in this region. So it is not being disturbed only thing that the it is whatever the material just above the opening that is coming out as a kind of a vertical column as shown here like this. Then the lateral flow begins from the topmost layer of the solid.

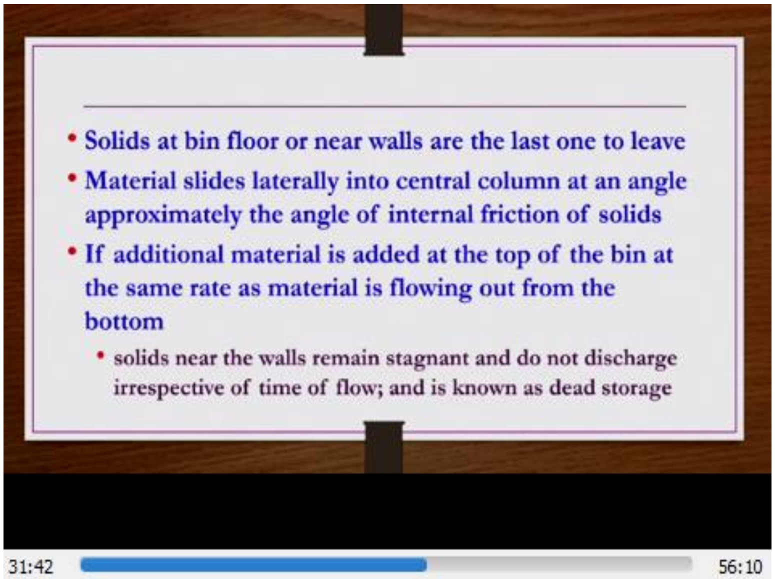
So then what happens after having a kind of a vertical channel it is also known as the rat holes in general. So once this is forming, so then what happens the lateral motions, the particles are initially know they are like horizontal surface like this, then lateral motion start from the top most layer of the solids like this and then those materials flow out through this rat holes only - through this vertical channel whatever is there.

So like this they flow out, they flow out and then and the material goes out like this. So there will be a kind of a conical depression at the surface of solid mass and then here again the D is diameter, H is the average depth of the material, H_D is the dynamic flow depth in funnel flow, theta is the hopper angle, beta is the aperture opening. So here in this process what happens let us say this material has been withdrawn now it is shown as a kind of two sections. Let us say this one section up to this section.

The material is the withdrawing or you might how established a kind of steady flow rate, let us say. Then if you are continuously adding material at the same rate at which you are collecting the materials out. That is, let us say, m_o and then let us say m_i, so after establishing the steady flow rate, you are allowing this additional material you are pouring that is $\dot{m}_i$ is equal to approximately equal to the $\dot{m}_o$. So then what happens so the flow pattern will be like this this material, whatever this material stagnant at the slanted walls here in this close to the opening here in the side walls close to the opening.

So this material will not be disturbed. Whereas the additional material will continuously flowing out like these things. So whatever this material that is not being disturbing, or that is staying there as a kind of stagnant layer that is known as the kind of dead capacity. That is the known as a kind of dead capacity or that is the material that is going to flow out last, at the last. So though this material has reached, entered the container at the beginning but it is going in the last.

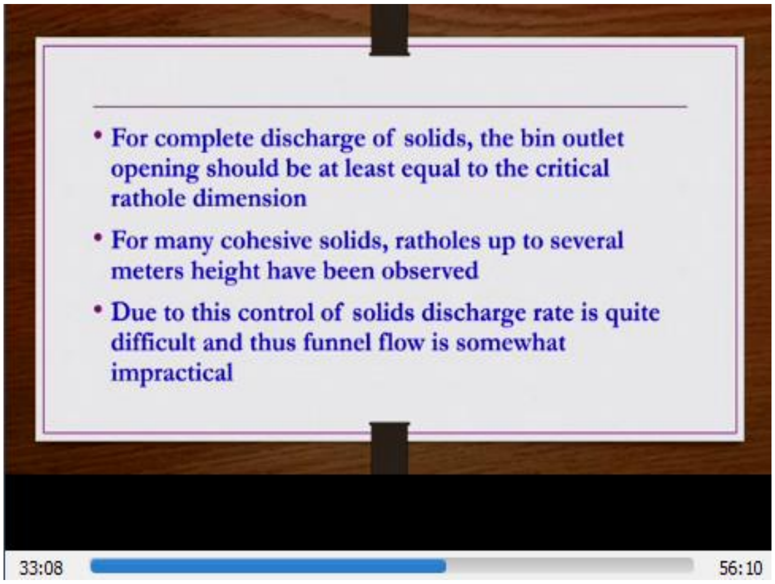
(Refer Slide Time: 30:52)



After all the material has been drawn from the top then only this material may be going out. So this is what known as the funnel flow. So then solids at bin floor or near walls are the last one to leave. So material slides laterally into center column at an angle approximately the angle of internal friction of solids. So this slanting whatever the materials they are falling down like this. They are coming out coming down like this.

They are slant coming down at a kind of certain angle. This angle is approximately equal to the internal friction angle of the solids or angle of internal friction of solids. As is mentioned if additional material is added at the top of the bin at the same rate as material is flowing out from the bottom, then solids near the walls at the bottom remains stagnant and do not discharge irrespective of the time of flow. Whatever the time of flow you allow that material is not going to flow and then that is known as the dead capacity or dead storage.

(Refer Slide Time: 31:50)

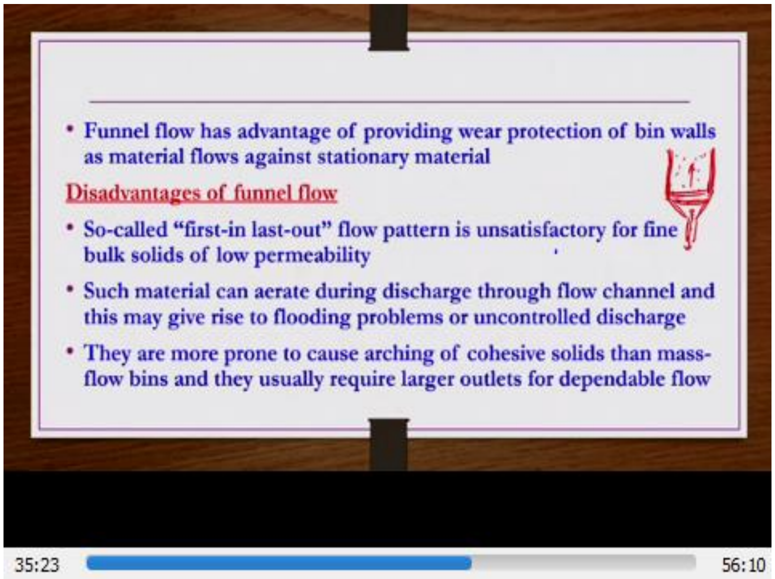


So for complete discharge of solids, the bin outlet opening should be at least equal to critical rathole dimensions. So whatever the vertical channel there is a vertical channel the material is going down, going out. So that channel is known as a kind of a rathole and then it is having certain dimensions and then you will be surprised to know that rathole dimension may be several meters in general. It not necessarily be very small.

It may be a several meters. So then what is the opening requirements, so the opening should be at least equal to or more than the dimension of the rathole or the vertical channel column diameter, whatever that that that much. I know you that that bigger opening you should have so that you can have a complete discharger of solids from this, funnel flow bins.

For many cohesive solids, ratholes up to several meters height have been observed experimentally and because of this, rathole formation and then the material flowing getting into the bins first, but going in the last because of this one, or the because of the dead storage and rathole formation the control of solids discharge rate is quite difficult. And because of this reason funnel flow is found to be somewhat impractical.

(Refer Slide Time: 33:23)

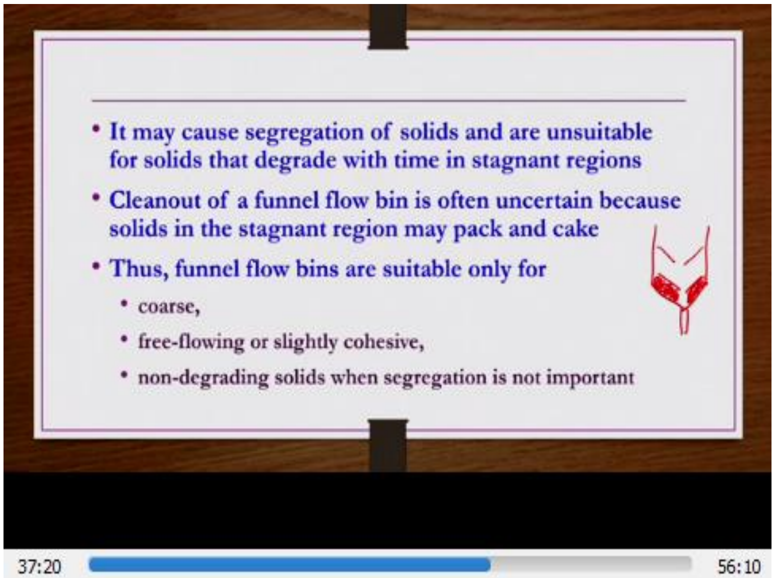


However, the funnel flow has advantage of providing wear protection of bin walls as material flows against stationary material. So because of that one, it provides a kind of wear protection of the bin walls. Though it is the only advantage of the funnel flow, there are several disadvantages. Something like the so-called first in last out flow pattern. That is the material which enters first is leaving last after the rest all the material, top material is flowing out then only it is living so that is what first in last out flow pattern is unsatisfactory especially for fine bulk solids of low permeability.

Such materials can aerate during the discharge through flow channel and this may give rise to flooding problems or uncontrolled discharge. That is the other problem associated with this funnel flow bins. Then they are more prone to cause arching of cohesive solids then then the mass flow bins and they usually require larger outlets for dependable flow as I mentioned. So these kind of material if you have the funnel flow kind of bins or the bin is designed such a way that a kind of funnel flow is developing. For this funnel flow, the flow itself is not the kind of reliable or good one.

In addition to that one if you have taken a kind of cohesive material, then what happens , it is possible that it may be forming a kind of bridging or arching kind of thing may be forming, where below the arching layer of the solids, the solids are passing out. Whereas the material above it, that is lifted by the that is hold by this bridges of the cohesive materials. And then that is those bridges are not allowing the solids to pass through.

(Refer Time Slide: 35:34)



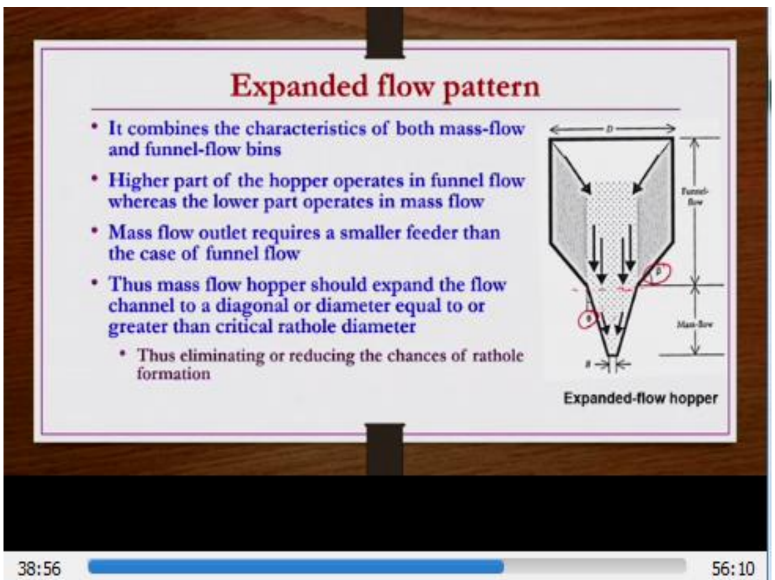
So that is the another problem of this funnel flow, especially if you take cohesive material in this kind of funnel flow bins. It may cause segregation of solids and are unsuitable for solids that degrade with time in stagnant regions. So it is clear that the along the hopper walls, whatever the material is there at the at the solid wall that is going last. So that is going to stay longer time in the bin. So because of that one if the material is a kind of, degrading material with respect to time, this not going to be helpful.

Another disadvantage is that cleanouts of a funnel flow bin is often uncertain because solids in the stagnant region may pack and cake. So whatever the material on the hopper walls that is on these walls that is being of forming a kind of a kind of stagnant layer kind of thing. This material over the time what happen they may become packed because of the compaction kind of thing and they may have a kind of cake formation, etc kind of thing all is also possible especially if you have a cohesive material of very small size.

So then even if you draw out the entire material; that material may be sticking there only because of the packing and caking formation kind of thing and that is, because of that reason complete clean-out of funnel flow bins is also very difficult, very uncertain. So the funnel flow bins are suitable only for coarse, free flowing or slightly cohesive not strongly cohesive, you cannot ensure that completely free flowing material in general.

So most of the material may be free-flowing but they are still having some amount of cohesive nature. So slightly cohesive, coarse, free-flowing materials, non-degrading solids when especially segregation is not going to affect the quality of the solids. Then the funnel flow bins can be used for those kind of things. So for the mass flow bins you can use any kind of material especially if you have cohesive materials then you go for a kind of mass flow bins.

(Refer Time Slide: 37:45)

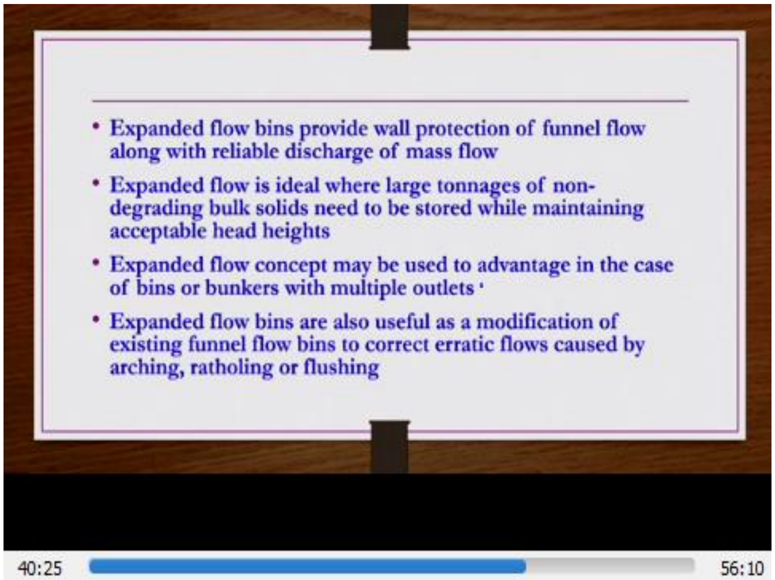


If you have a kind of a coarser material you can use anyone but it is preferable to have a kind of funnel flow bins. Then next one is the expanded flow pattern. It combines the characteristics of both mass flow and funnel flow bins where higher part of the hopper operates in funnel flow pattern, whereas the lower part operates in mass flow pattern kind of thing. So pictorial if you see it looks something like this. Now what we have rather having one hopper angle, we have a two hopper angles here.

So when the characteristic dimension critical dimension of the ratholes in general for the funnel flow. So then below that one you can have a kind of a another hopper kind of thing like this where you can have a kind of mass flow kind of things. So it is a kind of a modification of funnel flow. Also we can say so that to avoid the some of the disadvantages of the funnel flow that we have seen. Here mass flow outlet requires a smaller feeder than the case of funnel flow.

Thus, mass flow hopper should expand the flow tunnel to a diagonal or diameter equal to or greater than critical rathole diameter so that mass flow can take place and then above which the material can flow comfortably. So that will be eliminating or reducing the chances of rathole formation.

(Refer Slide Time: 39:05)



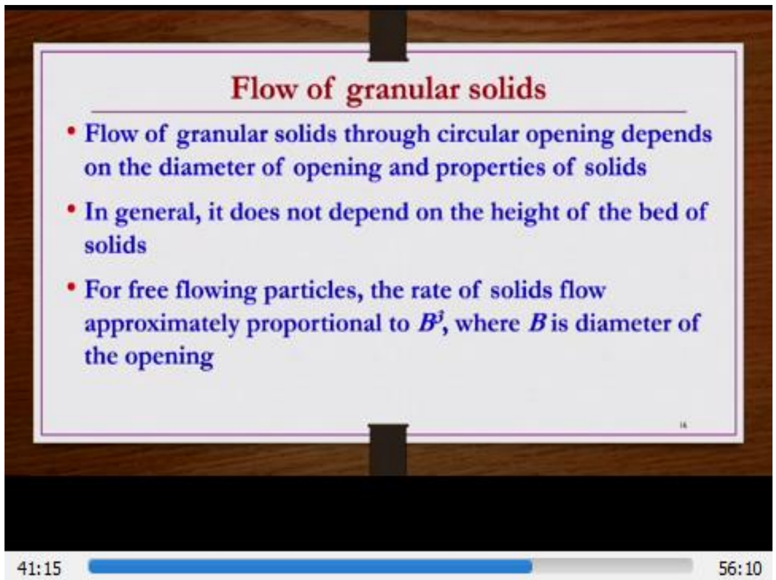
So then the expanded flow bins provide both the advantages of funnel flow and then of mass flow bins. What is the advantage of the funnel flow bins that it provides the wall protection? Wear protection for the walls it is providing because the most of the material is being handled by the whatever the discharge in material. And then mass flow, what is the advantage of the mass flow? It provides the reliable discharge uniform flow it provides.

So both the uniform discharge as well as the wall protection can be obtained by this expanded flow. So which are the individual advantages of the mass flow and then funnel flow, but if you combine together here in expanded flow you can expect both of them to have. So expanded flow is ideal where large tonnage of non-degrading bulk solids need to be stored while maintaining the acceptable head heights.

Expanded flow concept may be used to advantage in the case of bins or bunkers with multiple outlets. If you have more than one outlets then also it is, this concept is going to be useful. Expanded flow bins are also useful as a modification of existing funnel flow bins to correct the erratic flows caused by arching, ratholing or flushing that we have seen in the case of funnel flow.

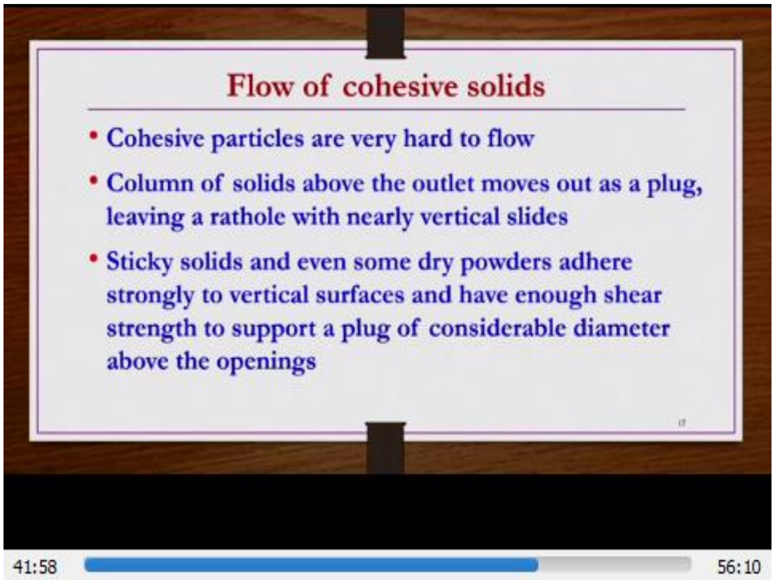
Whatever the arching may take place because of the cohesive material taken in kind of funnel flow or whatever the ratholing kind of things are going to form general in funnel flow. Those kind of thing, causing some kind of errors in the kind of discharge flow rate or the outlet, the solids flow rate you may not have a kind of uniform constant flow rate with respect to time, so that can be avoided by modifying the funnel flow using this expanded flow concept.

(Refer slide Time: 41:01)



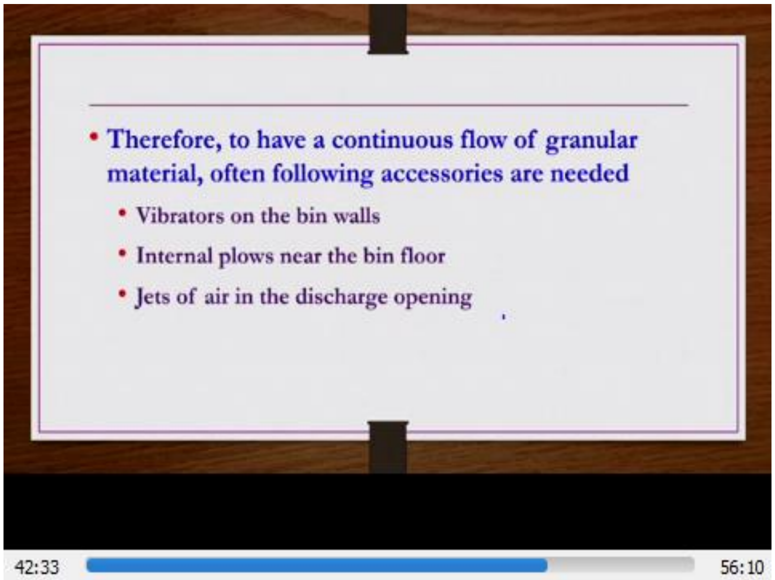
So now flow of granular solids. In general, what are the requirements? Flow of granular solids through circular opening depends on the diameter of opening and properties of solids. In general it does not depend on the height of the bed of the solids. And for free flowing particles the rate of solids flow approximately proportional to B^3, where B is the diameter of the opening or that the feeder opening or the-dimension of the feeder. Whereas in the case of cohesive solids.

(Refer Slide Time: 41:29)



Flow of cohesive is solids is very hard very difficult to maintain because a column of solids about the outlets moves out as a plug, leaving a rathole with nearly vertical slides as we have seen in a kind of funnel flow pattern. So that especially happens with respect to the cohesive solids. And in sticky solids and even some dry powders adhere strongly to vertical surface and then have enough shear strength to support a plug of considerable diameter above the opening.

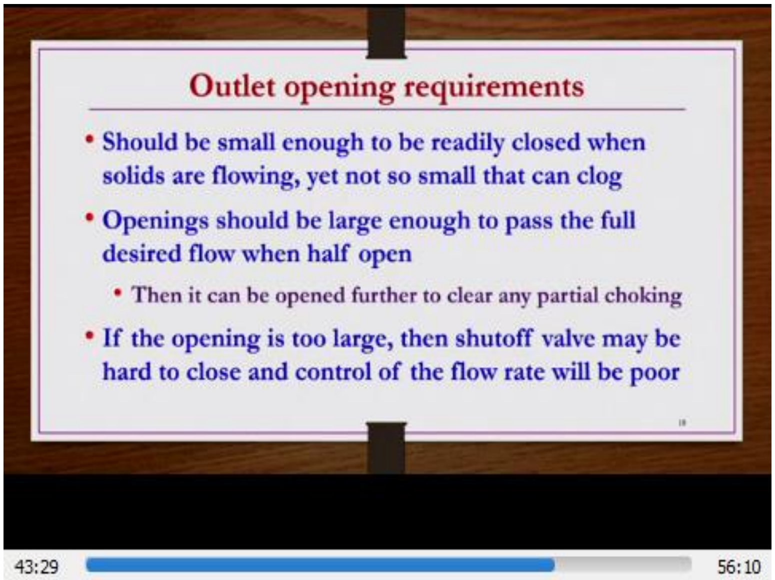
(Refer Slide Time: 42:13)



That is the reason in order to have a continuous flow of granular material, often following accessories are needed. Something like vibrators on the bin walls. If you have the vibrate at the bin walls, you can vibrate so that the material whatever the sticking or stagnating on the walls that can be taken away and then that can flow out eventually that will avoid or reduce the rathole concept rathole formation.

You can also have internal plows near the bin floor and then you can also have jets of air in the discharge opening so that to avoid the arching kind of a phenomena. Then what should be the outlet opening requirements?

(Refer Slide Time: 42:41)



Specific outlet requirements should be calculated based on the design concepts of these things. But however in general what you expect to have the outlet, what you expect the outlet to perform; it should be small enough to be readily closed when solids are flowing, yet not so small that material may be clogging.

But opening should be large enough to pass the full desired flow even half of it is open not completely open even half of the wall or the feeder is open. You must have a kind of desired flow rate. So that large should be the opening requirement and then it can be opened further to clear any partial chocking if it is there. But the opening is too large then shut off valve may not be possible. If you have to bigger openings and the materials are coming in tons of kgs per second or something like that that is going to affect you know the subsequent process.

So you cannot close it immediately. So you cannot have afford to have a very large opening so it should be optimum. It should not be very small that clogging kind of take place it should not be very large that closing of valve becomes very difficult or by the time you close the valve, lot of material is flowing out. So those kind of things should not be there. It should be very optimum. That is what you expect to have I know outlet opening requirements.

(Refer Slide Time: 44:16)

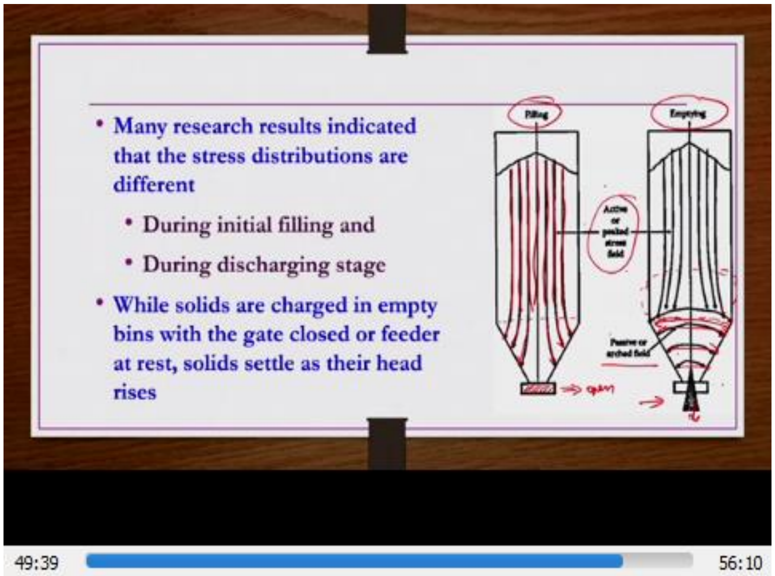
Then most important thing is wall stresses in axisymmetrical bins. We are going to take only axisymmetrical bins some discussions will be doing. So estimation of load on walls of a bin is important for the design because in order to design bin structure efficiently and economically, it is required to estimate the pressure at the walls. So that is going to decide whether the design the constructed silo or hopper is of sufficient strength or not to withhold so much of material at static as well as the dynamic conditions.

So based on this pressure distribution, or they how much pressure is there on the wall etc. So based on those calculation only one is going to design decide how much material one can store the store in a kind of a container. And then what flow rate one can take the material. Because both the static and dynamic conditions are very important and, both are both of them are going to have effect on the pressure on the of the bins.

So that is the reason this pressure calculation is going to be very crucial in the design of the storage solid storage vessels. There are several analytical and numerical approaches are available for measuring the pressures. In general, so many numerical things are available. So using the numerical simulation packages one can estimate the pressure at each and every location inside the bin; both in the static as well as the dynamic conditions and then one can have a kind of a clear picture how this pressure is varying point to point.

However load is directly proportional to the: what kind of flow pattern is there inside the silo when the discharge is started or the when the feeder is open to take out the material out. So then what kind of a flow pattern is existing inside the bin that is again going to have a kind of a very important role on this pressure. Flow patterns in mass flow bins as we understand is relatively easy to predict than in the funnel flow bins. Thus it is important that you can have a simple and symmetric bins rather having kind of chisel shaped bins, etc. So it is always better to have simple and symmetric hoppers.

(Refer Slide Time: 46:33)



And then many research results indicated that the stress distributions are different both in the filling stage as well as the in the discharging stage. During the initial filling and during this disturbing stage, whatever the pressure is there that is going to be different or the stress is going to be different. While solids are charged in empty bins with the gate closed or feeder at the rest, solids settle as their head rises as shown in picture. We have two picture; one in the case of filling and another one in the case of emptying.

We have a kind of silo here at the bottom. There is a gate or a feeder that is closed initially when you are filling. When you fill the material what happens; material comes as you draw in the material. Then what happen, the solids height rises and then the solids they contract vertically. And then a kind of almost a vertical pressure distribution, vertical stress distribution you can see almost like this vertical lines up to this part at least.

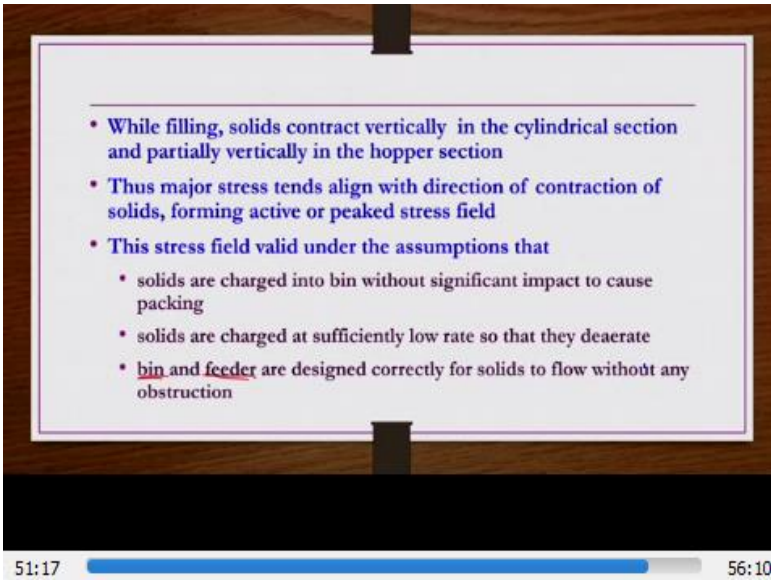
So almost vertical things you can see here because the solids contract vertically at least up to this point and after this point also almost like kind of it is it not exactly vertical almost kind of vertical kind of contraction of the solids you can see. So the pressure will also be in the same direction in the similar pattern only.

So whatever the stress distributions are there in the these conditions, they are known as the active or peaked stress field. Now when you open this bottom opening. Open it so then you have like this, you are opening; so the materials you are collecting like this. Then what happens, so then here so at least in this portion that is in the conical section not in the cylindrical section in the conical section whatever the material is there , that is moving laterally that is mostly moving a kind of a lateral motion is there and then material, contracting in the lateral direction. So the stress is also moving in a kind of lateral direction.

So these stress fields are known as the passive or arched field. And then above it what happens the whatever the active or peaked stresses are there. So at this location just above this conical section in the previous case just above the conical section they are almost vertical but here they are not vertical they are the somewhat arched to certain more distance like this. So, because the material is flowing the material contracting in the lateral direction.

So then the stresses are also distributing in the lateral direction. So this because of the lateral contraction the stresses are arched direction shown like this. So this is what happens in general the; this is how the pressure distribution is different while filling as well as the emptying the as well.

(Refer Slide Time: 49:45)



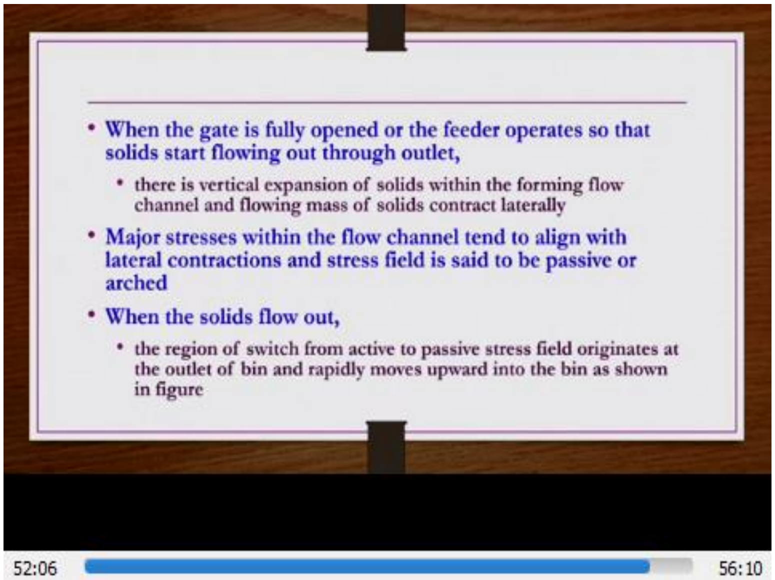
So while filling solids contract vertically in the cylindrical section and partially vertically in the hopper section that is the conical section at the bottom. Thus major stress tense align with the direction of contraction of solids, forming active peaked stress field.

And then this stress field valid under the assumption that the solids are charged into bin without significant impact to cause packing so they are just filling without; we are not considering the research results that we proposed, discussed in the previous figure. Or having this kind of assumption that the solids are charged into bin without significant impact to cause any kind of packing of the material.

Packing of the material is not taking place; that is the material coming in, when solid particles are coming in lying on to the others without having any kind of compact or without causing any kind of compact packing while the filling. Solids are charged at sufficiently low rate so that they aerate. And then bin and feeder are designed correctly for solids to flow without any obstruction. This is very important if the feeder and then bins both of them are not properly designed then we can have a kind of funnel flow kind of things and the things may be very different.

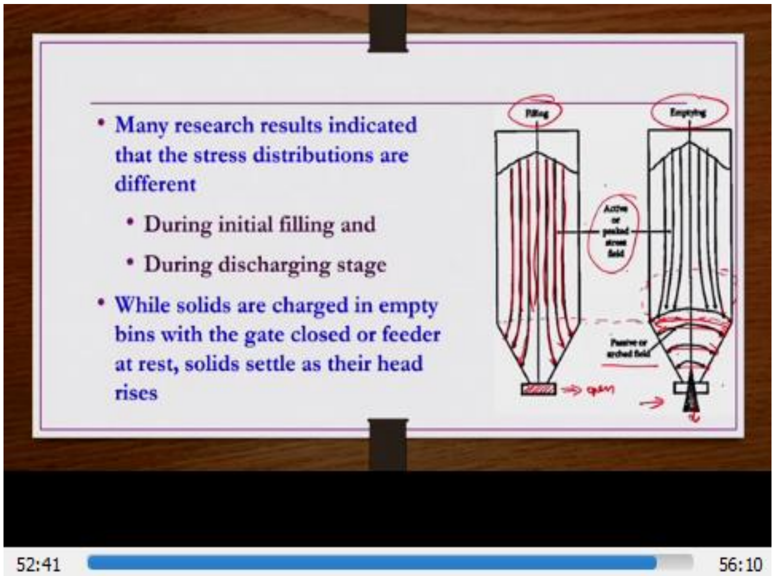
So whatever the things that stresses that we are discussing mostly valid kind of mass flow patterns, where the free-flowing of the material is taking place. If the bin and the feeder are not properly designed so then it is not possible to have a kind of a mass flow pattern. So you may experience a kind of a funnel flow pattern. So those kind of things are absent as per this analysis. We are not considering those problems. Then when the gate is fully opened or the feeder operates so that solid start flowing out through the outlet.

(Refer Time Slide: 51:35)



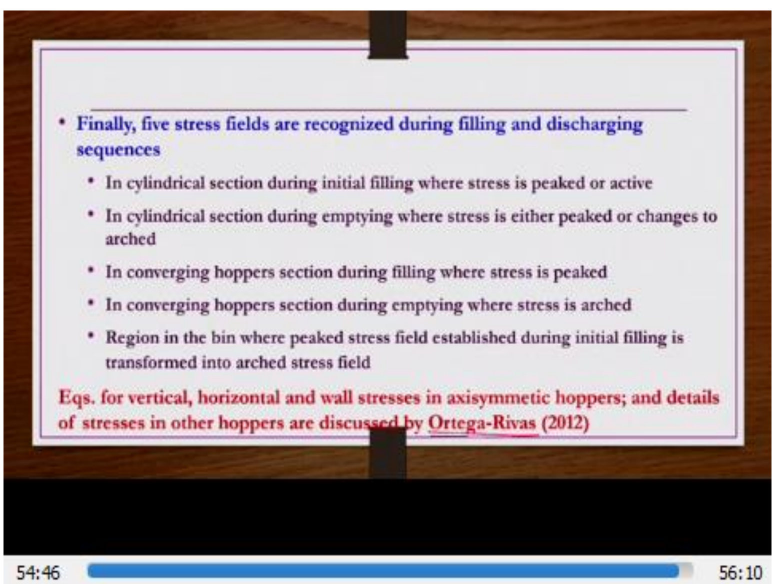
There is vertical expansion of solids within the forming flow channel and flowing mass of solids contract laterally within that hopper region or within that, I know, conical section that we have seen. And then major stresses within the flow channel tend to align with lateral contraction and stress field is said to be passive or arched. When the solids flow out the region of switch from active to passive stress field originates at the outlet of the bin and rapidly moves upward into the bin as shown in the picture that I have shown already.

(Refer Slide Time: 52:19)



Like here when you are taking the material so then whatever the lateral motion, is there, so that causes a kind of the switching of this region. So up to initially it is upto this point, it is almost kind of vertical. But because of this one the vertical motion is being disturbed up to certain location. So the switching of a active to arched field is taking place up to this region, but it starts at the outlet and then it moves upward rapidly. So finally what we see:

(Refer Slide Time: 52:51)



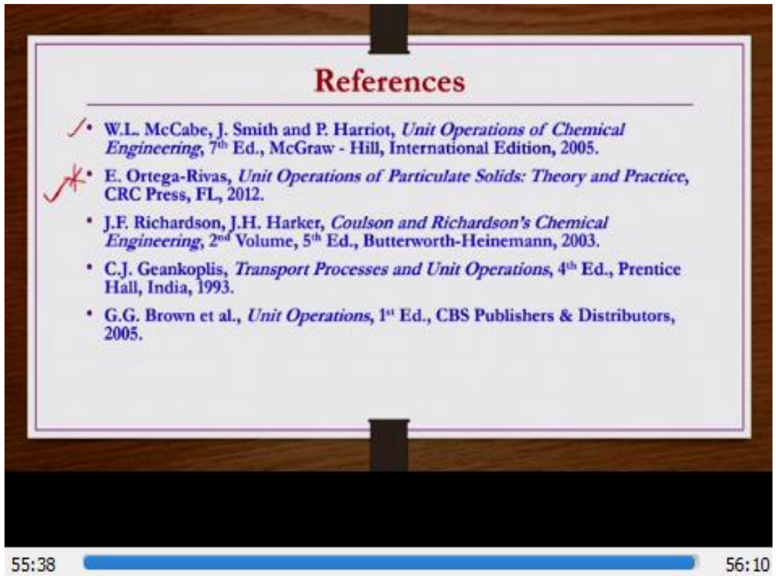
Five stress fields during the filling and discharging sequences of a silo, where simple mass flow pattern is taking place. So what are they? Once again to recapitulate. In cylindrical section during initial filling, where the stress is peaked or active that is in the cylindrical section while filling. And then again in this cylindrical section, but during emptying where the stress is either peaked or changes to arched because when the material is drawing out, whatever the lateral moment is there, that is happening taking place at the bottom.

And then that is rapidly moving up because of that one. The switch over from active to passive, that is going to take place because of that one. Some of the peaks may not be active but they are arched even in the cylindrical section while emptying the column while drawing out the solids. Then the converging hopper section, conical section during the fill, filling, where the stress is peaked almost vertical those kind of things we have seen. Then again converging hopper section.

But during empty, where is where the stress is arched kind of lateral contraction is taking place and then stress is having a kind of a arched shape. Then finally, the reason in the bin where peaked stress field established during initial filling is transferred into arched stress field. So these kind of 5 stress field that we have seen in pictorially also. The same thing of presentation presented as a kind of summary here.

Further I know equations for vertical pressure horizontal pressure and wall stresses in axisymmetrical hoppers and the details of stresses. In other type of hoppers are discussed thoroughly in this reference book Ortega-Rivas so those things we are not going to see those design equations, etc. We are not going to see because they are not required at the UG level. But however, if someone interested may go through this book, to find more details

(Refer Slide Time: 55:01)



References are 'Unit operations of chemical engineering by McCabe, Smith and Harriet'. Then 'Unit Operations of Particulate Solids Theory and Practice by Ortega Rivas'. Most of the details presented in this lecture have been taken from the second book. A few details are also taken from this first book McCabe, Smith and Harriet. Other reference books; we have 'Coulson and Richardson's Chemical Engineering Series', second volume by Richardson and Harker. Then'Transport processes and unit operation'by C.J Geankoplis, then 'Unit Operations' by Brown et al and finally 'Introduction to Chemical Engineering' by Badger and Banchero. Thank you.