INDIAN INSTITUTE OF TECHNOLOGY, GUWAHATI

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NPTEL ONLINE CERTIFICATION COURSE
AN INITIATIVE OF MHRD

SUBSURFACE EXPLORATION: IMPORTANCE AND TECHNIQUES INVOLVED

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LECTURE: 14
GRAVITY SURVEY

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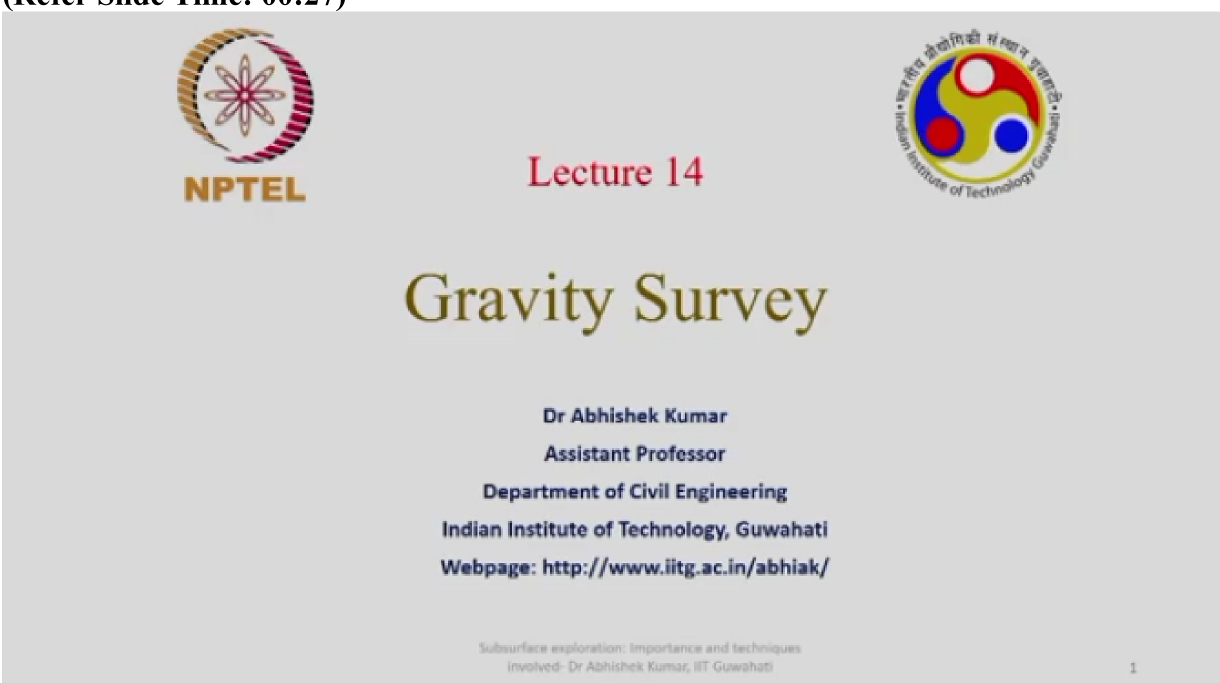

Welcome all to lecture 14 on Subsurface Exploration Importance and Technique Involves. So far we have discussed about different geophysical methods including seismic reflections survey, seismic refraction survey, electrical resistivity test, sounding and profiling test, then magnetic anomaly test.

In today's class we are going to discuss another very important method which is particularly use for soil exploration even for understanding the tectonics of the region, even for oil and mineral exploration as well, so it's a very important method which we are going to discuss that is gravity survey.

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So we discussed broadly like what are the different topics we had covered so far is seismic reflection survey, we discussed like how we go for field recording, then once we know the field record how to interpret the data which is primarily the objective of any subsurface exploration program, then seismic refraction survey, so what are the advantage of seismic refraction survey over seismic reflection survey, what are the limitation or what are the condition in which seismic refraction survey may not be applicable.

We had discussed typical recordings, interpretation of the results based on the time of rival of different kind of waves depending upon what kind of source are used, then electrical resistivity survey we have discussed based on the apparent resistance offered by the ground surface depending upon electrode and potential and current electrode spacing, how the apparent resistance is going to change.

Then suspension logging, we also discussed about magnetic anomaly method also,
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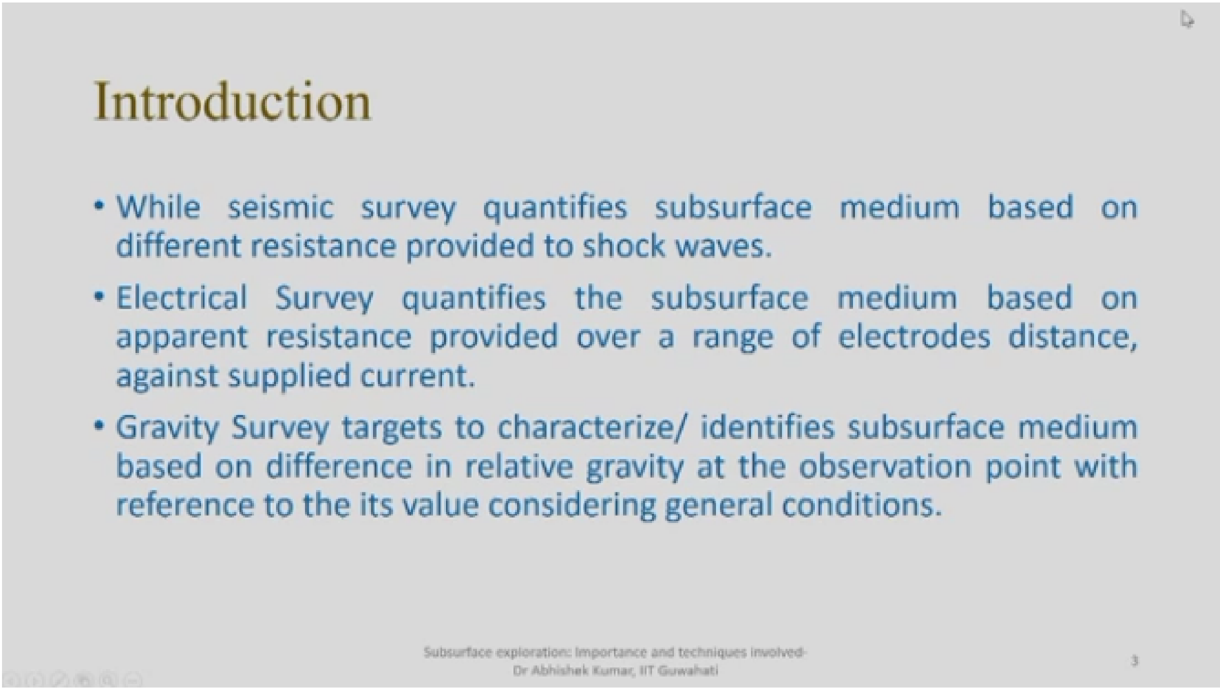

and so today's class we are going to discuss before going into further detail about gravity methods, we all know like when we go for seismic method in quantify the subsurface medium based on the resistance offered by the medium against shock waves either artificially created or from other sources.

In electrical resistivity survey we tried to again quantify the subsurface medium based on the resistance offered by the medium against externally applied current, of course this resistance will be measured over a range of electrode distances so that we can understand the average or the apparent resistance offered by different subsurface medium with respect to the depth.

Now when we come to gravity survey, we are interested to find out, see our the objective of this course or different method which we are going to discuss in this course, the object will remain same to identify different medium which are available beneath the ground surface, it can be bed rock, it can be different material, the material can be different in terms of stiffness, material can be different in terms of mineral composition, material can be different in terms of even moisture content also, so in gravity survey what we are interested, we target to determine or to classify or to understand the variation in subsurface lithology based on the difference in gravity or difference in gravitational force existing at the site of the interest like considering that the entire area is homogenous we will be having some known value of gravitational force at the site of interest considering its location, but once we go to a particular site and then we start measuring the value of gravitational force there, we will see there will always be a difference, most of the time there will be a difference because the general, based on the general understanding about the gravitational force along the earth surface which will consider most, which will not consider the site specific or region specific change in subsurface medium characteristic, so gravitational survey targets to understand this change in gravitational force existing at site of interest, and this change will be there because of change in subsurface medium, so if you consider the medium is homogenous or it's not changing with respect to the surrounding region you may find more or less same value, but most of the time what happens you will find some denser medium, you may find some discontinuity, you may find some buried object, or you may find some kind of other characteristics at the site which are not matching with the general trend of the study area, as a result of which there will be a change in the gravity, because gravity can be affected by different parameters, so in gravity survey we are interested to find out, we are interested to understand based on the gravity anomaly this is called as anomaly because this is showing something which is known based on the generalize understanding about gravitational force at the site of interest and which is possibly an indication of that the subsurface medium has some anomaly or has some change with respect to it's the general understanding about the geology of the structure, geology or lithology of the site.

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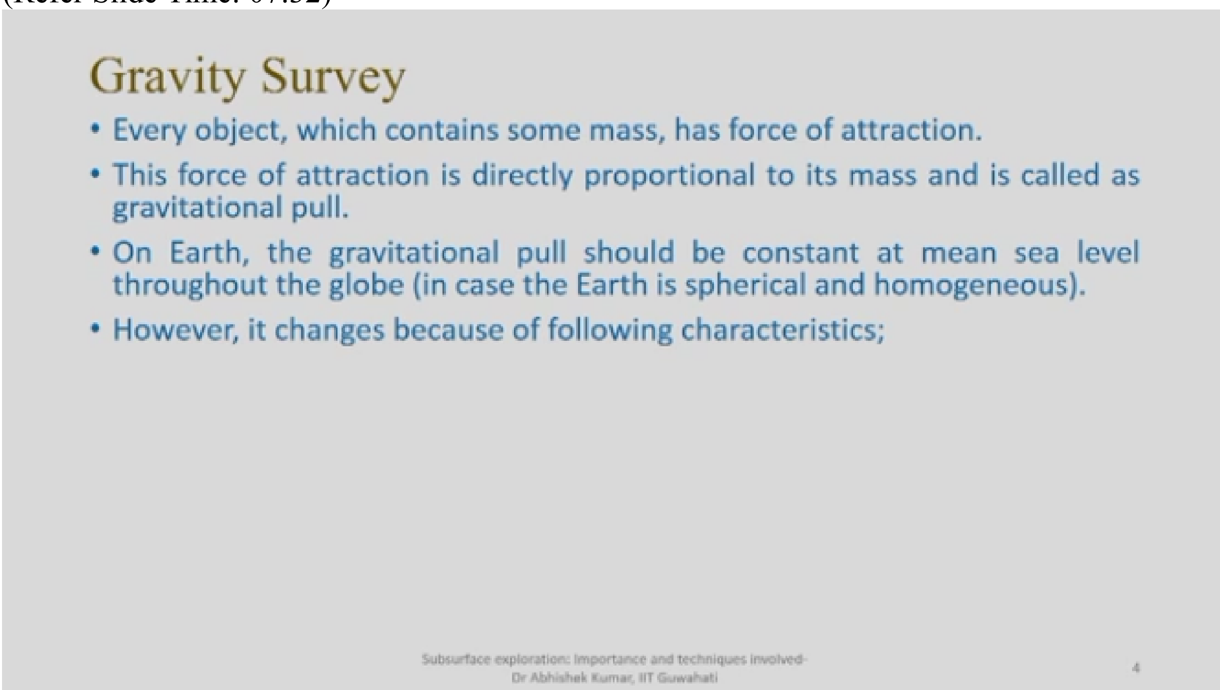

So gravity survey targets to characterize or identify subsurface medium based on the difference in relative gravity, okay, there are two ways we can measure it, one is we can go for absolute gravity which is at times very complex to measure and more over it is very expensive effort, however at the site of interest we are our objective we are interested to see how the lithology is varying, how the mineral composition is varying within the site itself, so even if we go for relative measurements of gravity with respect to maybe observation point, with respect to mean sea level with respect to datum that give you sufficient information about change in lithology, change in mineral composition of the site of the interest, so that's why we call it as difference in, because whatever you are measuring it is called as difference with respect to the first one, so difference in relative gravity.

Difference because the relative gravity considering the site location, there should be some value of gravity, and then whatever you are measuring at the site of the interest, so the difference of these two and you are measuring in terms of relative gravity, so relative means with respect to your datum, with respect to maybe your mean sea level, with reference to some other reference point you are interested to find out how this difference is going to increase or decrease at your observation point or at the site where you are going to go for gravity survey, yeah, gravity survey conduct if you do.

So at the observation point with reference to the, with reference to initial value considering general condition, like we know the earth, we know the gravitational force on the earth, but considering the size of the earth, considering the shape of the earth it may not be a constant value, okay, so we will discuss that in the slides.

So gravity survey we know like every object which contains a mask has a force of attraction as well, this force of attraction is directly proportional to its mass, and is called as gravitational pull of that particular object, it can be there for earth, it can be there for mars, it can be there for moon, it can be there for sun, it can be there for every planet and even if depending upon the size of the, and mass of any object the gravitational pull may change from one object to another object.

On earth the gravitational pull if you consider the earth to be perfectly spherical further if you consider earth to be composed, I mean the institution, the material or mars considered to be homogeneous then the gravitational pull throughout the earth surface will be constant, independent of its geographical location, independent of its altitude, independent of its topography, independent of so many other parameters, but what happens when we go for any kind of particular site for gravity measurement we always find some kind of difference is which is particularly because of so many parameters, so because of which, particularly considering the earth shape is not spherical, considering the earth is not homogeneous there will be always some kind of change in the gravity overall along the earth surface, this change can be because of many parameters can be there which is responsible for the change in gravitational force.

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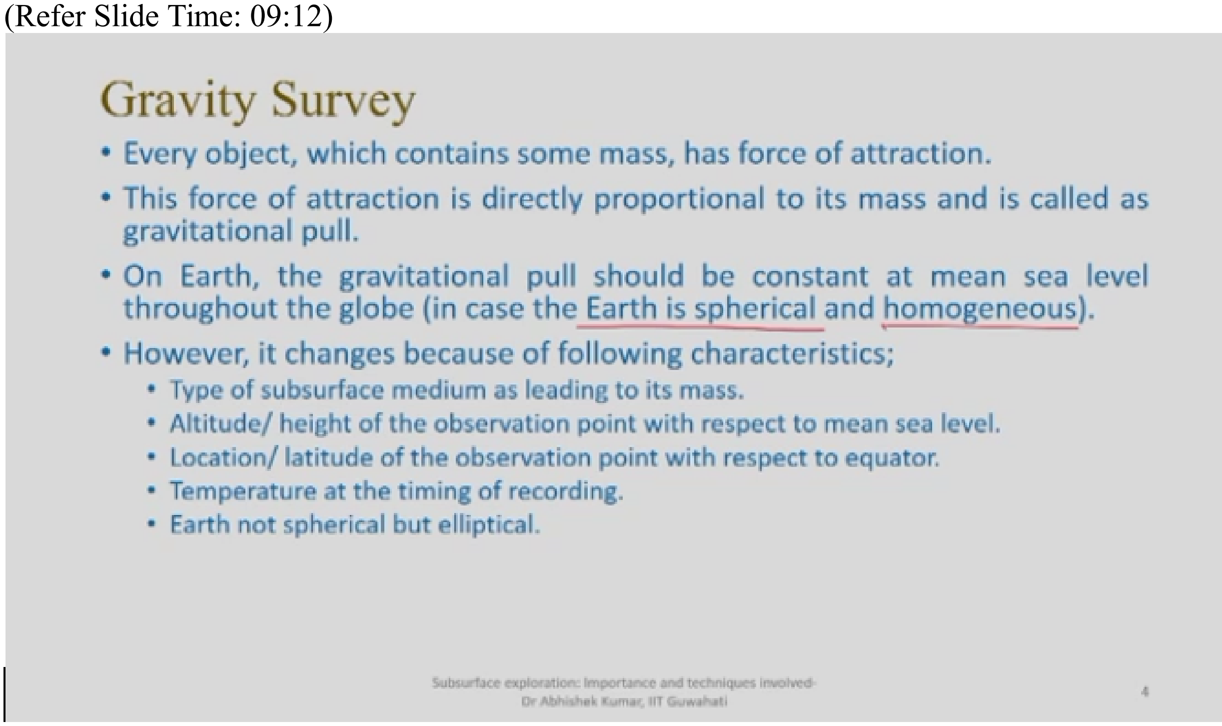

One among this which is primarily of our importance is type of subsurface medium, because if the surface medium is going to be lighter, it is going to affect your gravity, if it is going to be dense site it is going to increase your gravity value, though the difference in increase or decrease would be very small in comparison to the escalation due to gravity the normal value, but there will be always some difference which is an indication of change in the mass of subsurface medium, change in the density of the subsurface medium.

Second thing altitude or height of the observation point with respect to mean sea level or with respect to maybe first point of observation or maybe datum, because as you are going away from your earth surface, the increase in the distance between the earth center and your observation point will lead to reduction in the gravitational pull, so that's why this can also lead to change in your gravitational force.

Third thing is location and latitude of the observation point, we know earth is not spherical, that I mean the radius of the earth at pole is lesser in comparison to the diameter of the earth at equator considering its elliptical shape, as a result of which even the gravitational pull will not be constant throughout the earth surface, it is going to change, the best way is which I mean, if you consider the change in gravitational pull with respect to its location we can go for, we can take into account the latitude of the observation point with respect to equator, so this particularly when we take into account the change, we always measured the normalized one value with respect to the equator.

Then next one is temperature at the time of recording that can also affect your, it can affect maybe because of tidal consideration it can be because of instrument constraints as well, so then whenever there is a change in temperature particularly throughout the day, even at the drift in the instrument, so that can also lead to change in your gravitational pull even at the same site of interest.

And then that's precisely I told you because the earth is not spherical, but elliptical in shape, so there will be always some change in your gravitational force.

So what we understood here that the gravitational pull throughout the earth is not constant, it can be, it can vary with respect to the temperature,
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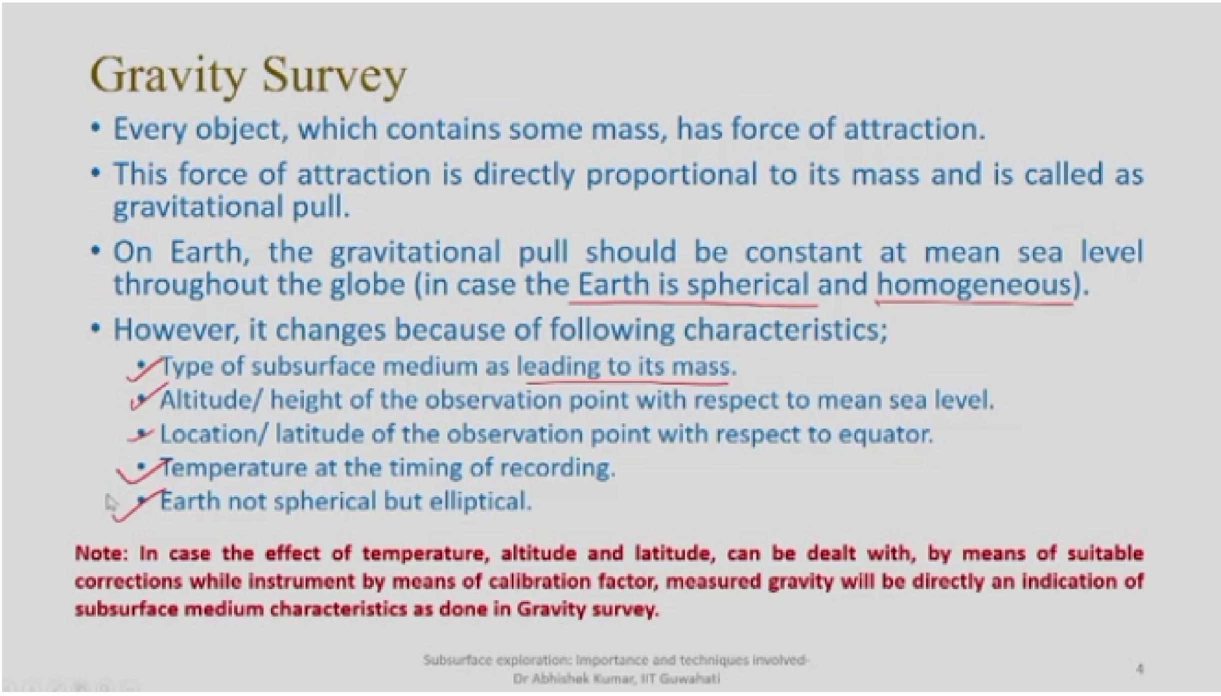

it can vary with respect to altitude, it can vary with respect to latitude, so each of this variation can be dealt by applying suitable corrections, if you know your observation point, if you know the values of these correction because of altitude, latitude, temperature, and so on, you will be able to understand if you apply this connection you will be able to understand how much is the corrected gravity value at the site of the interest, of course you have to apply some kind of calibration factor also depending upon what kind of instrument you are using, so that is going to give you the measured value of gravity at the site of interest which is an indication of subsurface medium characteristics, so you will be having some value which takes into account the generalize gravitational force at the site of the interest, you apply some correction which is an indication of those factors which can affect your gravitational force at the site of the interest, once you apply all those corrections at the last you will be having some value of gravitational force which is, that value will be only indication of actual value of gravitational force at the site of interest, removing the effect of temperature, latitude, altitude, even some time plate correction are also required because of some additional material which is available beneath the bedrock and the ground surface, and once you apply all those correction you will get an idea about how much is the actual value of gravity.

If you take the difference of this actual gravity with respect to the generalized value of gravity, that will be possibly indication like there is a stiffer material, there is lighter material which is available at the surface within the ground surface, ground medium which is possible indication of various change in medium characteristics. And that’s how you target for understanding in the gravity survey.

Now as I mentioned here consider two material X1, Y1, Z1 having mass M1, having mass M2, X2, Y2, Z2, so the force of attraction between two materials, force of attraction between mass M1 and M2 can be given by F = G times M1 M2 over R square, where R is the distance between M1 and M2, so the value of R can be understood as X2 – X1 whole square + Y2 – Y1 whole square + Z2 – Z1 whole square, that we can get from the geometry, now the value of M1 is mass of 1, M2 is mass of 2, G is gravitational constant, constant having a value of 6.67 x 10 to the power -11 meter cube per KG, per second square.

Now again from Newton's second law of motion, Newton's second law, force in an accelerating mass can be given as A times M, so this is 1, this is 2, if I am considering force at mass M1 will be given like this, so we can equate equation 1 and 2, equation equate 1 and 2 we will get A times M1 = G M1 M2 over R square, so you will get if M2 you consider the mass of the earth, mass of earth and R you consider radius of earth, so the mass of the earth M2 I can say, how much is the mass of the earth? Mass of earth is given as 5.977 x 10 raise to the power 24 KG, now this is considering mass of homogeneous earth that the medium characteristics is not changing throughout the volume of the earth, mass of homogeneous earth.

Second thing the value of R which is given as 6371 kilometer, if you put these two things here in equation 3 what you will get, you will get A equals to, okay, this will be minus, so A = -G M R over R square, which will be called as acceleration due to gravity that is GN, 9.81 meter per second square, so G M R square times this, G M over R square,

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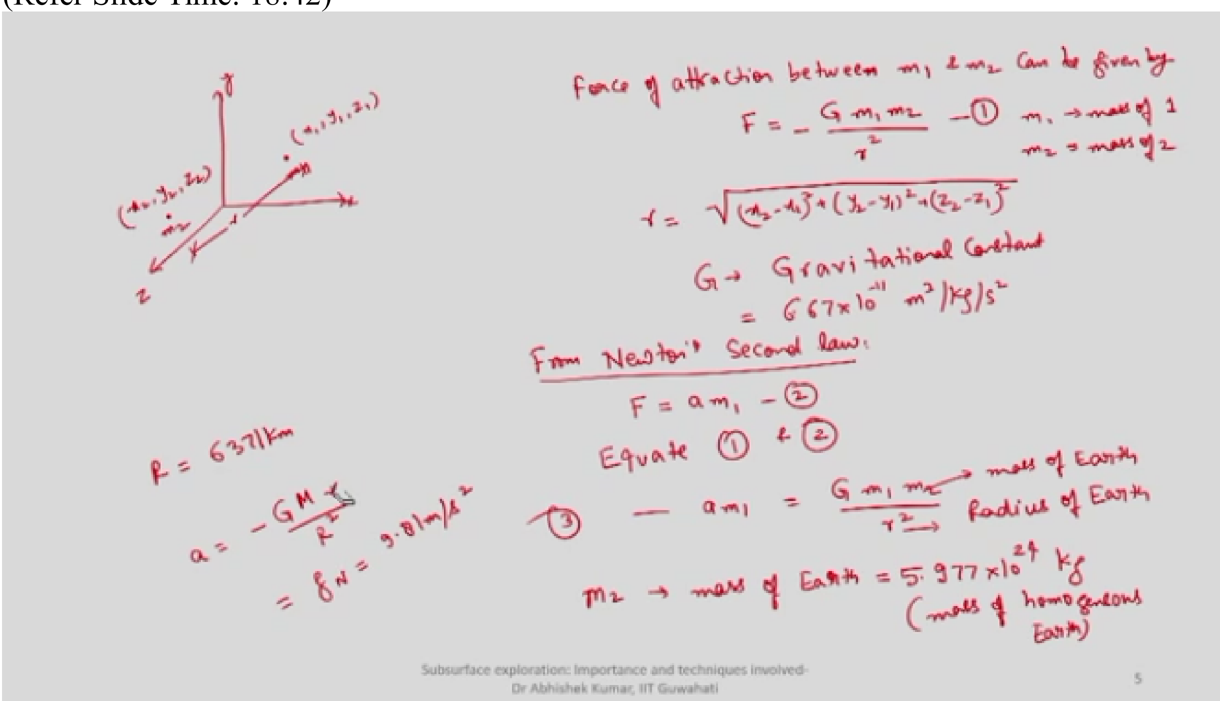

so this is going to give you the value of, so this is the value of gravitational pull considering, so this is gravitational pull, this gravitational pull I'll again write this as maybe equation number 4.

Equation 4, however is applicable to a homogeneous and spherical earth, however in actual neither the earth is homogeneous nor spherical, it's not homogeneous you can get an idea about considering the density of soil at the surface and considering the mass density of core medium, you can see significant difference in the material characteristics even at the mental, even the bedrock medium, bed itself can get you an idea about, and within the soil medium also you will not have same kind of soil everywhere, so it's not homogeneous, in spherical it is not there, if you consider spherical it is like this, but in actual your earth, so this is our earth you can consider here this is like pole, this is equator, this is pole, so the radius of the earth, equator is equals to radius of earth at pole + 21 kilometer, and this is given as 6378 kilometer, so when the radius itself is not constant, the earth is not spherical, as a result of which if you consider here, because of its rotation there will be some centrifugal force, there will be some gravitational pull normalized one, and as a result of which there will be a resultant GR, we call GR = GN + GC, so the gravitational pull again you can see here the gravitational pull because it is not constant, the radius is not constant, so every time the gravitational pull direction will be perpendicular to the earth, but it will be change in throughout the earth surface, so the resultant will always be changing which is our target for the present study area, for present survey.

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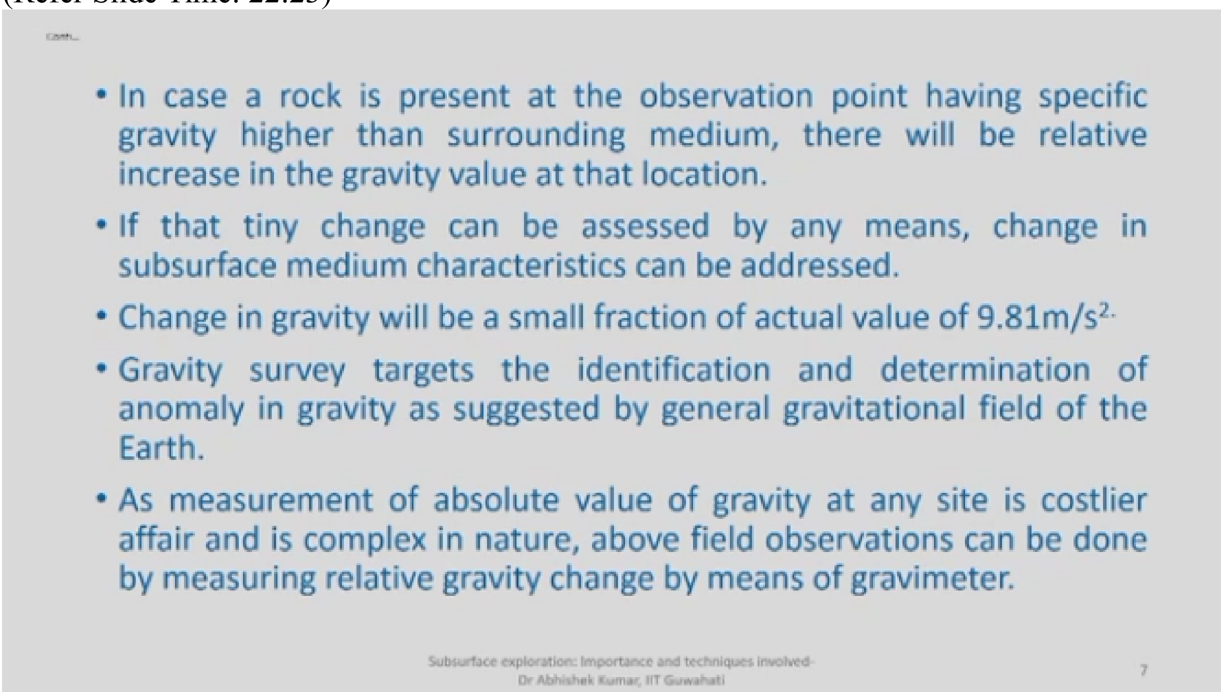

Now what we do here, so we are interested to find out how much will be the resultant force at the site of interest based on your gravitational pull, based on your centrifugal force, what we do, we will go to the particular site based on these consideration, we will try to find out how much will be the gravitational force ideally at that particular site of interest, but at the same time in case a rock is present at the observation point which is particularly called, which is adding more heterogeneity to the medium and it is possible considering the complexity of the site, considering I mean foreign material which can be deposited by different agencies or maybe by human interference also, so there will be some always some material which is not supposed to be there at that particular site of interest, but it is actually existing, so in case a rock is present at the observation point, having a higher specific gravity in comparison to the surrounding medium like soil is there within the soil there is a big boulder of significant size as a result of which you are going to measure the gravity value considering the rock deposit there, you will get some value of gravity, but if you are actually going to measure at the site, you will get some value which is significantly higher than the value of considering the normal site condition or soil condition, so there will be a relative increase.

Why there is an increase, because you are having a rock medium which is not supposed to be there or which is, which is adding some kind of heterogeneity, and having specific gravity significantly higher than the surrounding soil medium, so there because of any external material, foreign material with higher density as a result of which it is going to increase your density or specific gravity or the gravity itself.

If that tiny fraction of gravity which is because of, for the presence of rock can be assessed by any means this is going to give you an indication about the change in subsurface medium characteristics, so that is what our interested, we will be interested to find out how the subsurface medium characteristics are going to change, if we are able to understand that just by understanding this tiny change in gravitational pull or relative gravity at the site of interest, so this change in the gravity will be function, will be a small function of gravitational pull that is the value of 9.81 meter per second square.

Gravitational survey targets identification and determination of anomaly, we are calling it as anomaly because there is something which is leading to change in your gravitational pull with respect to the gravitational pull, supposed to be at the site of the interest, so that's why it is called as anomaly, it is because of something else, because of change in the medium characteristics as highlighted by a gravitational test or gravity survey, so the gravity survey targets the identification of, identification and determination of this anomaly as I suggest with respect to the gravity measurement suggested by general field of gravitational field of the earth.

Now as measurement of absolute value as I highlighted earlier, measurement of absolute gravity at the site is very costly, but we are not interested in actual gravity value, our purpose will be solved if you are able to find out the change in gravitational force or the relative gravity, so above field observation can be done by measuring the relative gravity, the instrument what we use it is known as gravimeter, so we can set the instrument at first observation point and then from there onwards we will try to find out the relative change in the apparent gravity or relative gravity, or difference in the relative gravity value at different, different observation point, we can divide the entire area into number of grids and then we'll conduct that gravity survey at each of these grids, and whatever observations we made we have to process those observation in order to understand the subsurface medium change perpendicularly, so this can get you an idea in order to give you, in order to give you better idea like this is homogeneous medium, so the gravity if you go for any kind of measurement you can call it as gravitational pull or gravitational force at the site of the interest, if it is homogeneous like throughout the medium it is like homogeneous at this particular depth, so you will be having something like this, it is something like this, again this is your gravitational pull.

However at the site suddenly you find some rock medium, rock pocket I can say here, as a result of which what will happen, there will be increase in your gravity value, so this increase first of all this was your general trend which you can determine based on your general understanding about the gravitational field at the site of the interest, but there will be because of rock pocket or I can say here denser medium, denser material, so because of denser material what will happen, the relative density or the mass adjusting at that particular section will increase, that will lead to increase in gravitational pull, and this increase you can call it as gravity anomaly which unless you do the test at the site of interest you will consider the medium is quite homogeneous you will get same value of gravity, so this is called as gravity anomaly, this is about rock medium, same way if you have a ground surface, you have some kind of fault here, and generally it happens like on either side of the fault there will be some kind of relative movement, or there will be different kind of material deposited, because of the moment along the fault, so if I call it as fault or discontinuity,

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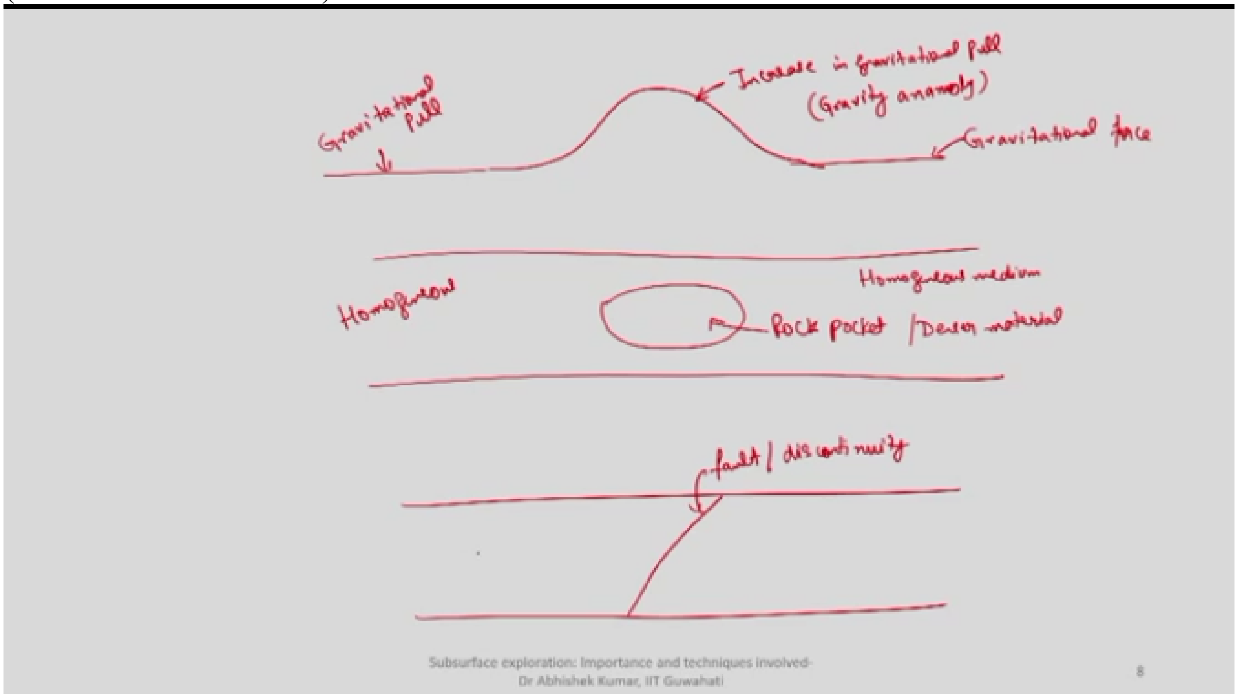

what will happen I can say here, lighter medium, lighter medium then you can have denser medium, as a result of which if you measure the value of gravity here there will be slow increase because of this discontinuity, and because the other side you are having relatively denser medium, so this is increase due to denser medium, so this gradual increase is possibly going to give you an indication, okay, there is sudden change because you see here at this observation point it is changing in this region then this observation point it is dominated by this density, but once you reach at this observation point most of your gravity is contained or dominated by the denser medium, that's why you can see here suddenly there is a complete increase in the gravity.

So this gradual change possibly can indicate you also some kind of fault or discontinuity, continuity which is available in the medium,

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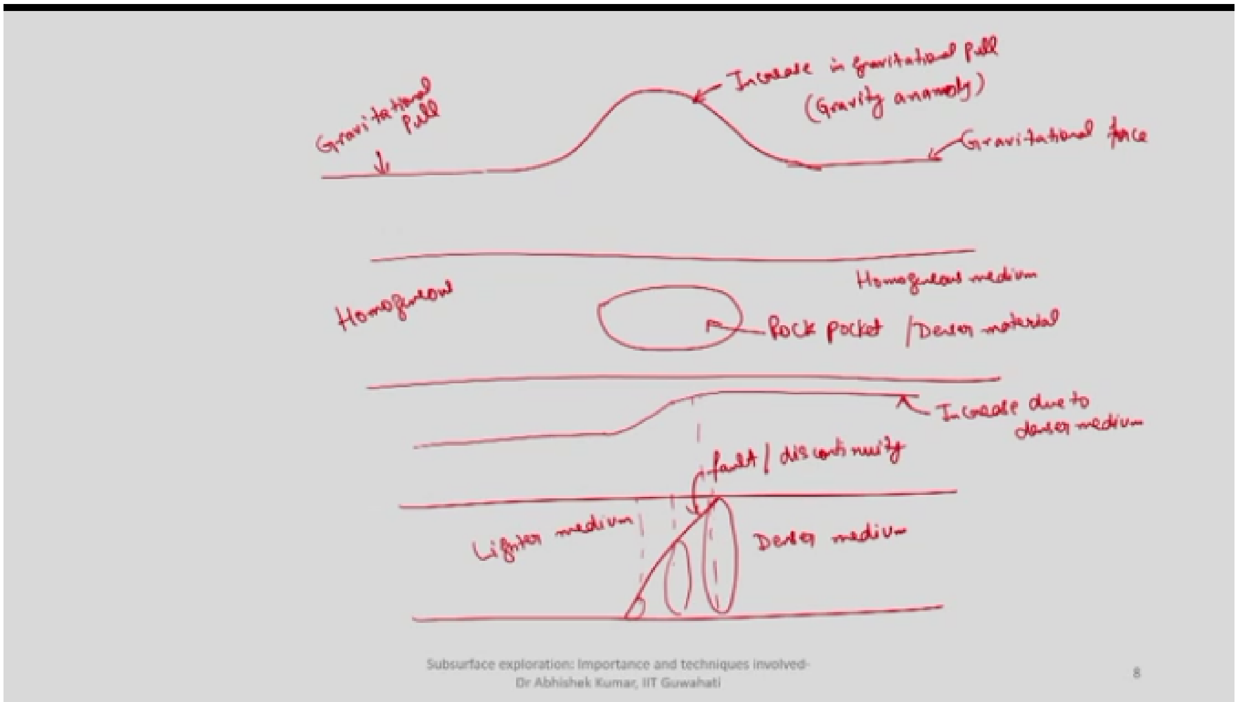

so this is possibly I have given you two case studies, I can differentiate also if I put just, so one case study above this line which is possibly indication of rock pocket.

Second case study below the line which is possibly indication of some fault or discontinuity, and on the other side it is containing the denser medium, and this kind of anomaly whatever you are seeing here based on what you identify again this can be called as gravity anomaly, so based on that you can get lot of idea about what kind of medium is available beneath the surface, whatever change happen, whatever change is happening below the ground surface, okay.

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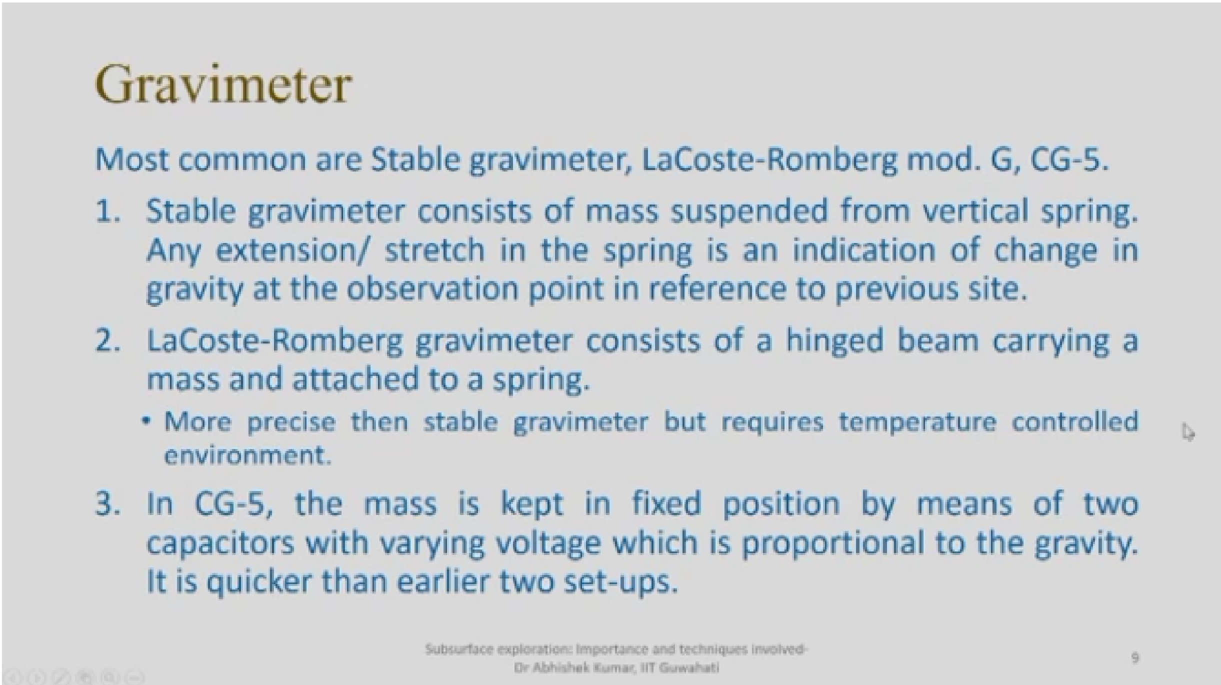

So we discussed like what are targets when we go for gravity survey, what we are actually interested to find out, once we go for gravity survey, we generally measure relative gravity by means of instrument called as gravimeter, most common are three kinds of instruments, one is called as stable gravimeter which consists of a mass hanging from spring, so the extension of the spring can be considered as an indication of change in the gravitational pull at the observation point.

Second one is LaCoste-Romberg gravimeter, so again in this also you are having a spring mass which is was hanging from a particular in client beam, and this beam is also suspended from spring, this is more précised then stable gravimeter, but requires because of the change in the temperature there will be always some kind of creep in the spring, so this particular LaCoste-Romberg gravimeter requires temperature controlled environment whenever we go for any kind of field measurement.

The third one is CG-5 in which there is a mass which is supposed to be at fixed position, so because of change in the gravity value, the mass may move at different location and which will be bring out to its original, will be brought to its initial position by a means of supplying some potential difference, this potential difference measurement, how much is the potential difference you have applied to bring the mass to its original position is proportional to the gravity value existing at the observation point, so that’s how you can get an idea by means of mass spring system, based on the displacement or stiffness of the spring or the mass dial gauge, reading on the micrometer or by means of potential difference as we do in CG-5 kinds of gravimeter. It has been highlighted by different experts like the last one CG-5 gravimeter, it is quicker, it is more rapid when we go for field measurements in comparison to stable gravimeter or LaCoste-Romberg gravimeter, further details about this you can check with the manufacturers.

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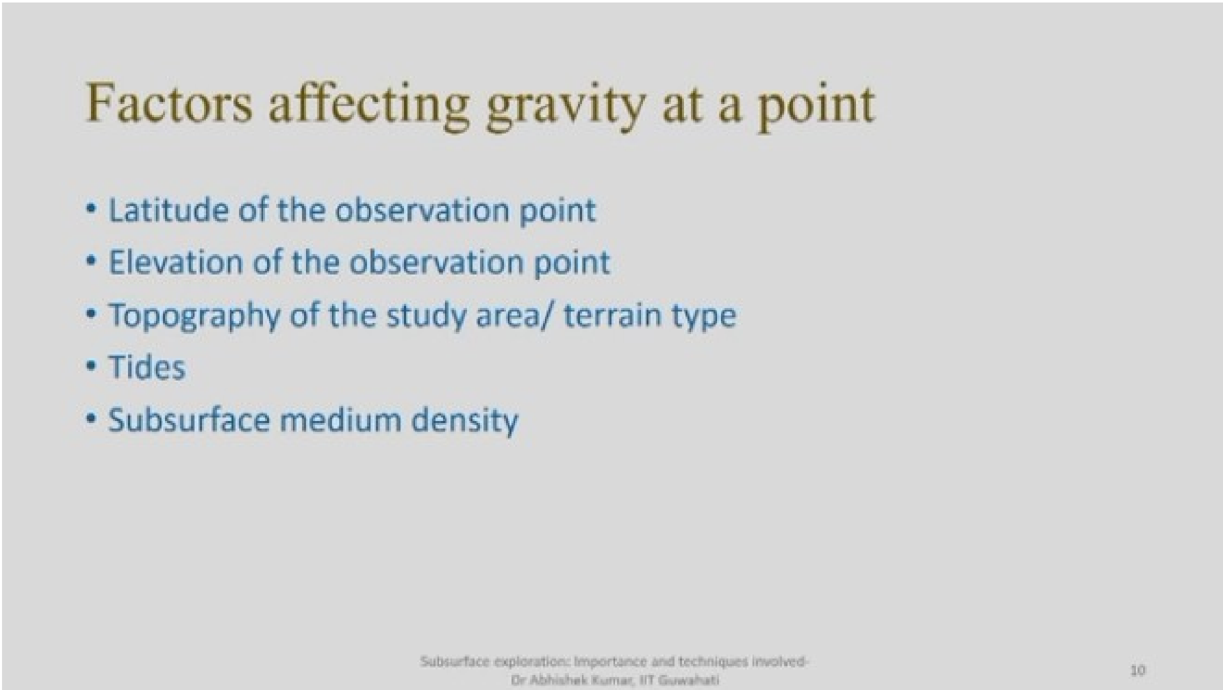

Now we discussed about, we have been discussing like the gravity value at a particular site of interest is not constant, so it's not constant that means it is going to change by means of different factors, some of those factors are listed here, the latitude of the observation point, even if the subsurface medium is constant the value of gravity, if we are measuring at pole and at equator will be different, and same way in between those two locations because of change in the latitude, because with respect to the latitude your gravitational pull is going to change and that is going to control your result and gravitational force.

Second thing elevation difference, as we saw in equation 1 and 2 that the gravitational pull is inversely proportional to the distance between the source, between the center of the earth and your observation point, so as you go for higher elevation the distance keeps on increasing and you will have this gravitational force keeps on reducing.

Then topography, it is also observed like with respect to change in the topography there will be additional pull because of topographical effects or terrain type, this can also affect your gravity at the observation point.

Fourth point tides, as we know like depending upon the proximity or depending upon the position of earth with respect to sun or the position of moon with respect to earth there are always the force of attraction from the sun or the moon which is responsible for moon tides and sun tides, this can also had some kind of additional factor, some tiny fraction into the measured gravity.

And the last and most important which we are targeting to measure in this test is subsurface medium density, so wherever subsurface medium density is going to change your gravitational pull or measurement of gravity is going to change.

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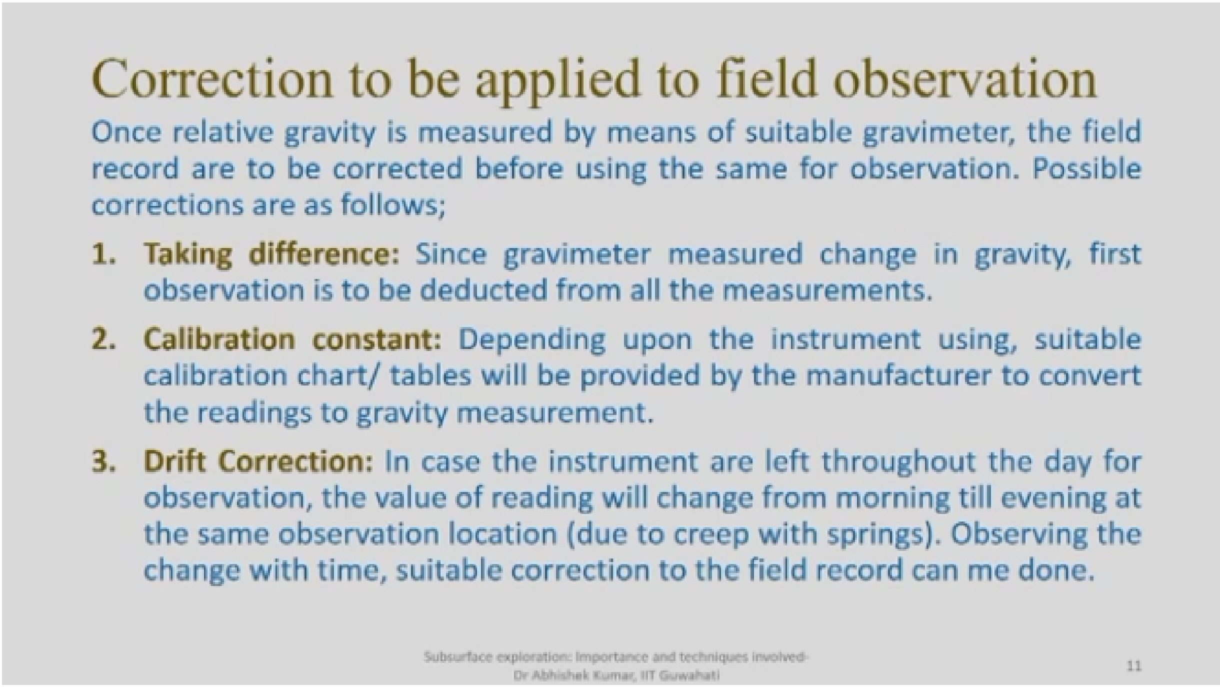

Now we discussed like different parameters which can affect your gravity value at the site of interest, so first of all we have to understand in order to account for each of this parameters, what are the corrections to be applied so that everywhere we are going to measure the gravity value, it is more or less normalized values or like the base factors which can change the gravitational value other than the subsurface medium characteristics it will remain applicable to everywhere.

So the correction which are to be applied to field observations are as follows, first one is taking difference, as I mention here in gravitational survey or gravity survey what we do, we try to find out the relative change in the gravity with respect to datum or maybe mean sea level or any reference point, so whatever measurements you are doing at second, third and further observation point, so grid points you have to take difference with respect to the first point in order to see how with respect to the observation point the change in the gravity is taking place, so this is called as taking difference.

Second is calibration constant, as I mentioned you go for stable gravimeter, you go for LaCoste gravimeter, you go for CG-5 gravimeter, each of those are having a particular way of measuring, so either one is measuring in terms of dial gauge reading of indicating the extension of spring, stretch of the spring, other one is measuring in terms of potential difference, so there will be some kind of calibration constant so that by multiplying those calibration constant with the instrumented record you will get an idea about how much is the gravitational, how much is the measured gravity at that site of interest, so this is called as calibration constant.

Third thing is called as gravitational drift, what happens, considering the, in case the instruments are left, instruments are left throughout your day you will see like with respect to morning, afternoon, the gravitational measurement will change, same way if you go for late evening it will again change, because of the change in temperature if the change in temperature is significant it is going to affect the creep or the extension in the spring, and then it will have direct effect on the measured gravity value, so drift correction is applied so that the change in your stiffness of the spring because of change in temperature throughout the day time, we can take into account, so this is called as drift correction.

Next one I would like to highlight here like all this measurements of gravity is done in terms of mili Galileo which is called as MGAL, which is equivalent to, so one mili Galileo you can consider 10 raise to power -5 meter per second square.

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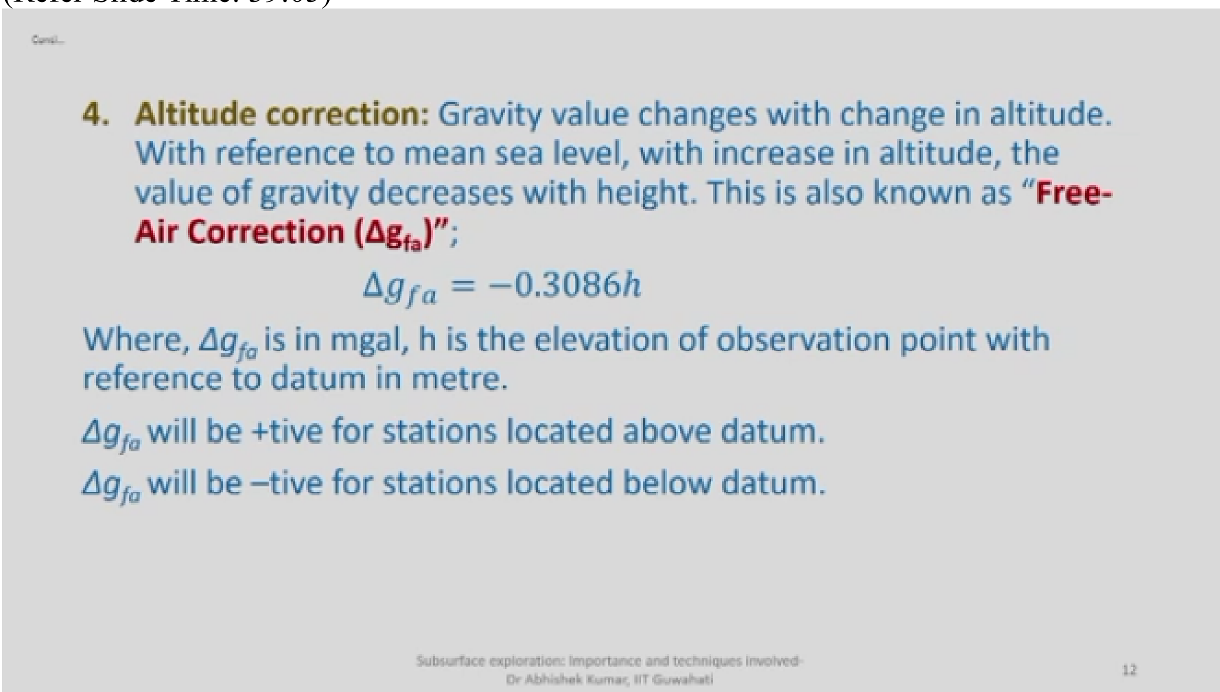

Next one is altitude correction as I mention here because of in case in the distant between the center of the earth and your observation point with respect to change in the elevation particularly increase in the altitude of the observation point, the gravitational pull is going to reduce, so the gravity value changes with change in the altitude with reference to the observation point if there is an increase in the altitude, there will be decreased in the gravity value, this altitude correction is also called as Free Air Correction, delta GFA in different text books you can find the Free Air Correction is referred by different symbols, so depending upon the altitude of the observation point with respect to your datum, with respect to your mean sea level, this is how you can get an idea the change in your gravity value because of change in the altitude, so keeping other things as constant, but because of change in the altitude with respect to the datum at your observation point if you know the value of H, that is the difference between observation point or your datum or observation point and your mean sea level that is going to give you an idea about how much will be the value of altitude correction.

As you are going away from, as you are going above the datum, so this correction which is already given in minus sign will remind positive, that means you will add up this correction, second thing if you are going below the datum so this correction that is Free Air Correction will become negative because you are actually reducing the gravities you have to add minus and minus there will be a plus sign, okay, so this is about altitude correction.

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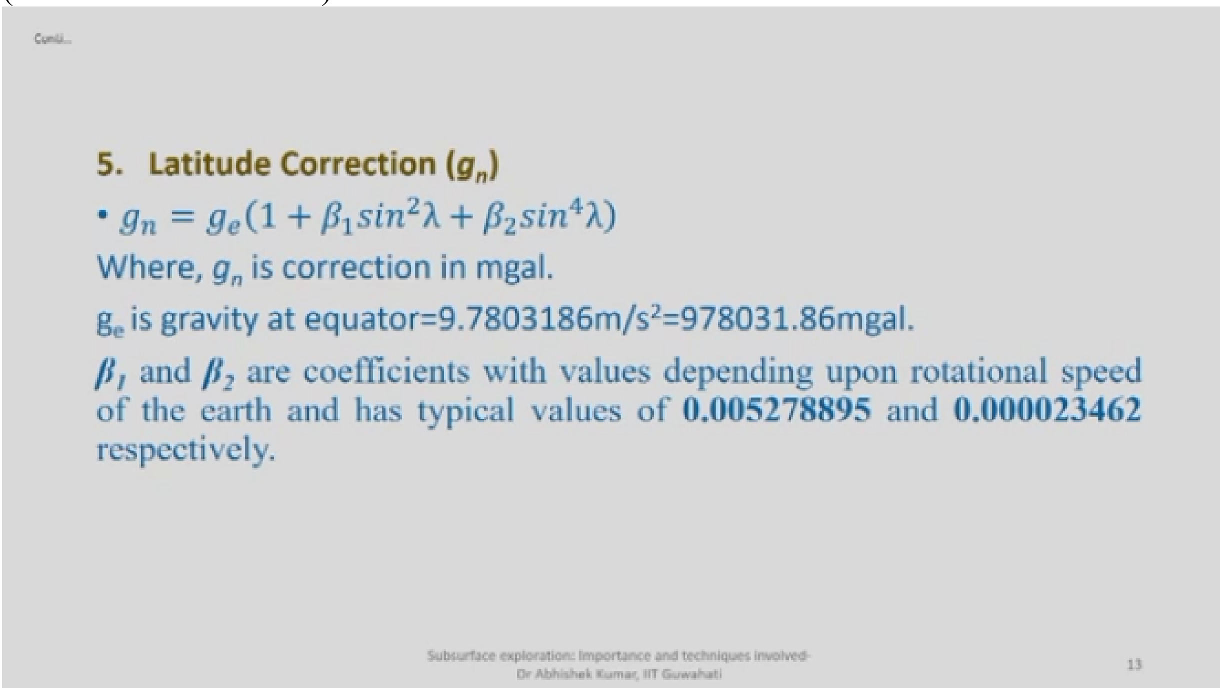

Then comes latitude correction because we know considering the size of the earth, considering the rate at which the rotation is happening of the earth the gravitational pull between the equator and the pole is going to change considering the location of the site, so this is called as, we are interested to find out the normal or the gravitational pull because the gravitational pull and centrifugal force is going to control how much will be the result and gravity at your observation point, so this value of GN with respect to GE that is, the gravity value at equator that is 9.78 meter per second square or to be more précised 9.780318.6, yeah .86 million Galileo, this is the equation of, this is the value of gravity or pulled due to gravity at equator.

The other constants beta 1 and beta 2 are the coefficients which depends upon rotational speed of the earth, typical values are given as 0.005278895 and 0.000023462, so these are the values of B1 and B2, again you can refer if maybe some charts which can give you a value about considering different value of rotation speed, the value of lambda which is not given, so it is the latitude of observation point, the point at which you are actually measuring the gravity value, observation point or observation station, if you know the latitude of that point you can get an idea about, so if you put those values, the value of lambda, the value of beta 1, beta 2 as given here, the value of G that is gravity at equator you can get an idea how much will be the correction because of geographical location of that particular observation point or site.

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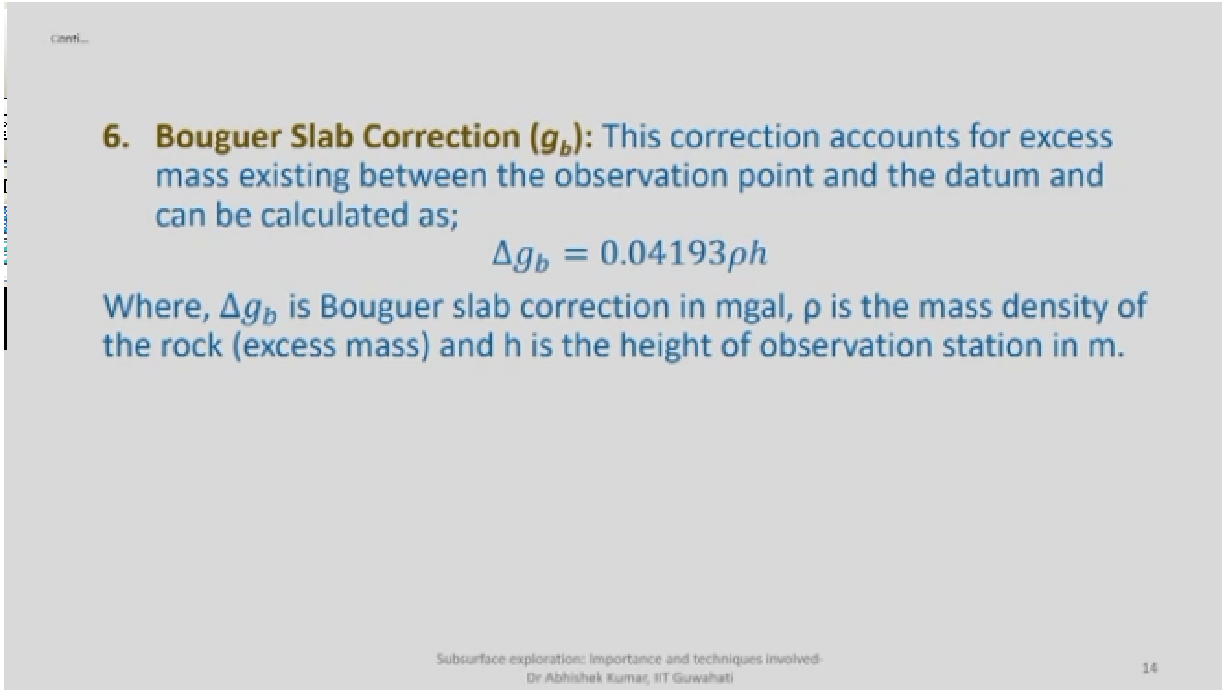

Then Bouguer Slab Correction that is indicated by GB, so this correction takes into account between the bedrock which is more or less similar in the larger area, and between the ground surface or in between this where the subsurface medium is there, whatever, what access mass is existing in addition to other than the heterogeneity available in the shallow and medium.

As a result of which there will be additional gravitational pull at your observation point, so this is called as Bouguer Slab Correction, so you consider between bedrock and your top surface medium, some additional deposit if it is available in terms of slab which is inducing, we considering its density, if it is densities higher than the surrounding medium so the correction will be positive, if it is lesser so accordingly the correction you will be applying, so this correction can be given as delta GB, because you are interested in relative gravity with respect to the observation point, so this can be given as 0.04193 rho times H, so rho is the mass density of the medium or the slab medium, material, and H is the elevation at which the slab is existing, and then the observation station, so once you put this value you can get an idea about Bouguer anomaly, so you had drift correction, you had instrument correction, you have taking difference, you have altitude correction, you have latitude correction, you have Bouguer slab correction, so you understand these are the possible region because of which in addition to heterogeneity in the medium, the gravity value measured at the site of the interest can change, so one by one we are actually removing the effect of all those corrections other than the medium heterogeneity which can affect the gravitational pull at the site of the interest.

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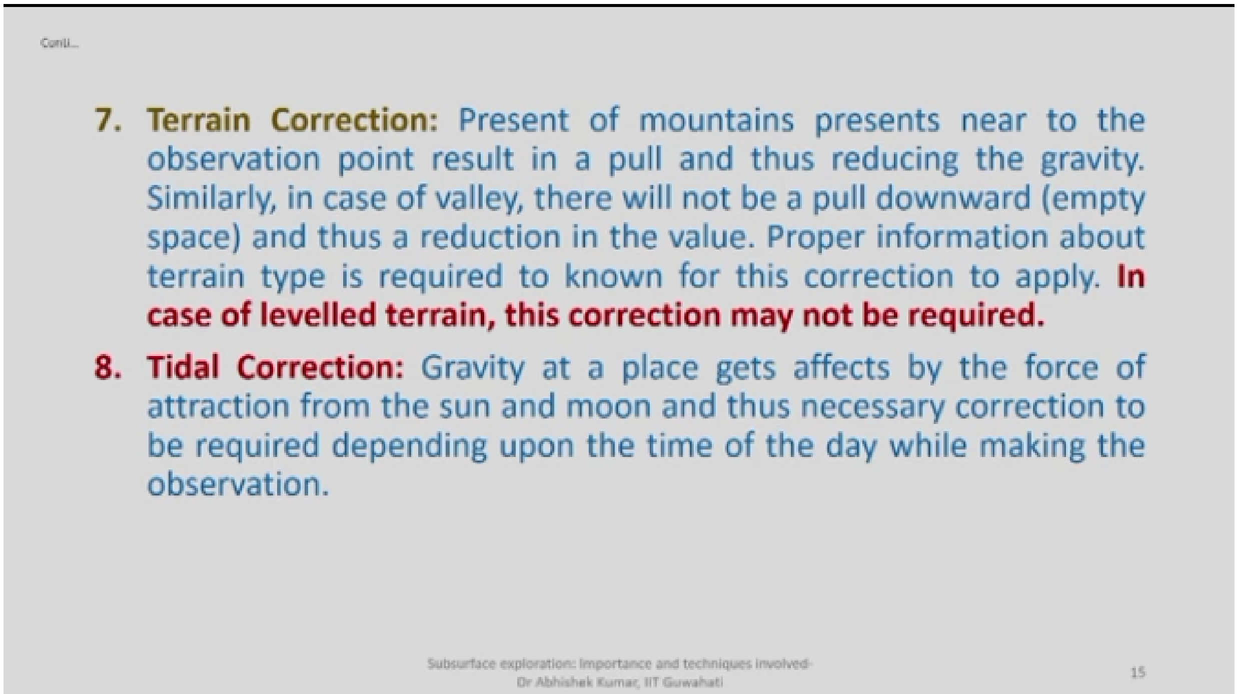

Then terrain correction, it has been we can highlight here like the presence of mountain near to the observation point what will happen, as a result of those mountains above your observation point there will be additional pull in the gravity values because it is against the gravity which is available at the observation point, so mountain is there, which is actually pulling, so the actual value of gravity at the site of interest is going to reduce.

Similarly in case of values which is actually vault spaces I can tell, so there is no denser medium available, ideally if the denser medium will be there, it is going to increase the value, but it is not there so it is actually reducing the value of gravity at the site of the interest, so you have to apply more correction if considering the terrain type to account for terrain correction, you have to highlight, I'd like to highlight here like in case of level ground surface, or level terrain this correction will not be required, because there will not be any kind of value or mountain which is going to reduce your actual gravity at the site of the interest.

Tidal correction as I mention here because of the force of attraction from the moon and as well as the sun there will be always tides, so depending upon what time of that you are measuring, what is the position of those tides you can apply suitable correction if it is required, so tidal corrections, gravity at a particular site affects by the force, from the force of attraction from the sun as well as moon and thus necessary correction to be required depending upon the time of the day, so 8 corrections are there.

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Now before going to solve any numerical problem let's discuss like these gravity survey, so you consider at your observation point you had, depending upon whether its terrain is leveled or not, depending upon whether tidal correction will be required, depending upon whether latitude correction how much will be the value, Bouguer correction, altitude correction, and so on and so forth, and then calibration constant for the measuring instrument, once you apply all those things you will get some value of gravity, and then there will be some generalized value of gravity at that observation point, the difference of these two is possibly going to give you an indication about that difference will always be there, because there will be always some kind of heterogeneity in the subsurface medium, so this difference between the generalized gravity and the gravity after applying all those corrections that is called as Bouguer gravity BG, that is going to give you an indication about what kind of heterogeneities available beneath the ground surface, so this method gravity survey you can use it for fossil fuel exploration, you can use it for mineral deposition exploration, you can use it for subsurface investigation, you can use it for identification of cavities, I had given already one example to understand the geology in the region, in order to understand regional and global level tectonics studies, so that also you can get an idea.

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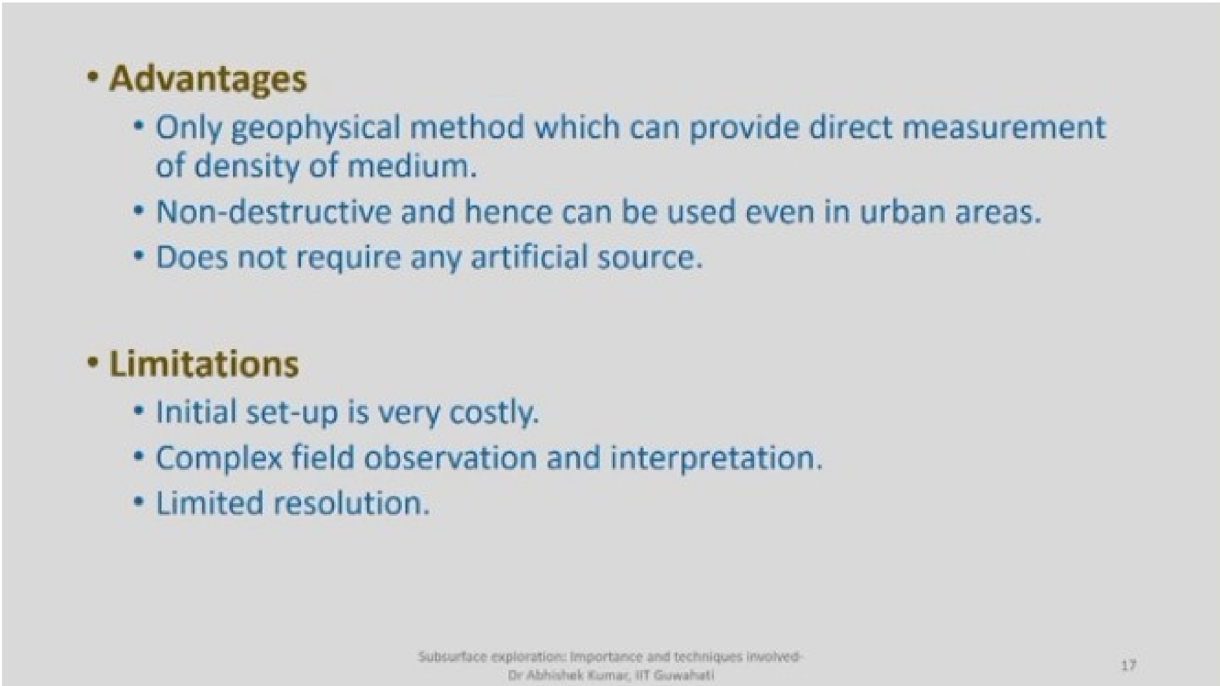

Now there are certain advantages as well as disadvantages here, advantage is it's the only method which gives you direct indication about how much is the rock density below the ground surface, second advantage here as you might be seeing like we have small instrument we go to the site and measure it, so we don't require any kind of external source or artificial source for generating any kind of resistance in the, because of which the soil or the subsurface medium is going to offer any kind of resistance, and it is nondestructive, you are simply measuring any kind of gravity pull at the ground surface, so it is more suitable for urban areas where you can, you required to do some test to understand subsurface medium characteristics without disturbing, or without causing much of noise.

Limitations, initial setup is very costly, second is complex field observation because you have to have expertise whatever I showed you simple observation, but considering the regions for heterogeneity and the region which can affect your gravity at the site of interest, then how much will be the tidal correction, how much will be the terrain correction, that requires particular expertise so that you can get an idea more precisely how much will be the correction required.

Then limited resolution, depending upon the geology of the site, the depth up till which you can get an idea about interpretation that will restrict your resolution with respect to the depth, as you go for larger and larger area you can get more idea about tectonics, you can get more idea about cavity, you can get more idea about mineral deposition, geology variation and so on and so forth.

Now we discussed about advantages, we discussed about limitation, we discussed application, also we discussed about different corrections to apply for field observation so that the final value you can use it for interpretation.

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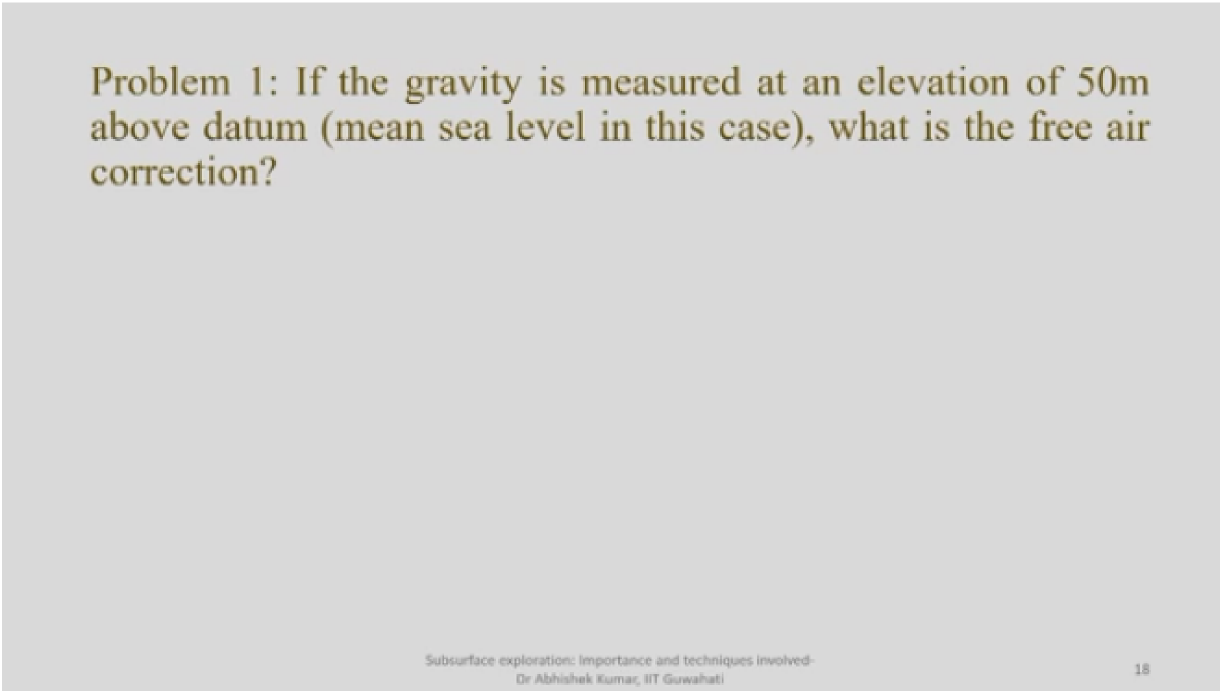

Now let’s see some numerical problems, so the first problem is if the gravity is measured at an elevation of 50 meter, see you have some gravimeter, you took to some observation point which is 50 meter above datum in this case maybe mean sea level, so it is required you have to find out how much is the altitude correction or free air correction, so let’s solve this, so what is given here, the value of H is given as 50 meter, if you remember the free air correction delta GF it was given as -0.3086 times H, if you put the value here you will get -0.3086 times 50 that will be equals to -15.43 mili Galileo, so this is the depending upon the altitude of your observation point, this is the correction which will be required to take into account the altitude correction, so this is the value of free air correction.

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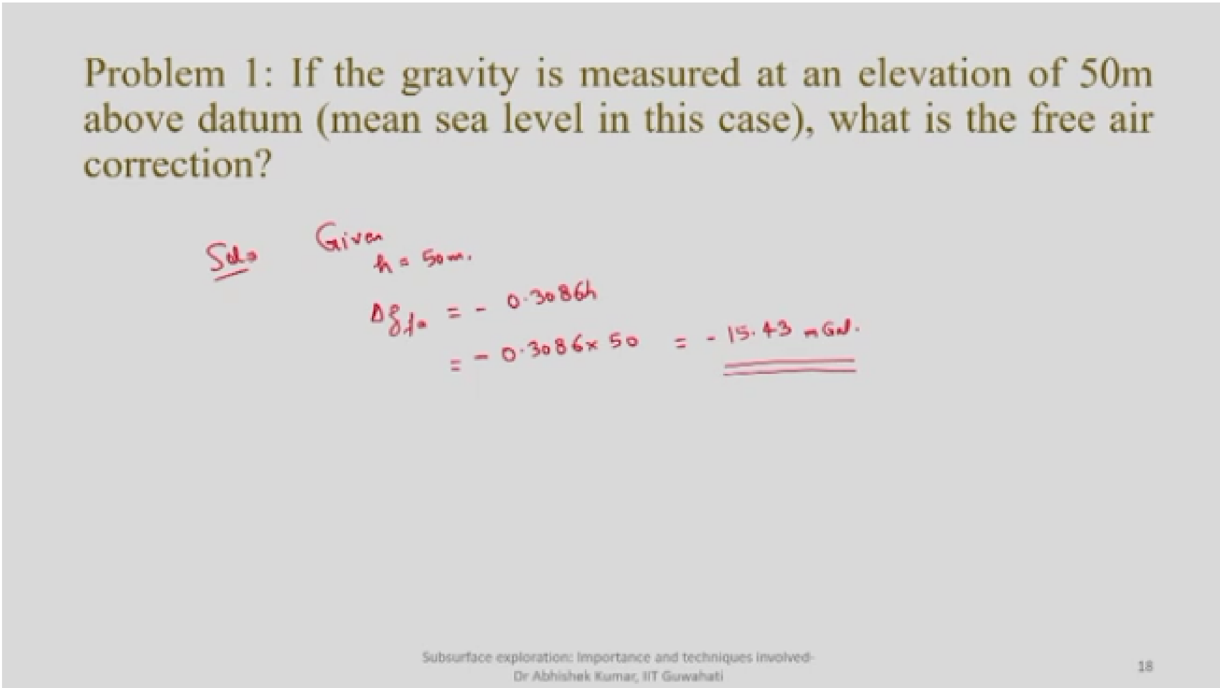

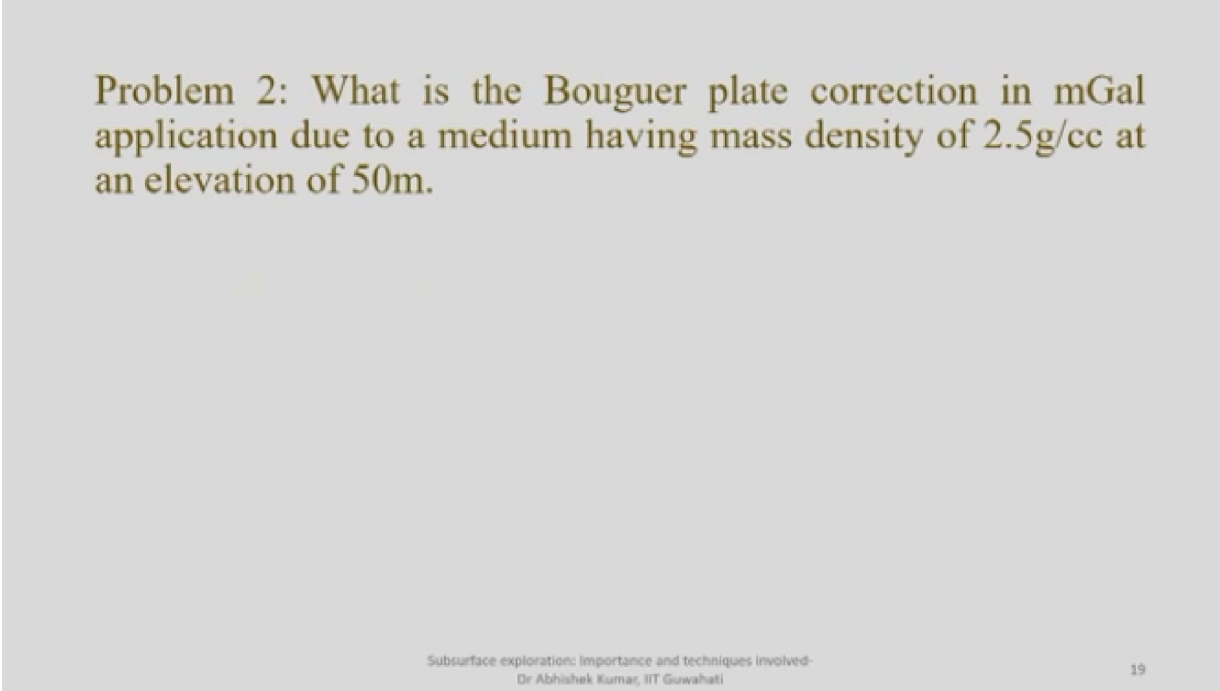

Second what is the Bouguer plate correction in mili Galileo due to the medium having mass density of 2.5 gram per CC at an elevation of 50 meter, so you have some material which is available having a density of 2.5 gram per CC above bedrock and the observation is made at 50 meter elevation, so the Bouguer elevation that is delta GB was given as 0.04193 times rho times H, the rho value is given here as 2.5 gram per CC, H is given as 50 meter, same value is because already there is constant value of 0.04193 has been developed considering the value of rho, the standard value of gram per CC, then elevation in meter, so you can directly put this value here 0.04193 times 2.5 times 50, so this is going to give you the value as 5.24 mili Galileo, that is Bouguer correction.

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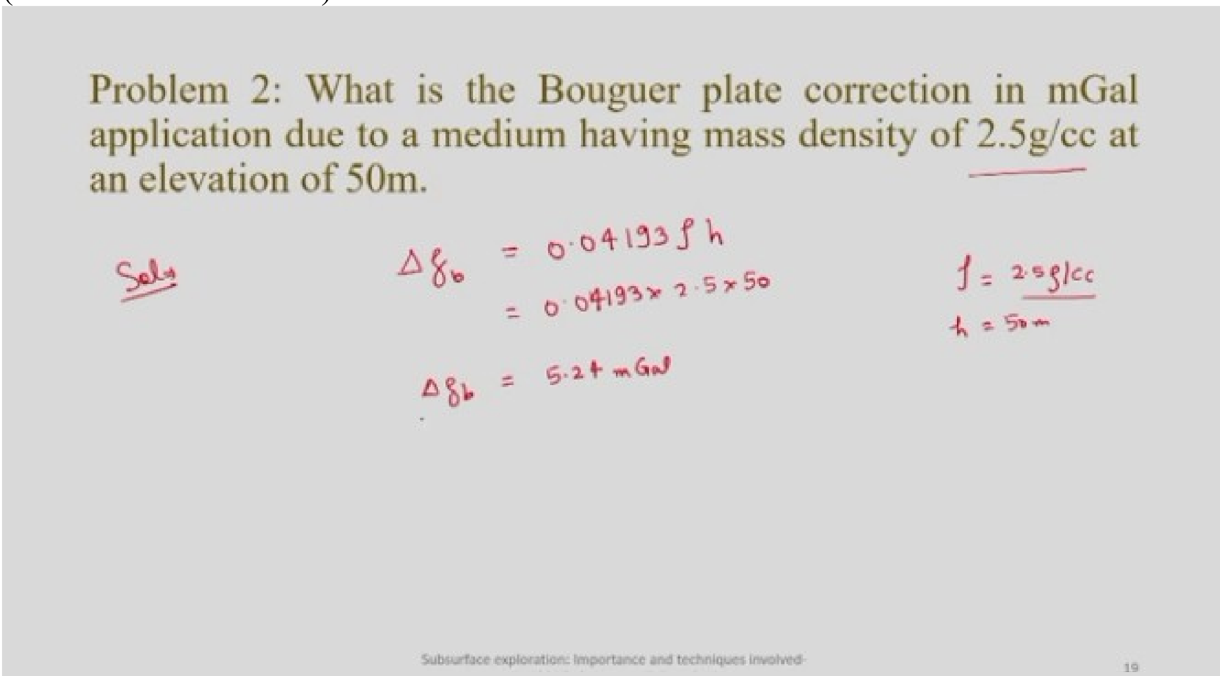

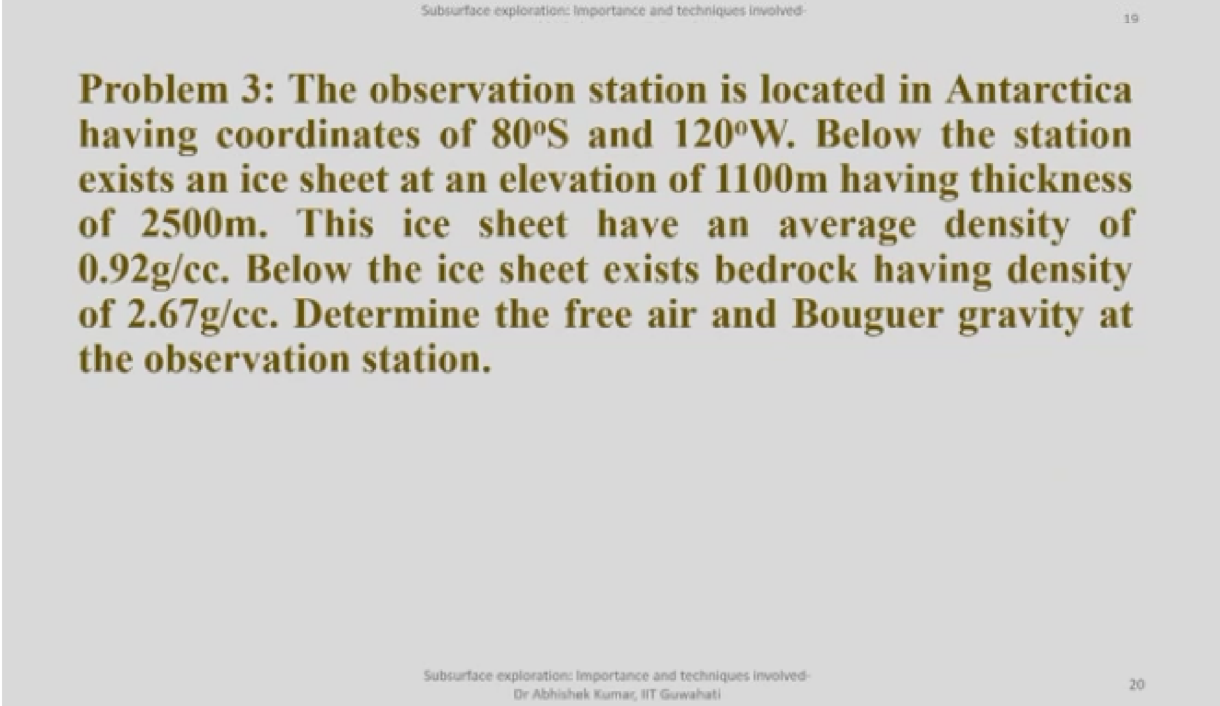

Now these are like one by one if you know the corrections, now third correction is, third problem is the observation station is located in Antarctica, so longitude and latitudes are given in addition it is found like below the observation point there is an ice sheet, so because of the presence of ice sheet above the bedrock there will be some kind of full or maybe reduction in the gravity depending upon the density of the medium, the ice sheet is having a thickness of 1100 meter located at an elevation of 2500 meter, located at an elevation of 1100 meter, so three things are given here, density is given of ice sheet so that means you are interested to find out Bouguer correction, elevation is interested given, so you are interested to find out free air correction then altitude correction is given, so three corrections are required to be determined here.

Now let's solve this problem, so first is given as if you go for solving first one delta is given as 80 degree, beta 1 is given as 0.005278895, beta 2 is given as 0.00002342, so what was the correction given GN that is latitude correction, GN is given as GE 1+ beta 1 sine square lambda + beta 2 sine 4 lambda, now put the values here, we know the value of gravity, 1 + beta 1 0.005278895 times sine square 80 + 0.00002342 sine 4 80 that is going to give you the value as 983060.7 mili Galileo.

Remember when you're solving it, depending upon the value of G where that it is in Galileo where that it is in mili Galileo the value of GN will be there, then apply the second one that is free air correction, delta GFA so we know the value of delta GFA is given as -0.3086 times elevation, elevation is given as 1100 meter, so that is going to give you the value as -339.46 mili Galileo, so free air gravity that is called as free air gravity, after I applying free air correction that will be called as GN, that is gravitational pull at the site considering its latitude and + delta GFA, so this will be equals to 983060.7 – 339.46 that will become like 982721.34 again mili Galileo.
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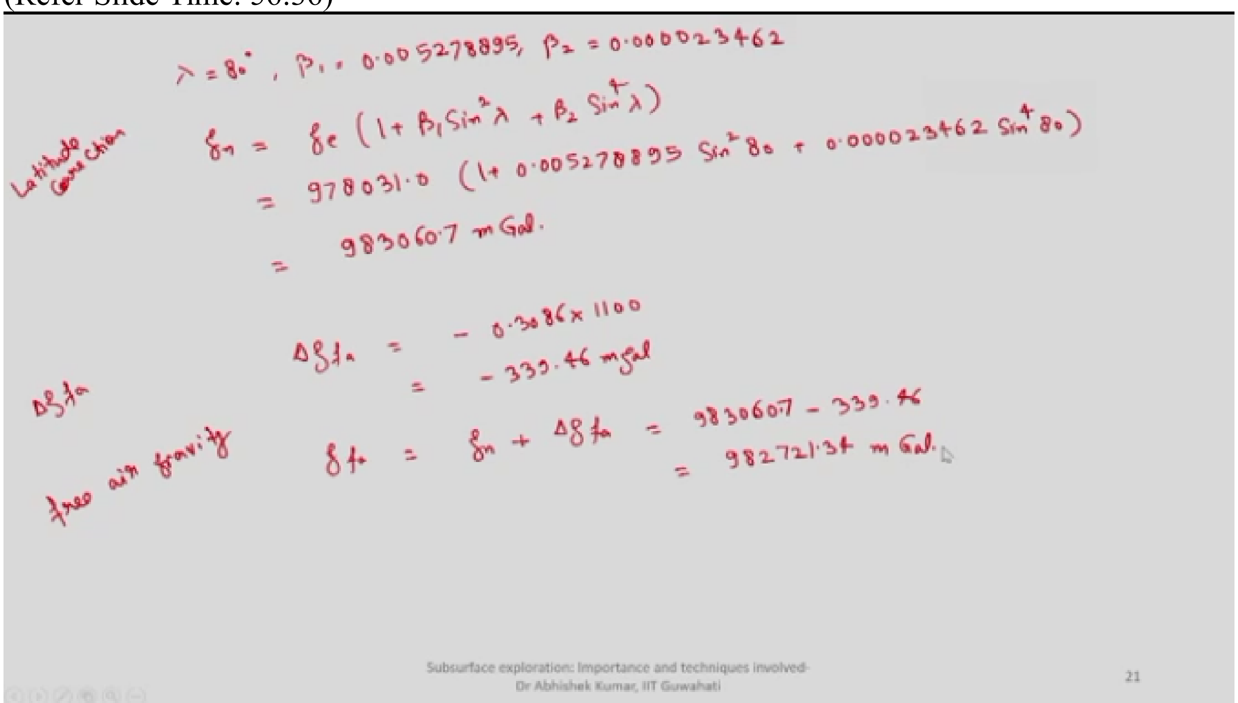

Next one we are going to apply is Bouguer correction, Bouguer slab correction that is delta GB, so delta GB is given as 0.04193, we are already discussed I'm just reusing this formula, 0.04193 the density of ice medium is given as 0.92 gram per CC, so we can use it 0.92 into 1100 was the elevation of observation points that's how you can get an value of 42.43 mili Galileo, now this was about Bouguer corrections, so how much will be the Bouguer gravity that is GB value will be called as GN + delta GFA + delta GB and so on, if you have tidal correction you have terrain correction, you keep on adding those things finally you get your corrected gravity anomaly. So 983060.7 – 339.46 + 42.43, so this is going to give you the value of

982763.7 mili Galileo or 982.76 Galileo, so this is your actual gravity at the site of interest considering the location and other parameters.

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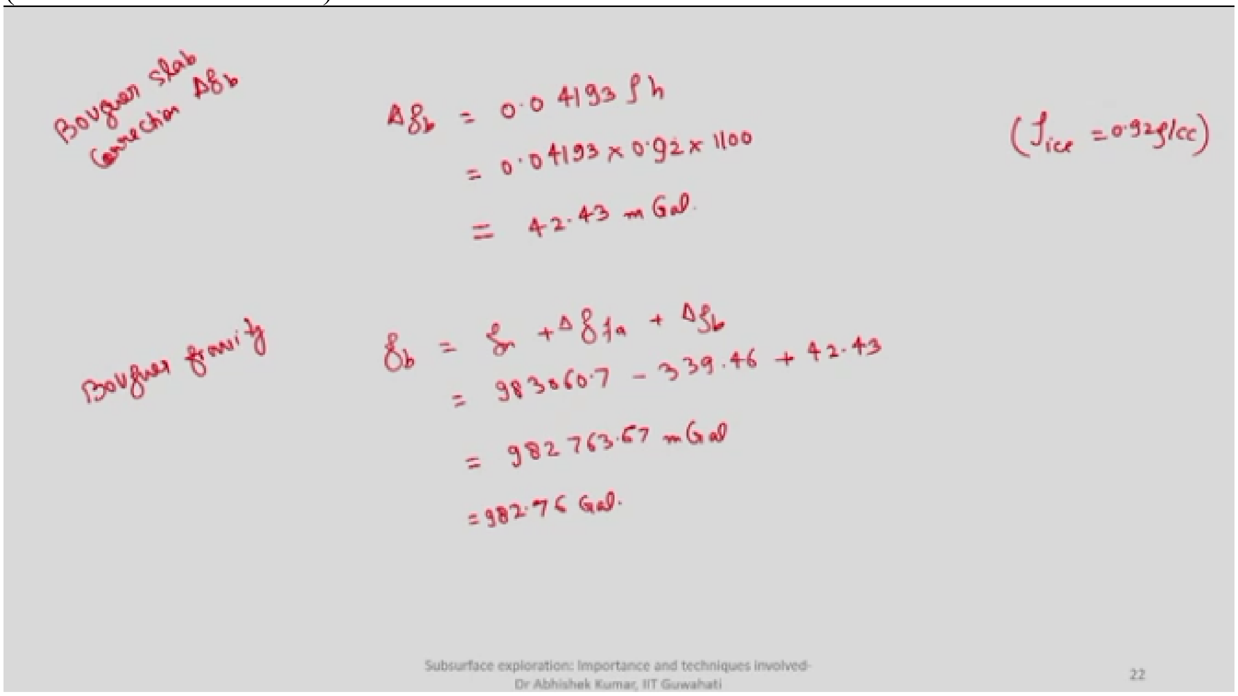

Now same side you go and if you do field recording and the difference of that and this correct will give you how much is the change in your subsurface medium characteristics, so that's how more and more parameters are there, more and more information is there, more and more correction keeps on applying and then that's how you will be able to interpret how much will be the value of gravitational pull and how much is the subsurface heterogeneity available, so thank you so much.

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