Applied Seismology for Engineers

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Week – 02 Lecture - 03

Lecture – 04

Hello everyone, welcome to lecture 4 of the course Applied Seismology for Engineers, myself Dr. Abhishek Kumar. In the earlier 3 lectures, we discussed primarily the continental drift theory, elastic rebound theory, and how these give an explanation about different land masses across the earth, which are in continuous motion with respect to each other. So, there are some boundaries which are moving towards each other, some boundaries where there is movement away from each other, and then there are boundaries which are moving past each other or relative motion with respect to each other in the horizontal direction. So, depending upon the type of movement, depending upon the rate at which the two boundaries are moving, there will be accumulation of strain energy along the plate boundaries.

Primarily, when these are happening along the fault planes, these will lead to an increase in the buildup of stresses. When the stress buildup exceeds the institution's strength of the material, there will be failure in the material. This failure may be in terms of heat, in terms of rupture, and subsequently, there will be development of seismic waves which will be propagating from the point of origin or the point of release of energy, interacting with the near-surface medium, interacting with deeper layers also, and subsequently, there will be attenuation in the seismic wave characteristics, which we will discuss in later lectures. At a particular site of interest, if you are interested in basically the response of the site, of the building, or the soil with respect to these seismic waves, which are significantly altered in terms of their properties as moving from the focus towards your site of interest.

So, how the system is going to respond to those seismic waves that will define whether the system will undergo complete collapse, whether there will be major cracks, whether there will be minor cracks, or whether there will be loss of strength. So, whenever we are seeing the outcome of earthquakes, it is primarily in terms of damages, in terms of casualties, but the entire process which is behind these damages is starting from the origin, that is, from the focus or the release of energy from the focus, then subsequently interacting along the propagation path, interacting with the material, and reaching at a particular site again it will be interacting with the material. So, it is the modified ground motion which is responsible for loss of damages, lots of building collapse. In lectures 2 and 3 we discussed what fault plane solution is, then we also discussed that fault plane solution is basically a plane, but the orientation of the plane is given in terms of two parameters. One is the strike value, which is going to give you how much is the inclination of the intersection of the fault plane with respect to the ground surface. So, the intersection of the fault plane with respect to the ground surface is going to give you a trace on the ground surface, primarily a linear feature on the ground surface. So, what angle this particular linear feature is making with respect to north. So, this particular angle is called the strike of the fault. We can go to the next slide, okay.

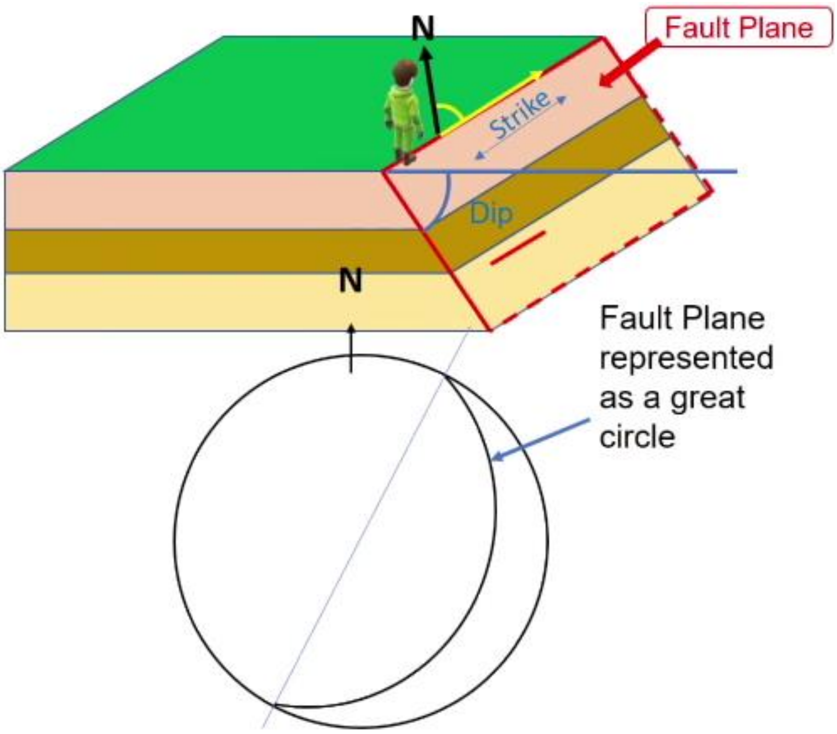


Fig.1 Representation of a 3-D Fault Plane in 2-D using Stereographic Projection

So, where we can see basically this is the fault plane on which there is movement. So, you can see this is one fault block and adjacent to this particular fault block there will be another fault block where the two fault blocks are moving, either moving towards each other or moving away from each other, or there is relative motion between the two. So, one is moving towards each other, the other one is moving away from each other, or there is relative motion between the two blocks. So, depending upon the type of movement, even this particular mechanism which is happening at the focus, based on which we can classify whether it is normal faulting, whether it is reverse faulting, or strike faulting. So, primarily, as I mentioned, once we are interested in finding out the fault plane solution. So, basically, we are interested in finding out what is the orientation which the fault is making with respect to strike or with respect to the north. So, if this is the direction of the north along the ground surface, then what angle this particular fault trace, which is, you can say, the intersection of the two-dimensional fault plane with respect to the ground surface. So, in the fault plane which is inclined and the ground surface when two are intersecting, it is going to create linear features or the trace on the ground surface. So, what this particular linear feature is going to make with respect to north is going to define the value of strike. Again, this is the feature which is available on the ground surface. So, whenever we are looking at any fault maps or any, maybe, seismological atlas, the orientation of the faults as appearing on the map or on the ground surface will be indicated or will be represented on such maps in terms of their respective strike values. Now, looking at this particular picture, what we can understand is that strike is basically only the representation where the fault plane is meeting with the ground surface.

It is not going to give you a complete picture of the two-dimensional plane. This is the fault plane which is actually taking part in terms of accumulation of strain energy and subsequently in terms of earthquake occurrence. So, in addition to strike, we have to have one more parameter that is dip angle. So, dip is basically if you consider the fault plane, it is an inclined surface where the intersection of this inclined surface with respect to the ground surface is marking an indication of the inclination of the fault trace with respect to north. Same way, if this inclination we are going to see, so how much this inclination with respect to the ground surface, this particular angle it is making is called the dip.

So, dip is going to give you how much is the inclination of the fault plane with respect to horizontal. Strike is going to give you how much is the inclination of the fault trace with respect to north. See, strike and dip alone are sufficient to define a fault plane, but in order to understand whether the particular fault plane is undergoing movement towards each other, or the two blocks along the fault plane are undergoing movement towards each other, away from each other, or sliding past each other, we have to have one more parameter that is called the rake angle. So, one more parameter which is defined as rake angle is basically going to tell you for a known value of strike, for a known value of dip, whatever is the fault plane, below this particular fault plane there will be a footwall; above this particular fault plane, there will be a hanging wall.

So, during a particular earthquake, or the ongoing process which further leads to an earthquake occurrence, during this particular process, what is the nature of relative motion between the footwall and hanging wall? Usually, it is the movement in which the hanging wall is moving with respect to the footwall. So, if we say this is the footwall and this is the hanging wall, how the footwall is moving with respect to the hanging wall, it is moving in this direction, it is moving along the strike direction, it is moving along the dip direction, or any other direction other than purely in the direction of dip or strike, it is going to give you the value of the rake angle measured with respect to the strike of the particular fault. So, depending upon the direction in which the footwall and the hanging wall are moving with respect to the footwall, how this particular inclination is making an angle with respect to the strike, that particular angle is called the rake angle, which has been discussed earlier also.

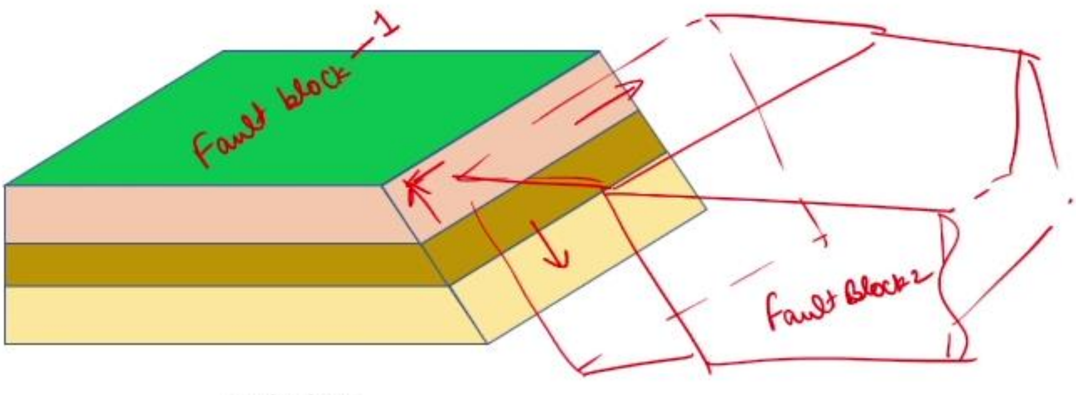
So, primarily, if we are interested in representing the fault plane solution, so three angles are required. One is the strike value; the second one is the dip value. These two will be required and sufficient to represent a fault plane. If we have to represent a particular mechanism, fault plane solution as well as the mechanism during a particular earthquake, then in addition to this, we will also be requiring a value of the rake angle so that you can very explicitly represent the nature of movement which triggered during a particular earthquake or if some movement, some GPS measurements are also there, going to give you what is the in-situ measurement which is happening, maybe per year or per decade. Even those can also be presented in terms of dominating fault mechanism. So, finally, what we understood is that the plane which is leading, to rupture, it is leading to melting of the material, it is leading to heat; it is basically a two-dimensional plane, but this two-dimensional plane in general is located in a three-dimensional space.

So, you are having a sphere; you are having the earth. On the ground surface, you might be having some trace of the fault, but it is basically a two-dimensional structure, but considering the dip angle also. So, it is basically represented in three-dimensional space: some value of inclination, then some length, some width, and this again is not constant every time. So, it is again rotating with respect to the north. So, you can say the plane is two-dimensional, but in the three-dimensional space where the strike and dip values also can possibly change, we are talking about some three-dimensional parameter. So, whenever we are talking about the representation of these three-dimensional features, which is primarily indicating the dimension of fault strike, dip, as well as the potential rake angle, we have, in general, it is in three-dimensional space, but whenever we are interested in representing. So, that we can understand what is the dominating fault mechanism on a particular fault or in a particular region, or how these dominating fault mechanisms of two nearby faults are influencing the failure mechanism or maybe the fault plane mechanism of a third fault which is significantly influenced by the seismic activity of these two faults, we can have those studies. Thirdly, if we have to have an understanding about what are the characteristics of ground motion which can be generated, we can again take that information about strike and dip into account to find out what is the orientation of my fault plane solution and, in addition, if the rake angle is there or whether the information about a particular earthquake was strike-slip faulting or dip-slip faulting or normal faulting. So, that can also be accounted for and then subsequently can be used in terms of both understanding the ground motion characteristics as well as in order to generate synthetic ground motion. So, the actual phenomena or actual problem at a particular site is happening in three dimensions, but to represent this, to represent the fault plane solution and typical movement during a particular earthquake, it is very much important that such representation should be done on a piece of paper, such that some maps, which are giving you an indication about past earthquake locations, which are also giving you information about the trace of the fault plane. But in addition to these two, as the dip angle we cannot show on the two-dimensional map, rake angle we cannot show on the two-dimensional map. So, what additional thing can be done is you can take help with respect to maybe beach ball solution, which was discussed in earlier lectures, which will also give you an indication about depending upon the arrival nature, the nature of first P-wave arrival, which was compression or tension at a number of recording stations in your epicentral region. Taking that into account, one can develop, which we also discuss in terms of animation, like if it is normal faulting, what is the basis upon which the beach ball solution can be developed.

Similarly, when we are talking about reverse faulting also, again, what is the basis? What is the nature of P-wave which are dispersing? Taken into account the nature of stresses which are there primarily along the fault plane and another perpendicular plane to the fault plane, that is, the auxiliary plane. So, we have already discussed this in earlier lectures: how we can represent a particular mechanism of faulting during a particular earthquake or in two-dimensional space in terms of the beach ball solution. So, the beach ball solution is going to give you in terms of relative motion which is happening along the fault plane, what are the components which are compressive, and what are the components which are tensile in nature, based on first P-wave motion. Whenever we are interested in finding out P-wave motion or the development of the beach ball solution, we will be requiring a lot more information about the first P-wave arrival from nearby recording stations. So, that is related to the development of the beach ball. If, in a particular region, we are having information about the fault plane solution, we can take that information and, again, with respect to stereographic projection, which we will be discussing in today's lecture, one can again represent the fault plane orientation, the dominating direction of movement, or the rake angle again on two-dimensional space.

So, three-dimensional is actually the problem which will be in terms of fault plane solution and typical movement, but representing it on a two-dimensional plot, which is basically the map, we can say, maybe seismic atlas map, or if we are discussing about maybe mineral depositions, again we can refer to this. So, that we can find out what are the bedding planes, what are the directions of mineral depositions. If we are again talking about faults, so, everywhere we can refer to, even the orientation of conformity we can discuss and we can take the help of stereographic projection to represent those in terms of two-dimensional space. So, as I mentioned, there are a lot more applications for this two-dimensional projection of three-dimensional features primarily related to orientation, and if some signatures, in-situ signatures, are there related to the indication of movement, they can also be represented. So, here, stereographic projection can be done or can be used in cartography, it can be used in crystallography, it can be used in structural geology also. So, what are the bedding planes, what are the planes of discontinuity, and then depth direction, as I mentioned, not only related to fault planes, but also in terms of general understanding about the rocks which are available, what are the typical bedding planes available in particular geological formations. Then, of course, in stereoscopic photographs also, one can take stereographic projection into account to represent the variation in terms of physical dimensions which are happening perpendicular to your ground surface on which generally you represent a particular two-dimensional characteristic. So, basically, in stereographic projection, what we try to do with the help of stereonets, which is again a graphical representation of maybe great circles and small circles or representation of latitude or longitude of a particular plane or a position, we can take into account and try to represent it on a two-dimensional space. As mentioned over here also, so in this particular figure, we can see the actual fault plane is in three-dimensional space; we are having some value of dip, we are having some value of strike, and in actuality, keep on considering that the strike value as well as the dip can change. So, it is basically we are dealing with three-dimensional space. So, how these three-dimensional space characteristics can be represented on two-dimensional space is called stereographic projection.

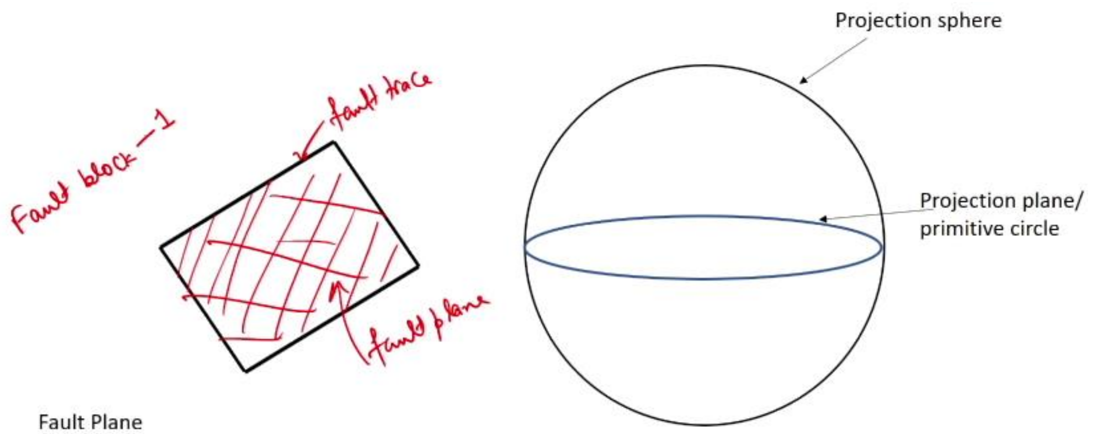
So, one typical example given over here is about the primitive circle, and then you can see the plan remains the same. So, you are still talking in terms of two-dimensional space, but whatever was available over here has been represented using stereographic projection in two-dimensional space. How we are going to do it and how these two things are correlated with respect to each other, that we will discuss in subsequent slides. So, overall, stereographic is basically the representation of the fault plane along with the dominating direction of movement of the footwall with respect to the hanging wall using stereographic projection.



Fault Plane

So, let us come back to the same problem; that means we are having a fault block. You can call this a fault block. This is a fault block, or you can say this is a fault block one; subsequently, there will be another fault block. If we remember our problem, this might be another fault block which is undergoing some kind of movement. So, you can say this is fault block 2 and then depending upon the direction you can say if this is going like this, the other fault block is going like this, you can say it is primarily a strike faulting. On the other hand, you can have the hanging wall going like this, the footwall going like this, normal faulting, or when the two blocks are moving towards each other, that is the typical representation of reverse faulting. The nature of movement and the definition has already been discussed in earlier lectures. So now this we can remove because now this is the representation of what are the different fault planes which are available in terms of governing the fault plane orientation during a particular earthquake. So, this is their fault block 1, and based on our understanding so far, we can say this is our fault plane along which typical movement has happened. Remember one thing here that we will be using stereonets or even beach ball solution; we will be only representing the orientation of the fault plane as well as, if possible, the rake angle. Now, where we will be representing here what is the area which is undergoing rupture.

In a later stage, we will also discuss what rupture is and how that is referred to in this particular lecture related to earthquake occurrence. So, we are not talking here about the rupture characteristics of a particular fault plane or of a particular fault. So, this is the fault plane. If you go to the ground, this fault trace may be available. If the fault is exposed on the ground surface, you may see some fault trace; otherwise, you can go and seek for linear maintenance, further go for additional traces which are an indication of the presence of a fault in a particular region. Go for detailed investigation and find out whether there is a possibility that a fault is present in a particular region or not. Ok, so this is the three-dimensional space, and primarily we are looking into a two-dimensional plane in this.



Now, here, this is the plane which we are talking about, the fault plane. So, what we do is basically whenever we are told that we have to develop stereographic projection or this on a stereonet, we have to project a particular fault plane. So, this is the fault plane. What we are trying to do in this particular lecture is consider this a projection plane, which is usually perpendicular to your horizontal plane, or as an observer, I am looking perpendicular to this projection plane. So, if I am looking in a straight direction, in the horizontal direction, I am seeing a sphere which is lying in front of me, and then I am interested to find out or interested to develop the projection of this particular fault plane, which is actually the orientation beneath the ground surface on a particular plane which is called a projection plane or primitive circle, which is actually a plane lying horizontal. So, you can say initially I took a projection sphere, and then on this particular projection sphere, I took a projection plane, maybe a two-dimensional rectangle, and the intersection of this two-dimensional rectangle is a two-dimensional rectangle or a projection plane. So, once this particular projection plane cuts the projection sphere, we will get, along the periphery, along the circumference of the sphere, whatever points we are getting. If you join all those points, we will get the primitive circle, which is again located in the horizontal plane; this is the plane in which one is interested to represent a particular fault plane. So, this is basically a primitive circle used to represent a fault plane. So, whenever we are told that a fault plane has to be represented, we will be representing how this particular fault plane, in terms of projection—different ways are there in which projection can be taken, but finally, we will be representing the fault plane on the primitive circle. So, if the map is ready, we will be looking at the primitive circle such that how the fault plane will be represented if you are looking from the top. So, I will be looking from the top. Whenever I am looking at some stereographic projection or a stereonet, how the lines on a stereonet are shown. It is basically you are looking from the top, as an observer, when you are looking from the top, I am looking from the top on a particular two-dimensional plane in which some signature of the fault plane, which was not located completely on the primitive circle but now, if you see this particular fault plane, you can see point O is representing the circle of this primitive circle. I have to put my fault plane such that it should pass through this particular point O. The fault plane remains the same, so I have just taken the fault plane over here; slightly, I have increased the size so that it can match the size of this particular projection sphere. Now, here we can see, so there is a sphere along which on this particular sphere I have put my fault plane. So, wherever the projection plane, and the fault plane are intersecting, we can get this type of figure, which is you can say is the intersection of the fault plane with the projection sphere. So, the projection sphere and then you put your fault plane over there. So, whatever interaction is there along the circumference or along the boundary of the sphere, this is called the projection of the dipping plane. This is basically, if you see, this is the direction in which it is dipping. So, fault dip—how it is dipping beneath the ground surface. This is to measure the strike value; this is to measure the orientation; this is used to measure the dip value. So, this is called the projection of the dipping plane. Now, whenever I am interested in developing the stereographic projection, I am basically interested in how the projection of this, the projection of the dipping plane, can be transferred to the primitive circle because the dipping plane is, again, if you see, the dipping plane is some points or the intersection of the fault plane in the projection sphere. I will not be using the projection sphere; rather, I will be using the projection plane or primitive circle to represent the fault plane in the two-dimensional space. I will not use the projection sphere there.

So, if you look into this particular part or the projection of the dipping plane, it is still giving me an intersection or idea about what is the orientation of the fault plane in the dipping plane as the intersection of the fault plane with respect to the projection sphere. What I am interested in is the projection of this dipping plane on the primitive circle because finally, I will be representing the fault plane on the primitive circle. So, what are the orientations that are being transferred from this particular dipping plane on the primitive circle? That is going to give me the stereographic of my dipping plane. So, this is the projection of the dipping plane; this is the dipping plane projection. And which are given over here, this is the projection of the stereographic projection of the dipping plane. So, we had some dipping plane; how the projection of this dipping plane is being transferred to another plane, which is called the primitive circle or projection plane. Finally, whatever you are getting over here, this is the stereographic projection. So, when basically we are asked, like we have to go for stereographic projection or we have to find out based on a stereonet what is the fault plane solution, we are basically interested to find out the orientation of the fault plane on a primitive circle as it will be appearing on the ground surface. So, I am considering the projection plane or primitive circle as my ground surface on which I will be representing. Later on, if I am going to use this particular solution or stereographic projection, I can use it further whenever we are having information about fault trace, maybe past earthquake information, epicenter location of those earthquakes. In addition to those, we can also take this into account and put over there representing what is the orientation of the fault plane, dipping plane, and possibly the rake angle.

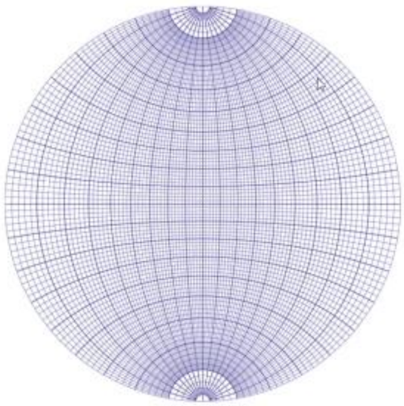


Fig.2 Wulff net (Equal angle)

- Used when angles are meant to be preserved.
- Used in mineralogy.
- Projection is done onto both the upper and lower hemispheres of the sphere of projection.

So, typically, as I mentioned earlier, not only in fault understanding but also stereographic projection has many applications primarily in rock mechanics, in mineralogy, in crystallography, and in stereographic photography also. So, primarily there are two types of projection which can be done. You can go with the first one. The first one is called Wulff's equal angle projection. We can see over here all the projections which are shown—again, this is the primitive circle. So, you can say this is the primitive circle; that means whatever we are looking at is basically a graph representing the ground surface or how the ground surface is represented on the stereographic projection. All is the ground surface; taking the strike value and dip value, we will be representing on the ground surface the fault plane solution. So, Wulff net—that is the first type of stereographic projection—is generally used in such a way that angles remain conserved or the shape remains conserved. So, if we are interested in taking the projection of a circle, finally, the projected shape will also remain the circle; that is why it is called equal angle. So, whatever was the angle with respect to the reference point before, the same will remain conserved whenever we have transferred or we have taken the stereographic projection. So, it is generally used when the angles are meant to be preserved. So, here even in terms of projection, you can see all these are part of circle and these are appearing also like a circle because the angle has been preserved while developing these stereonets. Primarily, these are used in terms of mineralogy. Again, whenever we are discussing the Wulff net, the projection is generally done; it can be done in the upper or lower hemisphere, taking into account the primitive circle as well as the projection sphere. So, the projection sphere we take—maybe the top half or bottom half of the projection sphere—and then transfer the projection. Usually, we will take the bottom half and then transfer the projection of the fault plane or the dipping plane on the primitive circle. So, in this particular case, the equal angle will be preserved, and it is more useful in terms of mineralogy.

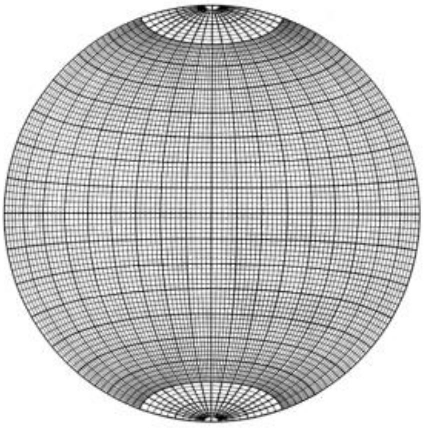


Fig.3 Schmidt net (Equal area)

- Used when area is meant to be preserved.
- Used in structural geology.
- Projection is done onto the lower hemisphere of the sphere of projection.

On the other hand, we have another method of stereographic projection that is called the Schmidt method, in which you can see, though we are not preserving the shape. That is why you can see, as we are taking the projection, you are not getting a circle but rather something other than a circle; it is more like an ellipse. So, if we see with respect to the actual area on the bedding plane, the projection in such a way that it will not ensure that the shape remains constant, but the area which is taken for the projection will be conserved. That is the objective of the Schmidt method related to stereographic projection development. So, it is generally used in the case of structural geology; it can be used for fault plane solution. Geologists also use it in terms of bedding planes; it can be used in order to represent the orientation of the bedding planes with respect to their strike and dip values on the stereographic projection. So, that is generally done in terms of equal area projection. Now, in this particular method, the projection is generally done on the lower hemisphere of the projection sphere or the main circle with respect to which the projection circle was there, with respect to which we will be transferring the projection on a primitive circle, which is located at the base of this particular projection sphere. In the first one, the projection sphere was there, and then the primitive circle was made to cut the projection sphere in half. In the second one, the projection sphere is there, and the primitive circle is kept at the base, and then, followed by which, you can keep maybe the lower hemisphere of the projection sphere onto the primitive circle.

So, that is the basic difference. In the first case, you will have the angle preserved; in this particular case, the projection sphere will remain the same, but the primitive circle will pass through half of the projection sphere, representing the ground surface. In the second one, the primitive circle will be passing through the bottommost point. So, you can say this is the bottommost point of the lower hemisphere; so, the primitive circle or the projection plane will be passing through the bottommost portion of the lower hemisphere of the primitive circle of the projection plane.

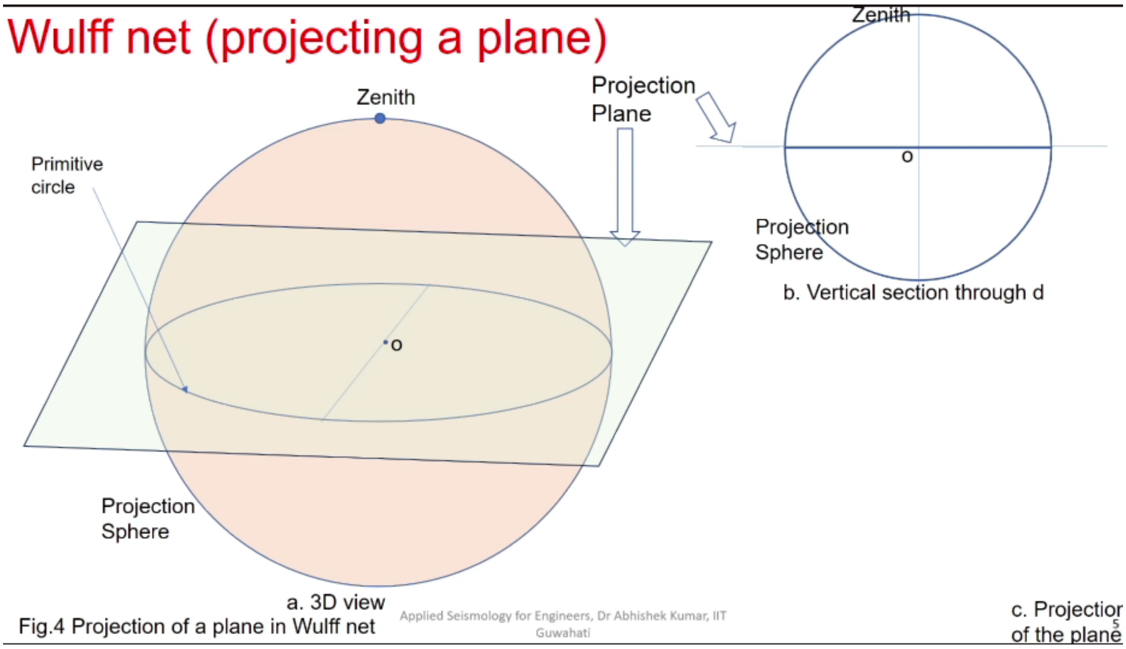


Fig.4 Projection of a plane in Wulff net

So, the Wulff net, generally, as I mentioned, will be doing two kinds of projections. One is where the fault plane is given to you, and you have to transfer the orientation of this fault plane on the primitive circle or the projection plane. There can be another possibility: rather than a complete plane, there might be some lines available, making some angle with respect to the ground surface. So, such representation, primarily called the projection of a line, will also be done in terms of Wulff net or Schmidt net. So, in both cases, we will have, in general, two planes which we will be talking about: one is the projection sphere and the second one is the projection plane. So, you can say this is the primitive circle, or this is called the projection plane; the intersection of the projection plane with respect to the projection sphere is going to give you this particular circle, which is called the primitive circle.

And if we recollect whatever was discussed in the previous slide, the entire stereographic projection has been the projection of great circles and small circles on the primitive circle, which is mentioned over here. So, we will try to firstly locate our plane or a line in the projection sphere, then transfer the projection from the projection sphere to your primitive circle. So, this is in a three-dimensional view where you can see perpendicular to your line of sight is your projection of the grid sphere or projection sphere, and then perpendicular to or along the horizontal plane with respect to your line of sight, whatever is located, is the primitive circle. Extending it because initially, we put a projection plane—so the projection plane is there—and then along the periphery of the projection plane and projection sphere, we will get the primitive circle. Again, Figure B is showing you how the entire process of projection will appear on a vertical plane. So, you can say this is the projection sphere; you can say this is the projection plane. So, this is the projection plane, this is the primitive circle, and the one which is located over here is the projection sphere. There will be another point which is called the zenith, which is basically considered the point which is exactly located above the point of observation. So, in this particular case, we will say the primitive circle is there, and just above the point O on the projection sphere, whatever point is there is called the zenith. So, zenith, again, in the vertical plane, is located over here. So, the topmost point on the projection sphere, located just above the center of the primitive circle, is called the zenith. And remember, whenever we are having any bedding plane or fault plane, that has to pass through a particular point O in order to take the stereographic projection.

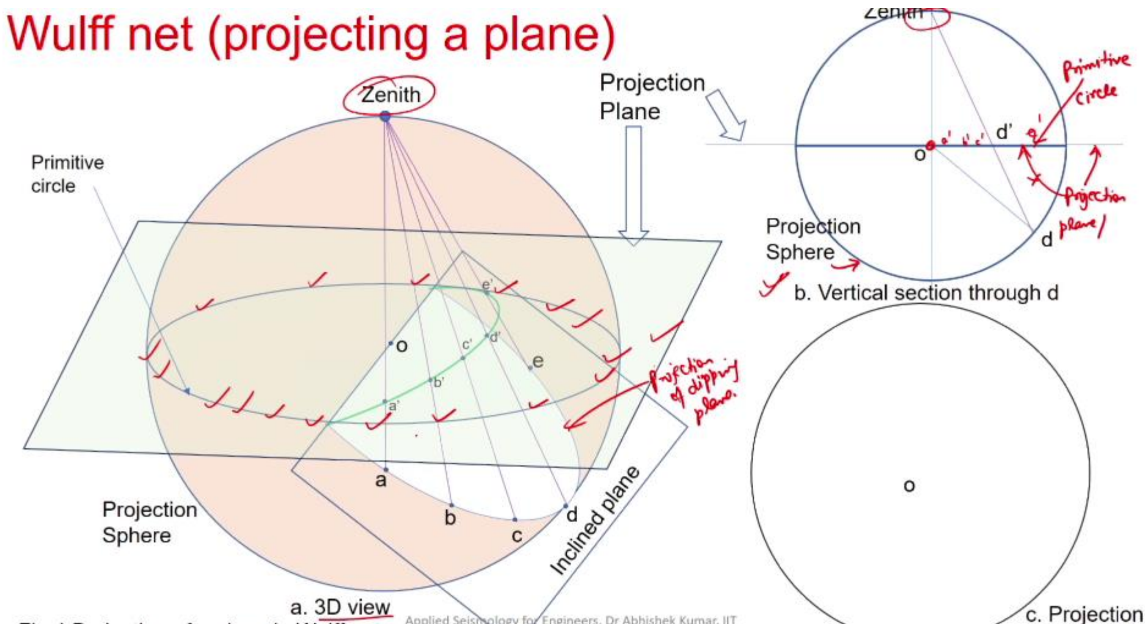


Fig.4 Projection of a plane in Wulff net

So, this is the inclined plane, as I showed in the previous slide also. The inclined plane is there, of which we have to firstly find out the dipping plane and then take the projection along the fault plane along the primitive circle. So, this is the dipping plane. You can see this is the projection of the dipping plane, which is basically the intersection of the inclined plane with respect to the projection sphere. So, in order to take the projection here, we will take some points, which are mentioned over here, along the intersection of the projection sphere along with the inclined plane or along the periphery of the dipping plane. We have some points. What we will do in order to transfer the projection of this particular bedding plane to the primitive circle is to join each of these points with respect to zenith point a, with respect to zenith point b, c, and the intersection of this line with respect to the primitive circle is marked subsequently as point a', b', c', d', and e'. So, we see all these points— a', b', c', d', and e'—all these points are located in the plane of the primitive circle. So, if we start locating these points in our Figure B, all these points will be in the same line, the same horizontal line of the primitive circle because we are seeing in the vertical plane. So, point d prime and subsequently all the points can also be located over here. So, we can have a', b', c', d', and e', and then subsequently you are having the endpoint. So, all these points from here are basically located over here as a', b', c' and so on. So, all the points are basically located over here. The third one is how the projection finally will look into the primitive circle. So, here again, we are talking about—this is the primitive circle, I mentioned earlier also. The primitive circle means you are talking about the horizontal plane. So, we got the points a', b', c', d', and e'. Join all these points, and we will get the projection, the stereographic projection of your inclined plane, which was shown over here as—so this is again still it is a line. It is appearing like a curve because it is a line representing on the stereonet.

So, this is the inclined plane, and this is its stereographic projection of the inclined plane. So, we have taken the projection with respect to the zenith on a plane which is defined by the primitive circle and joining all those points. So, we can actually see those points over here: primitive circle, inclined plane. So, you can actually see those points a', b', c', d', and e' over here. If you join all those points such that it is also passing through this particular point o—that is representing every time the starting and end point of a particular stereographic projection—if you join by a line, it should pass through point o. So, the inclined plane here, the plane becomes a line; this is the conclusion from here. Similarly, if you have lines rather than planes, those lines will be on a particular inclined plane, but we do not have a complete picture of the plane. So, what we will see are lines, meaning some inclination of the bedding plane or some representation of information along the bedding plane.

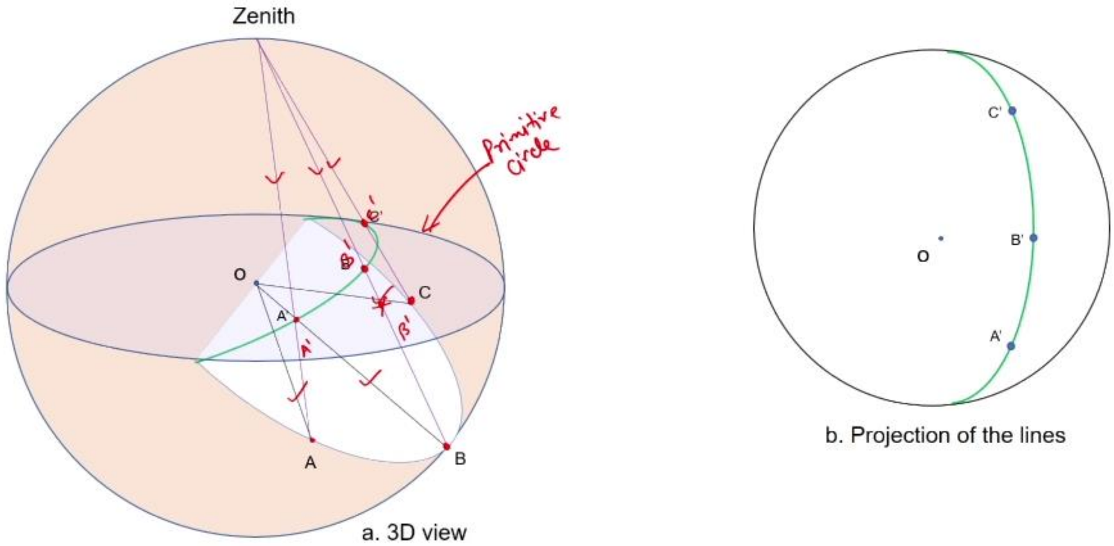


Fig.5 Projection of lines in Wulff net

So, you can see over here these are the three points or lines which are representing—so rather than a plane, we are having these lines this time. How can these lines be located in terms of stereographic projection? Again, we will repeat the same thing: we locate these lines or this particular plane on which these lines are located, then join all these points—this point, this point, and this point—we can join with respect to zenith points A, B, C. Join with respect to the zenith. The intersection of these lines with respect to the primitive circle—again, here, this is the primitive circle. So, the intersection of these lines with respect to the primitive circle is going to give you the points A', B', and C'. So, here you will be having point A', this is point B', and this is point C'. Joining all these points or mentioned over here, you can get an inclination of points. So, basically, this is—yes, so this is what you will get again if you transfer the same thing. So, you are having some intersection of zenith joining point A, and where it is intersecting with respect to the primitive circle, you get point A'. Similarly, with zenith with respect to B, where it is intersecting with respect to the—so there you can mark this as point B'. Similarly, with zenith with respect to C, you can mark this as C'. So, B', C', and A'—you join these points in this particular diagram. Basically, this is not B', which is represented by this particular line. So, A', B', C'—if you join all these points, we will again be able to represent a particular plane on which these three points A, B, C are located in a particular bedding plane. When we are taking the projection of a particular plane, we end up getting a line along the primitive circle. If we are getting the projection of a line, it becomes A point. So, you see this was the line OA; it was the line, and finally, we are getting a projection on the primitive circle in terms of just one point A'. Similarly, with respect to OB, we are getting the projection of point B'; similarly, with respect to C, we are getting the projection of point C. So, you join points A', B', C'—again, ensure that the starting and ending is passing through O. We will be able to get the projection of points or lines OA, OB, OC on the Wulff net. So, a line becomes a point.

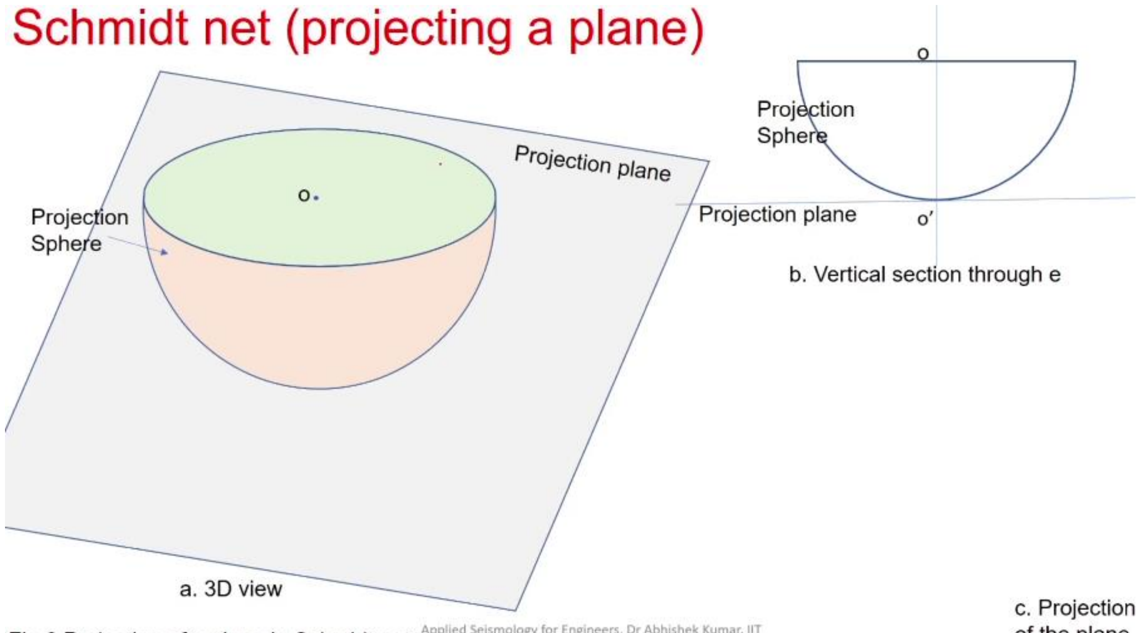


Fig.6 Projection of a plane in Schmidt net

Similarly, we are talking about the Schmidt method. As I mentioned, in the Schmidt method, what we do is take a lower hemisphere of the projection sphere, and the primitive circle or the projection plane should be kept at the bottommost point or should be passing through the bottommost point of your projection sphere. So, this is your projection sphere, and this is your projection plane, and this is the bottommost point, which is basically represented over here also. So, you can see; this is the projection plane, this is the lower hemisphere of the projection sphere. Again, we are seeing in a vertical direction or perpendicular to your line of sight, and you are looking parallel to your ground surface. So, this is again representing maybe the primitive circle. Where the primitive circle will come? Once you start transferring the projection of the boundary of your projection sphere, you will get the primitive circle plane. So, this I am writing as the primitive circle plane where the primitive circle, at a later stage, will be located. Again, there is one particular point P located on the upper hemisphere of this particular plane, which is like a circle of the projection sphere. So, you are having basically the point P, but that has to be transferred to your inclined projection plane.

So, what we will do—there will be corresponding to point O, there will be a point O', which is actually the point of intersection of the projection plane and the projection sphere. So, taking O' as the center and O'P as the radius, we will mark an arc which is touching the projection plane. So, wherever it is touching the projection plane, basically, that point is a representation of the projection of point P on the primitive circle. So, O'P will be equal to O'P' because it is representing the same radius. So, this is the primitive circle; if you take maybe 10 points along the periphery and take the projection very much similar to point P, taking the projection from all these points, you will get like this. This will end up getting you a primitive circle. So, that is how you can develop firstly a primitive circle on which one has to locate your projection of the fault plane. So, again, take into account—now your primitive circle is ready—take into account an inclined plane. So, whenever the inclined plane is passing through the lower hemisphere, again, we will get some points which are the intersection of the inclined plane on the lower hemisphere; you will get these points. So, transferring the projection, very much similar to the projection of point P, transferring the projection of these points, again, this inclined plane—you can represent over here. So, this is the inclined plane; you can say inclined plane, inclined plane appearing if you are looking in the direction parallel to your ground surface. So, this is the inclined plane representation.

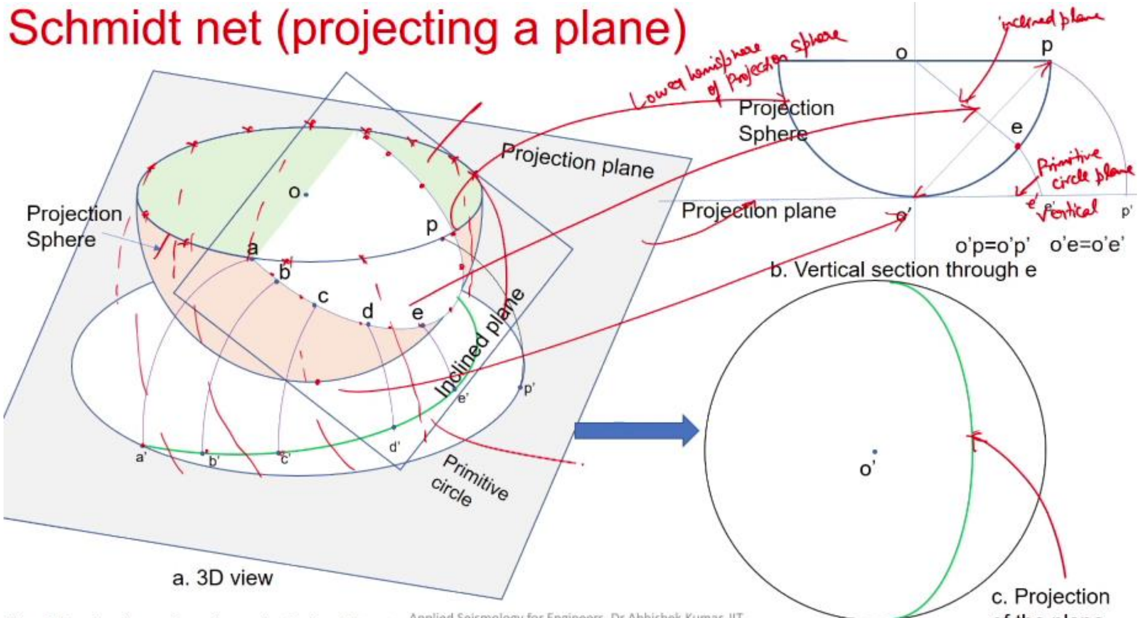


Fig.6 Projection of a plane in Schmidt net

So, this is the plane which is represented over here like this. As I mentioned, there will be a number of points which are the representation of the intersection of the inclined plane on the lower hemisphere. So, these points will start coming over here. There will be points which are basically located along this particular point. So, one point where E is over here, you can see, taking O'E as a radius, mark point E', which is located on the primitive circle. You will be able to transfer the projection of point E, which is the intersection of the projection sphere with respect to the fault plane. Similarly, we can get many more points, as can be seen over here also. So, A', B', C'—basically, these are the intersections; these are the projections of points A, B, C, D, E on the primitive circle using the Schmidt method, where the projection plane will be put passing through the bottommost point of your great sphere, lower hemisphere of the great sphere. So, again, this is the final result. So, your projection plane, inclined plane, everything was there, and finally, joining the points A', B', C', D', E', and further points, you will get the projection of this particular inclined plane. So, this was the inclined plane, and this is the projection of this particular inclined plane using stereographic projection. Basically, this is representing how the representation of stereographic projection—how the stereographic projections are used to represent a particular fault plane using the Schmidt method.

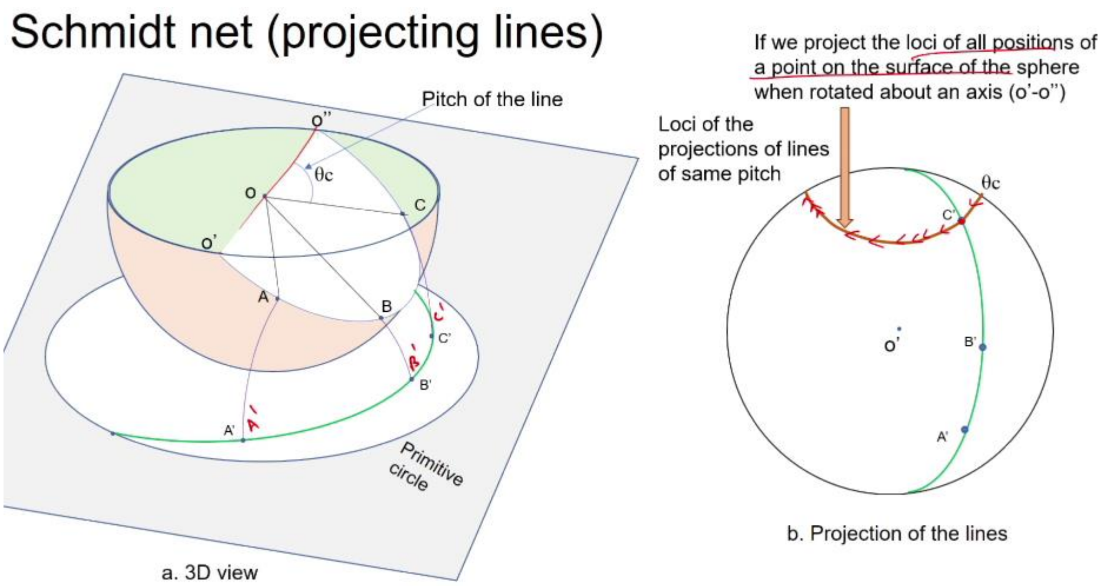


Fig.6 Projection of lines in Schmidt net

Again, if we are talking about lines, so again, we will be having some points. If you join those particular lines, we will be having some points. So, take those points a, b, c as was done in the case of the Wulff method—a, b, c points are there. So, again, taking o, the bottommost portion, and a, which is the intersection of—which is the point which is located along the periphery of the projection sphere—you can take that particular radius and then mark an arc. Wherever it is touching the primitive circle, we can get the projection. So, this will be a', this will be b', this will be c'. Joining these points, we can basically transfer the projection of this particular line in terms of points in the stereographic projection. So, this is the three-dimensional view, and this is the two-dimensional view. Now, this is—so far, what we have done is we have taken a particular fault plane and represented it by means of a line. We have taken some points and represented them by means of some points on the stereographic projection. Now, there will be another point which will come into the picture: what if this particular fault plane, whose strike value remains the same but dip value is changing, how that will be represented over here? That is represented, if you see this particular picture, so that means the inclination of o', o'' remains the same, but point o', a, b, c, o'', its orientation or dipping is changing. That particular dipping change can be represented by means of locating the loci of all the positions of a particular point—in this particular case, I am targeting with respect to point c. So, if there is a plane point c on the dipping plane, if the dipping plane orientation is changing, how the position of c is changing can be located by means of loci of all the points you can join. So, this is the representation; so, your primitive circle remains the same, but as you are moving your dip of the fault plane, it is changing, the position of c will move along this particular line. So, this is representing—so what is clear here is any particular value which will be measured in this particular direction is representing a change in the dip value, and if we see, if we change the orientation of o', o'', that will represent the change in terms of the strike value of the fault plane. So, this is called the pitch of the line, which is basically the loci of all the points having the same position; the strike value remains the same, but the dip value is changing.

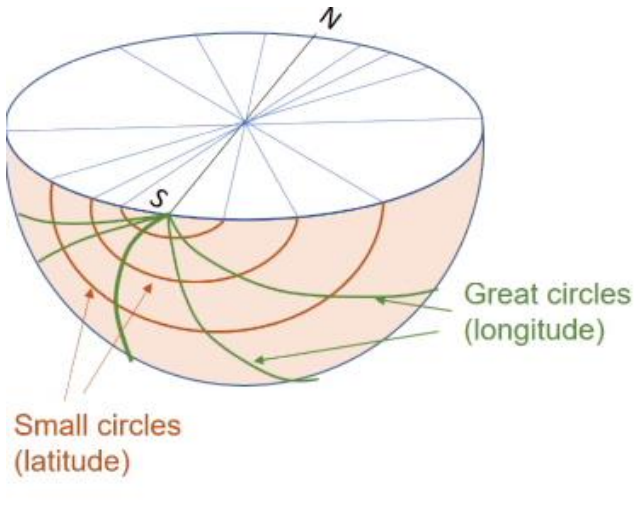


Fig.7 Comparison of projection sphere
with longitude and latitude

So, taking that into account, we can develop great circles, which are representations of longitude, and small circles, which are representations of latitude. Generally, the projection of small circles and great circles are done in terms of two-degree increments. So, whenever we are developing a great circle or a small circle, we will be taking into account the two-degree and ten-degree increments. So, small sections will be there which are two-degree increments, and then there will be bigger divisions which are representations of ten-degree increments.

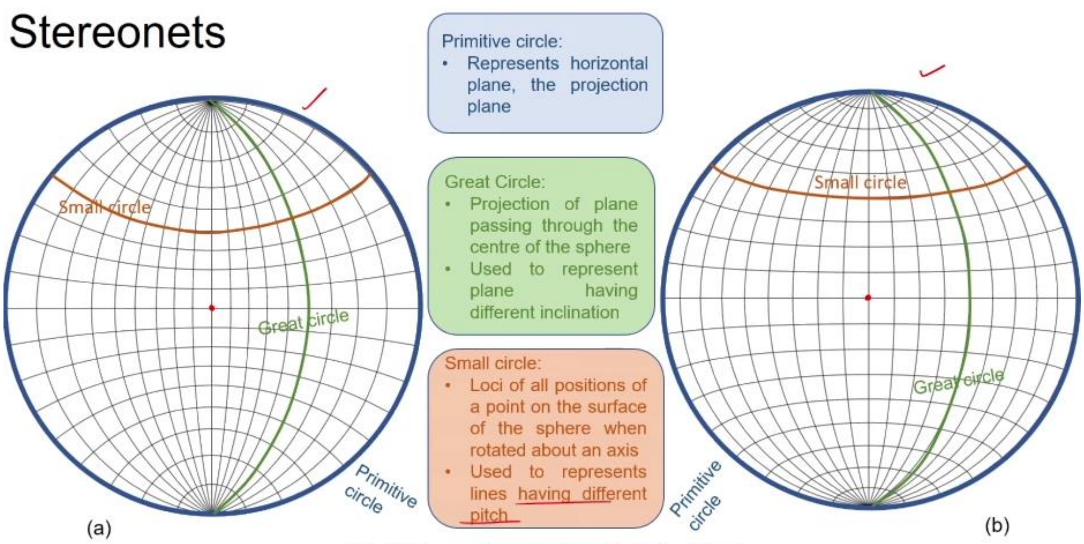


Fig.8 Stereonets a. Wulff net b. Schmidt net

So, typically, a stereographic projection, when you go with the Wulff method, it will appear like this. When you are going with the Schmidt method—that is, equal-area method—that will appear to be like point figure B. Mostly, we will be using this particular work related to the Schmidt method; that is the stereographic net given in terms of figure B, so it is basically, again, I am mentioning that it is the primitive circle. So, the primitive circle represents the horizontal plane, as I mentioned earlier also, which is the inclination of which is basically the projection plane on which we will take the stereographic projection and represent a particular fault plane. There are great circles, which are representations of projection of planes passing through the center of the sphere. So, every great circle will be representing a plane which is passing through the center—this is the center. So, whenever a plane is passing through this particular center—any particular plane—it can be passing like this; it can be passing like this—anything which is passing, or you can say the fault trace of a particular fault plane which has to be represented on this particular stereographic net has to pass through the center. So, whatever is the strike of the fault plane, the fault trace has to pass through here, which is called the center of the sphere. So, it is generally used to represent planes having different inclinations. Inclination means with respect to the north; how much is the inclination of the fault trace? That will be represented over here. So, small circles, as I mentioned, will be representations of the dip angle of a particular fault plane—the loci of all the points which are changing their position as you are rotating or changing the dip of a particular fault plane are used to represent lines having different pitches. So, we understood great circles in which the strike value will be measured, and small circles along which the dip will be measured.

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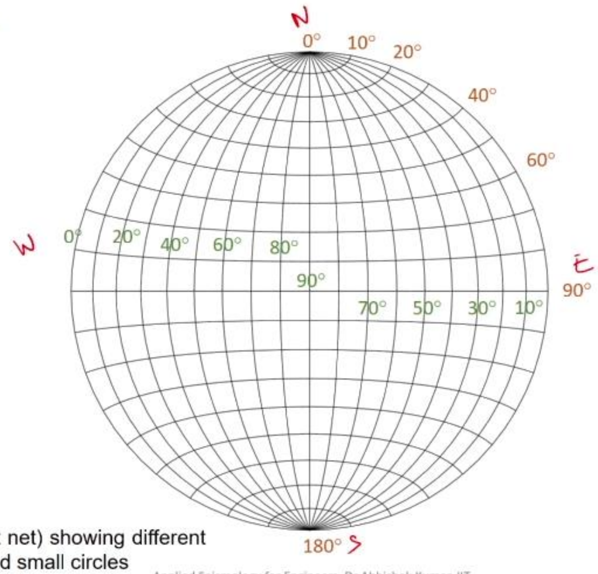
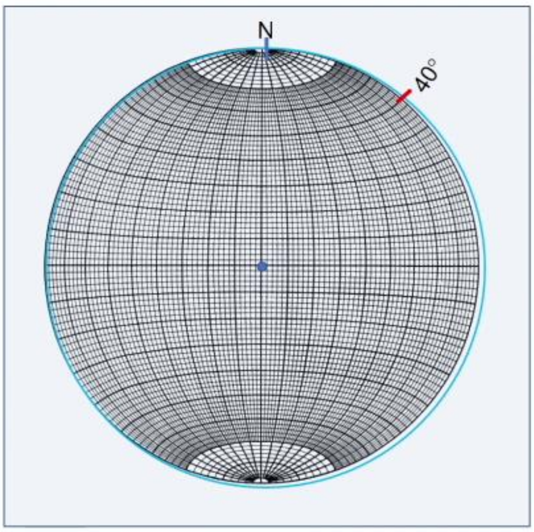


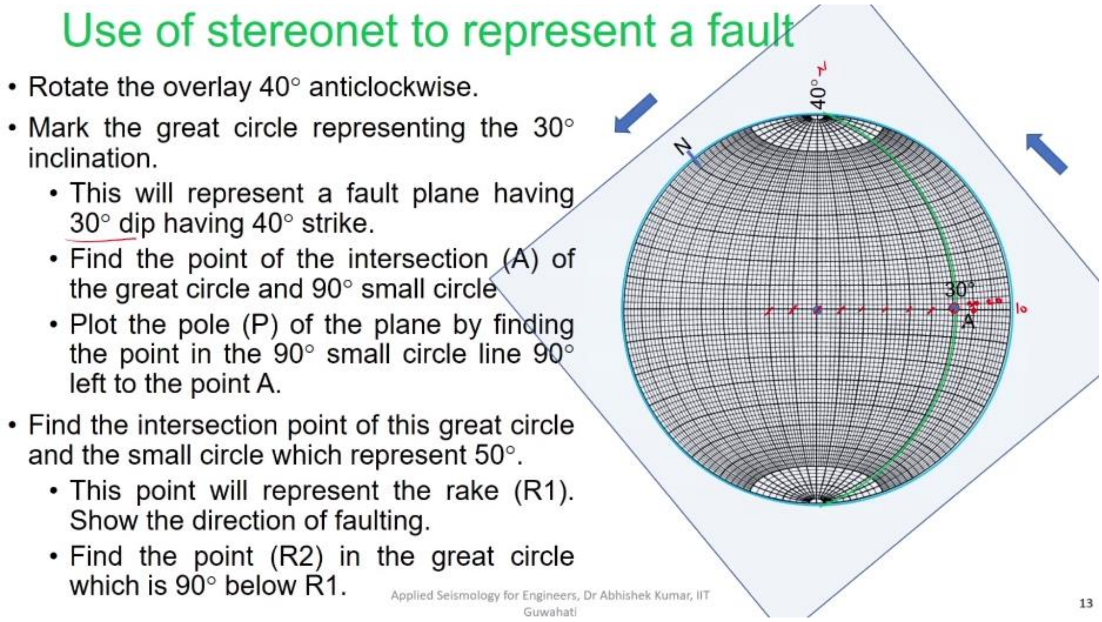
Fig.9 Stereonet (Schmidt net) showing different angles of great circles and small circles

So, overall, it will appear like this: anything which is having a strike value of 0 means you are oriented towards north-south; if it is towards east-west, it can be represented like that. So, now here, with respect to this, we will be measuring how much is the strike and how much is the dip value.

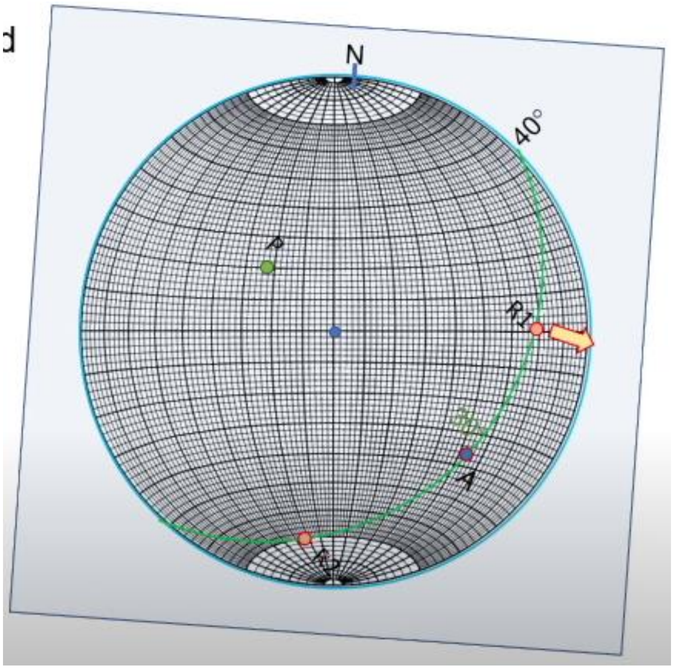


Let us see the numerical over here: we are interested in representing a particular fault plane having a strike value of 40 degrees, a dip value of 30 degrees, and a rake angle equal to minus 50 degrees, or representation where the foot wall is moving away from the hanging wall with an angle of 50 degrees with respect to the direction in which the strike is measured.

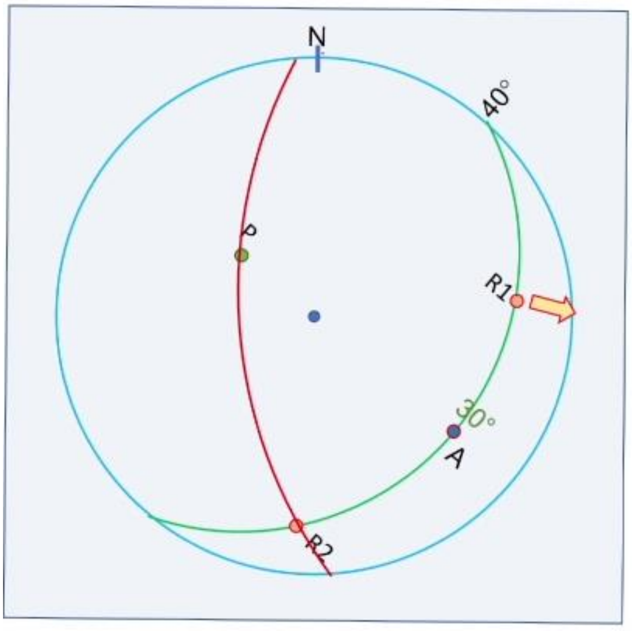
So, what we will do is take a sheet of paper and put it on the stereo net, fix the center—so this is the center which you are going to fix. Mark point east, west, north, south. Then, on that particular circle, in which you will be transferring the projection, basically, you will be taking a tracing paper on which the primitive circle is already marked but not the projection. What you will do is count 40 degrees, which is marking the strike value of 40 degrees. So, you can count like here: 10 degrees, 20 degrees, 30 degrees, and 40 degrees. So, you are counting the strike value, which is given over here as 30 degrees, and then orient your tracing paper like this.



Then what you will do is rotate; you will mark 40 degrees over there, which is a representation of the passing of the fault plane. Then rotate that 40 degrees such that it should come at the same place where initially north was there. Then mark the great circle representing 30 degrees inclination. Again, taking this into account, count 30 degrees. So, firstly, we will mark point A, which is the intersection of the great circle and 90-degree small circle with respect to this particular point. Count another small circle which is at 90 degrees inclination. So, this is the one: 10, 20, 30, 40, 50, 60, 70, 80, and this is the 90 one. So, we have located point P, which is basically a representation of a line passing through point P; it will be perpendicular to your fault plane having the value of 30 degrees. Then find the intersection of this great circle and small circle, which represent 50 degrees. So, what we will do—because now we have to locate the rake angle—so what we will do is count with respect to this point: 10, 20, 30, 40, 50. So, here, this is the point we will be counting from here. This is the rake angle because it was measured with respect to strike, so not this part, but we will count from the top, and we will locate the point R1, which is passing through a great circle which was also passing through point A. Then find another point R2 in the great circle which is 90 degrees below R1. So, with respect to R1, along the great circle, which is shown over here, mark a point R2 which is at 90 degrees with respect to point R1.



Now, rotate the overlay in such a way that point P and R2—you have to rotate your sheets such that point P and point R2 should fall in the same great circle.



Draw that great circle as shown over here, then remove the stereo net. Rotate the drawing in such a way that whatever north-south at the beginning you had marked, now it should be located in the same direction. So, rotate the drawing in such a way that north-south becomes vertical. Remember in the initial step, first step, what we had done: we marked north, east, west, and south—all the four permanent directions. Now we will rotate our sheet because we have got the value of the fault plane, which is having a 30-degree inclination, 40-degree strike, and perpendicular to this. So, this is basically your fault plane projection, and this is basically your auxiliary plane projection. If we recollect whatever was discussed in the beach ball solution, there will be two planes representing the same sort of beach ball: one is represented as the fault plane, the other one represented as the auxiliary plane. So, based on this, we are able to find out what is the fault plane and which is—the I mean, we will be able to locate basically two points over here, and then basically, based on the direction of dip, we can locate what are the compressions and what are the tensions over here. So, this is finally—you can say this thing—we can also determine with respect to the beach ball solution, and it is also now determined with respect to stereographic projection.

So, this is all related to how, if the stereonet is given and fault plane solutions and rake angles are given, how it can be used to locate the particular fault plane on this particular stereonet. This is going to give you an idea about. So, there are basically two ways: one is the beach ball solution based on first preview arrival, the second one is the stereonet is given how you can take the orientation of the fault plane and represent it in terms of stereographic projection. So, thank you, everyone. With this, we come to the end of lecture 4.