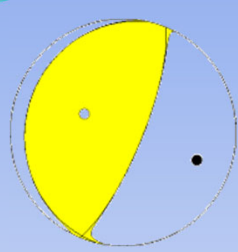
Petroleum Geomechanics

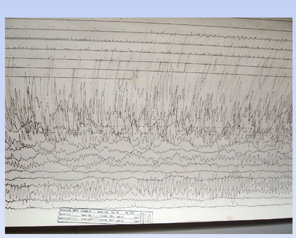
پایداری حفاری
با استفاده از
تصویر ناپیوستگی‌ها

Hasan Ghasemzadeh

Hemispherical projection

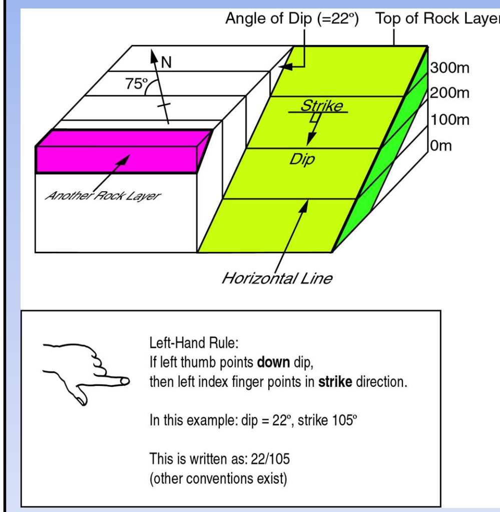


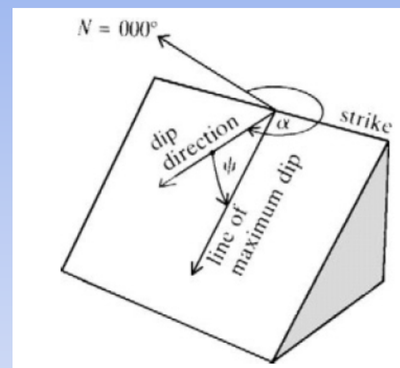
- ❖ تعاریف
- ❖ تصویر قطب‌ها
- ❖ تصویر استریوگرافی
- ❖ کاربرد استریوگرافی در پایداری حفاری‌ها



تعاریف

مشخصات صفحه ترک





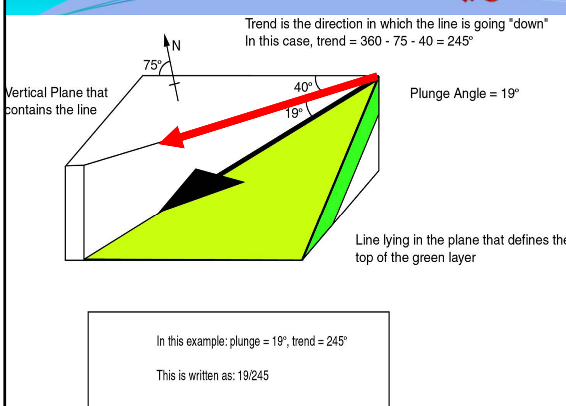
α Dip direction Azimuth

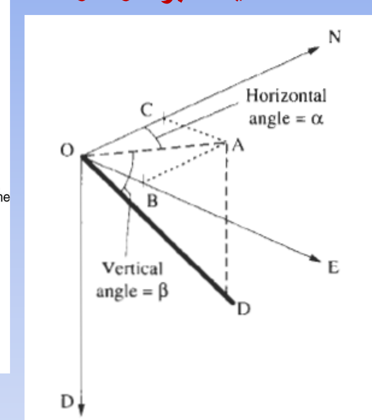
β Maximum Dip Dip

$$strike = \alpha - 90 \pm (180)$$

تعاریف

مشخصات یک بردار در فضا





$$\alpha \ : \ Trend \ = Dip\,direction$$

$$\beta \ : \ Plunge = Dip$$

OB	=	$\sin\alpha\cos\beta$
OC	=	$\cos\alpha\cos\beta$
AD	=	$\sin\beta$.

Strike=dip direction-90 (+180 or -180)

تعاریف

آزیموت و شیب عمود بر صفحه ترک

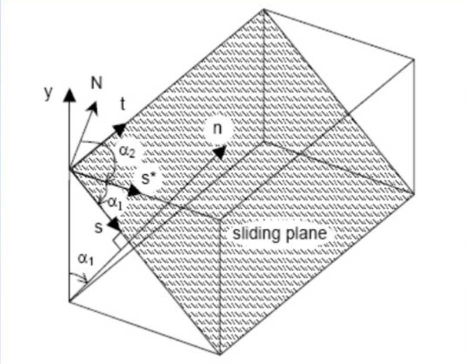
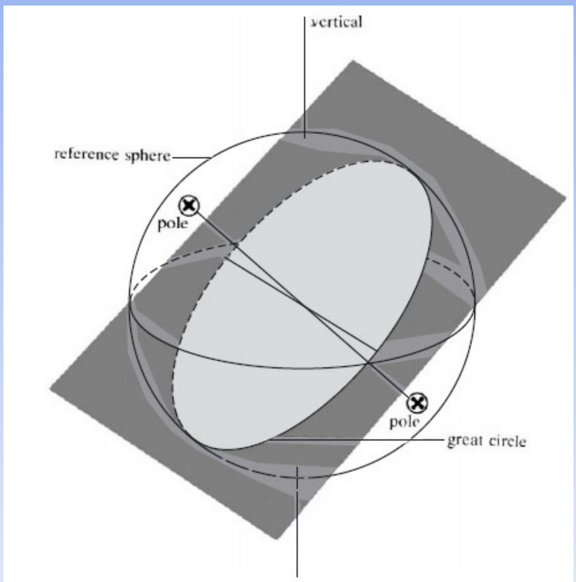


Figure 4.5 Definition of dip angle and dip direction

$$\alpha_n = \alpha \pm 180$$
$$\beta_n = 90 - \beta$$

تعاریف



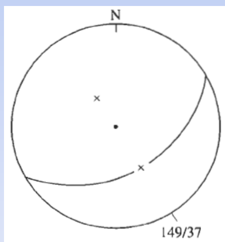
The intersection of the plane and the surface of the sphere is a great circle,

A line perpendicular to the plane and passing through the centre of the sphere intersects the sphere at two diametrically opposite points called the poles of the plane.

In rock mechanics, the lower-hemisphere projection is almost always used.
The upper-hemisphere projection is often used in structural geology

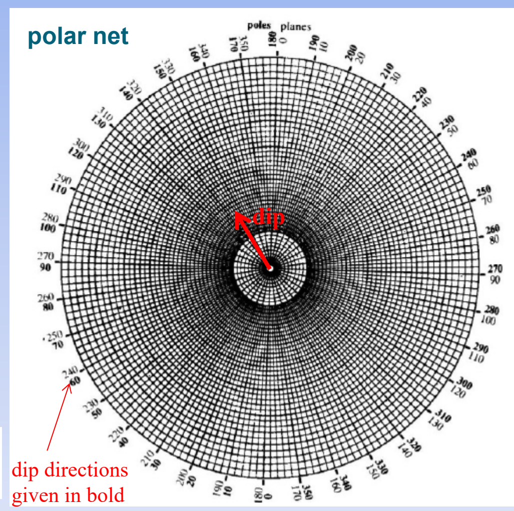
polar net

If the poles of planes rather than great circles are plotted, the data for large numbers of discontinuities can be rapidly plotted on one diagram and contoured to give the preferred or 'mean' orientations of the dominant discontinuity sets and a measure of the dispersion of orientations about the 'mean'



$$\alpha_{normal} = \alpha_{dip} \pm 180^\circ$$

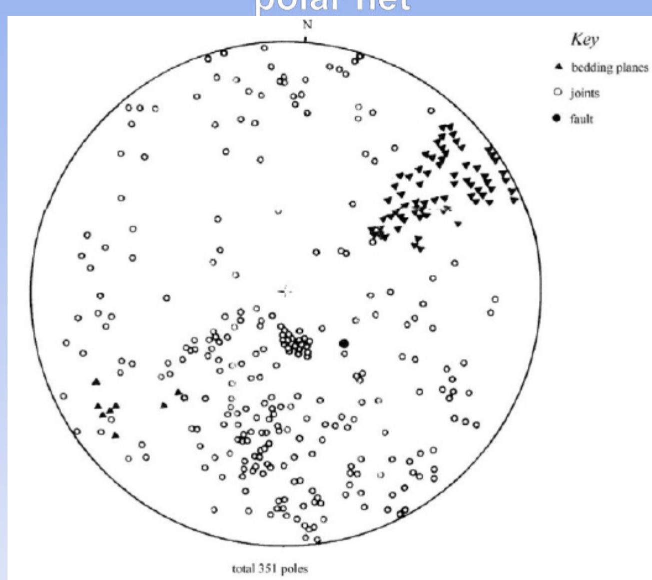
$$\beta_{normal} = 90^\circ - \beta_{dip}.$$



در پولار نت نیاز بیه چرخاندن صفحه و شرقی غربی کردن آن نداریم

polar net

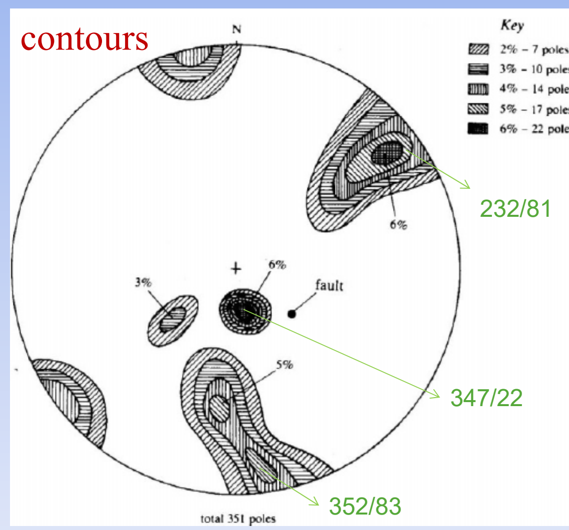
polar net



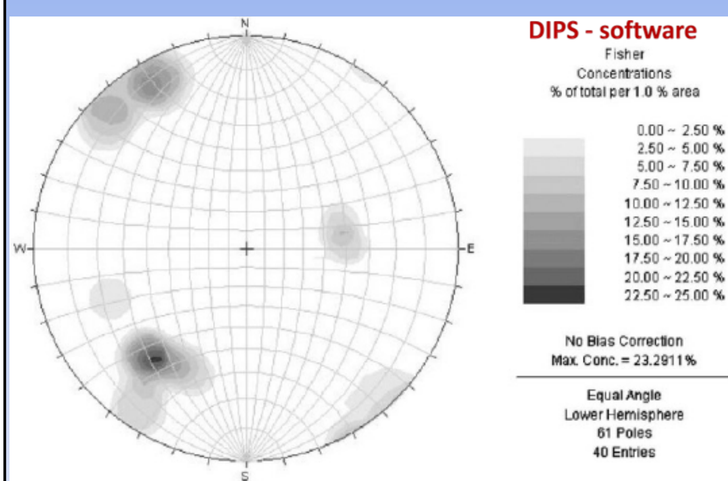
polar net
contours

the numbers of poles lying within successive areas which each constitute 1% of the area of the hemisphere are counted.
The maximum percentage pole concentrations are then determined and contours of decreasing percentage of pole concentrations around the major concentrations are established.

The central orientations (mean) of the two major joint sets are 347/22 and 352/83 bedding planes is 232/81



polar net
dispersion

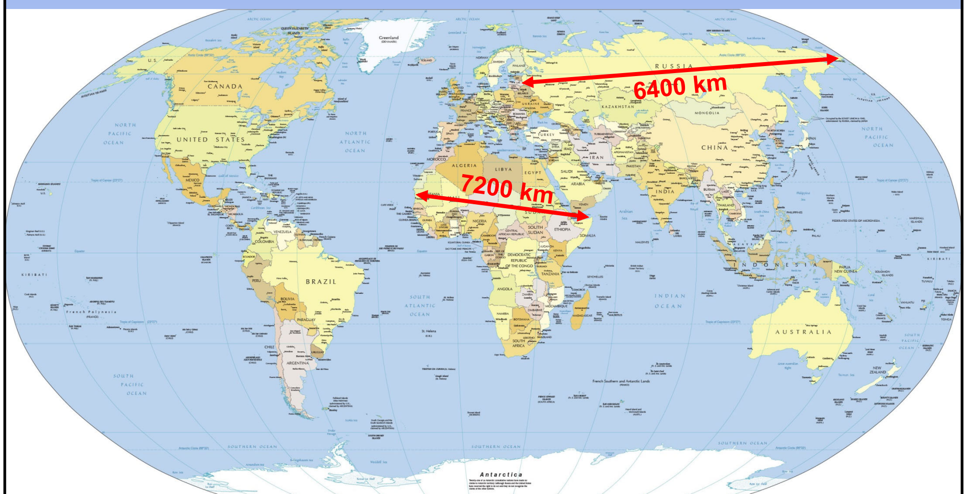


The higher the value of K, the less is the dispersion of values about the mean.
For a random distribution of poles, $K = 0$.

Hemispherical projection

1- Stereographic, Wulff, Equal-angle projection

2- Lambert, Schmidt or equal-area projection.



Hemispherical projection

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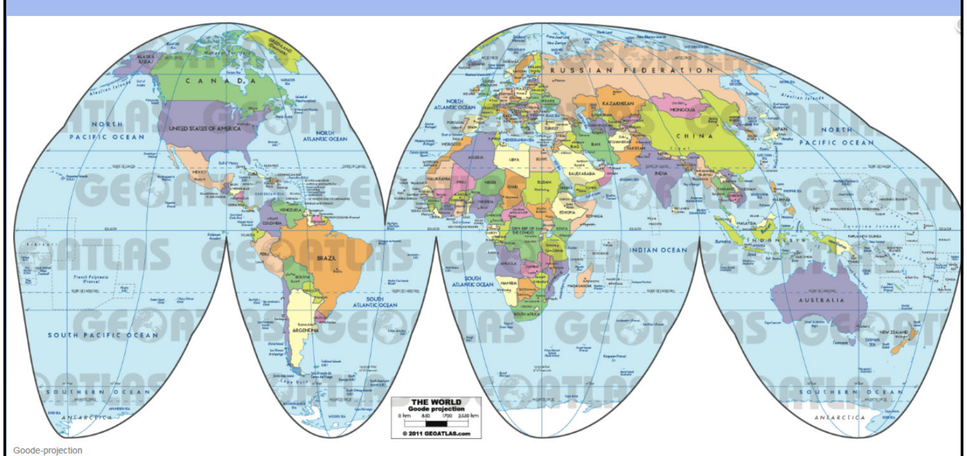

Hemispherical projection

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Hemispherical projection

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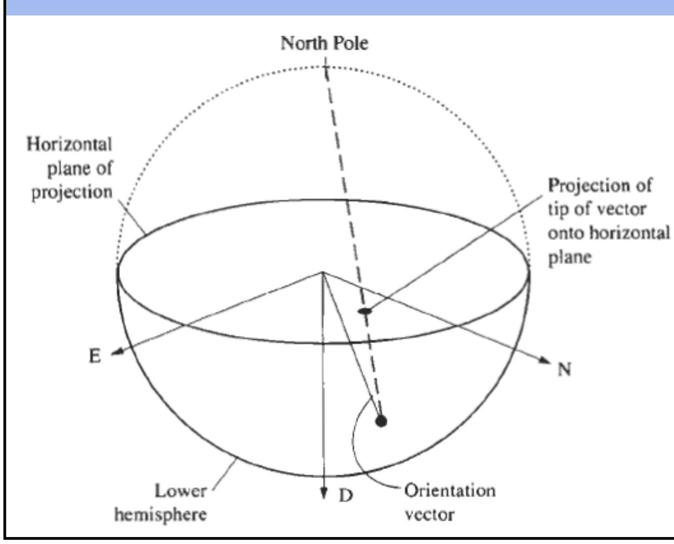
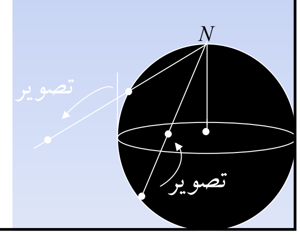
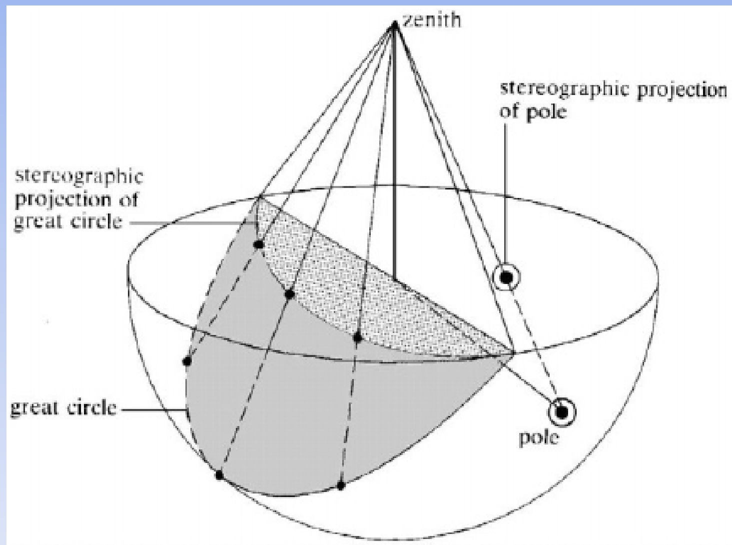


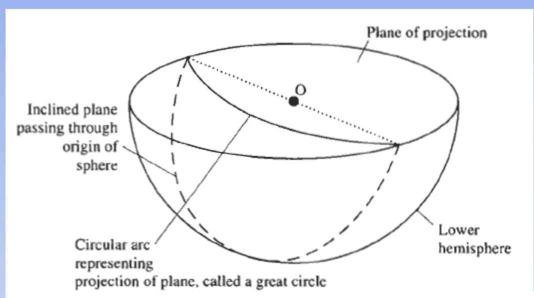


Hemispherical projection

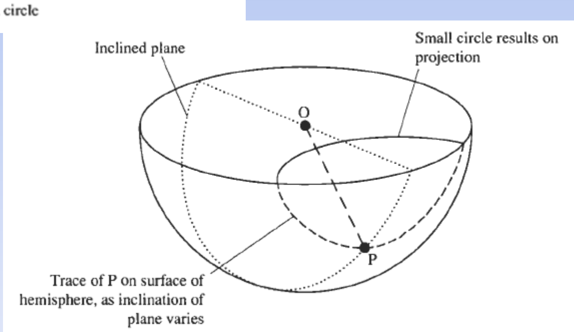
Stereographic – Wulff – Equal-angle projection



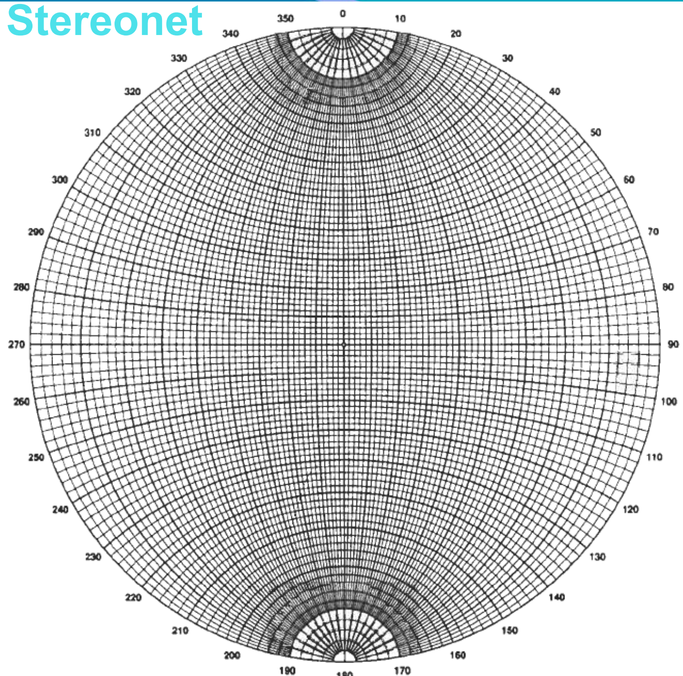
Hemispherical projection



Stereographic
Wulff
Equal-angle projection



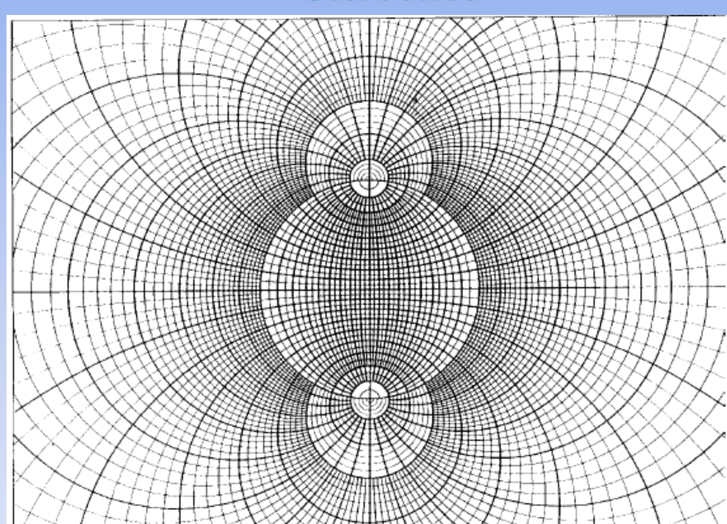
Stereonet



lower hemispheres

Hemispherical projection

Stereonet



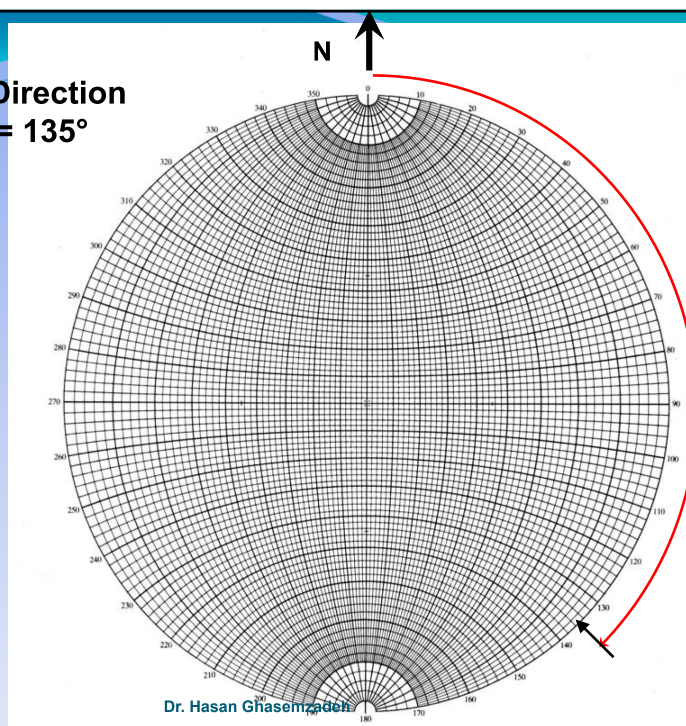
both upper and lower hemispheres

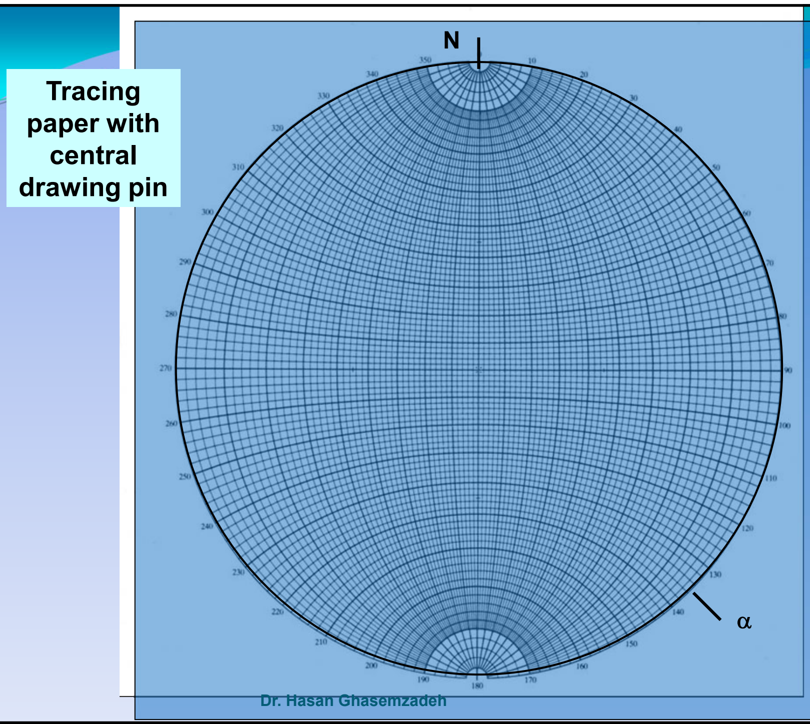
EXAMPLE

dip direction, $\alpha = 135°$
dip angle, $\beta = 50°$
denoted as 135/50

Plot also 000/90 and 090/00

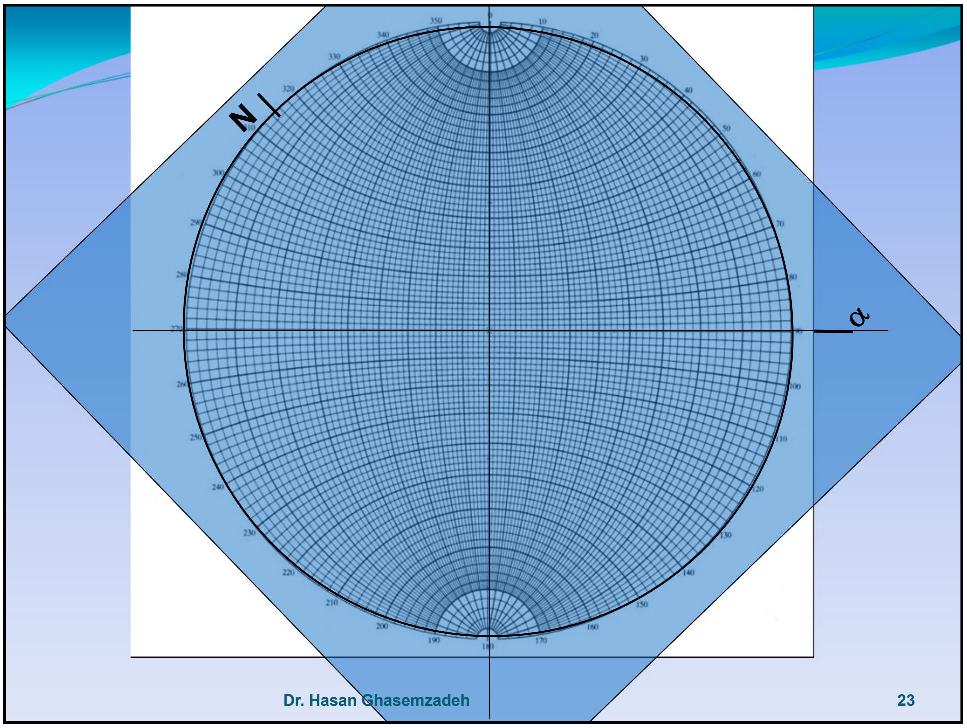
Dip Direction
$\alpha = 135°$





Step 1

- Rotate the paper until the line marking the dip direction corresponds with the equatorial position (90°)



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Steps 2 and 3

- Measure 50° (= the dip angle, β) from the outer circle RHS and trace the great circle for the plane as shown
- Measure (90 - β) or 40° from the outer circle, but this time from the LHS to locate the POLE of the great circle or plane

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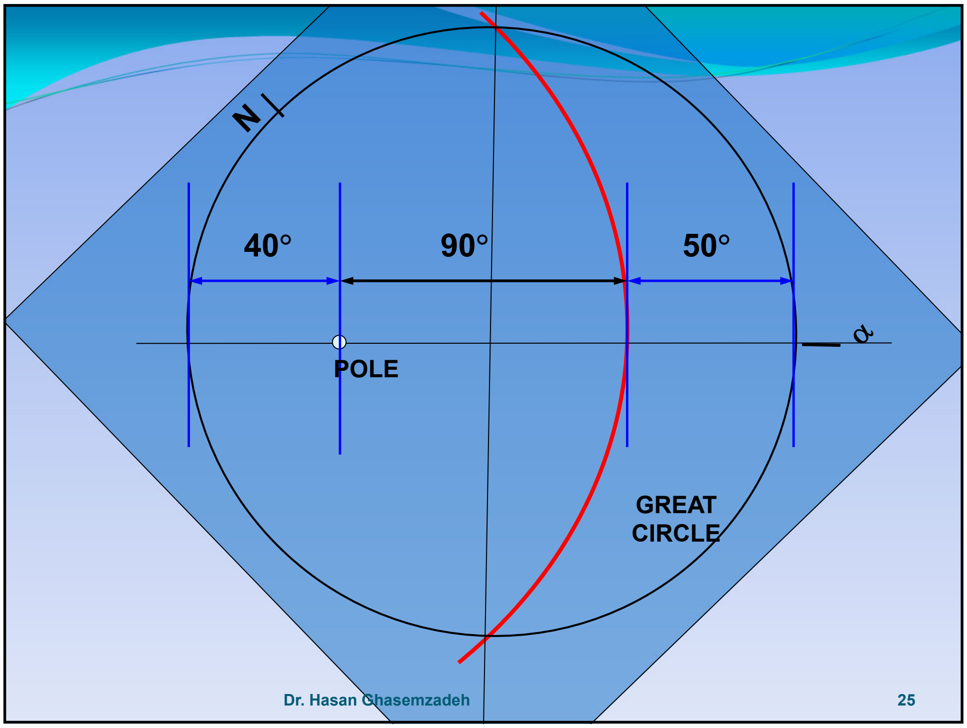
N
40°
90°
50°
α
POLE
GREAT CIRCLE
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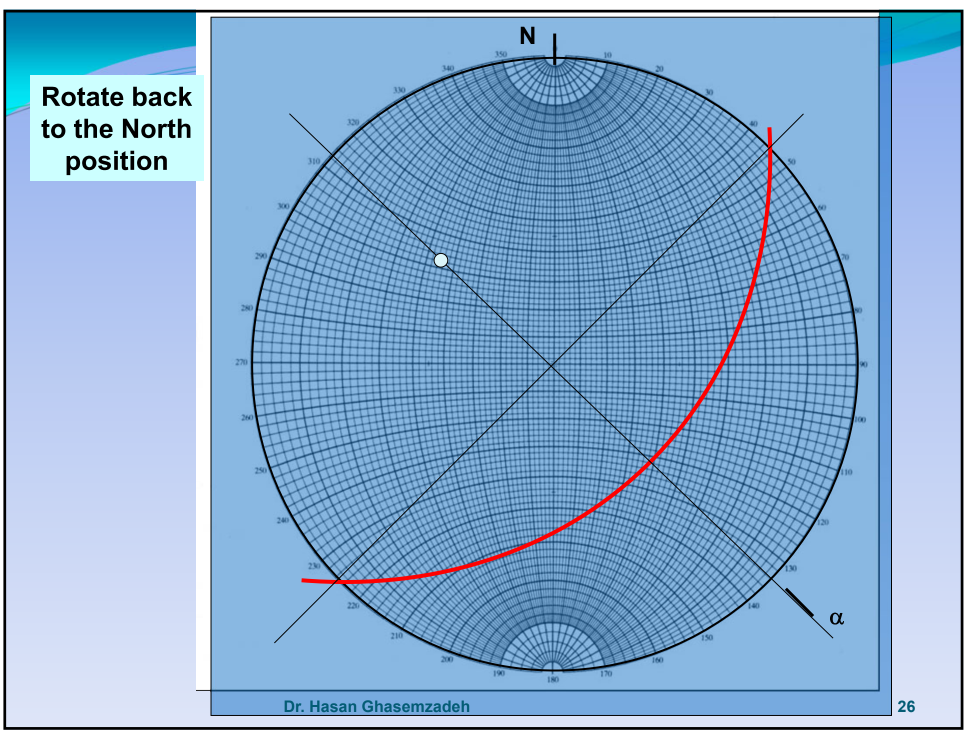
25


Rotate back to the North position
N
α
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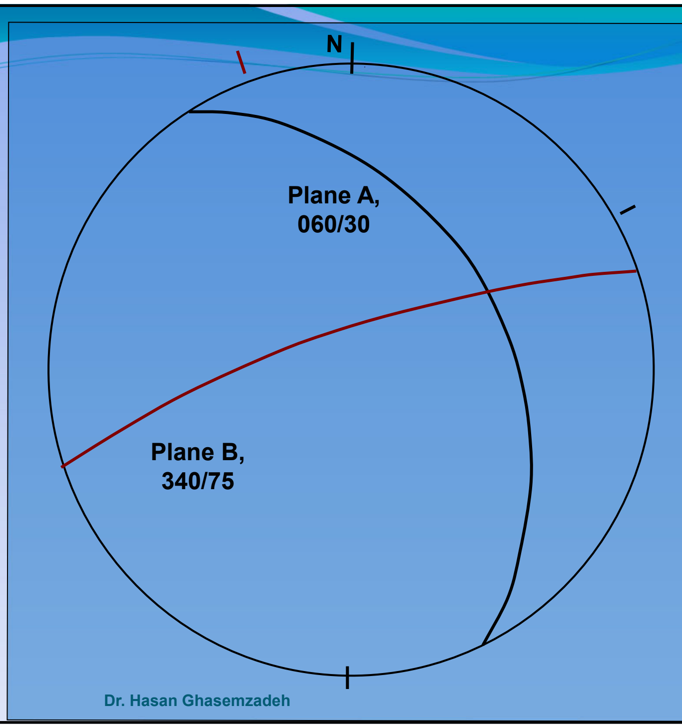
Intersections

Two planes A and B have orientations A:060/30 and B:340/75

These planes intersect on the stereonet at the point A:B

- this point represents the line of intersection of the discontinuities represented by the planes



Plunge of intersection line

- Rotate tracing until intersection point lies on the E-W line
- Read off the number of degrees from the perimeter to the intersection point

  = the plunge of the intersection line

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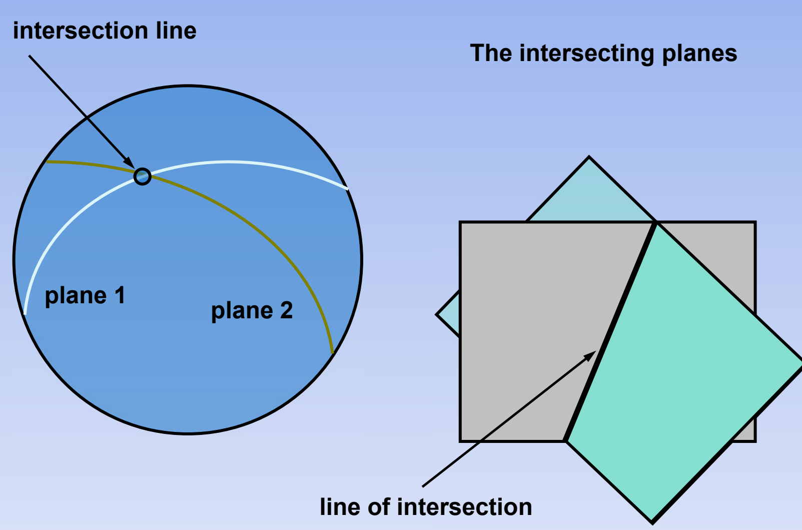

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Plunge of intersection line

- Rotate tracing until intersection point lies on the E-W line
- Read off the number of degrees from the perimeter to the intersection point

  = the plunge of the intersection line

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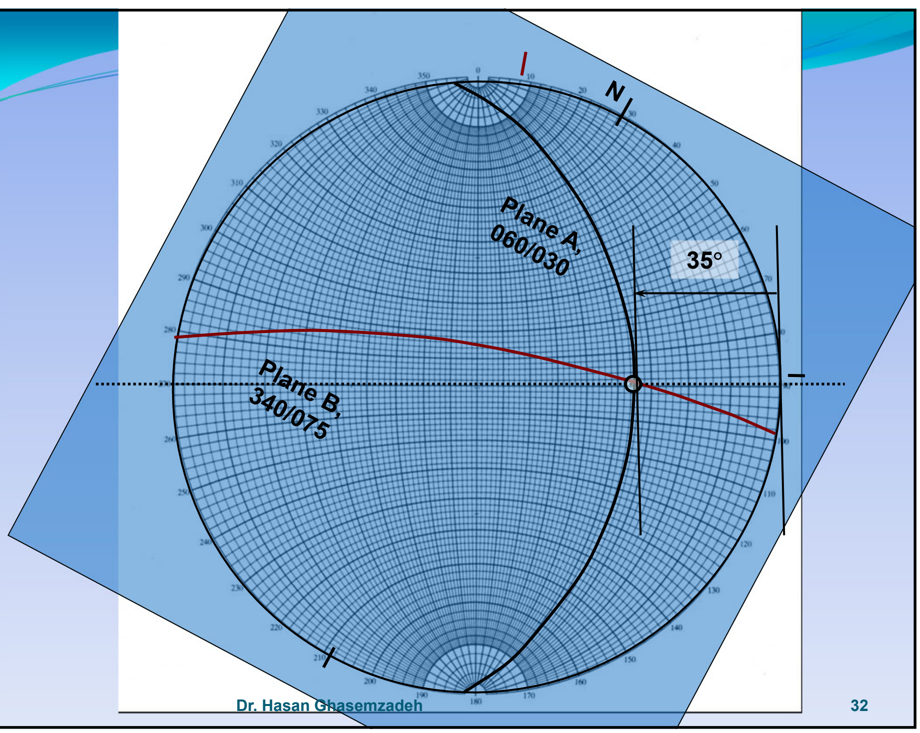

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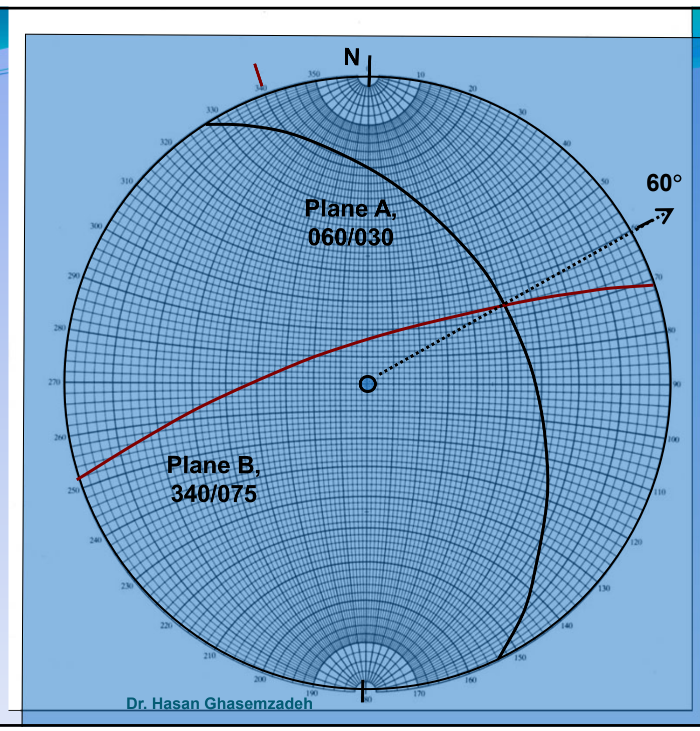
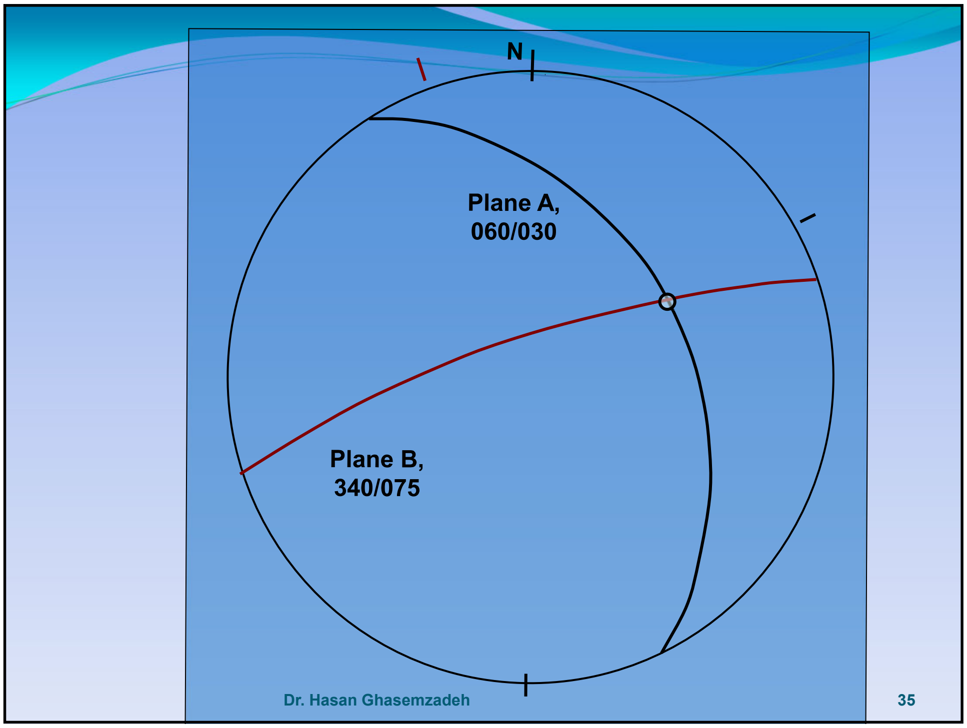
Dip direction of intersection line

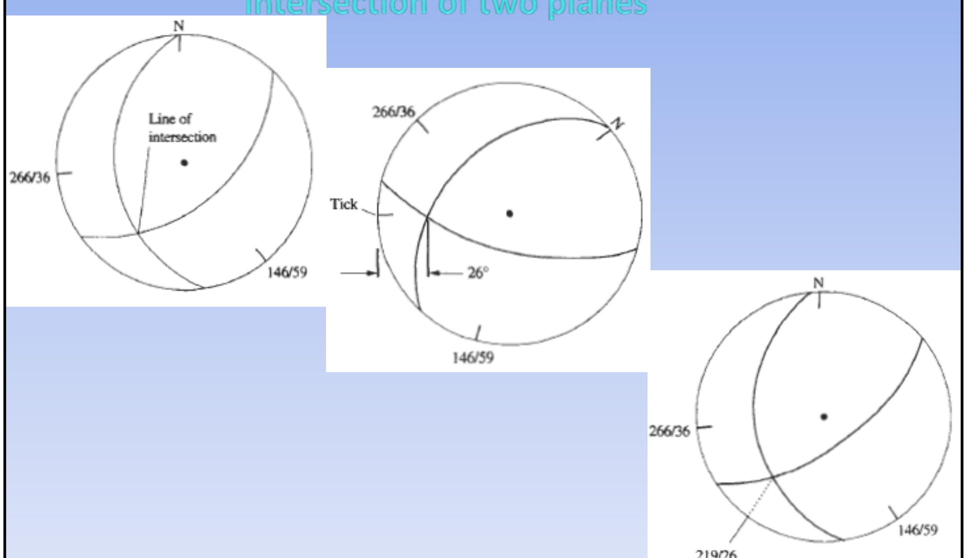
- Rotate tracing back to the datum
- Mark off dip direction as indicated
- The intersection point can be designated as 060/035





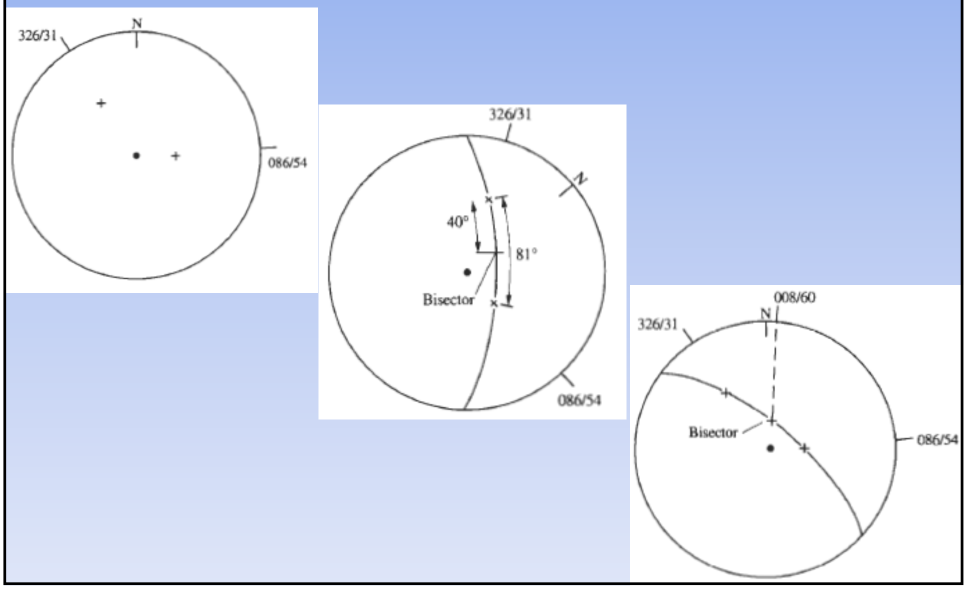
Hemispherical projection

Intersection of two planes



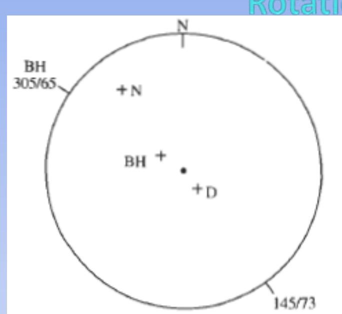
Hemispherical projection

Bisector of two vectors

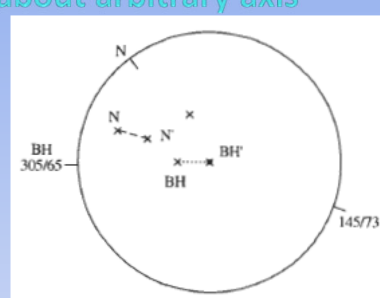


Hemispherical projection

Rotation about arbitrary axis



BH : the direction of the borehole vector,
D maximum dip of the discontinuity plane,
N for the normal to the discontinuity plane.



1-Rotate : borehole on the E-W line
2- move BH to the centre of the net-in 90-65=25
3-. Move the normal N through the same angle, but along the small circle.

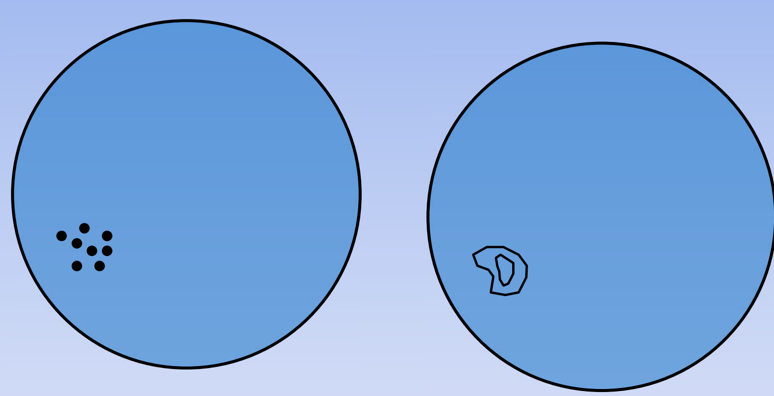
In effect, the net has been inclined to be perpendicular to the borehole.

APPLICATION: SLOPE STABILITY

Stereonet information can be used to indicate the likely instability

- Plots of the poles of discontinuity planes
- Contours to indicate high concentrations in areas of the net
  - prevailing discontinuities
- Position of discontinuities with respect to **the Great Circle for the Slope**?

APPLICATION: SLOPE STABILITY



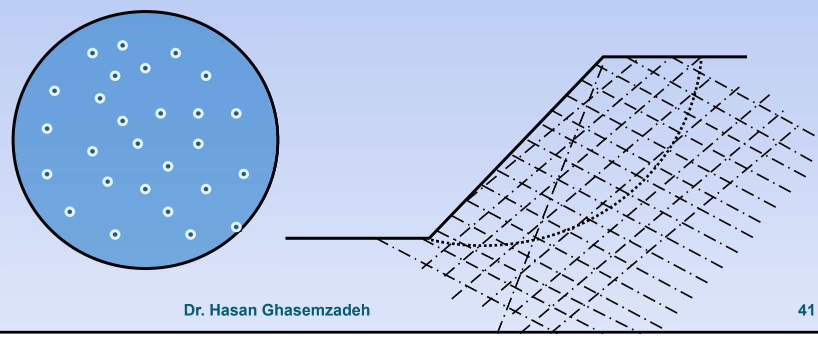
APPLICATION: SLOPE STABILITY

Typical Slope Instability

(a) no particular concentration of poles

- circular failure (*e.g. waste rock/ fractured slate)*

- similar to soil (use Bishop's method)



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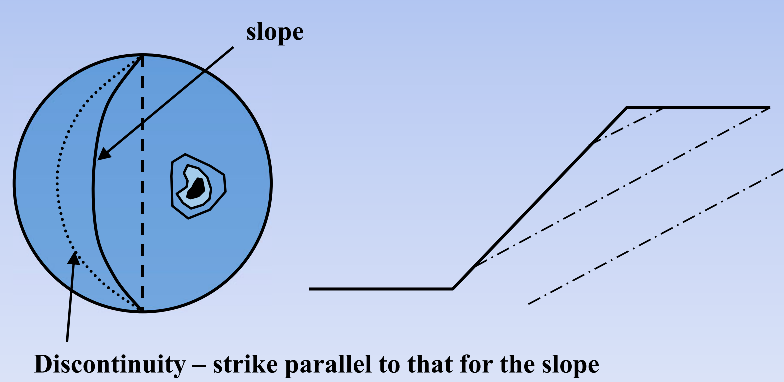
APPLICATION: SLOPE STABILITY

Slope Instability

(b) single concentration of poles <u>above cut slope</u>
- plane failure



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APPLICATION: SLOPE STABILITY

Conditions for planar failure

- The plunge of the slope > dip of the discontinuity

(Discontinuity **daylights** on the slope face)

- Discontinuity has a **dip angle > ϕ** for the joint
  - mechanically possible
- **Dip direction of the discontinuity and slope lie within ± 20°**

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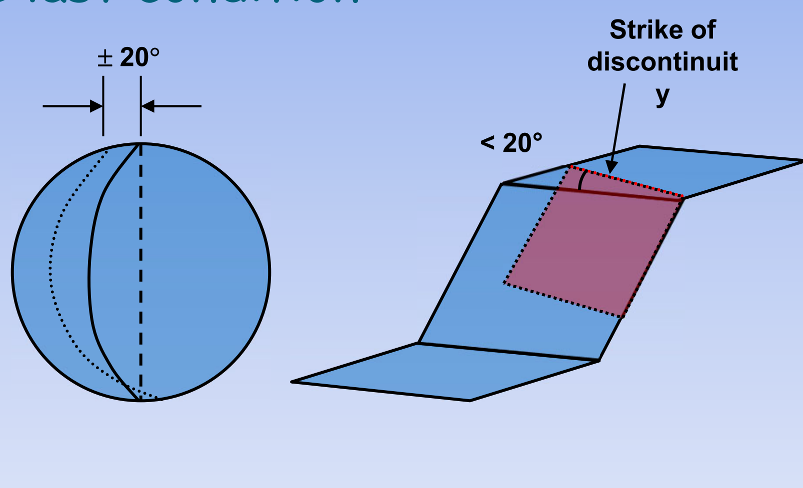
APPLICATION: SLOPE STABILITY

The last condition



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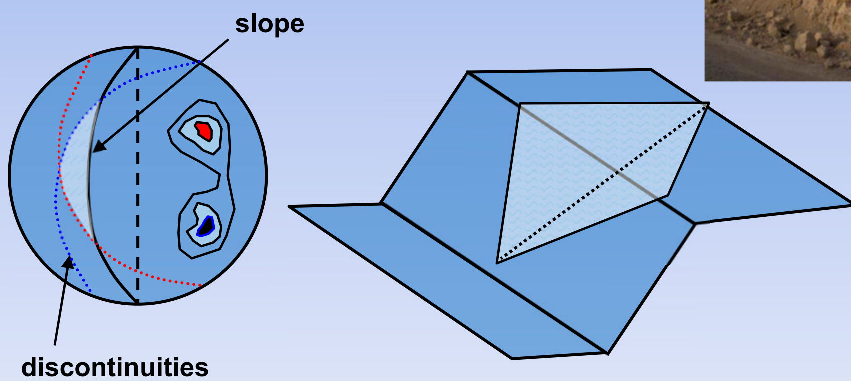
APPLICATION: SLOPE STABILITY

Slope Instability

(c) **double concentration of poles = intersecting joints**

wedge failure *most common*



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APPLICATION: SLOPE STABILITY

Conditions for wedge failure

- The plunge of the slope > dip of the Intersection line

(Intersection line **daylights on the slope face**)

- Intersection line has a dip angle > ϕ for the joints
  - **mechanically possible**

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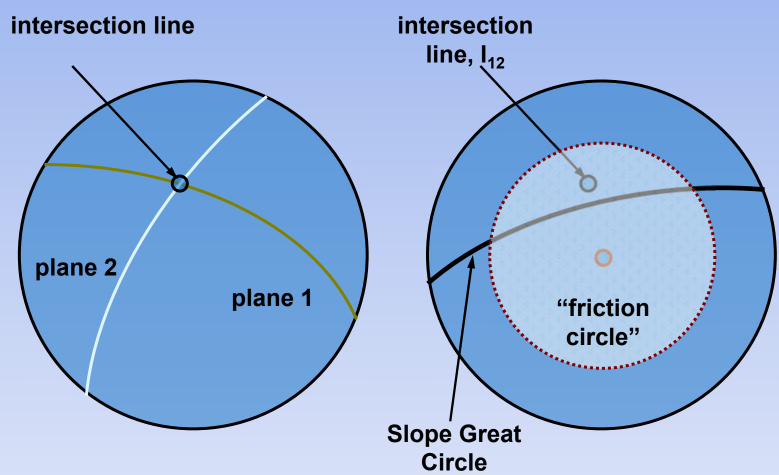
APPLICATION: SLOPE STABILITY

Dip of intersection > friction angle



UNSAFE slope!

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APPLICATION: SLOPE STABILITY

The Friction Circle

- **The meridional plot is overlaid by the friction circle (*same diameter*)**
- **The slope is safe if the intersection point, I_{12} is outside the friction circle (ϕ) for the joint**
  - **mechanically impossible to fail**
  - **assumes c = 0 kPa for the joint**

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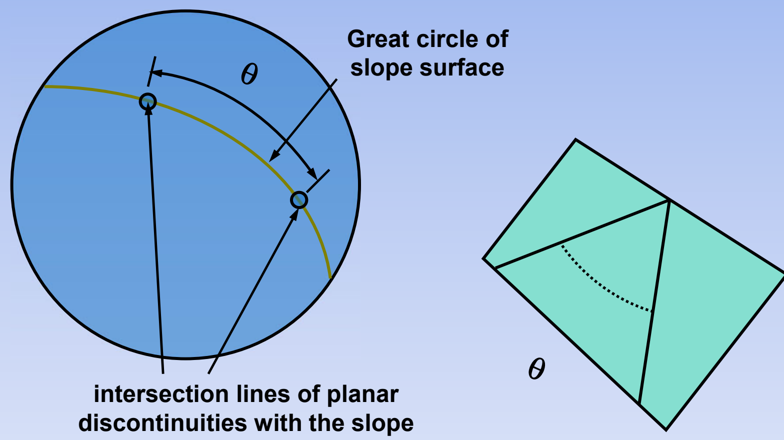
APPLICATION: SLOPE STABILITY

Wedges intersecting slopes



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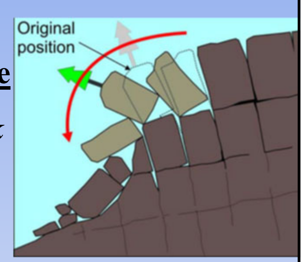
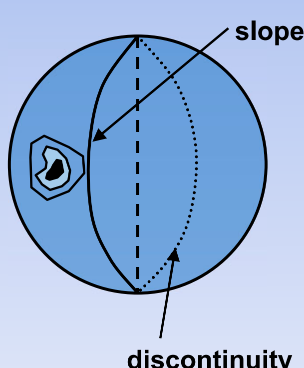
APPLICATION: SLOPE STABILITY

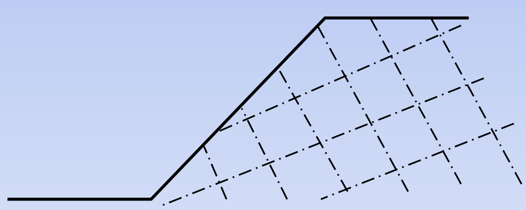
Slope Instability

(d) single concentration of poles <u>below slope</u>

- toppling failure *in hard rock*







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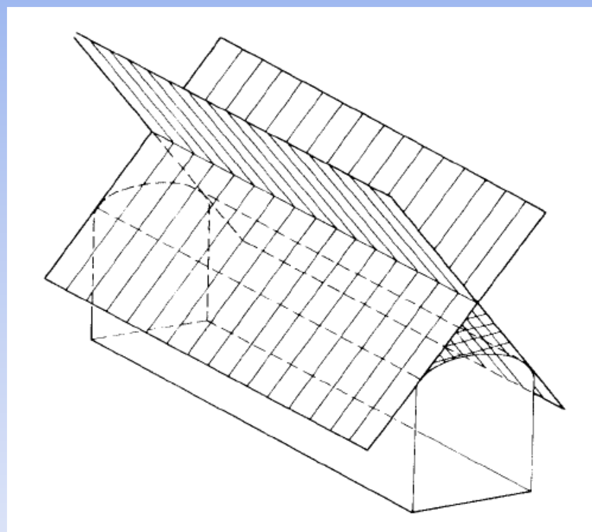
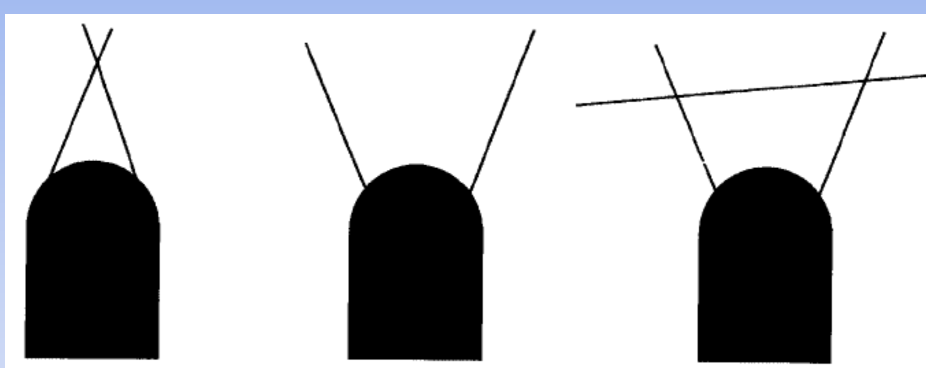
Excavation instability

Stereographic – blocky rock



Application: Excavation stability

Stereographic – blocky theory



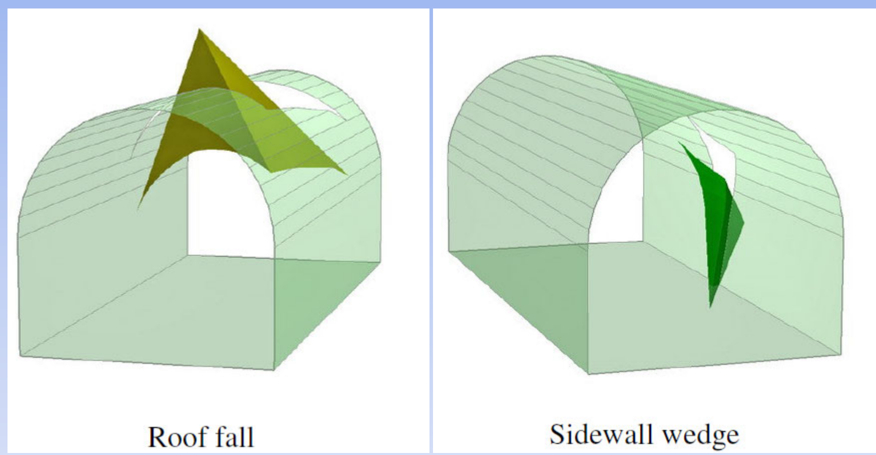
(a) Finite and non-tapered block — **Unstable**

(b) Infinite block — **Stable**

(c) Finite, tapered block — **Stable**

Application: Excavation stability

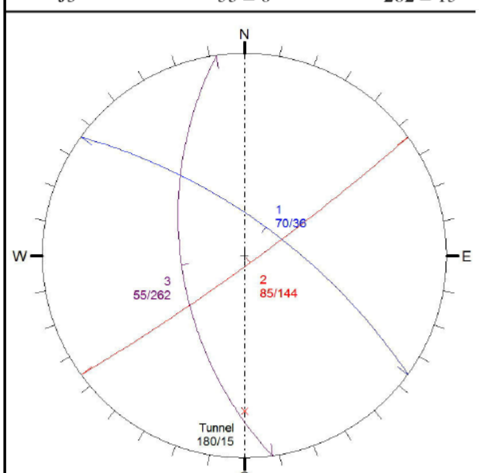
Stereographic – blocky theory

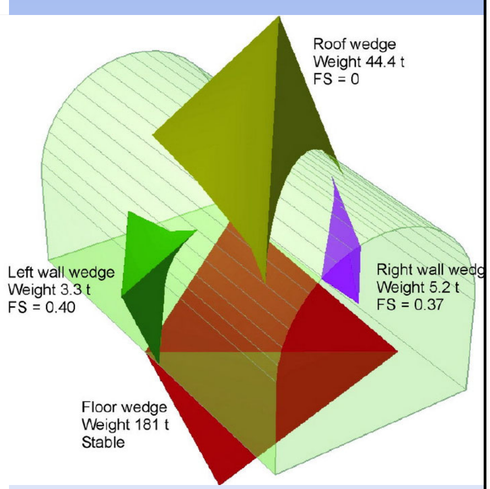


Application: Excavation stability

Stereographic – blocky theory

Joint set	*dip°*	*dip direction°*
J1	70 ± 5	036 ± 12
J2	85 ±8	144 ± 10
J3	55 ± 6	262 ± 15





Application: Excavation stability

Stereographic – blocky theory

block state

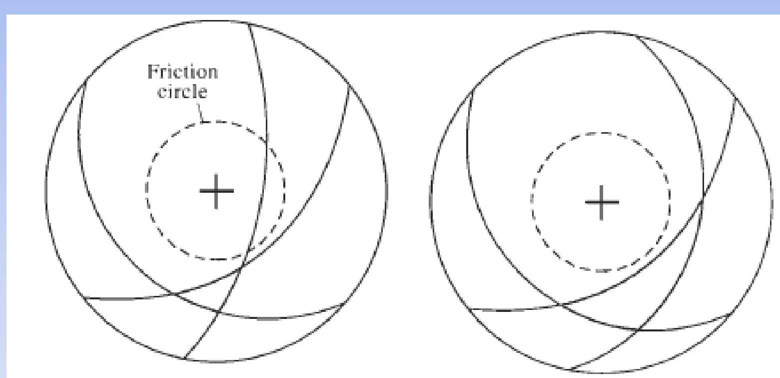
- the block is stable
- the block falls from the roof
- the block slides
(either along the line of maximum dip of a discontinuity, or along the line of intersection of two discontinuities)

Horizontal roof
Vertical wall

Application: Excavation stability

Stereographic – blocky theory

block is stable



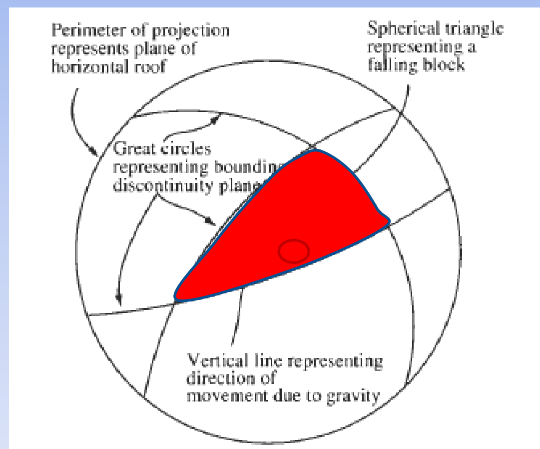
Horizontal roof

Application: Excavation stability

Stereographic – blocky theory

Block falls from the roof

Vertical direction

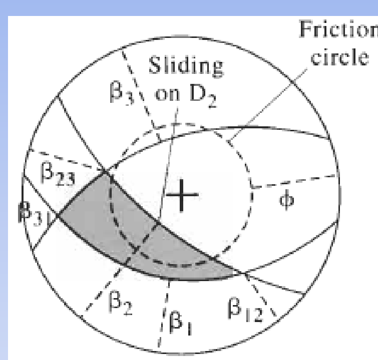


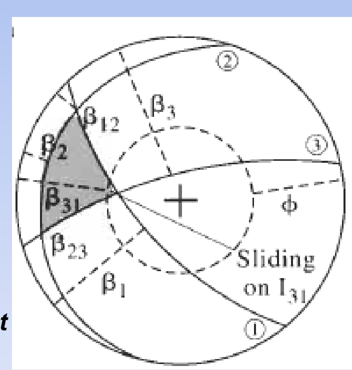
Horizontal roof

Application: Excavation stability

Stereographic – blocky theory

the block slides





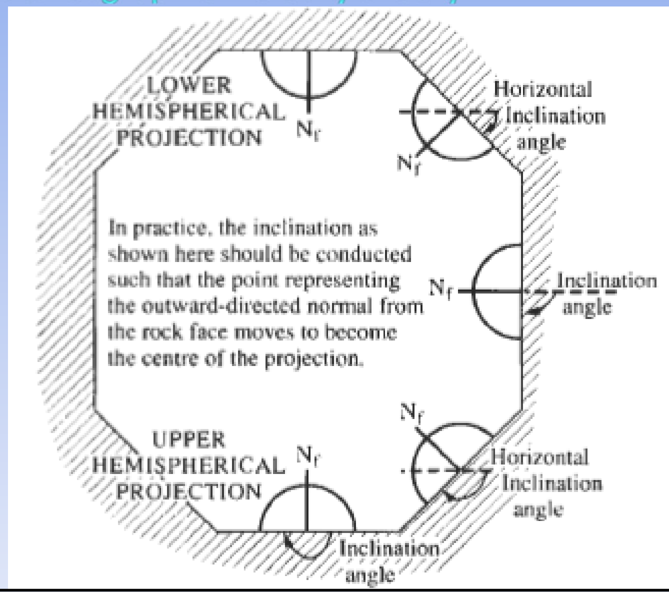
the line of maximum dip is not included within the block.

Horizontal roof

Application: Excavation stability

Stereographic – blocky theory

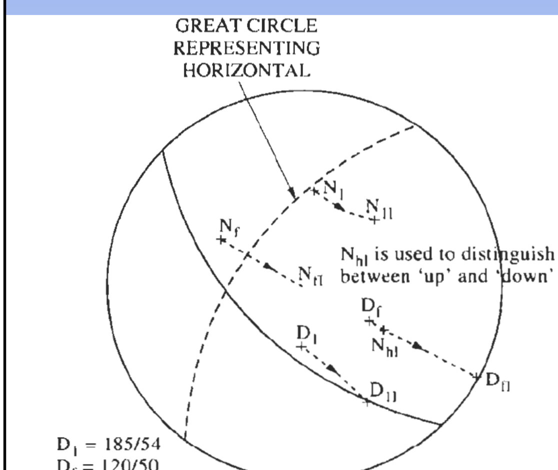
Inclination face



Application: Excavation stability

Stereographic – blocky theory

Inclination face



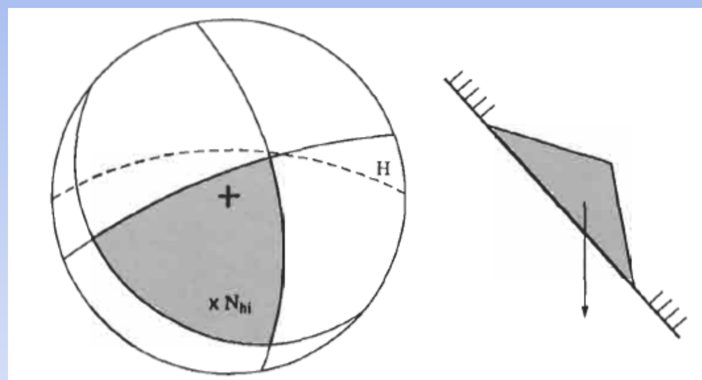
1- the normal to the excavation surface (N_f)
2- the normals to the various discontinuity surfaces (N_l, N_2)
3- the normal to the horizontal plane (N_h)
4- rotate such that N_f lies on the E-W line.
5- The inclination is then applied

any line which appears on the N_{hl} -side of the inclined horizontal plane is directed downwards

Application: Excavation stability

Stereographic – blocky theory

Block falls from the roof



great circle, H, representing the horizontal plane and the associated pole, N_{hl},

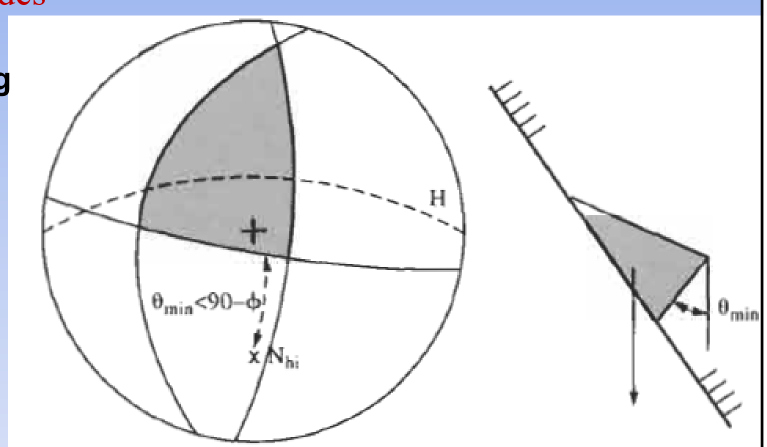
Application: Excavation stability

Stereographic – blocky theory

the block slides

Overhanging surfaces

N_{hl} is directed downwards



friction circle represents a cone of semi-angle (90 - ϕ) *around N_{hl} for overhanging* surfaces

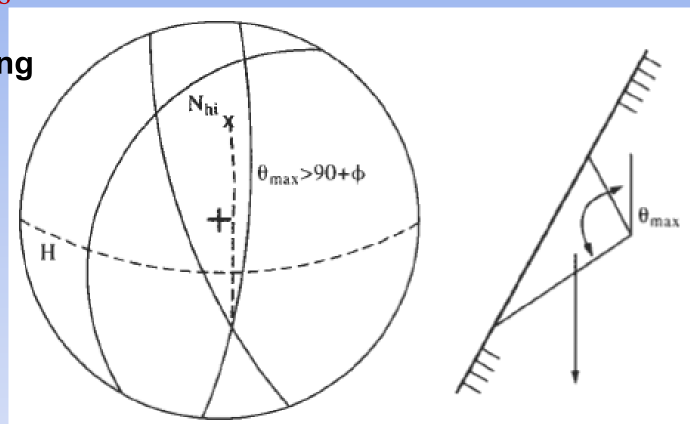
Application: Excavation stability

Stereographic – blocky theory

the block slides

Non overhanging surfaces

for non-overhanging surfaces, N_{hl} is directed upwards.

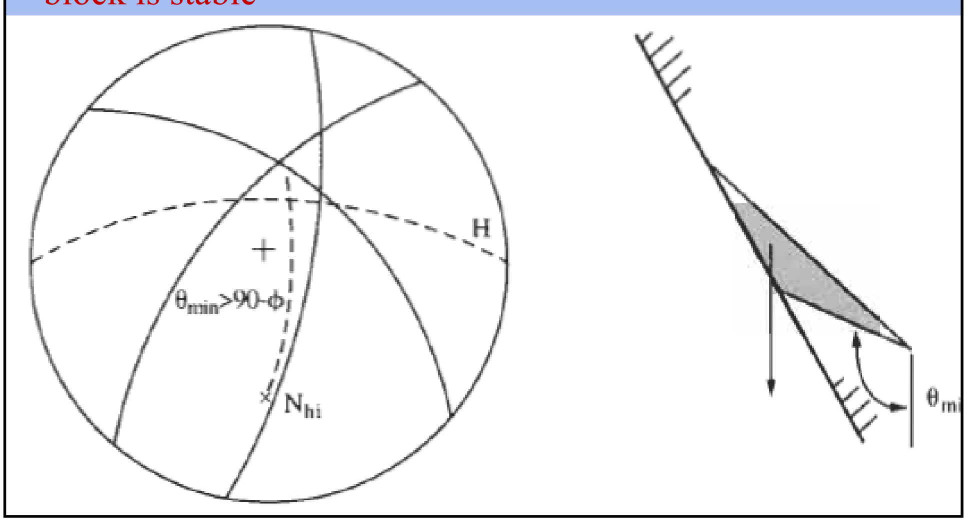


friction circle represents a cone of semi-angle (90 -+ϕ) *around* N_{hl} for non-overhanging surfaces

Application: Excavation stability

Stereographic – blocky theory

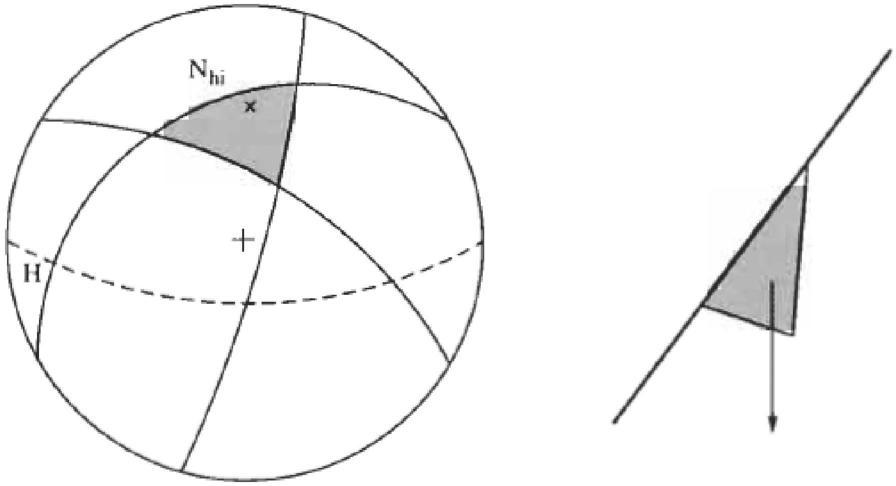
block is stable



Application: Excavation stability

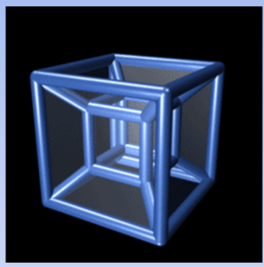
Stereographic – blocky theory

block is stable



Excavation instability

Stereographic – blocky theory

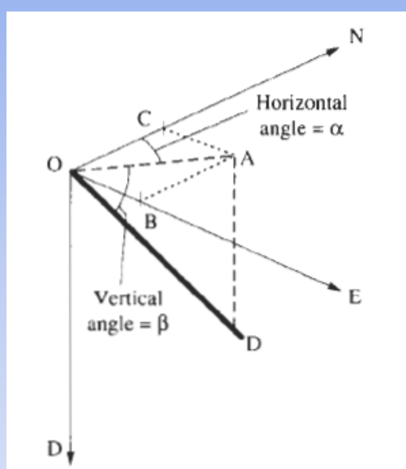


Excavation instability

Stereographic – blocky theory

Joint

جهت درزه – کسینوسهای هادی



α = trend — Dip direction

β = plunge — Dip

OB	=	$\sin\alpha\cos\beta$	$= m$
OC	=	$\cos\alpha\cos\beta$	$= l$
AD	=	$\sin\beta.$	$= n$

$$m_R = \frac{\sum m_i}{|\overline{R}|}$$

$$n_R = \frac{\sum n_i}{|\overline{R}|}$$

$$l_R = \frac{\sum l_i}{|\overline{R}|}$$

$$|\overline{R}| = \left[\left(\sum m_i\right)^2 + \left(\sum n_i\right)^2 + \left(\sum l_i\right)^2\right]^{1/2}$$

Joint

زوایای متوسط درزه های

$$\beta_R = Sin^{-1}(n_R) \qquad 0 \le \beta_R \le 90$$

$$\alpha_R = Cos^{-1}(l_R / Cos\ \delta_R) \qquad m_R \ge 0$$

$$\alpha_R = -Cos^{-1}(l_R / Cos\ \delta_R) \qquad m_R < 0$$

پراکندگی بردار ترک نسبت به برآیند

$$K_F = \frac{N}{N - |\overline{R}|}$$

پراکندگی کمتر K_f بزرگتر

$$Cos\ \psi = 1 + \frac{Ln\ (1 - P)}{K_F}$$

احتمال اینکه نرمال بر یک ترک زاویه ψ یا کوچکتر با بر آینه ترک ها بسازد

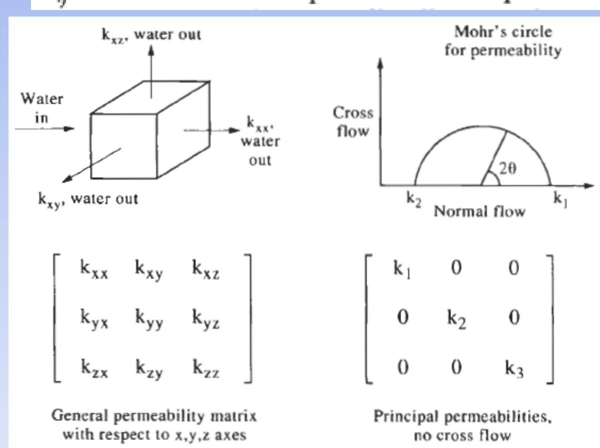
$$\overline{\psi} = \frac{1}{\sqrt{K_F}}$$

انحراف استاندارد

Permeablity

$$q_i = -\frac{k_{ij}}{\mu}\frac{\partial P}{\partial x_j}$$

q_i	is the specific discharge,
$\partial P/\partial x_j$	is the pressure gradient causing flow,
μ	is the fluid viscosity and
k_{ij}	are the components of the permeability tensor.



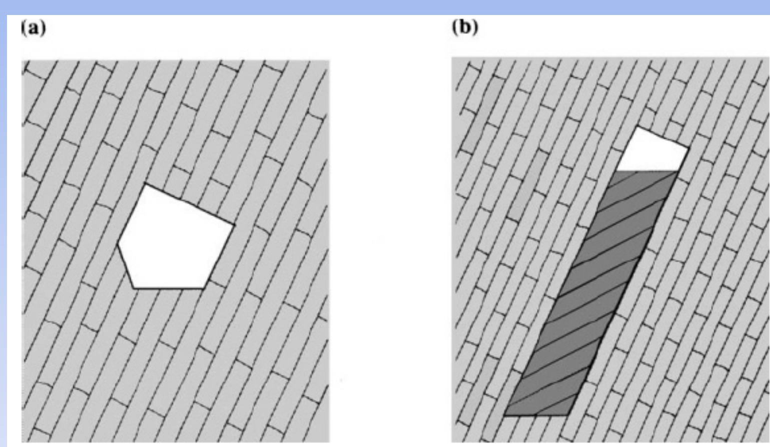
General permeability matrix with respect to x,y,z axes

Principal permeabilities, no cross flow

Hemispherical projection

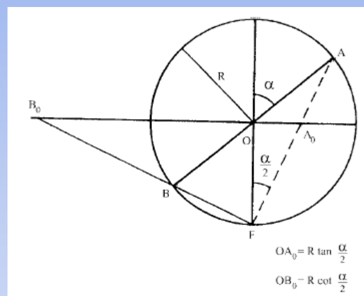
Excavation instability

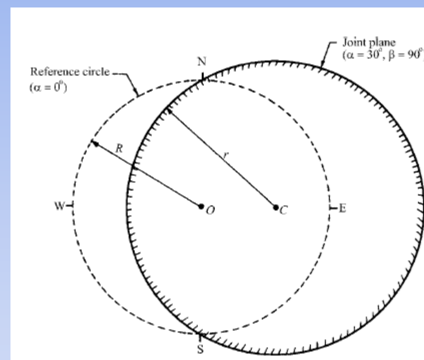
Stereographic – blocky rock



Excavation instability

Stereographic – Wulff – Equal-angle projection

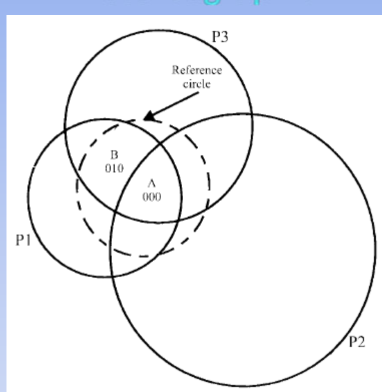


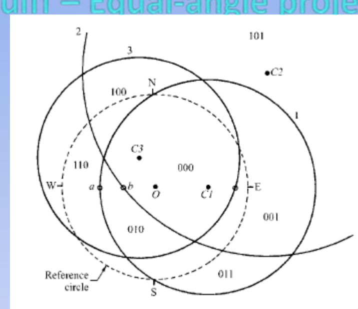


Given: ($\alpha = 30^0$, $\beta = 90^0$)
Choose $R = 5$, then:
$r = 5/\cos 30 = 5.77$
$O_c = 5 \tan 30 = 2.89$
(Lower focal point)

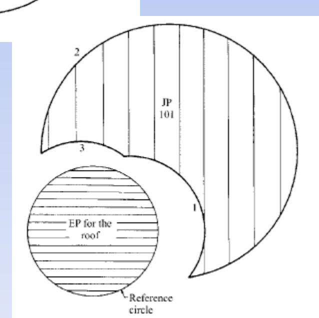
Excavation instability

Stereographic – Wulff – Equal-angle projection



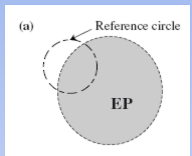


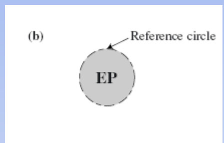
Discontinuity surface	Dip (α)	Dip direction (β)	Friction angle (φ)
1. Bedding joints	30°	90°	25°
2. Sheared surfaces	60°	45°	16°
3. Main joint set	20°	330°	35°

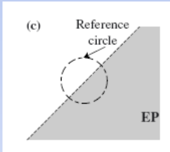


Excavation instability

Stereographic – Wulff – Equal-angle projection

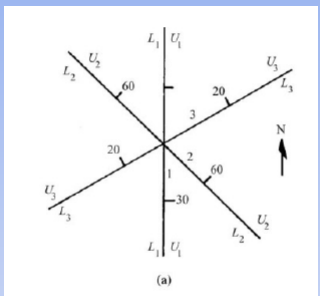


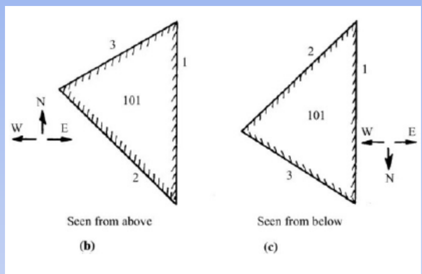




Hemispherical projection

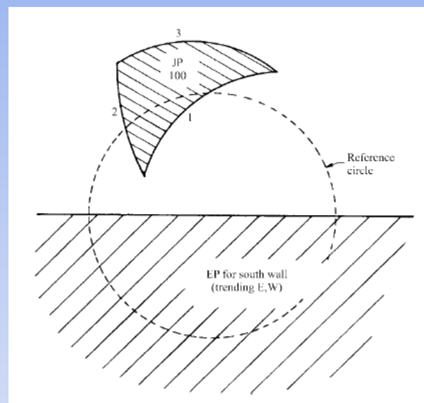
Stereographic – Wulff – Equal-angle projection



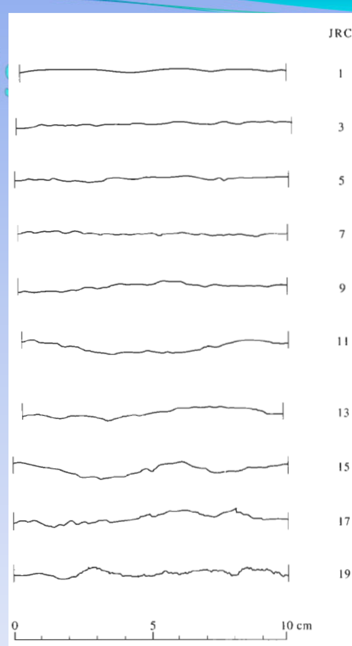


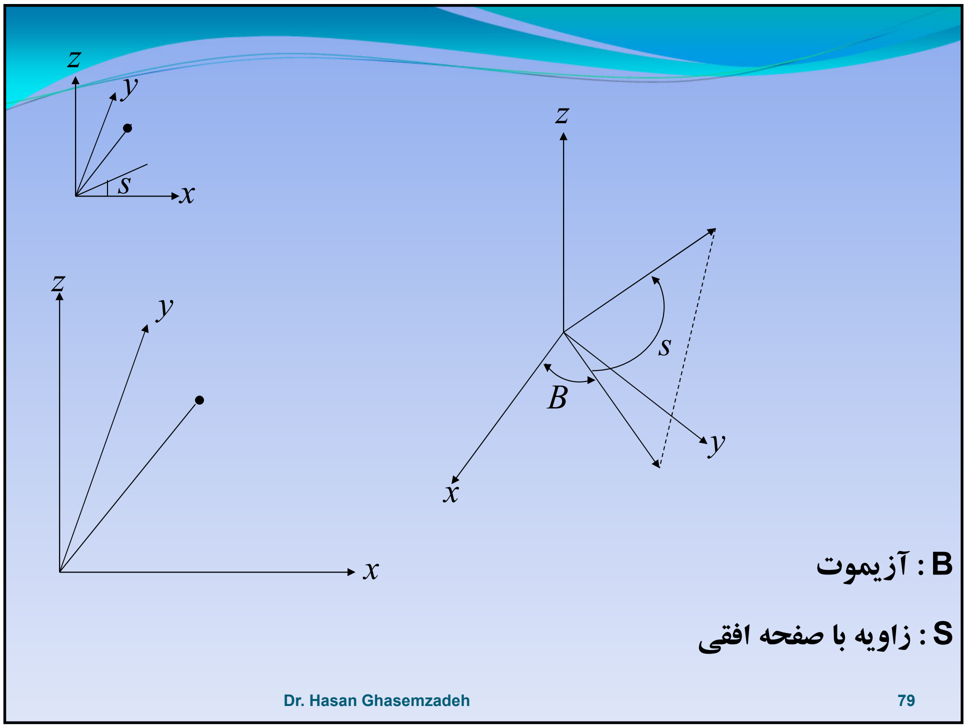
Hemispherical projection

Stereographic – Wulff – Equal-angle projection



Hemispherical projection

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B : آزیموت
S : زاویه با صفحه افقی
Dr. Hasan Ghasemzadeh
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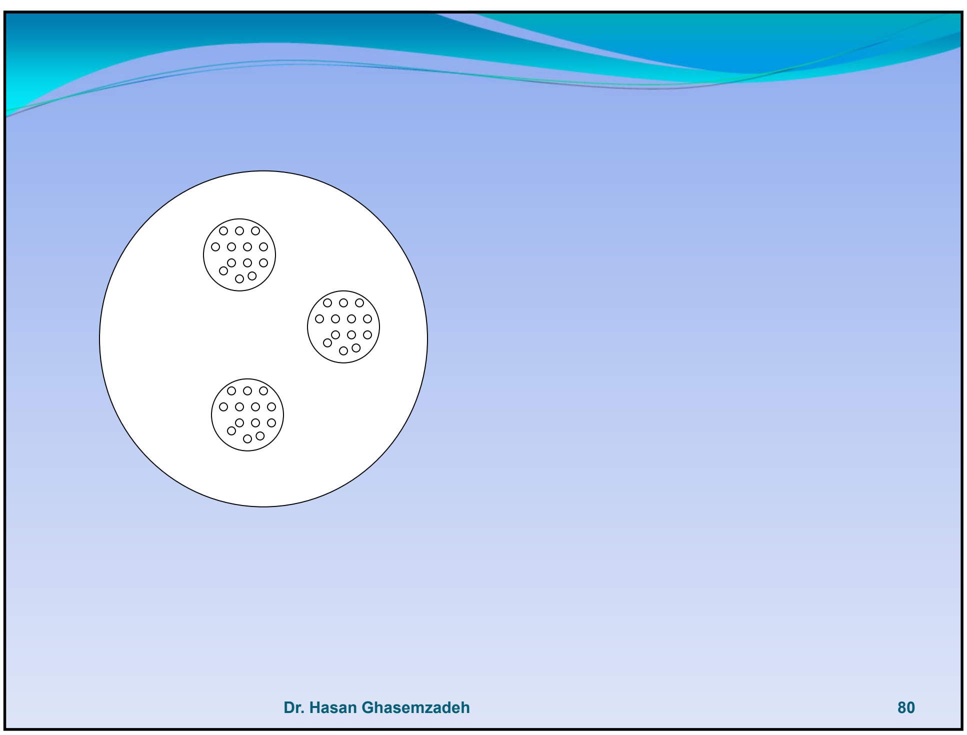
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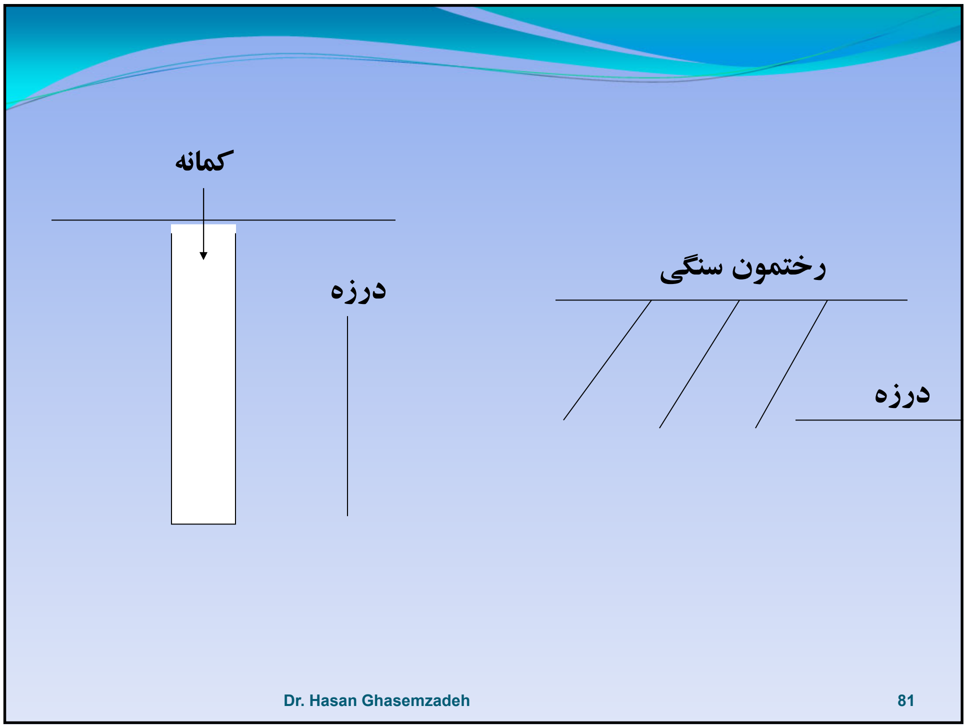
کمانه
درزه
رختمون سنگی
درزه
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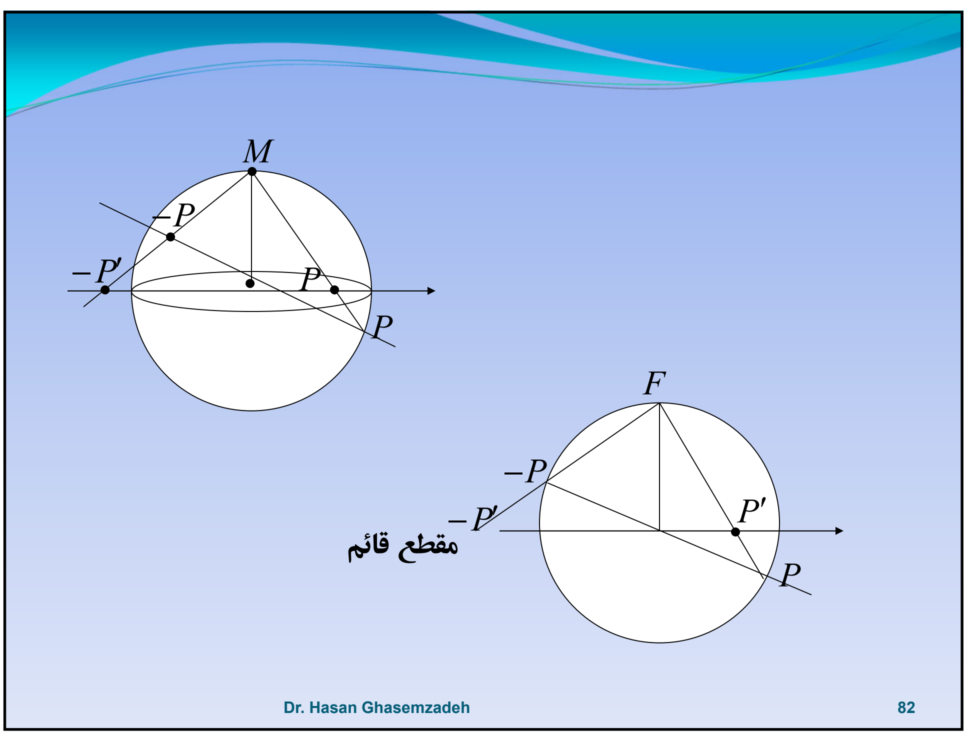
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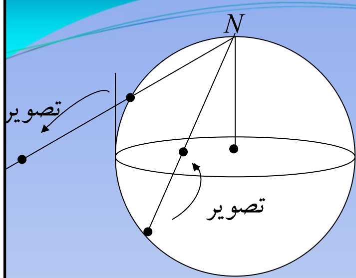
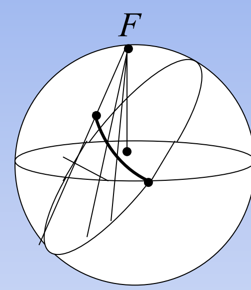
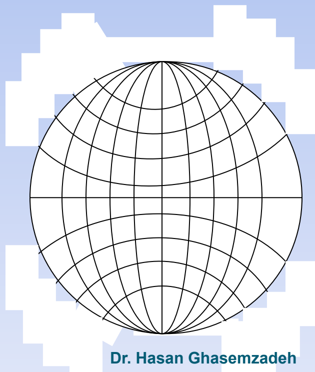
82







جهت درزه

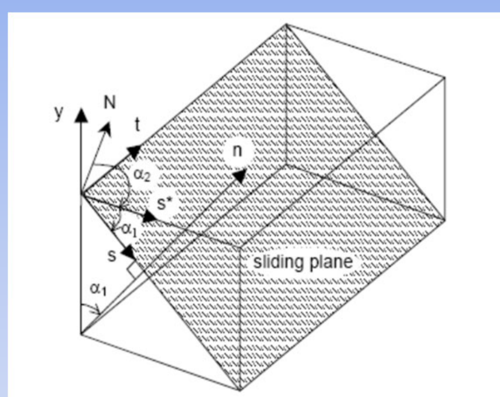
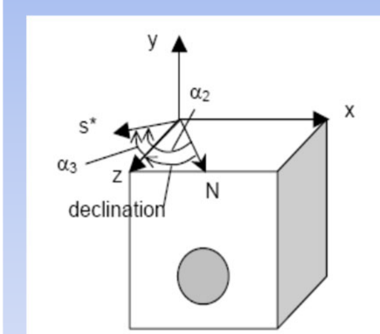


Figure 4.5 Definition of dip angle and dip direction



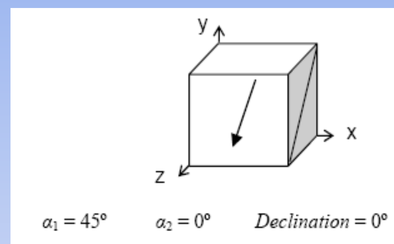
$$\alpha_3 = \alpha_2 - Declination$$

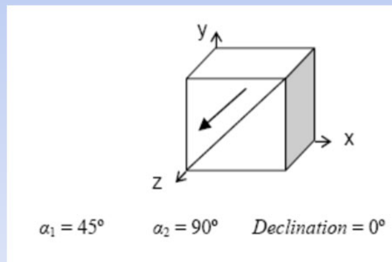
جهت درزه

$$\underline{n} = \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix} = \begin{bmatrix} -\sin\alpha_1 \sin\alpha_3 \\ \cos\alpha_1 \\ \sin\alpha_1 \cos\alpha_3 \end{bmatrix}$$

$$\underline{s} = \begin{bmatrix} s_x \\ s_y \\ s_z \end{bmatrix} = \begin{bmatrix} -\cos\alpha_1 \sin\alpha_3 \\ -\sin\alpha_1 \\ \cos\alpha_1 \cos\alpha_3 \end{bmatrix}$$

$$\underline{t} = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} = \begin{bmatrix} \cos\alpha_3 \\ 0 \\ \sin\alpha_3 \end{bmatrix}$$





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✓ مدل سازی گسسته

- روش المان های مجزا Discrete Element Method (DEM)
- روش شبکه شکستگی مجزا Discrete Fracture Network Method (DFN)

✓ مدل سازی ترکیبی

- FEM / BEM حل ترکیبی
- DEM / DEM حل ترکیبی
- FEM / DEM حل ترکیبی
- دیگر روش های ترکیبی

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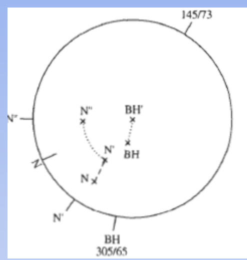
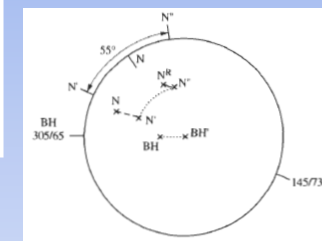
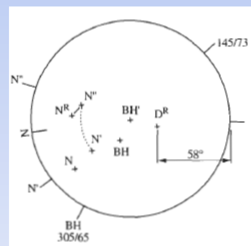
Hemispherical projection

Rotation about arbitrary axis





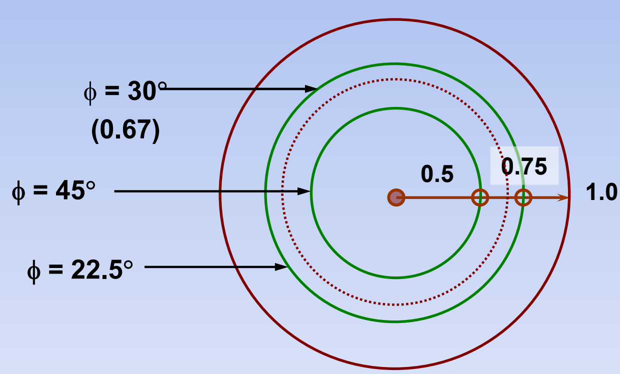


APPLICATION: SLOPE STABILITY

The Friction Circle

Outer radius = 1, represents $\phi = 0°$

Radius of friction circle = $(90° - \phi)/90°$



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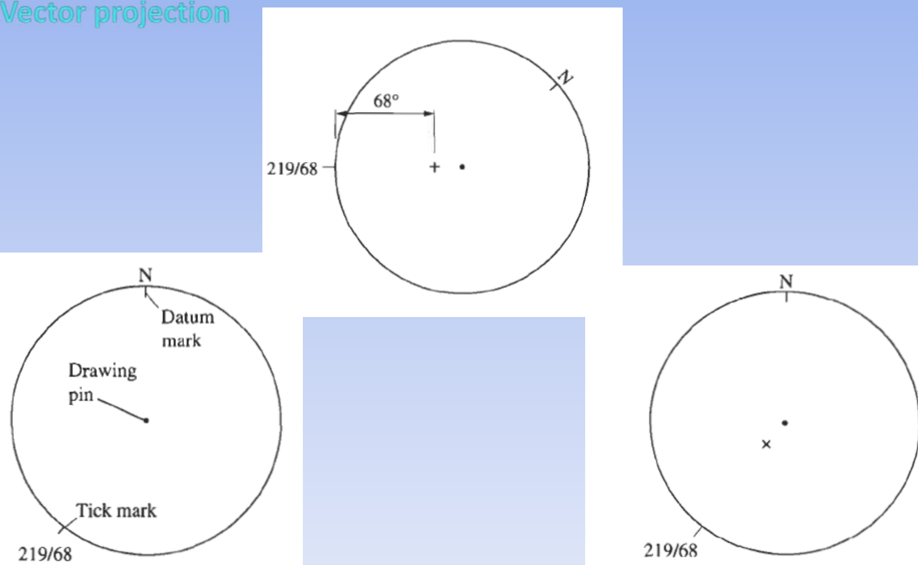
Hemispherical projection

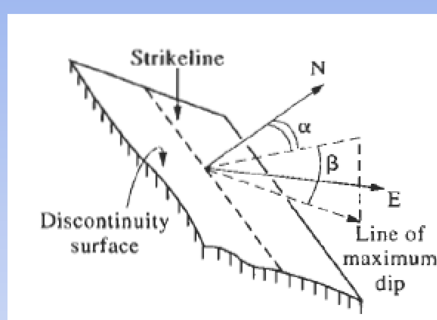
Stereographic

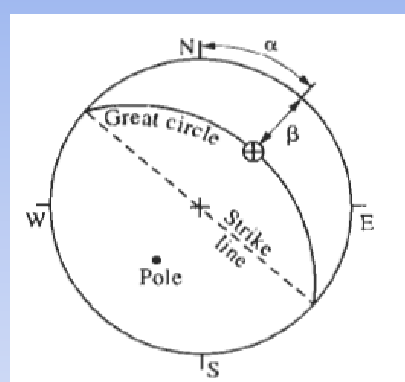
Vector projection



Hemispherical projection

Grand circle and pole projection



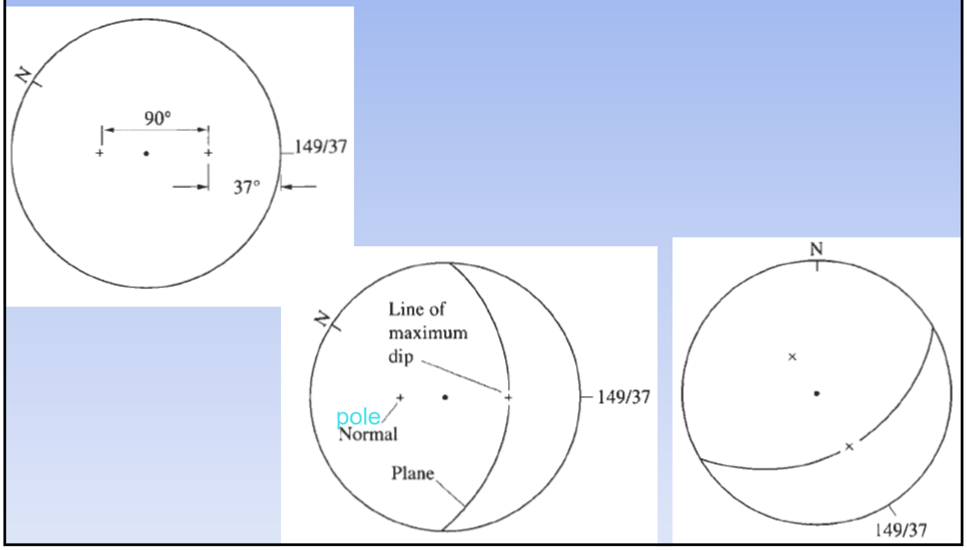


$$\alpha_{\text{normal}} = \alpha_{\text{dip}} \pm 180°$$

$$\beta_{\text{normal}} = 90° - \beta_{\text{dip}}.$$

Hemispherical projection

Grand circle and pole projection



Application: Excavation stability

Stereographic – blocky theory

2 Dimensional