6. Block theory for surficial excavations

1) Basic concepts

- Examples of rock slopes
  - Buildings, roads, bridges on rock slopes, dam abutments, portals of a tunnel (Fig.6.1)

- Slope failure
  - Fundamental failure: Sliding along one face (plane failure, Fig.6.3)

    Sliding along two faces (wedge failure, Fig.6.2)

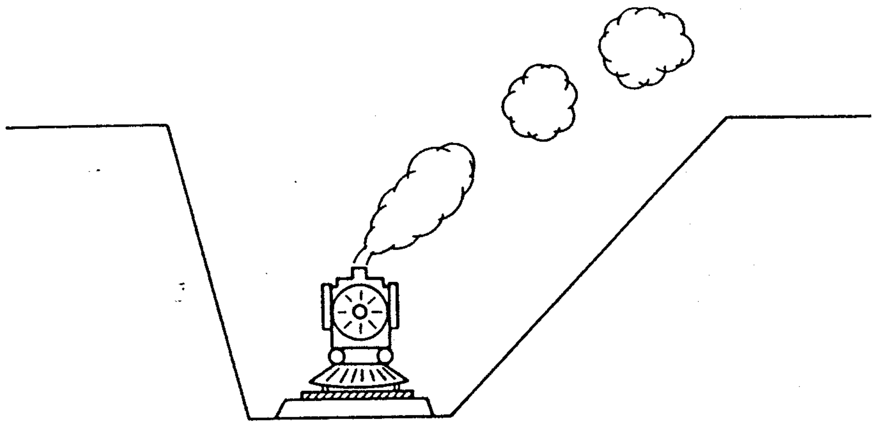
    Rotation (toppling failure, Fig.6.4)
  - Fracturing by stress (Fig.6.5)
  - Progressive failure (Fig.6.6): (= complex failure) combination of

    fundamental failures

1) Basic concepts

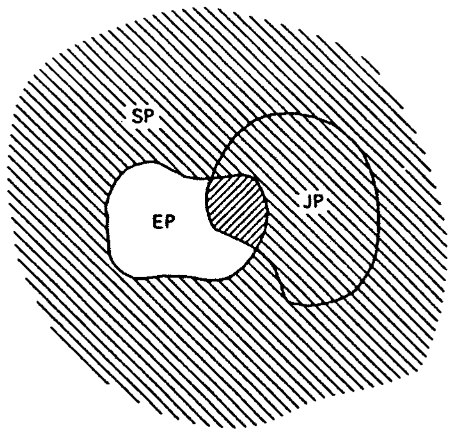
- Design

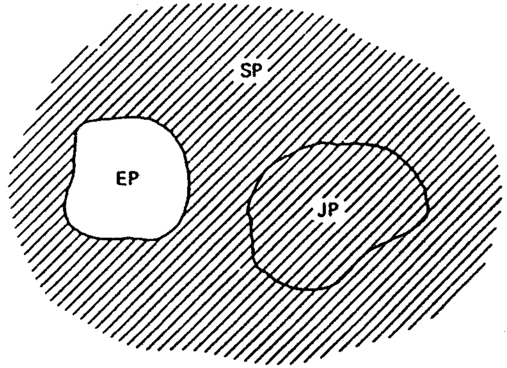
- Application of block theory: support design, slope strike/dip design
- Influence of discontinuities on slope stability: steep slopes can be more stable in some cases.



2) Conditions for removability of blocks intersecting surface excavations

- Infinite blocks
  - BP (= JP∩EP) ≠ Ø





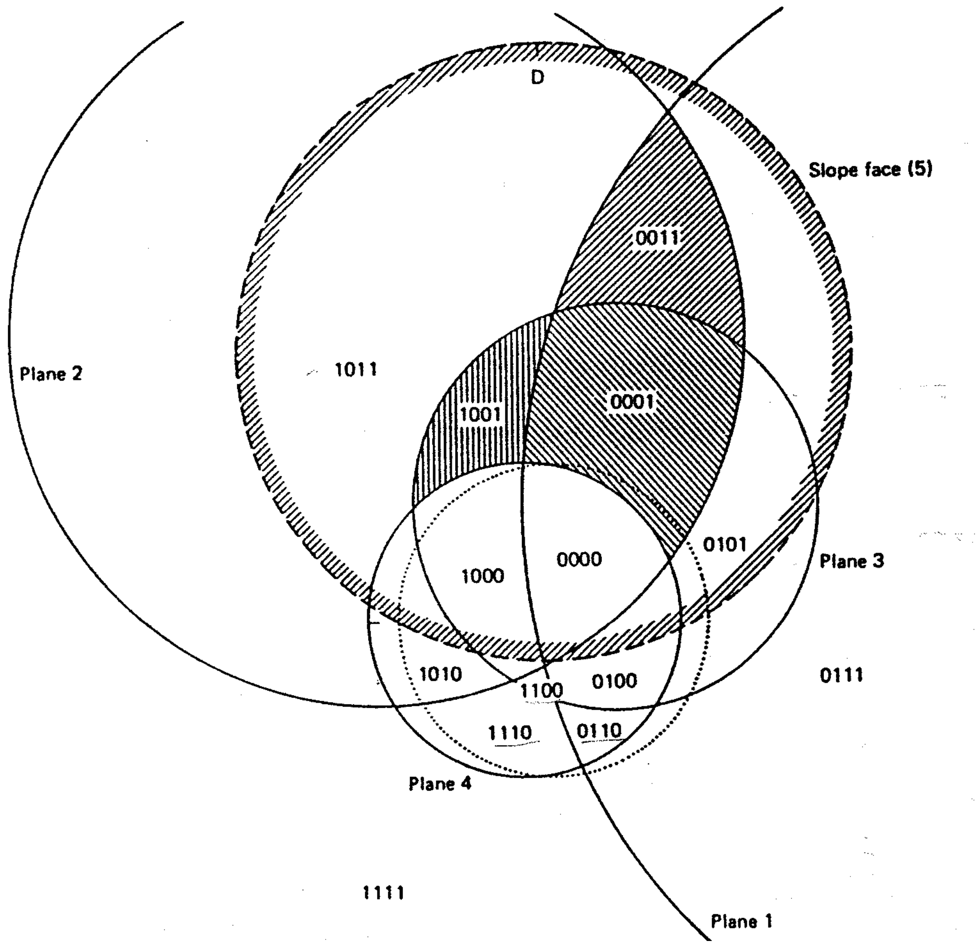
- Finite blocks
  - BP = Ø ≡ JP ⊂ SP
- Tapered blocks
  - JP = Ø (→ JP ⊂ SP)
- Removable blocks
  - JP ⊂ SP (finite) and JP ≠ Ø (not tapered)

3) Identification of key blocks using stereographic projection

- A slope formed by a single plane

TABLE 6.1 Joint and Slope Orientations for Example Problems

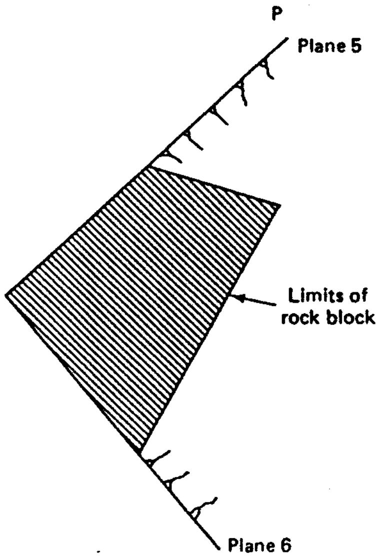
Joint Set or Slope Plane (Free Surface)	Dip, α (deg)	Dip Direction, β (deg)
1 (joint set)	75	80
2 (joint set)	65	330
3 (joint set)	40	30
4 (joint set)	10	270
5 (free surface)	60	0
6 (free surface)	80	90

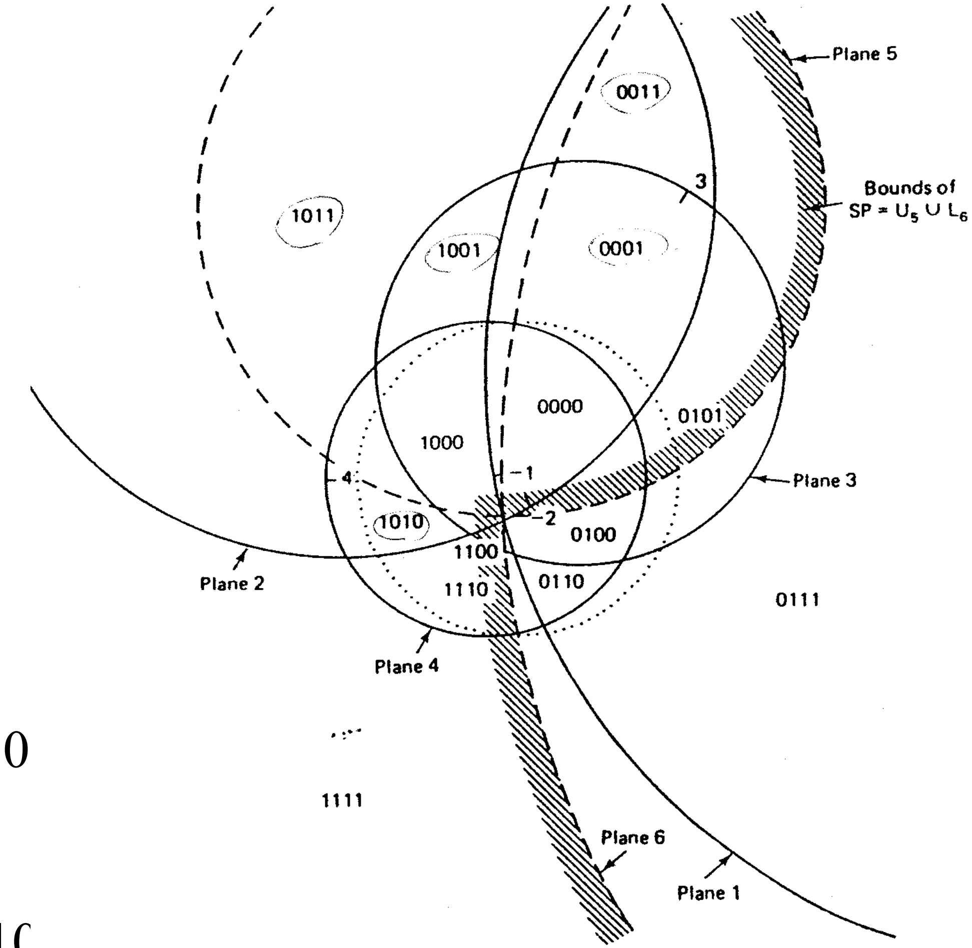


-Removable: 0001, 0011 and 1001
-Tapered: 1101 and 0010
-Infinite (11) : 1111, 0111, 1110…

3) Identification of key blocks using stereographic projection

- Convex slopes

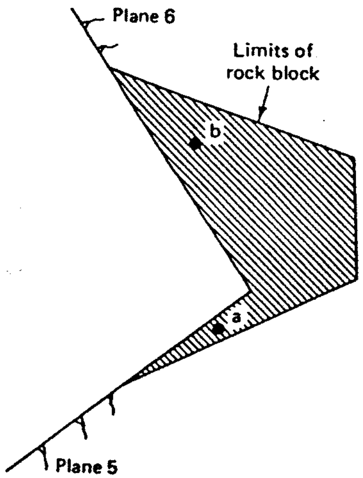


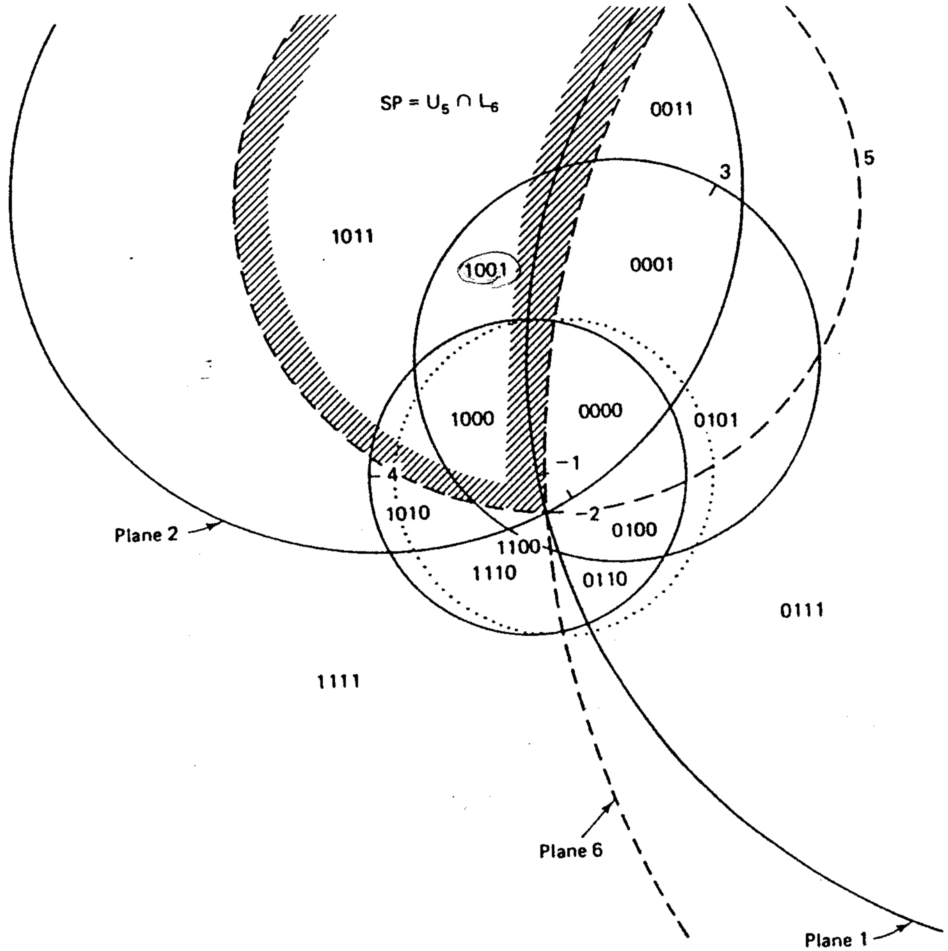


-Removable: 0001, 0011, 1001,1010
1011
-Tapered: 1101 and 0010
-Infinite (9) : 0000, 1000, 0111, 111(…

3) Identification of key blocks using stereographic projection

- Concave slopes

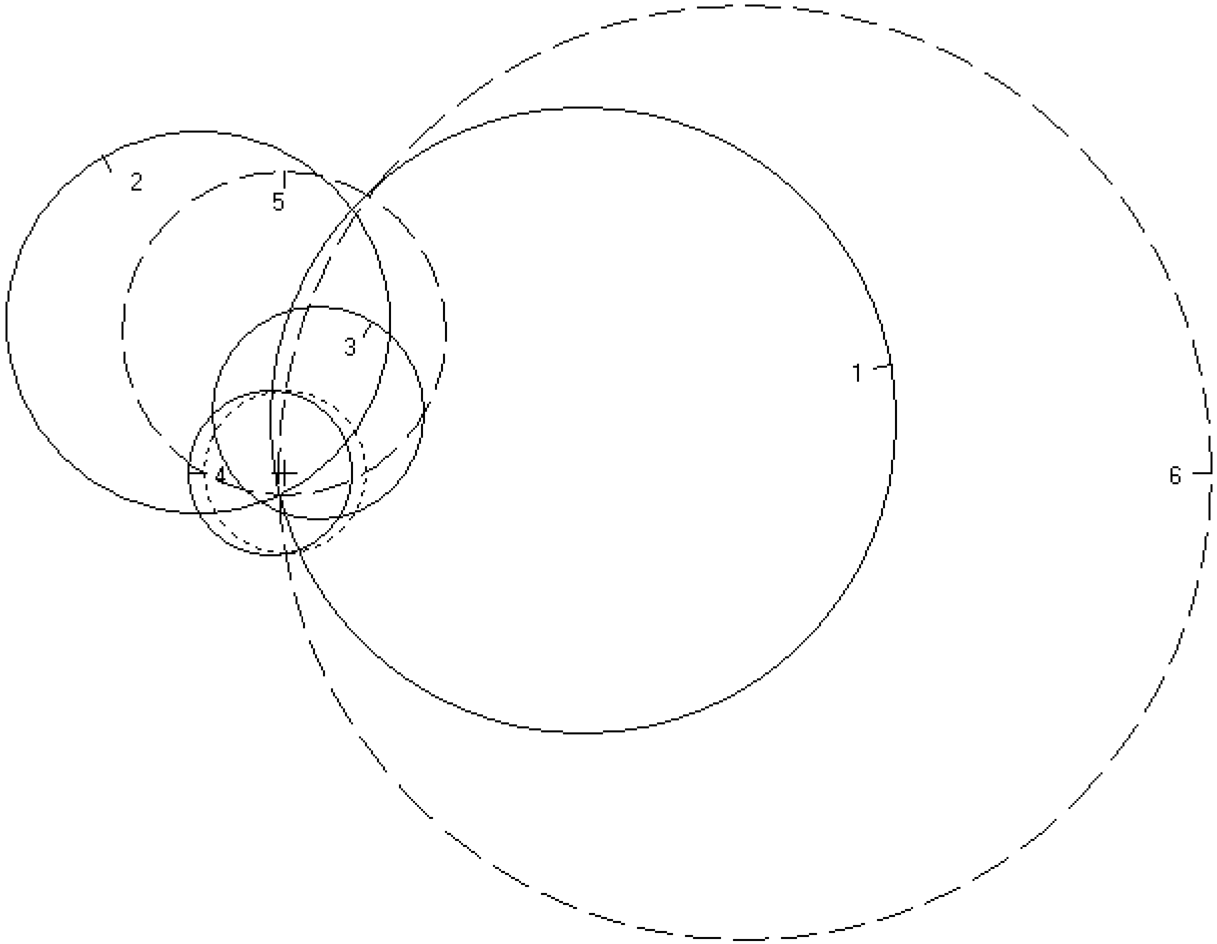




-Removable: 1001
-Tapered: 1101 and 0010
-Infinite (13) : 0000, 1000, 0111, 111(

3) Identification of key blocks using stereographic projection

• Horizontally convex slopes ?



-Removable:
-Tapered: 1101 and 0010
-Infinite ( ) :

3) Identification of key blocks using stereographic projection

- Removable blocks with one repeated joint set

Refer to Fig.6.20 and Table 6.2 (Plane 5) or
Table 6.3 (convex slope by plane 5 & 6)

- Removable blocks with two repeated joint sets

-Refer to Fig.6.21 and Table 6.4 (Plane 5)

-Case of the horizontally convex slope?

4) Evaluation of finiteness and removability of blocks using vector methods

- Finiteness test using an inequality system

$$\begin{aligned} A_1x + B_1y + C_1z &\geq 0 \\ A_2x + B_2y + C_2z &\geq 0 \\ &\vdots \\ A_nx + B_ny + C_nz &\geq 0 \end{aligned}$$

$$\Downarrow$$

Put $\pm\vec{I}_{ij}$ into the inequality system

$$\Downarrow$$

If there is no $\pm\vec{I}_{ij}$ satisfying all the inequalities the block is finite (BP=∅)

4) Evaluation of finiteness and removability of blocks using vector methods

- Finiteness test using an testing matrix (T)

Build a direction-ordering index I_k^{ij} matrix

$$I_k^{ij} = \operatorname{sign}\left[\left(n_i \times n_j\right) \cdot n_k\right] \quad \text{(Table 6.6)}$$

$$\Downarrow$$

Determine a signed block code index ($I(a_i)$)

$$I(a_i) = \begin{cases} +1 & \text{if } a_i = 0 \\ -1 & \text{if } a_i = 1 \\ 0 & \text{if } a_i = 2 \\ \pm 1 & \text{if } a_i = 3 \end{cases}$$

$$\Downarrow$$

Build a testing matrix $T^{ij} = I_k^{ij} \cdot I(a_k)$ and check out the signs of rows

$$T^{ij} = \left(I_1^{ij} \cdot I(a_1), I_2^{ij} \cdot I(a_2), \ldots, I_n^{ij} \cdot I(a_n)\right) \quad \text{(Table 6.7)}$$

4) Evaluation of finiteness and removability of blocks using vector methods

- Finiteness test of a block

$$\vec{I}_{12}\left(=\hat{n}_1 \times \hat{n}_2\right), \vec{I}_{13}, \ldots, \vec{I}_{56}$$

$$
\begin{aligned}
0.9512x + 0.1677y + 0.2588z &= 0 \\
-0.4531x + 0.7848y + 0.4226z &= 0 \\
0.3213x + 0.5566y + 0.7660z &= 0 \\
-0.1736x + 0.9848z &= 0 \\
0.8660y + 0.5000z &= 0 \\
0.9848x + 0.1736z &= 0
\end{aligned}
$$

Direction-ordering index, $I_k^{ij} = \mathrm{Sign}\left[\left(n_i \times n_j\right) \cdot n_k\right]$

i	*j*	*k*					
		1	2	3	4	5	6
1	2	0	0	1	1	−1	1
1	3	0	−1	0	1	−1	1
1	4	0	−1	−1	0	−1	1
1	5	0	1	1	1	0	1
1	6	0	−1	−1	−1	−1	0
2	3	1	0	0	−1	1	1
2	4	1	0	1	0	1	1
2	5	−1	0	−1	−1	0	−1
2	6	1	0	−1	−1	1	0
3	4	1	−1	0	0	−1	1
3	5	−1	1	0	1	0	−1
3	6	1	1	0	−1	1	0
4	5	−1	1	−1	0	0	−1
4	6	1	1	1	0	1	0
5	6	1	−1	−1	−1	0	0

4) Evaluation of finiteness and removability of blocks using vector methods

Direction-ordering index, $I_k^{ij} = \mathrm{Sign}\left[\left(\hat{n}_i \times \hat{n}_j\right) \cdot \hat{n}_k\right]$

i	*j*	*k*					
		1	2	3	4	5	6
1	2	0	0	1	1	−1	1
1	3	0	−1	0	1	−1	1
1	4	0	−1	−1	0	−1	1
1	5	0	1	1	1	0	1
1	6	0	−1	−1	−1	−1	0
2	3	1	0	0	−1	1	1
2	4	1	0	1	0	1	1
2	5	−1	0	−1	−1	0	−1
2	6	1	0	−1	−1	1	0
3	4	1	−1	0	0	−1	1
3	5	−1	1	0	1	0	−1
3	6	1	1	0	−1	1	0
4	5	−1	1	−1	0	0	−1
4	6	1	1	1	0	1	0
5	6	1	−1	−1	−1	0	0

Testing matrix for BC = (1 0 0 1 1 2)

i	*j*	*k*					
		1	2	3	4	5	0
1	2	0	0	1	−1	1	0
1	3	0	−1	0	−1	1	0
1	4	0	−1	−1	0	1	0
1	5	0	1	1	−1	0	0
1	6	0	−1	−1	1	1	0
2	3	−1	0	0	1	−1	0
2	4	−1	0	1	0	−1	0
2	5	1	0	−1	1	0	0
2	6	1	0	−1	1	−1	0
3	4	−1	−1	0	0	1	0
3	5	1	1	0	−1	0	0
3	6	1	1	0	1	−1	0
4	5	1	1	−1	0	0	0
4	6	1	1	1	0	−1	0
5	6	1	−1	−1	1	0	0

4) Evaluation of finiteness and removability of blocks using vector methods

- Finiteness test of a block with a repeated joint set

Direction-ordering index, $I_k^{ij} = \mathrm{Sign}\left[\left(\hat{n}_i \times \hat{n}_j\right) \cdot \hat{n}_k\right]$

i	*j*	*k*: 1	2	3	4	5	6
1	2	0	0	1	1	−1	1
1	3	0	−1	0	1	−1	1
1	4	0	−1	−1	0	−1	1
1	5	0	1	1	1	0	1
1	6	0	−1	−1	−1	−1	0
2	3	1	0	0	−1	1	1
2	4	1	0	1	0	1	1
2	5	−1	0	−1	−1	0	−1
2	6	1	0	−1	−1	1	0
3	4	1	−1	0	0	−1	1
3	5	−1	1	0	1	0	−1
3	6	1	1	0	−1	1	0
4	5	−1	1	−1	0	0	−1
4	6	1	1	1	0	1	0
5	6	1	−1	−1	−1	0	0

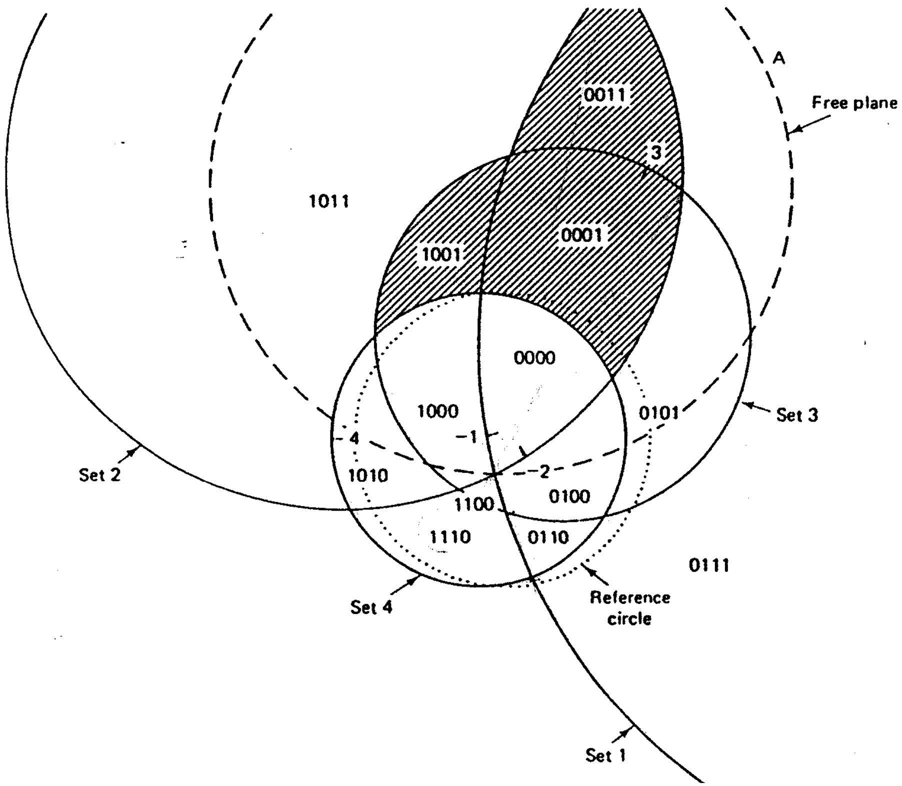
Testing matrix for BC = (1 2 0 3 1 2)

i	*j*	*k*: 1	2	3	4	5	0
1	2	0	0	1	±1	1	0
1	3	0	0	0	±1	1	0
1	4	0	0	−1	0	1	0
1	5	0	0	1	±1	0	0
1	6	0	0	−1	±1	1	0
2	3	−1	0	0	±1	−1	0
2	4	−1	0	1	0	−1	0
2	5	1	0	−1	±1	0	0
2	6	1	0	−1	±1	−1	0
3	4	−1	0	0	0	1	0
3	5	1	0	0	±1	0	0
3	6	1	0	0	±1	−1	0
4	5	1	0	−1	0	0	0
4	6	1	0	1	0	−1	0
5	6	1	0	−1	±1	0	0

5) Procedures for designing rock slopes

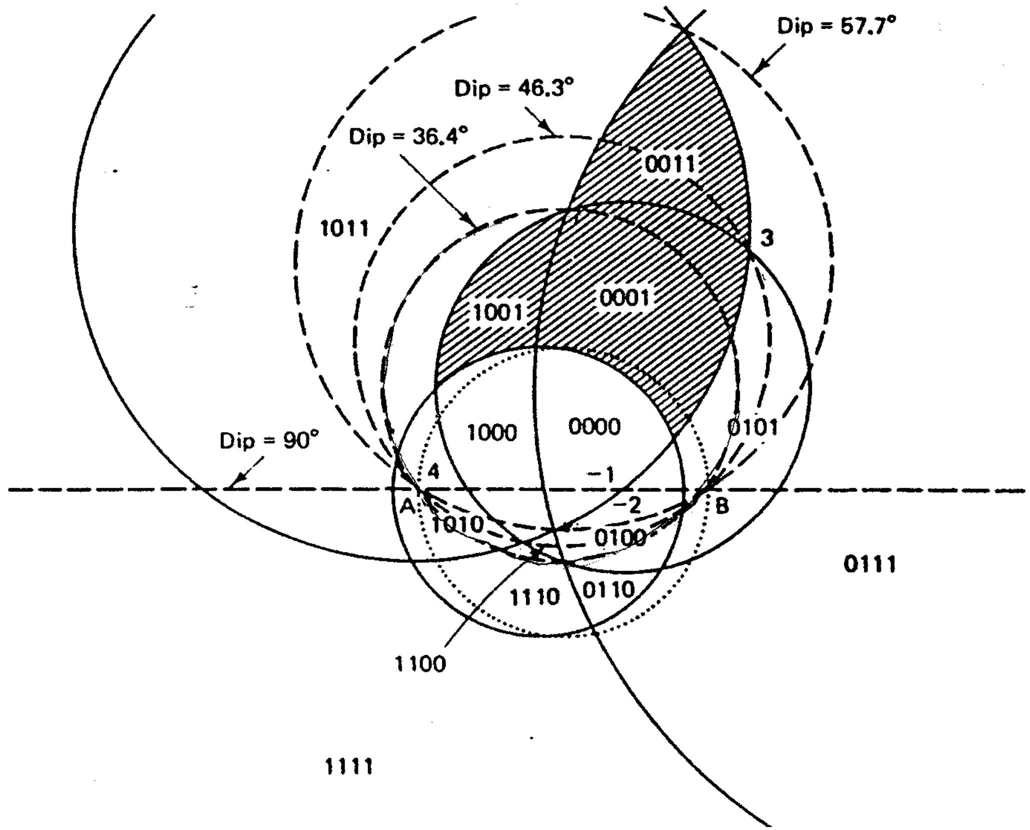
- Most critical key-block types

- Key blocks that are bigger or of higher net shear force are more critical.
  Net shear force = sliding force – resisting force
- Higher sliding force means steeper joints and joint edges (0011).



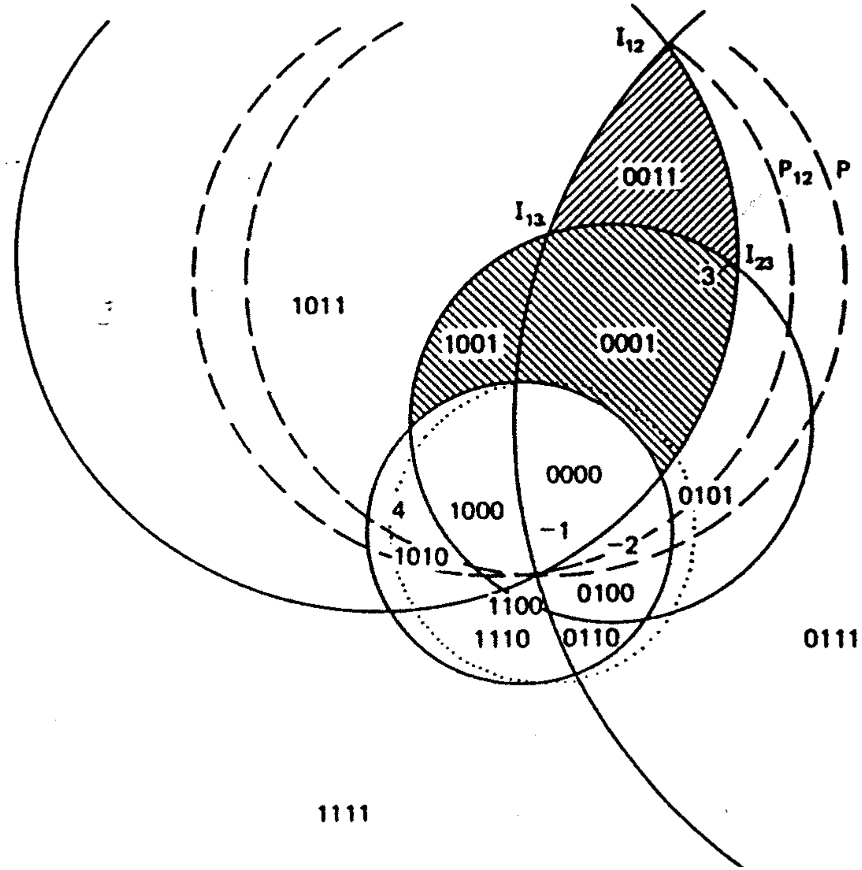
5) Procedures for designing rock slopes

- Determining the dip angle of a slope for an assigned strike



5) Procedures for designing rock slopes

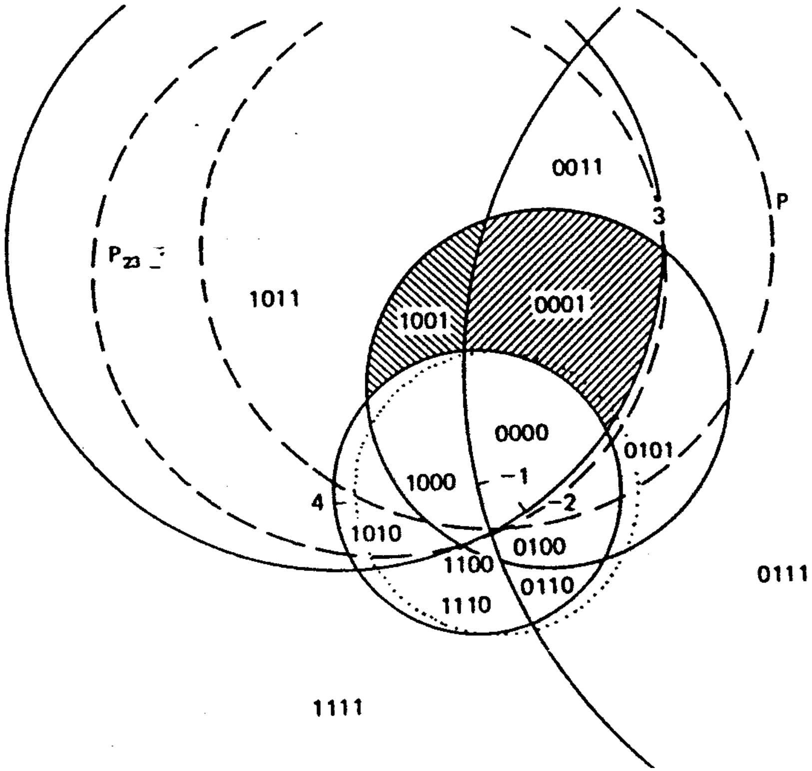
- Determining the strike of a slope for an assigned dip angle



Great circle containing JP 0011

5) Procedures for designing rock slopes

- Determining the strike of a slope for an assigned dip angle



Great circle
containing JP 0001