

## FLOW NETS FOR HOMOGENEOUS ISOTROPIC SYSTEMS

A **flow net** is a graphical solution to the equations of steady groundwater flow. A flow net consists of two sets of lines which must **always** be orthogonal (perpendicular to each other): *flow lines*, which show the direction of groundwater flow, and *equipotentials* (lines of constant head), which show the distribution of potential energy. Flow nets are usually constructed through trial-and-error sketching.

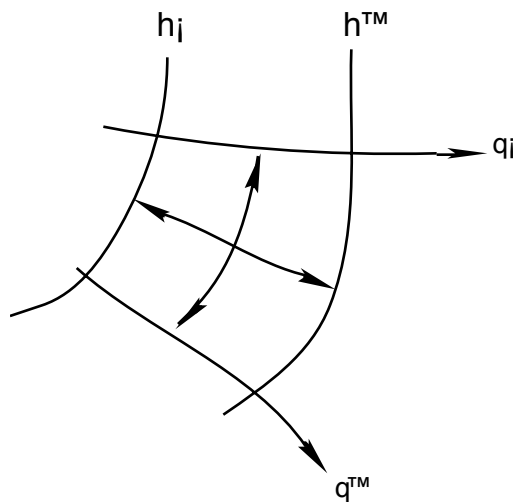
To construct a flow net:

1. make a two-dimensional scale drawing of the system under consideration (usually a profile, but may be a map view.)
2. determine or specify the boundary conditions, i.e., indicate/label the position of the water table, of any impermeable boundaries, of any points of known head or known pressure.
  - a. *any* surface of constant head (e.g., bottom of a flat-bottomed reservoir) is by definition an equipotential, and flow lines must meet it at right angles.
  - b. since flow cannot cross impermeable boundaries, the flow at such a boundary must be parallel to it, i.e., impermeable boundaries are flow lines, and equipotentials must meet them at right angles.
  - c. the water table is, by definition, the surface where  $P = 0$ ; it can thus be an equipotential *only* if it is horizontal. At *any* point on the water table (no matter whether it is flat or sloping)  $h = z$ , where  $z$  is the elevation of the water table above the datum.

If there is no seepage percolating down to the water table, it can be considered a flow line. In the general case however (sloping water table, seepage across it), the water table is neither a flow line nor an equipotential, and flow lines will intersect it at an angle.

3. Once you have defined the boundary conditions, start trial sketching of flow lines and equipotentials, following the rules in step 2 above, and being sure that the flow lines and equipotentials always intersect at right angles.

Try to make the flow net consist of curvilinear "squares", i.e., the boxes in the flow net may have curving sides, but the midline lengths of the "square" should be approximately equal. (arrows inside square in diagram below) This is especially important if the flow net is to be used for calculations of groundwater discharge.



Keep sketching and refining until you have a good set of "squares" which satisfies the boundary conditions.

- Determine the head at the left-most and right-most equipotentials and subtract them to get  $\Delta h$ , the total head difference across the net. Now determine  $N_d$ , the number of potential drops (i.e., squares) between these two equipotentials. The value of *each* potential drop is thus:

$$h_d = \frac{\Delta h}{N_d}$$

Knowing this, you can label each equipotential with its correct value of  $h$ .

- To determine pore pressure at any point on an equipotential  $h$ , simply measure the elevation,  $z$ , of the point above the datum. Then the pressure is given by:

$$p = (h - z)\gamma \text{ where } \gamma \text{ is the specific weight of water.}$$

### SOME HINTS FOR DRAWING FLOW NETS

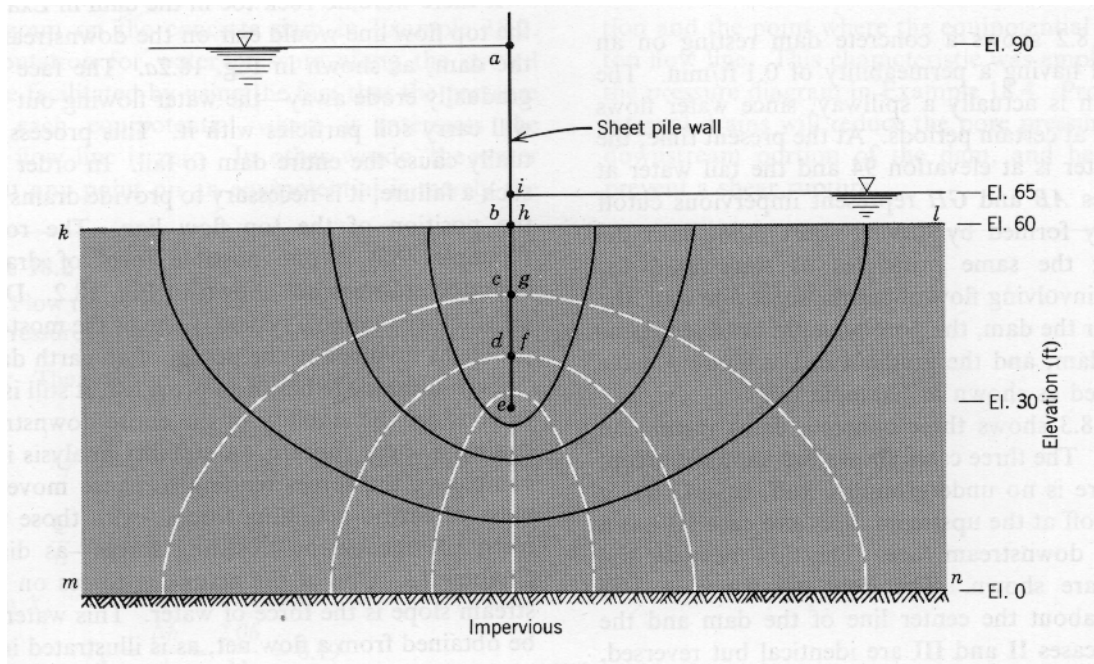
Rules that **must** be obeyed in drawing flow nets:

- In a homogeneous isotropic system, flow lines and equipotentials are *always* perpendicular and form curvilinear "squares".
- Equipotentials are always normal to an impermeable boundary  
Flow lines are always parallel to an impermeable boundary
- Equipotentials are always parallel to a constant head boundary  
Flow lines are always normal to a constant head boundary

Suggested procedure for drawing flow nets:

- First identify boundary conditions (Which boundaries are impermeable? Which are constant head?)
- Next think: where is water entering the system? Where can it leave?
- Always look for any symmetry in the boundary conditions.
- Decide on the number of flow tubes you want to use.
- Draw a trial flow line and then draw in other flow lines to define all the flow tubes; some trial-and-error sketching may be necessary
- Where flow tubes constrict, higher head gradients (more closely spaced equipotentials) are needed to move the same quantity of water through the flow tube.
- Fit together the curvilinear squares by drawing in the equipotentials. As you do this, you may have to revise the positions of some of the flow lines. Trial-and-error is the order of the day.

## EXAMPLE: FLOW BENEATH A SHEET PILE COFFER DAM



- Determine boundary equipotentials and flow lines:
  - lines  $kb$  ( $h_1$ ) and  $hl$  ( $h_9$ ) are equipotentials because they are at constant elevation and have constant water depth above them.
  - lines  $mn$  ( $q_1$ ),  $be$  ( $q_5$ ) and  $he$  ( $q_5$ ) are flow lines because they are impermeable surfaces
- Determine boundary heads: head along lines  $kb$  and  $hl$  are equal to elevation of boundary above the datum plus depth of water above the boundary:

$$h_1 = 60 \text{ ft} + 30 \text{ ft} = 90 \text{ ft}$$

$$h_9 = 60 \text{ ft} + 5 \text{ ft} = 65 \text{ ft}$$

- Sketch equipotentials and flow lines
- Find total  $\Delta h$  along flow lines (e.g., along  $q_2$ ):  $\Delta h = (h_1 - h_9) = (90 \text{ ft} - 65 \text{ ft}) = 25 \text{ ft}$
- Determine  $N_d$  by counting number of equipotential drops (squares) from  $h_1$  to  $h_9$ :

8 squares are traversed going along  $q_2$  from  $h_1$  to  $h_9$  so  $N_d = 8$

- Determine  $h_d$ , the head drop across a square :

$$h_d = \frac{\Delta h}{N_d} = \frac{25 \text{ ft}}{8} = 3.125 \text{ ft}$$

thus

$$h_2 = 86.875$$

$$h_3 = 83.750$$

$$h_4 = 80.625$$

$$h_5 = 77.500$$

$$h_6 = 74.375$$

$$h_7 = 71.250$$

$$h_8 = 68.125$$

- To determine pressure at point  $e$ :

determine elevation of  $e$ :  $z_e = 30 \text{ ft}$

point  $e$  lies on equipotential  $h_5$

$$h_5 = z_e + \frac{p_e}{\gamma} \quad \text{so} \quad p_e = \gamma (h_5 - z_e) \quad \text{where} \quad \gamma = 62.4 \text{ lb/ft}^3$$

$$p_e = (62.4 \text{ lb/ft}^3) (77.5 \text{ ft} - 30 \text{ ft}) = 2964 \text{ lb/ft}^2$$