SEEP/W Tutorial – Getting Started

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Introduction

This example is designed and intended to assist to new users with getting started using SEEP/W. This example is also described in the Getting Started with GeoStudio video series, "Introduction to SEEP/W". The problem being solved is a classic textbook example of seepage through a homogeneous embankment. The user will likely have some idea of what the solution should look like from an introductory geotechnical engineering university courses that includes a seepage analysis component. Having a mental image of what the solution should look like helps with knowing that the SEEP/W analysis has been done correctly.

The objective is to look at two cases; one with no toe under-drain and the other with a toe under-drain. When there is no under-drain, the seepage will exit on the downstream slope.

For the new SEEP/W user, it is a useful exercise to attempt to reproduce these analyses by starting with a completely new project. Doing so will lead to a good understanding of how to use SEEP/W for other, user-specific analyses. Note, it is possible to do this exercise with the Student Edition.

Background

Fundamentally, there are always three components to a finite element analysis. They are:

- Geometry;
- Material properties; and
- Boundary conditions.

Of these three, the last two are of more importance than the geometry. When we as engineers or scientists get introduced to a new subject, we tend to concentrate on the aspects which are the most familiar and easiest to understand. Consequently, novice users tend to spend a great deal of time on the geometry and brush over the material properties and boundary conditions. In numerical

modeling, this needs to be the reverse. More effort and detail needs to be devoted to the material properties and boundary conditions than to the geometry. Generally, the geometry should be as simple as possible (Barbour and Krahn, 2004; Krahn and Barbour, 2006).

Numerical Simulation

Figure 1 shows the example configuration. It is a homogeneous dam embankment that is 12 m high, with a 4 m crest width and with 2:1 side slopes. The embankment is retaining a reservoir that is 11 m deep.
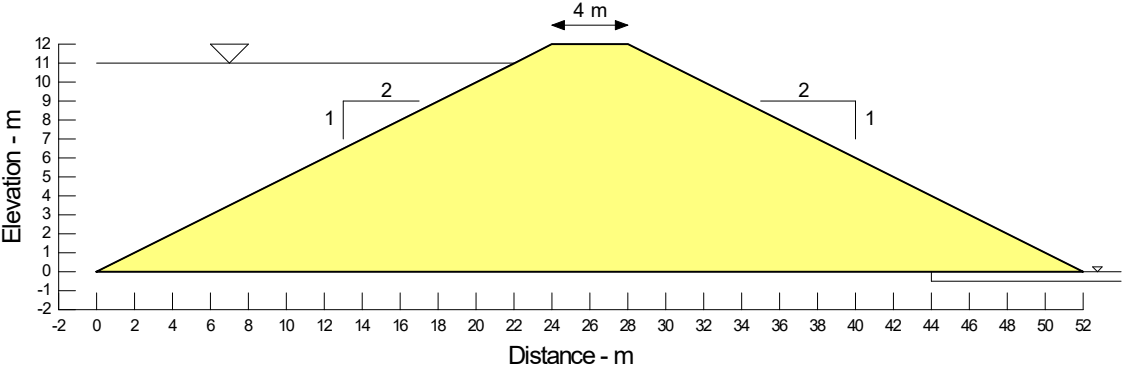

Figure 1. Problem configuration.

In GeoStudio, the geometry of a problem is defined with Points, Lines and Regions. These are known as geometric objects. A Point is a geometric object in space with x-y coordinates. A Line is a straight line object with Points at both ends. A Region is a closed polygon with a Point at each of the vertices. Boundary conditions and material properties can only be applied to geometric objects.

The illustrative example here only has one region as shown in Figure 2. The upstream slope is divided into two segments, with a point added at the elevation of the reservoir, so that the boundary condition representing the reservoir is applied only to the portion of the upstream face in which the water exists. The base is divided into two segments to accommodate modeling the under-drain. Defining the geometry lends itself reasonably well to self-learning and so this component of the analysis will not be discussed or highlighted any further here.
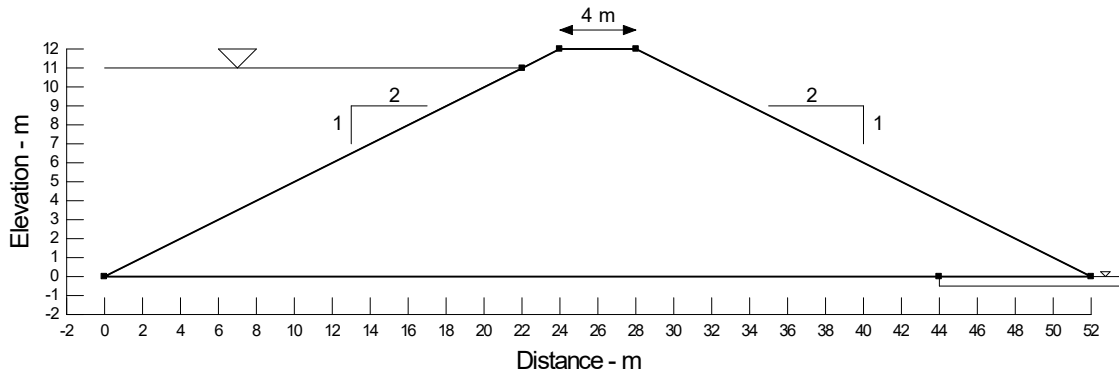
Figure 2.   Geometric Region and Points.

This analysis will include both saturated and unsaturated zones. Therefore, it is necessary to do a saturated-unsaturated type of analysis. For saturated-unsaturated conditions, the hydraulic conductivity (K) is not a constant. As the soil de-saturates, the hydraulic conductivity diminishes. The hydraulic conductivity consequentially becomes a function. The K function is typically estimated from a volumetric water content (VWC) function (Figure 3) and looks like the one shown in Figure 4.

SEEP/W includes a set of sample VWC functions for soils of varying texture. The VWC function adopted here is for a silt material with a saturated water content of 0.5 (Figure 3). The K function in Figure 4 is then estimated using the Van Genuchten method, with the saturated hydraulic conductivity (K_{sat}) specified as 1×10^{-6} m/sec.
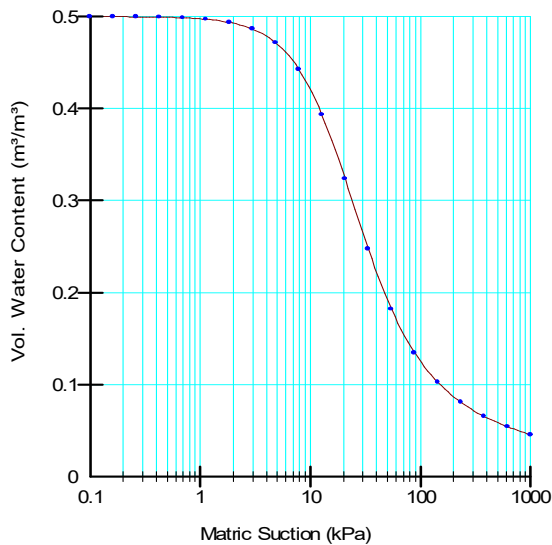

Figure 3. Volumetric water content function of the silt material.
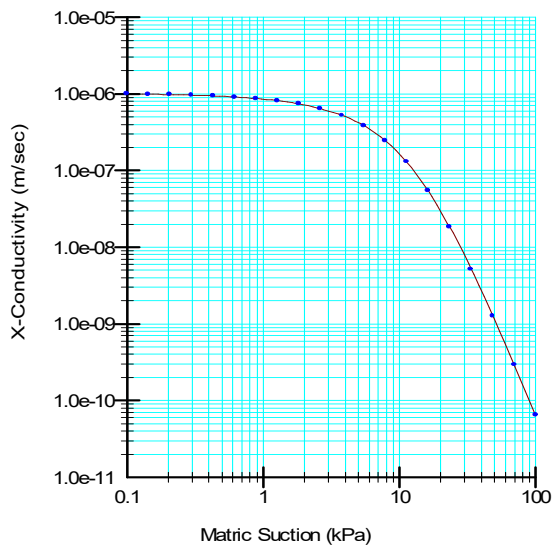
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Figure 4. Hydraulic conductivity function of the silt material.

Once these functions have been created, a Material can be defined as in Figure 5. The user needs to attach the K function and VWC function to the saturated-unsaturated Material.
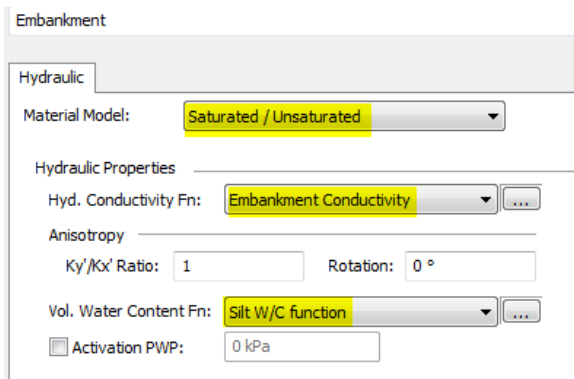

Figure 5. Material properties window for the saturated-unsaturated model.

Lastly, the material must be attached to the region with the Draw Materials... command. The color selected for the material then fills the region as in Figure 6.
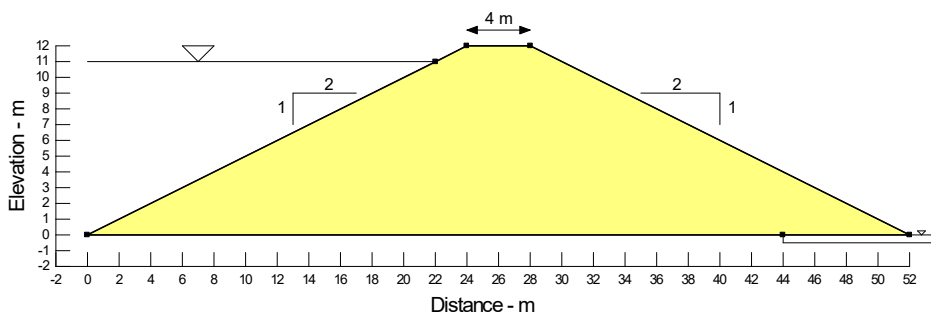

Figure 6. Configuration with the material attached to the region.

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Once the material has been attached to the region, SEEP/W automatically creates a default mesh. For this example, it was found that a small mesh refinement along the line representing the under-drain gives more pleasing results. This can be done with the Draw Mesh Properties command. The default element size is 1m. With the settings shown in Figure 7, the element size along the top of the under-drain has been changed to 0.5 of the default size.
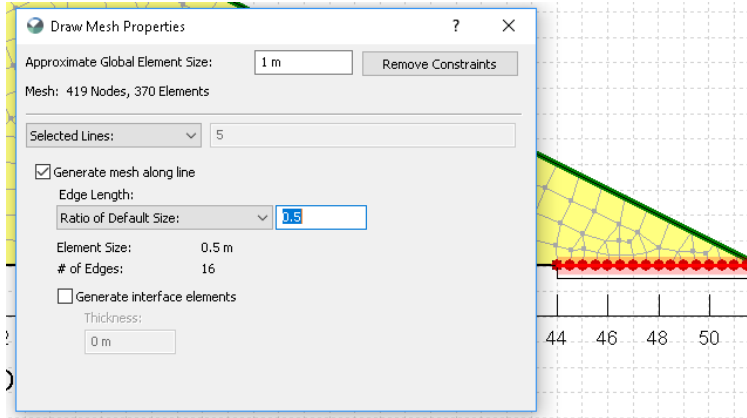

Figure 7. Mesh refinement in the Draw Mesh Properties window.

The presence of the reservoir needs to be specified as a boundary condition. This is best done with a total head type of boundary condition. The total head (h) is defined as:

$$h = h_p + y$$

where h_p is the pressure head and y is the elevation. The pressure head at the full supply level (FSL) is zero and the elevation (y-coordinate) is 11 m. The total head h, therefore, is 11 m. The pressure head h_p at the upstream toe is 11 and the elevation is 0 m. The total head h then is also 11 m. The presence of the reservoir can, consequently, be specified with a constant total head (h) boundary condition equal to 11 m.

Seepage will exit on the downstream face of the embankment. The location and size of the seepage area, however, is not known and cannot be specified. Determining this information becomes part of the SEEP/W solution. It is, however, necessary to indicate with a specified boundary condition where the potential seepage face will likely exist. This is done with the settings shown in Figure 8. The boundary condition needs to be a Water Rate (Q) boundary condition set to 0 m³/sec. Most importantly, the Potential Seepage Face Review option must be checked, as shown at the bottom of the dialog box in the figure.

Once the boundary conditions have been defined, they must be attached to the appropriate geometric objects. In this case, they will be applied to the appropriate line segments of the region. A zero pressure head boundary condition (h_p = 0m) will also be applied to the bottom point on the downstream side of the embankment.
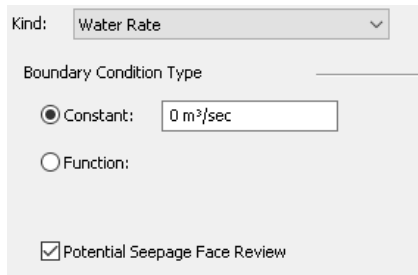
Figure 8. Conditions for a potential seepage face boundary.

The second case with the addition of the toe under-drain can be added to the Analysis Tree by cloning the first analysis in the Define Analyses window (Figure 9). Once cloned, the boundary conditions can be changed to simulate the toe under-drain analysis.

Figure 9. Multiple analyses added to the Analysis Tree.

One of the attractions of numerical modeling is that physical features can be modeled with the specification of a boundary condition without including the actual physical feature. Modeling the toe under-drain falls into this category. The effect of the toe under-drain can be included in the model simply with a zero pressure head boundary condition applied along the line representing the drain (Figure 10). Here, the drain is made up of coarse granular material. This means no potential energy will be lost by the flow into the drain. This means that the pore-pressure along the top of the drain will be the same everywhere. In this analysis, the potential seepage face boundary condition will also be removed from the downstream side of the embankment, as the seepage is expected to exit along the toe under-drain.
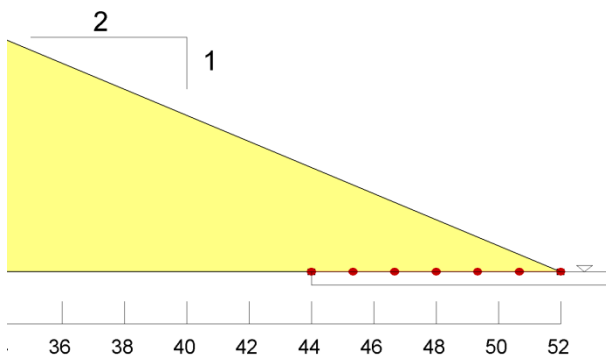

Figure 10. Addition of the toe under-drain with a zero pressure head boundary condition.

Results and Discussion

Figure 11 shows the computed results of the embankment, without the toe under-drain present, with total head contours or equipotential lines visible. The potential energy is constant along these lines. The lines can be identified with a label directly on the contour and by an optional bar-scale. Note, the equipotential lines are the same as in a flow net.
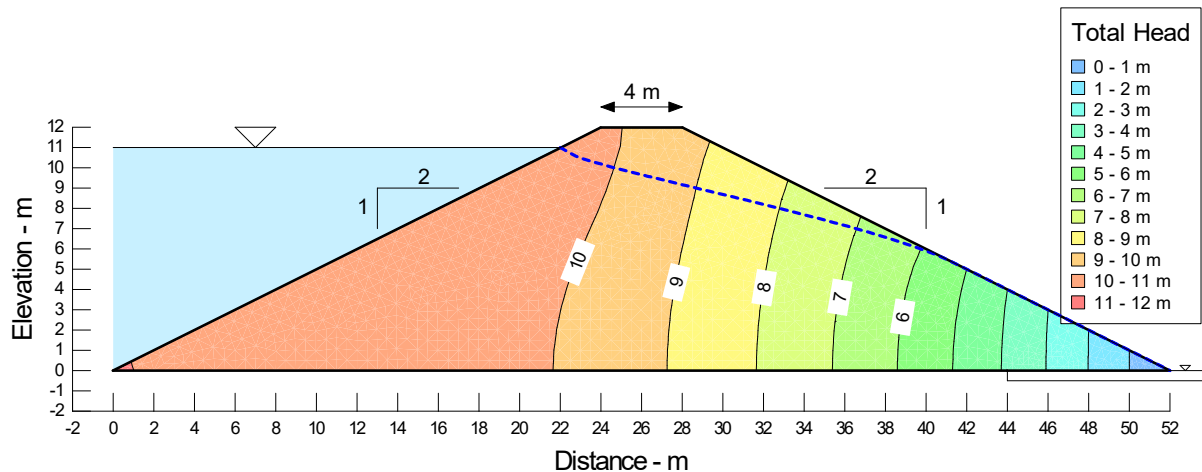

Figure 11. Total head contours or equipotential lines without the toe under-drain.

The dashed line in Figure 11 is a line of zero pressure. It is the representation of a piezometric line or water table. It is, however, not a flow line, as in a flow net. The dashed line is the division between the zone where the pore-pressure is positive and where the pore-pressure is negative.

It is possible to draw what are known as flow paths as illustrated in Figure 12. These lines are the path that a droplet of water would take from the reservoir to the seepage face. These lines do NOT make flow channels, as in a flow net. Placing the flow paths strategically, as in Figure 12, gives the appearance of a flow net, but it is not a true flow net. Note that the flow paths cross the equipotential lines at right angles, as they correctly must for a minimization of potential energy solution.
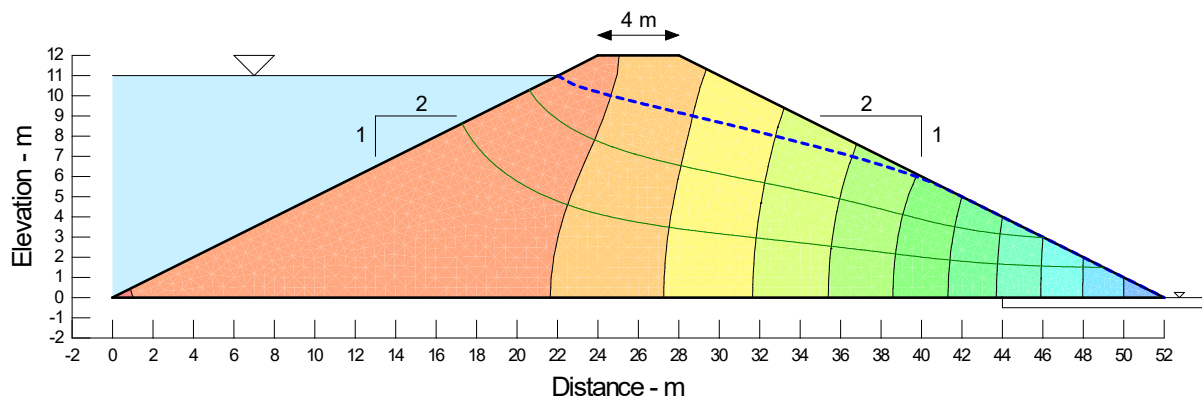

Figure 12. Illustration of flow paths without the toe under-drain.

The direction and relative magnitude of the seepage flow can be depicted with vectors as in Figure 13. The length of the vectors is an indication of the relative rate of the flow; the longer the vector, the faster the flow and vice versa. In the upstream toe area, the flow is so small and slow that the vectors are not visible.
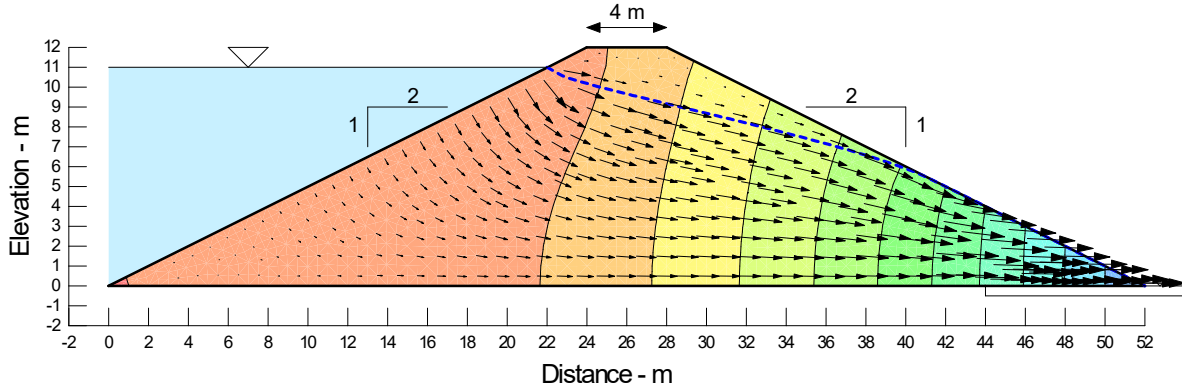

Figure 13. Velocity vectors of the embankment without the toe under-drain present.

Notice, vectors are present above the zero-pressure (piezometric) line.   These vectors show that there is some flow where the pore-pressure is negative. This flow is primarily in the capillary zone, where the soil is saturated, but the pore-pressure is negative.

The amount of seepage leaving along the seepage face of the embankment can be determined with the Graph command. The graph settings are given in Figure 14 for the Water Rate versus Time graph. This gives the flow at all the nodes along a selected line. Toggling on the "Sum" option at the bottom of the dialog box gives the total flow for the selected line. The "Set Locations" command makes it possible to indicate where the seepage rate is to be computed.
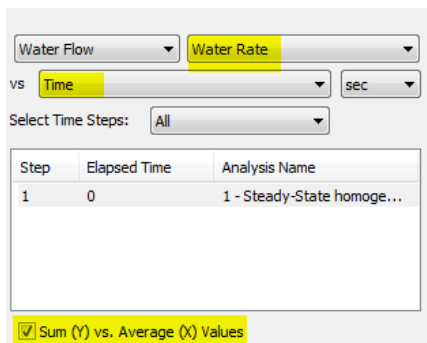

Figure 14. Graph settings for determining the total rate of seepage.

Selecting the downstream face gives the graph in Figure 15, with a single data point. Hovering over the data point displays the exact value, which in this case is -2.14x10^{-6} m^3/sec (0.18 m^3/day). The negative sign means flow is moving out of the domain.
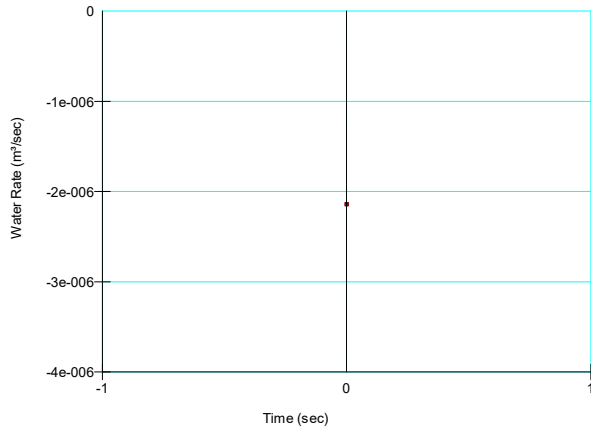
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Figure 15. Total water flow rate leaving the seepage face of the embankment.

Selecting the upstream face as the graph location, where the reservoir is in contact with dam, gives a water rate of +2.14x10^{-6} m³/sec. The positive sign here means flow is moving into the domain. The in and out amounts are the same, as the flow into the domain must equal flow out of domain, leading to a storage change of zero, in steady-state conditions.

Next, the results of the embankment with the toe under-drain will be discussed. With the toe under-drain, the flow regime is as shown in Figure 16. All of the seepage now exits into the drain. Note how some of the leakage comes through a zone where the pore-pressure is negative (Figure 17).
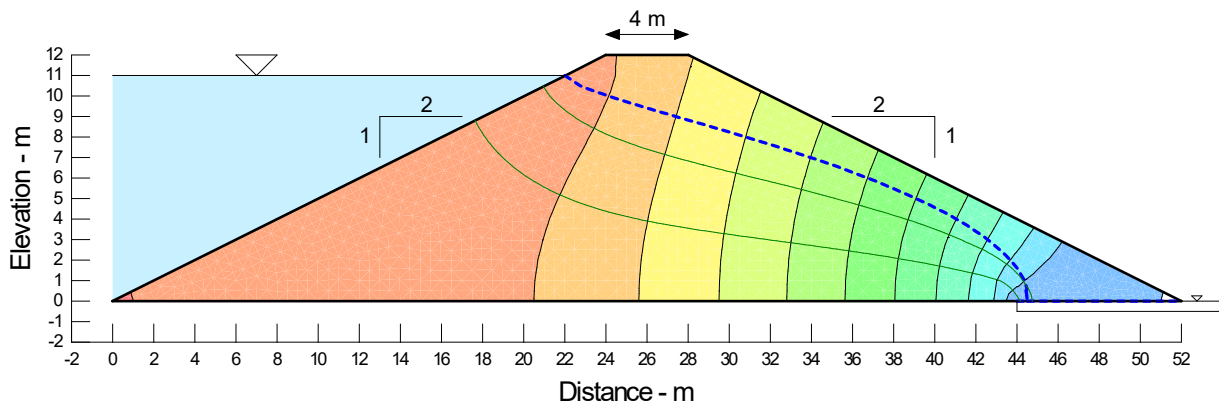
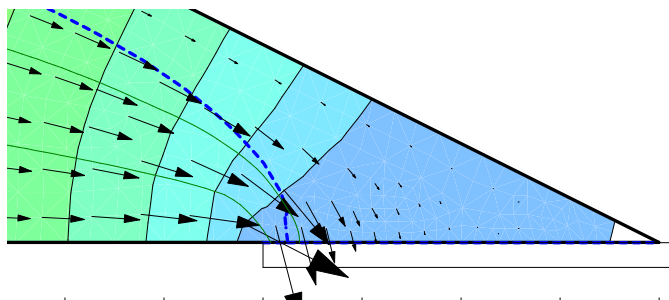

Figure 16. Flow regime with a toe under-drain.

Figure 17. Flow into the drain.

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Figure 18 shows the rate of flow into the drain from the embankment. This is created by using the Draw Graph command and creating a Water Rate vs. X graph, with the location set to the line representing the drain. Most of the seepage comes into the drain at the left side, but there is also some that comes into the drain through the unsaturated zone just above the drain.
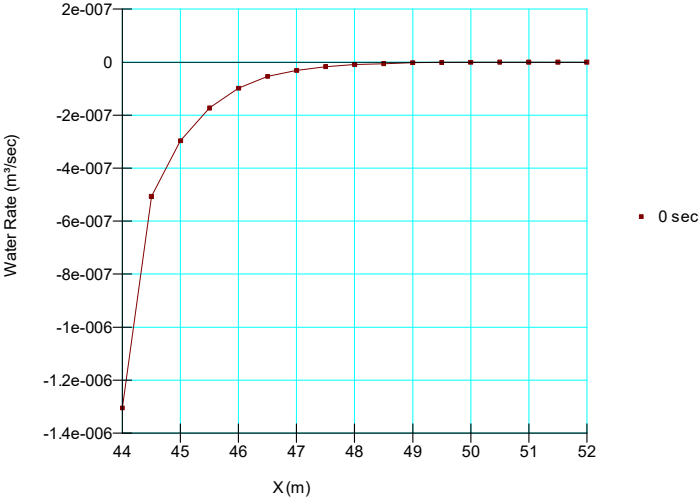

Figure 18. Flow into the drain at each node.

Using the same technique as in the previous analysis, the total flow rate into the drain is -2.499×10^{-6} m^3/sec. Again, this matches the inflow on the upstream side of embankment to satisfy the steady-state requirements ($+2.499 \times 10^{-6}$ m^3/sec).

Summary and Conclusions

This example was developed to provide new users of SEEP/W some instruction on the development of a well understood engineering problem. The example included two cases, where flow through an embankment was analyzed: one without a toe under-drain and one with a toe under-drain. The resulting total head contours, piezometric line, flow paths and vectors were described to help understand the water transfer processes occurring in each scenario.

References

Barbour, S.L. and Krahn, J. 2004. Numerical modelling – prediction or process? Geotechnical News, December 2004: 44-52.

Krahn, J. and Barbour, S.L. 2006. Numerical modeling in Geotechnical Engineering. American Society of Civil Engineers, Geo-Strata 2006 1: 12-14.