rocscience

RS3

Groundwater Analysis with Relief Well

Examples

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1. Relief Well

1.1. Problem Description

Relief wells are installed to relieve subsurface hydrostatic pressure of a permeable ground. This example demonstrates the effect of relief wells in dewatering (part 1), as well as slope stability (part 2). For this purpose, 3D Numerical models of a dam resting upon a multilayer-soil foundation are constructed to perform steady state finite element seepage analysis and Shear Strength Reduction (SSR) analysis. It is considered that a 115 ft water table is retained by the dam.

1.2. Model Setup

This example constitutes six models and is divided into two parts (See Table 1.1). The groundwater seepage analysis is computed with Model 1 and 2 (Part 1) and SSR analysis with the remaining models (Model 3 – 6) to investigate the impact the relief well has on the groundwater behaviour and the stability of dam (Part 2). All models share the same geometry with the sole difference in the presence of relief well, and their spacing if present. In addition, Section 1.5 - Steps on Adding Relief Wells describes detailed steps on adding relief wells to the model. The steps are applicable to other RS3 models as well.

Table 1.1. Model Comparisons

Part #	Model #	Number of Relief Well	Groundwater Boundary Conditions	Compute Method[1]	SSR option	Ponded Water Load	Restraints
Part 1	Model 1	0	Yes	GW	Off	No	No
	Model 2	4	Yes	GW	Off	No	No
Part 2	Model 3	0	Yes	SSR	On	Yes	Yes
	Model 4	2	Yes	SSR	On	Yes	Yes
	Model 5	4	Yes	SSR	On	Yes	Yes
	Model 6	8	Yes	SSR	On	Yes	Yes

Note:
1. GW represents Groundwater and SSR represents Shear Strength Reduction

The foundation is 350 ft long, 200 ft wide, and 55 ft deep with slight variation in elevation across the surface. Along its depth, the foundation consists of five layers of different materials. A dam of 66 ft long, 200 ft wide, and 10 ft high is constructed with a retaining wall on top of the foundation. A small area of backfill on the toe slab of the retaining wall is also constructed.

All models are under steady state groundwater condition. The groundwater boundary conditions shared between all models are hereby defined. As shown in Figure 1.1, water table at upstream of the dam (right-hand side from retaining wall) is applied with a groundwater boundary condition of 115 ft total head. The seepage face is applied on the other side of the dam with an unknow (P=0 or Q=0) groundwater boundary condition. The location of relief well within the foundation (for Model 2, 4, 5, and 6) is portrayed with blue dotted line in Figure 1.1.

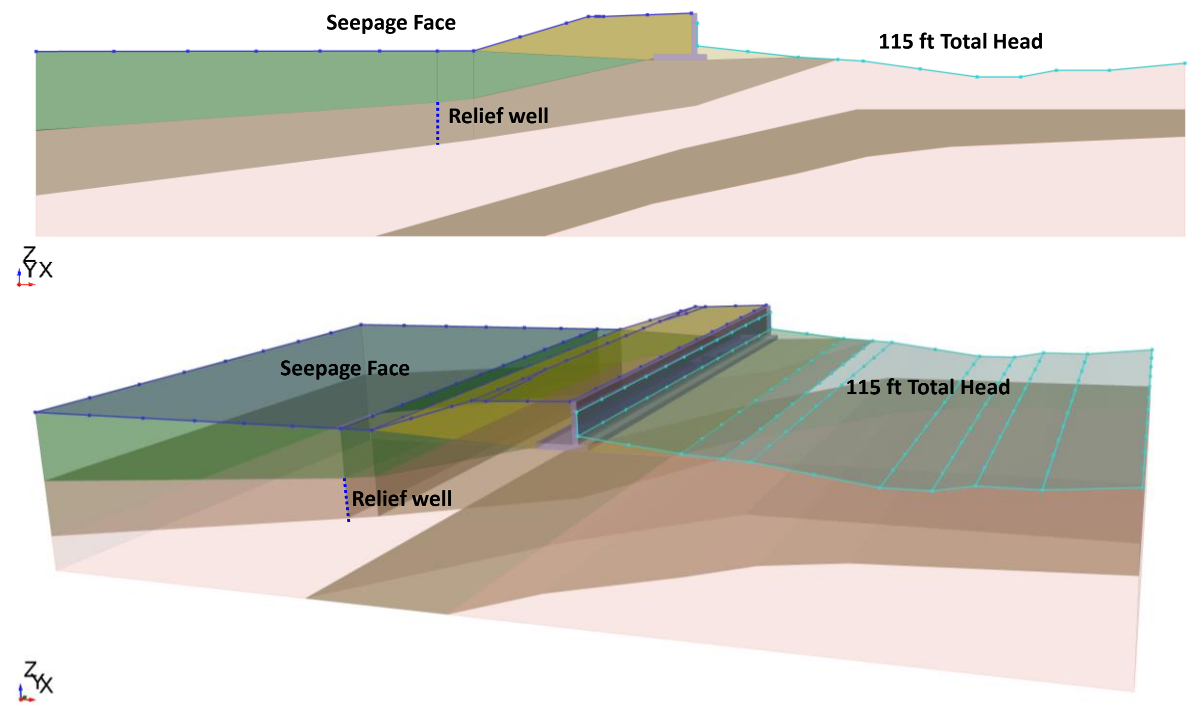


Figure 1.1. Model geometry with ground water boundary condition

Additional conditions were applied for Part 2 models, including water load and boundary restraints. Ponded water load equivalent to 115 ft total head is applied to the upstream surfaces of the dam, where 115 ft total head boundary was applied (See Figure 1.2). No restraint was applied on the top surface, however; Y restraints are added to front and back sides (parallel to xz- plane), XYZ restraints, to other sides of the model.

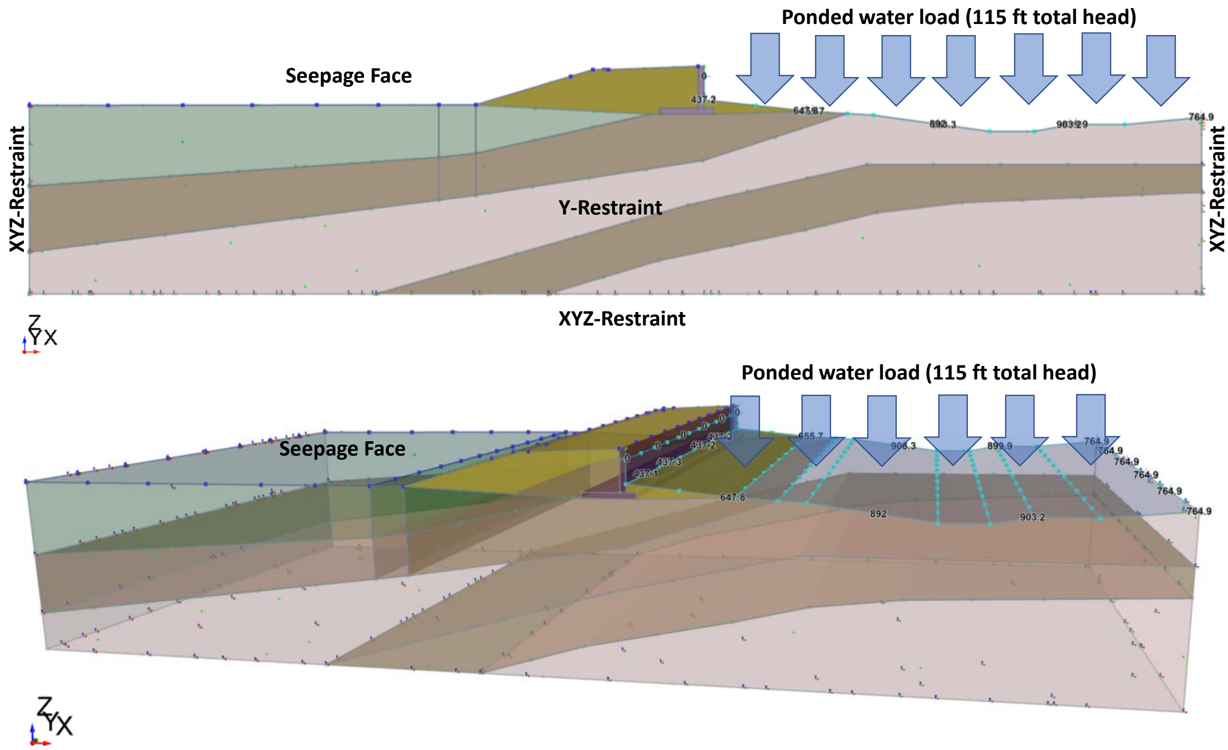


Figure 1.2 Model Geometry with the illustration of ponded water load

1.3. Material Properties

The material properties used for soil and dam, and relief well properties are summarized in Table 1.2 and Table 1.3 respectively.

Table 1.2. Material Properties

Material		Silty clay	Fat Clay -1	Fat Clay -2	Levee Fill	Retaining Wall
Initial Conditions	Initial Element Loading	Field Stress & Body Force			Body Force Only	
	Unit Weight (lbs/ft3)	125	135	125	125	150
Stiffness	Type	Linear Isotropic				
	Poisson's Ratio	0.4				
	Young's Modulus (psf)	1,000,000				5.85E08
Strength	Failure Criterion	Mohr Coulomb				
	Material Type	Plastic				Elastic
	Peak Cohesion (psf)	25	40	50	30	41770.9
	Peak Friction Angle (degree)	35	25	22	27	35
	Peak Tensile Strength (psf)	25	40	50	30	41770.9

	Residual Cohesion (psf)	25	40	50	30	-
	Residual Friction Angle (degree)	35	25	22	27	-
	Residual Tensile Strength (psf)	25	40	50	30	-
Hydraulic	Hydraulic Model	Simple				
	Material Behavior Type	Drained				
	Porosity Type	Porosity				
	Porosity	0.5				
	Method	Linear Isotropic				
	K (ft/s)	1.00E-06	4.80E-09	2.00E-09	1.00E-08	1.00E-14
	Soil Type	Sand	Clay			General

Table 1.3. Relief Well Properties

#		Model 2	Model 4	Model 5	Model 6
Number of Points	**X**	1	1	1	1
	Y	4	2	4	8
Grid Origin	**X**	-77.632			
	Y	25	50	25	12.5
Length (ft)		12.78			
Type		Relief Well			
Pressure Type		Total Head			
Total Head (ft)		106.486			
Diameter (ft)		0.3			

1.4. Analysis

This example contains two parts of analysis. Part 1 focuses on the effect of relief well in reducing water pressure, while Part 2 focuses on slope stability sensitivity analysis on the absence/presence of relief walls and their spacing.

1.4.1. Part 1 – Groundwater

To demonstrate the effect of relief wells, the steady state finite element seepage analysis is performed with models with and without relief wells using Model 1 and Model 2, respectively. The total head and pressure head are compared between results computed from the two models. It is presumed that the presence of relief wells should reduce the subsurface water pressure.

Results

The modeling results are presented from Figure 1.3 to Figure 1.6. As shown in total head contour plots, Model 2 result shows a greater decrease in total head across the foundation, compared to Model 1 result. Moreover, a noticeable reduction is shown at the area of relief well installation. Between pressure head contour plots of two models, an overall decrease in pressure head within the downstream area is manifested from Model 2. Hereby, the modeling results successfully show an effective reduction in hydrostatic pressure with the presence of relief wells.

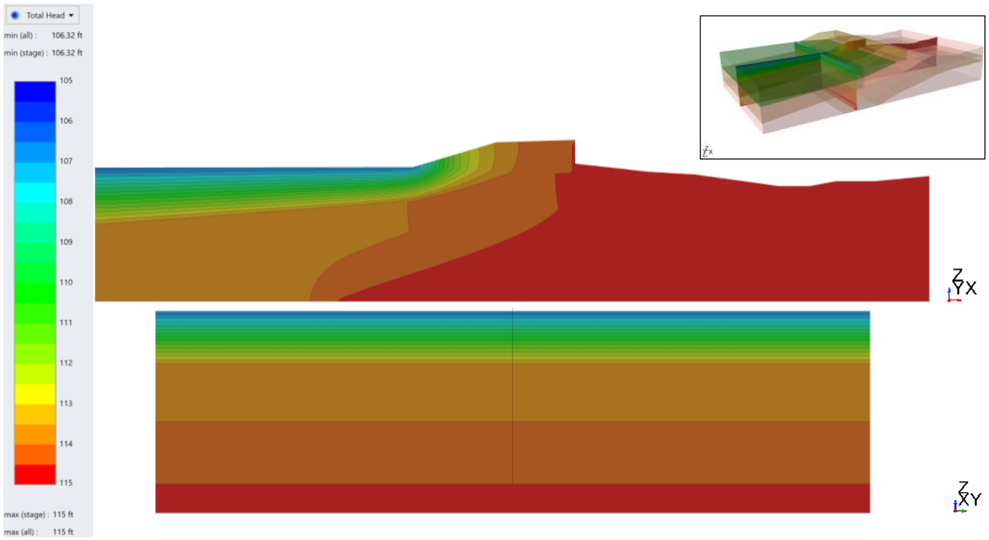


Figure 1.3 Total head results for Model 1 (no relief wells)

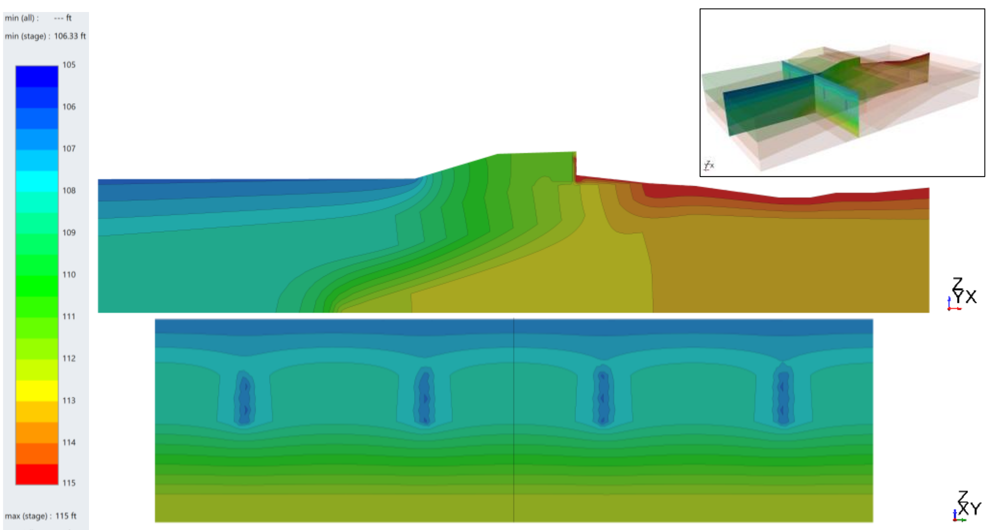


Figure 1.4 Total head results for Model 2 (with relief wells)

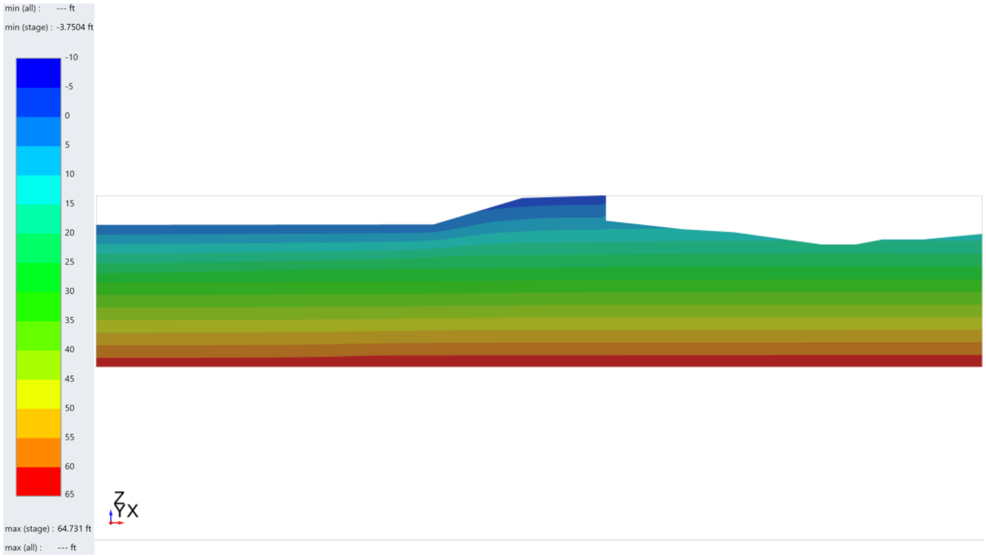


Figure 1.5 Pressure head results for Model 1 (no relief wells)

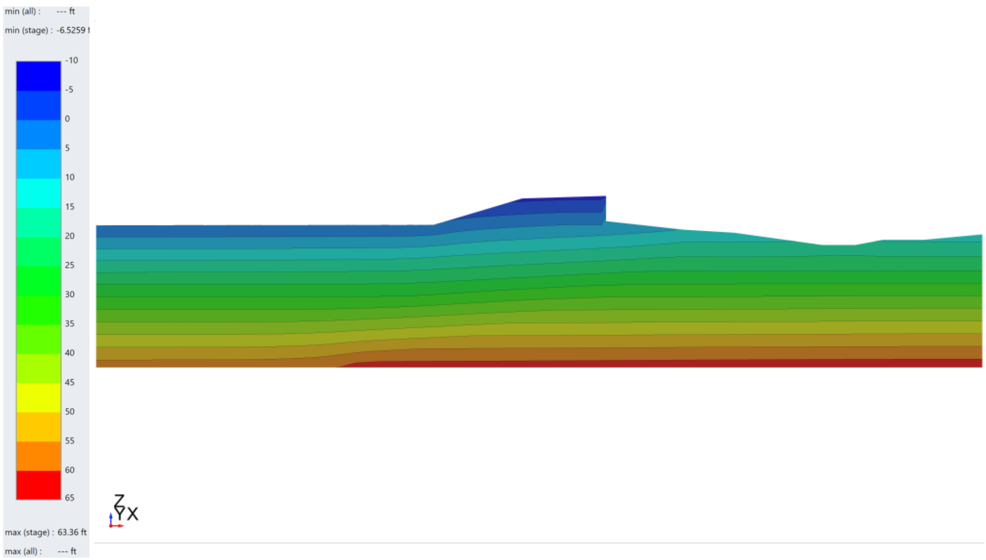


Figure 1.6 Pressure head results for Model 2 (with relief wells)

1.4.2. Part 2 – SSR

To assess the impact the relief well has on the slope stability, sensitivity analysis was conducted using RS3 models with different number of relief wells across the width of the model. The analysis includes four cases with no relief well, and 2, 4, and 8 evenly spaced relief wells (Model 3 to 6). The RS2 model constructed with the section of RS3 is also presented as part of the 2D analysis. It is important to note that due to the nature of 2D models, it is limited to represent spacing between adjacent relief wells with RS2.

Results

The SSR analysis computed with each model provides the critical SRF and the potential failure plane from maximum shear strain diagram. As shown in Figure 1.7, the geometry and the location of the computed failure planes are similar between all models; however, the critical SRF varies. The sensitivity analysis successfully showed the improvement in slope stability with the presence of relief well. Moreover, the correlation between the number of relief wells and the stability was well demonstrated.

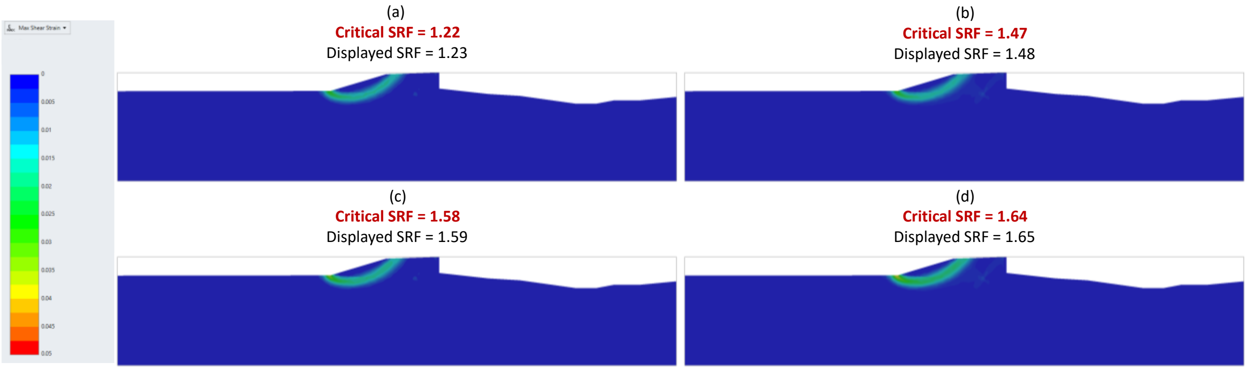


Figure 1.7 Shear strain contour diagrams from 3D numerical models with (a) 0 well, (b) 2 wells, (c) 4 wells, and (d) 8 wells

The 2D SSR analysis showed results that are in agreement with the series of analysis conducted in 3D. The geometry and the relative position of the failure planes are identical between the models with and without the relief well (Figure 1.8). Moreover, they match with the failure planes generated from 3D numerical analysis. The 2D numerical results also showed the improvement in slope stability with the installation of relief well. The summary of modeling results is provided in Table 1.4.

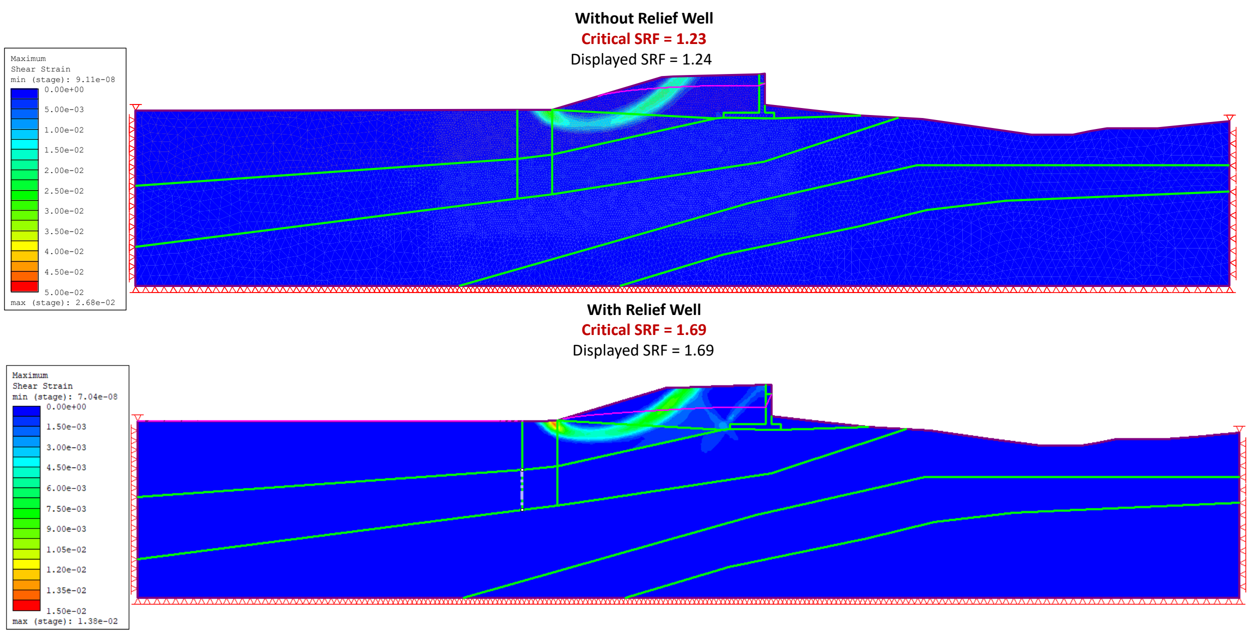


Figure 1.8 Shear strain contour diagrams for different relief well spacing based on 2D analysis

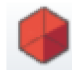
Table 1.4. SSR Analysis Results

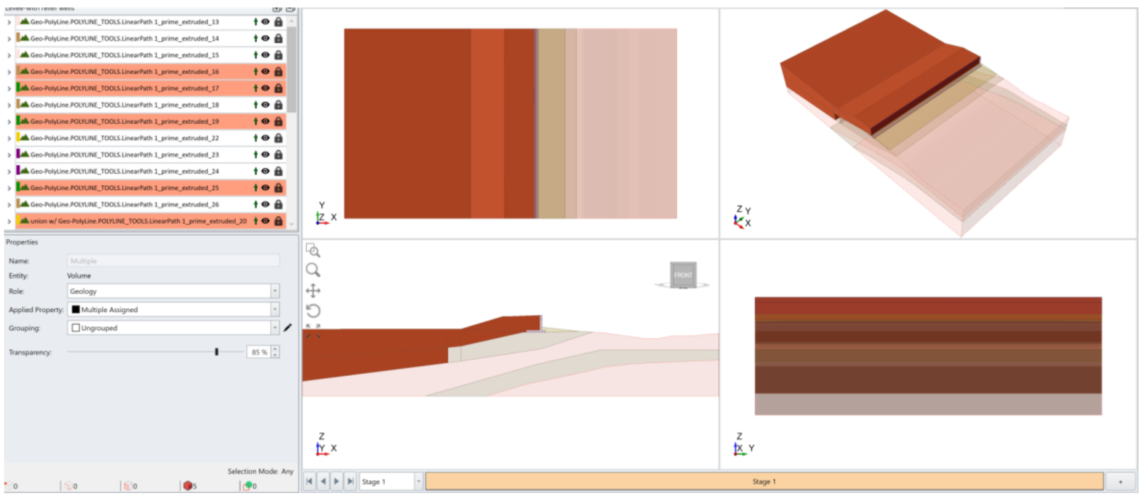
Number of relief wells	Critical SRF (RS3)	Critical SRF (RS2)
0	1.22	1.23 (Without relief well)
2	1.47	1.69 (With relief well)

4	1.58	
8	1.64	

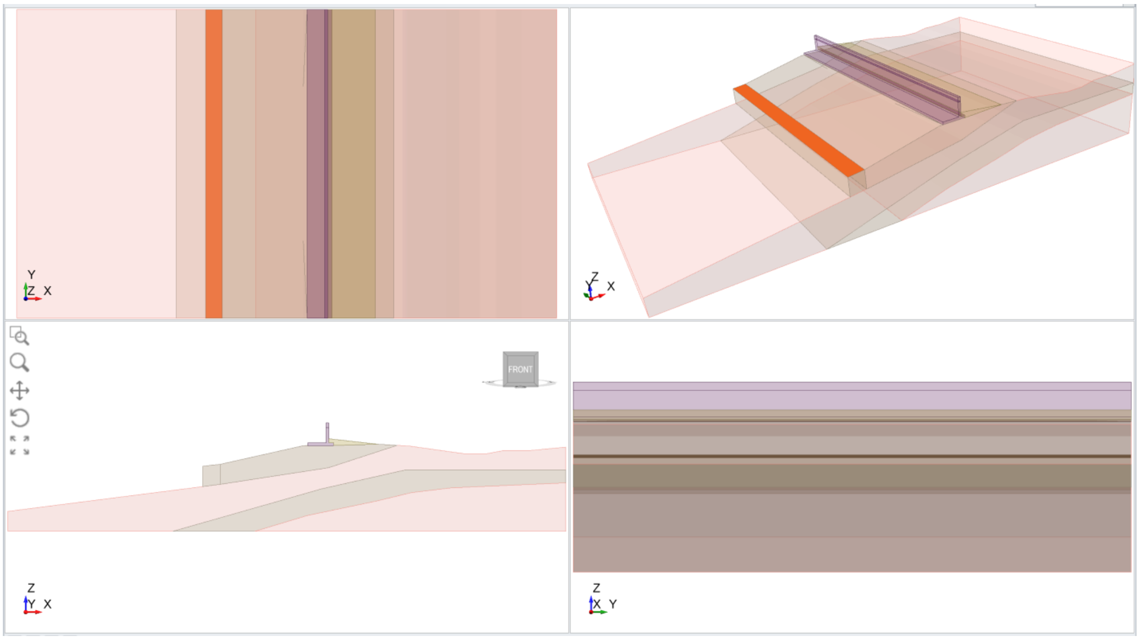
1.5. Steps to add relief wells

Follow the steps to add relief wells to you RS3 model.

1. Uncover the geometry volume which you will assign relief well to.
    a. **Turn on** the Entity Selection mode  from the toolbar
    b. **Select** the entities above and in front of the one that relief wells will be assigned to, as also heighted under the Visibility Pane as shown below. **Click** the icon to hide selections 

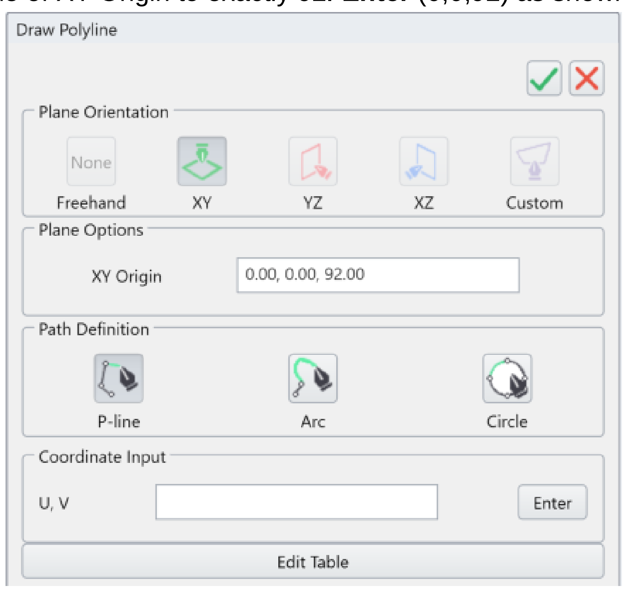


2. Define the top surface for relief wells.
    a. **Turn on** the Face Selection mode  from the toolbar
    b. **Select** the top surface of the volume



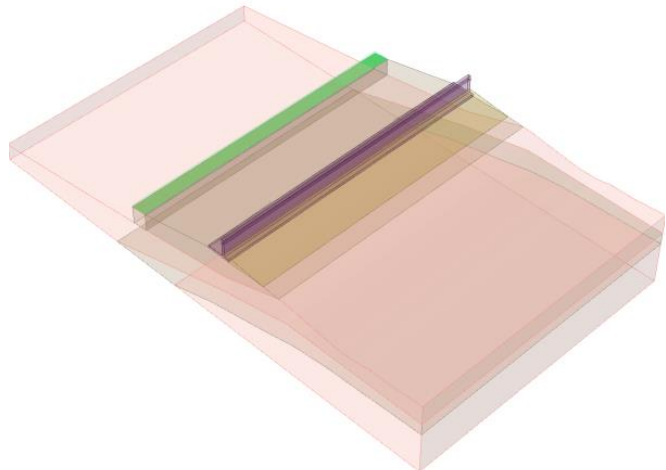
c. **Select** the **Add Wick Drain Region** option from the **Groundwater** menu, and the Draw Polyline pane will appear.

d. The polyline should be drawn on a XY plane at the elevation just below the surface. Change the Z value of XY Origin to exactly 92. **Enter** (0,0,92) as shown below.



e. In the viewport, **select** the four corner vertices of the selected top surface in the same direction, to enclose a polyline around it.

The area within the polyline will be highlighted in green as shown below, which will be the top surface of the relief wells, and you will be prompted to a dialog.

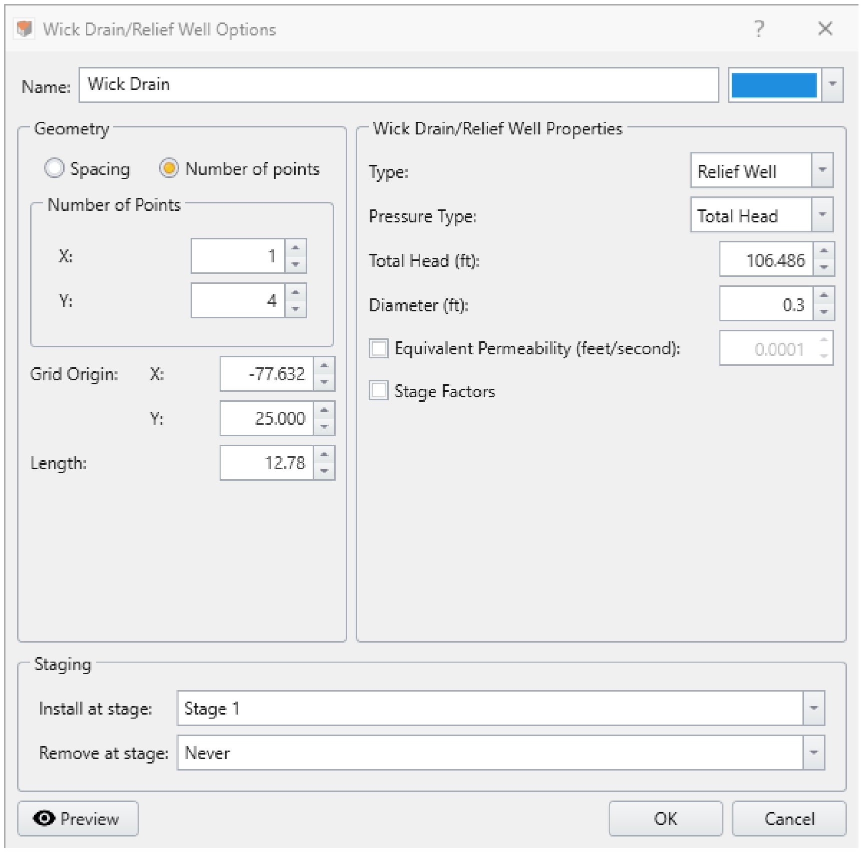


3. Define Relief Well properties.

   A row of relief wells is applied to the left side of the volume. There are four evenly spaced relief wells installed along the foundation into the page (Y axis). Each relief well is 0.3 ft in diameter, extends 12.78 ft deep, and has a total head of 106.486 assigned.

   a. **Enter** the followings in **Wick Drain/Relief Well Options** dialog, as shown in the screenshot below. **Click** OK to apply.
      - Name = Relief Wells
      - Geometry = Number of Points
      - Number of Points: X = 1, Y = 4
      - Grid Origin: X = -77.632, Y = 25
        - A grid origin should be specified to secure the relief well position in XY plane.
      - Length = 12.78
      - Wick Drain/Relief Well Properties: Type = Relief Well, Pressure Type = Total Head, Total Head (ft) = 106.486, Diameter(ft) = 0.3

   b. The relief wells are now added to the model, as highlighted in blue. The relief wells entity is under the Visibility Tree.


Wick Drain/Relief Well Options
Name: Wick Drain
Geometry
Spacing
Number of points
Number of Points
X: 1
Y: 4
Grid Origin: X: -77.632
Y: 25.000
Length: 12.78
Wick Drain/Relief Well Properties
Type: Relief Well
Pressure Type: Total Head
Total Head (ft): 106.486
Diameter (ft): 0.3
Equivalent Permeability (feet/second): 0.0001
Stage Factors
Staging
Install at stage: Stage 1
Remove at stage: Never
Preview
OK
Cancel