ASSESSMENT OF STABILITY OF MOSUL DAM

Ahmed Mufty, Ph.d., P.Eng.
Geomechanics Specialist
Rocscience Inc., Toronto, Canada

STATIC AND DYNAMIC STABILITY OF MOSUL DAM

The goal of the study is to check the stability of critical sections of Mosul Dam and is made of two parts,

Part 1, Finished study for slope stability analysis performed using:

1. Ordinary method of slices (The Swedish or Fellenius method)
2. Simplified Bishop Method

And the methods applied for static conditions and seismic conditions using the pseudo static analysis with earthquake acceleration in horizontal and vertical seperately.

Part 2, On going study for slope stability analysis using *Slide2* software which includes in addition to the two methods above other methods,

1. Janbu simplified method
2. Janbu corrected method
3. Spencer method
4. Corps of Engineers methods #1 and #2
5. GLE Morgenstern-Price method – General Limit Equilibrium
6. Sarma vertical slices method

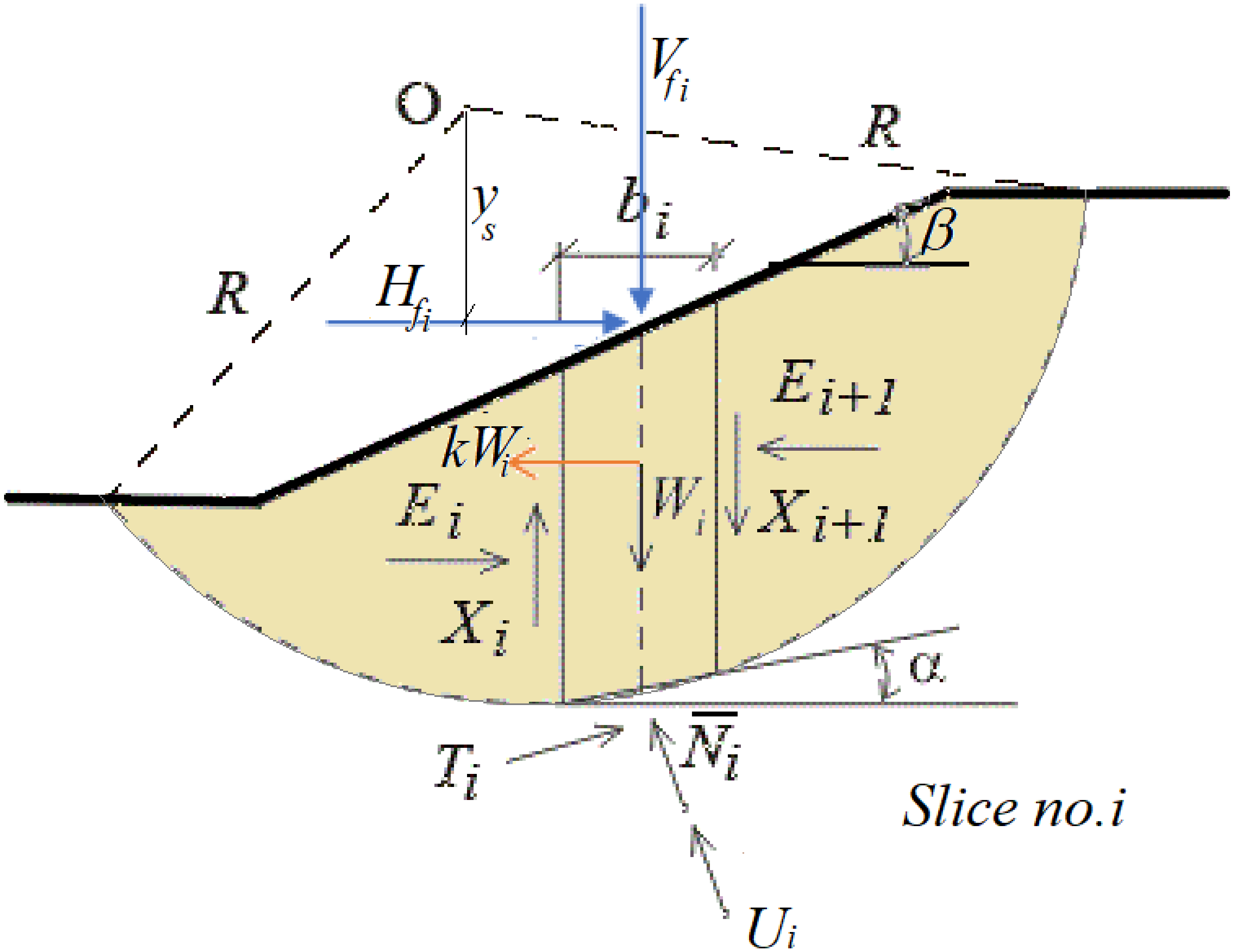
And there are other methods which are not tried in the study.

In *Slide2* The seismic coefficients may be applied simultaneously in both directions as well.

GENERALIZED EQUATION FOR CIRCULAR SLICES METHOD

Ordinary method of slices

$$
\begin{aligned}
&for\ each\ slice\ i\\
&b = width\ of\ the\ vertical\ slice\\
&\beta = angle\ of\ slice\ from\ horizontal + ve\ CCW\\
&\alpha = angle\ of\ secant\ at\ slice\ bottom\ surface\ from\ horizontal + ve\ CCW\\
&W = weight\ of\ the\ slice\\
&k = seismic\ coefficient\\
&p = pressure\ on\ surface\ of\ the\ slide\\
&V_f = vertical\ resultant\ of\ p = pb\\
&H_f = horizontal\ resultant\ of\ p = pb \tan\beta\\
&U = resultant\ of\ pore\ water\ pressure\ at\ bottomm\ of\ slice\\
&\bar{N} = normal\ effective\ force\ on\ on\ bottom\ of\ slice\\
&T = shear\ force\ at\ bottom\ of\ slice\\
&R = radius\ of\ failure\ circle\\
&O = origin\ of\ circle\ defined\ by\ coordinates\\
&y_s = vertical\ distance\ from\ the\ origin\ to\ the\ center\ of\ the\ surface\ of\ the\ slice
\end{aligned}
$$


O
R
R
V_{f_i}
y_s
b_i
H_{f_i}
β
E_{i+1}
kW_i
W_i
E_i
X_{i+1}
X_i
α
T_i
$\overline{N}_i$
Slice no.i
U_i

$$M_D = \{W \sin\alpha + V_f \sin\alpha + 0.5kW \cos\alpha + y_s/R(0.5kW - H_f)\}R$$
$$M_R = \{c'b/\cos\alpha + (W\cos\alpha - kW\sin\alpha + H_f\sin\alpha - U)\tan\varphi'\}R$$

$$factor\ of\ safety$$
$$F_s = \frac{\sum M_R}{\sum M_D}$$

While in simplified Bishop method $\bar{N}$ is found by $\sum F_y = 0$

Then from $\sum M_R = Fs.\sum M_D$

$$F_s = \frac{\sum\left[\left(W + V_f - ub\right)\tan\varphi' + c'b\right].1/m_\alpha}{\sum\left[W\sin\alpha + V_f\sin\alpha - \dfrac{H_f y_s}{R} + 0.5kW(\cos\alpha + y_s/R)\right]}$$

$$m_\alpha = \cos\alpha(1 + \tan\varphi'\tan\alpha\,/F_s)$$

As F_s is in both sides an initial value is given and the final value is found iteratively.

Discretization and width of slicces

A special method is used to discretize the domain. It is a method introduced by the author and can be found in

"RASTER SCAN ALGORITHMS FOR ZONING OF SOIL MEDIA FOR SLOPE STABILITY ANALYSIS" M.Sc. Thesis, Feb 2004 University of Baghdad by *Ghassan Ali Abdul-Hassan*

The width of slices is chosen as 0.25m.

Seepage analysis may be performed using the same method but as the core is the main cut-off the water flow may be estimated also compared with monitoring system records of pore water pressure.

Seismic Coefficients

The equations shown were for a horizontal acceleration. Similar equations are derived for vertical acceleration.

The values for k_h and k_v were taken as 0.15 and 0.1 respectively

This will put the dam under an earthquake intensity VIII-IX on modified Mercalli scale (corresponding to a magnitude of 5.5 to 6 in Richter scale).

For comparison purposes value for k_h of 0.25 as very extreme case was also considered.

Hydrodynamic effects on the water pressure

The hydrodynamic pressure is approximated as

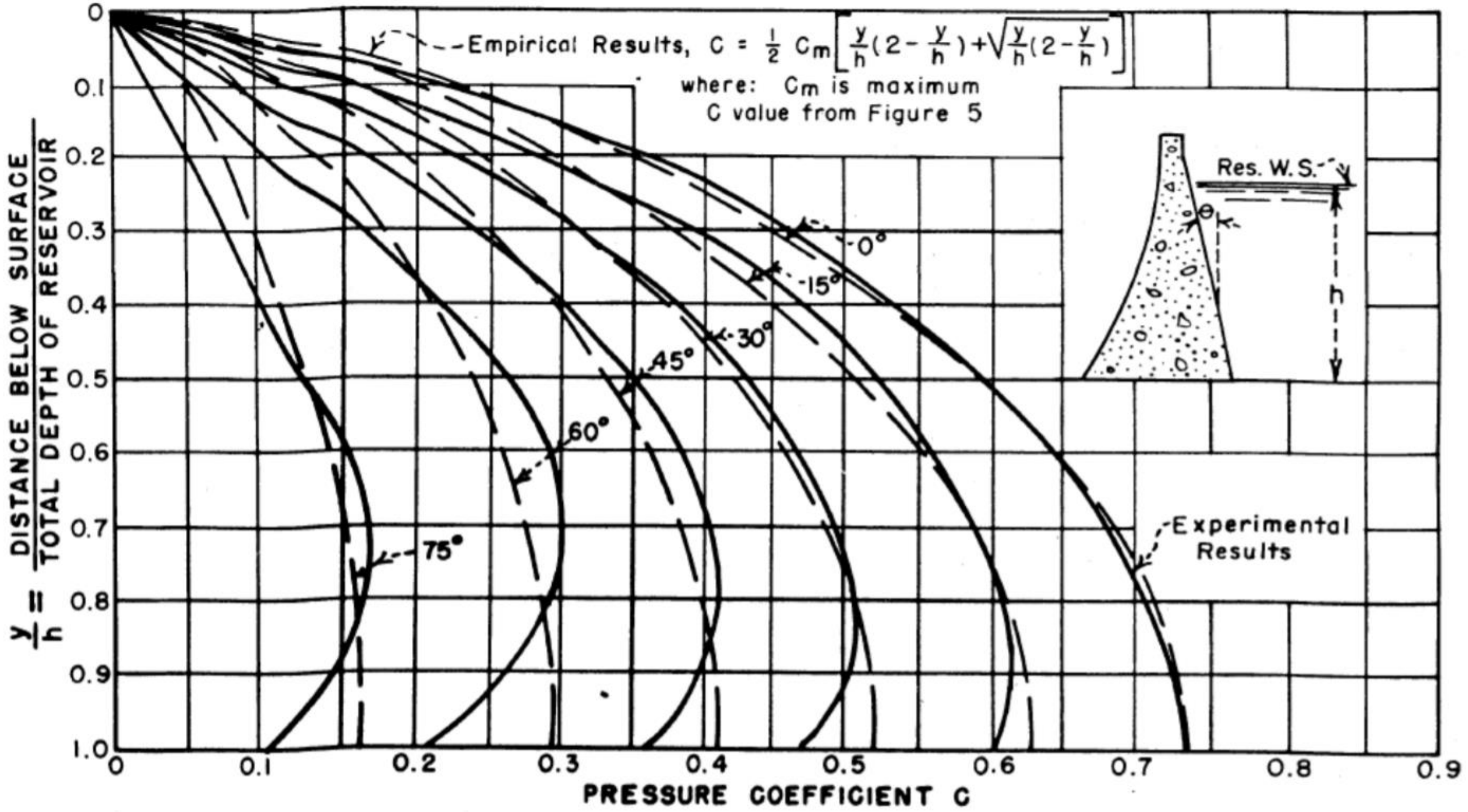
$$u_{hydrodynamic} = u_{hydrostatic}\,(1 \pm k_w)$$

Where k_w is a seismic coefficient that is found by hydrodynamic analysis to approximate the water pressure distribution during earthquake. The plus or minus sign should be chosen to give the worst case F_s

FEM was used by Dr. Rafaa Al-Suhaily in 1999 for the values of horizontal acceleration and vertical acceleration close to the above..

Zangar 1952 method was also used to decide what should be used in the analysis as k_w

Zangar Method



Comparison of experimental (solid line) and empirical (dashed line) pressure distribution Zangar (1952).

Values comparing Zangar and FEM of Al-Suhaily at CH.3200

The FEM can handle multi surface angles with depth while Zangar is for one slope for the dam surface.. Both theories assume solid dam surface.. Slope for the top part of the dam body is the worst case and it is around 1:2.5

y/H	Kw FEM	Kw Zangar
0.14	0.120	0.086
0.28	0.090	0.076
0.43	0.076	0.063
0.57	0.037	0.053
0.71	0.034	0.047
0.85	0.029	0.040
1.00	0.027	0.036

The value of k_w used in our analysis was 0.04 and 0.08 to count for nonlinearity effect.

y is measured depth from surface of water in the lake
H is the depth of water from +325 to the lakebed which is at 245,265,265 and 273 for Ch 3200, 3000, 2700 and 2400 respectively corresponding to H values of 90m, 70m, 70m and 62m respectively.

Sections in this study

Ch. 3200, Ch.3000, Ch. 2700, Ch.2400

Top center of the dam 0,400

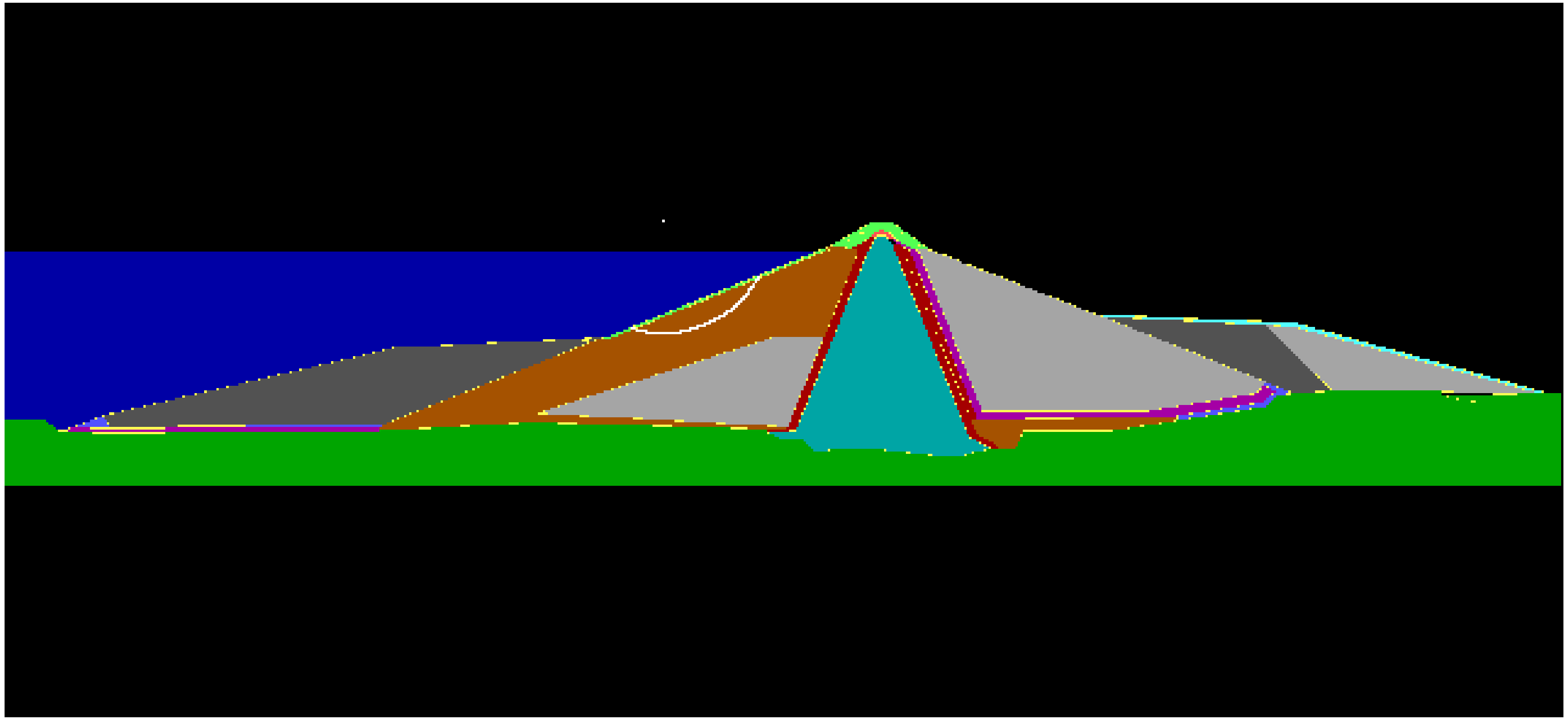
Water level full at +330

Water level empty reservoir +283 (dead storage level)

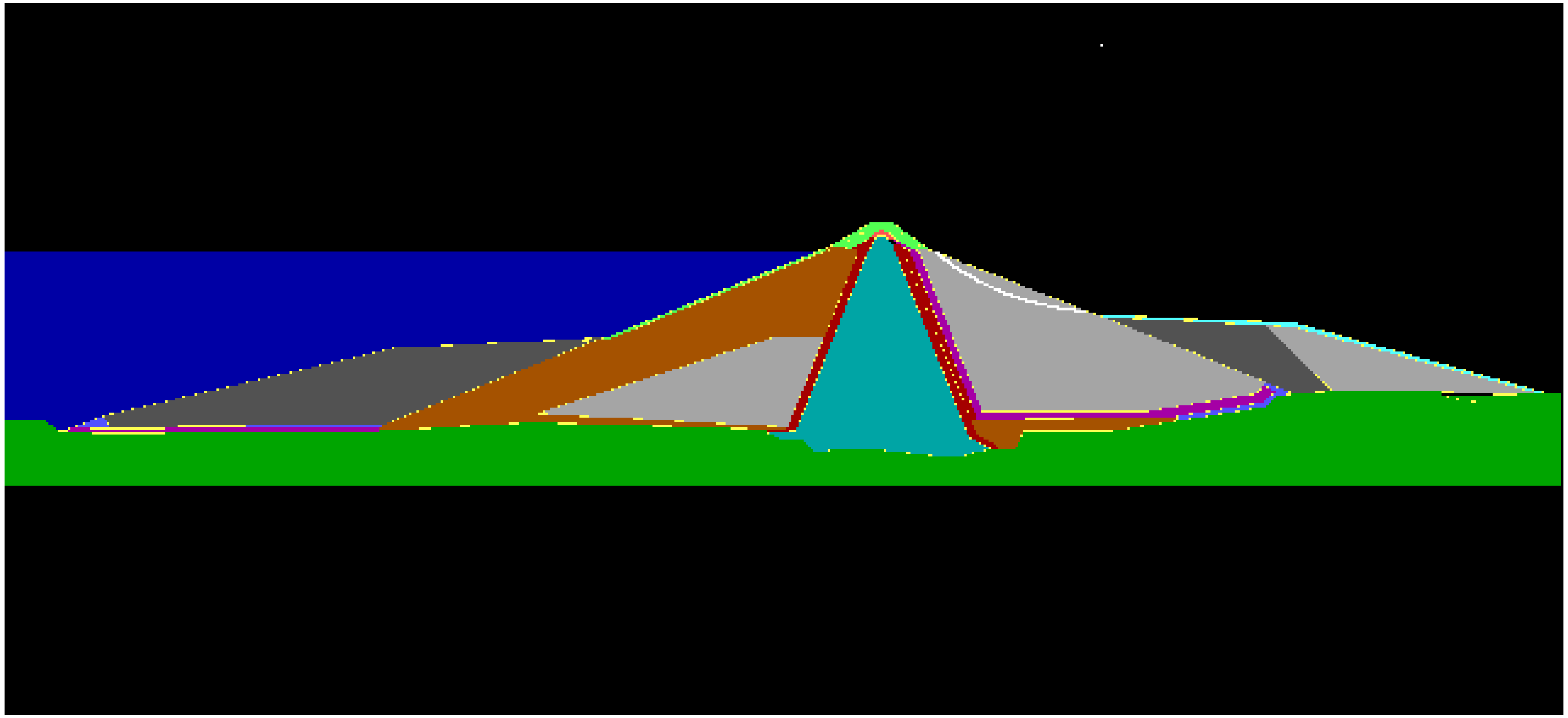
Water level at the toe side +256

Search steps 1mx1m and radius steps 5m

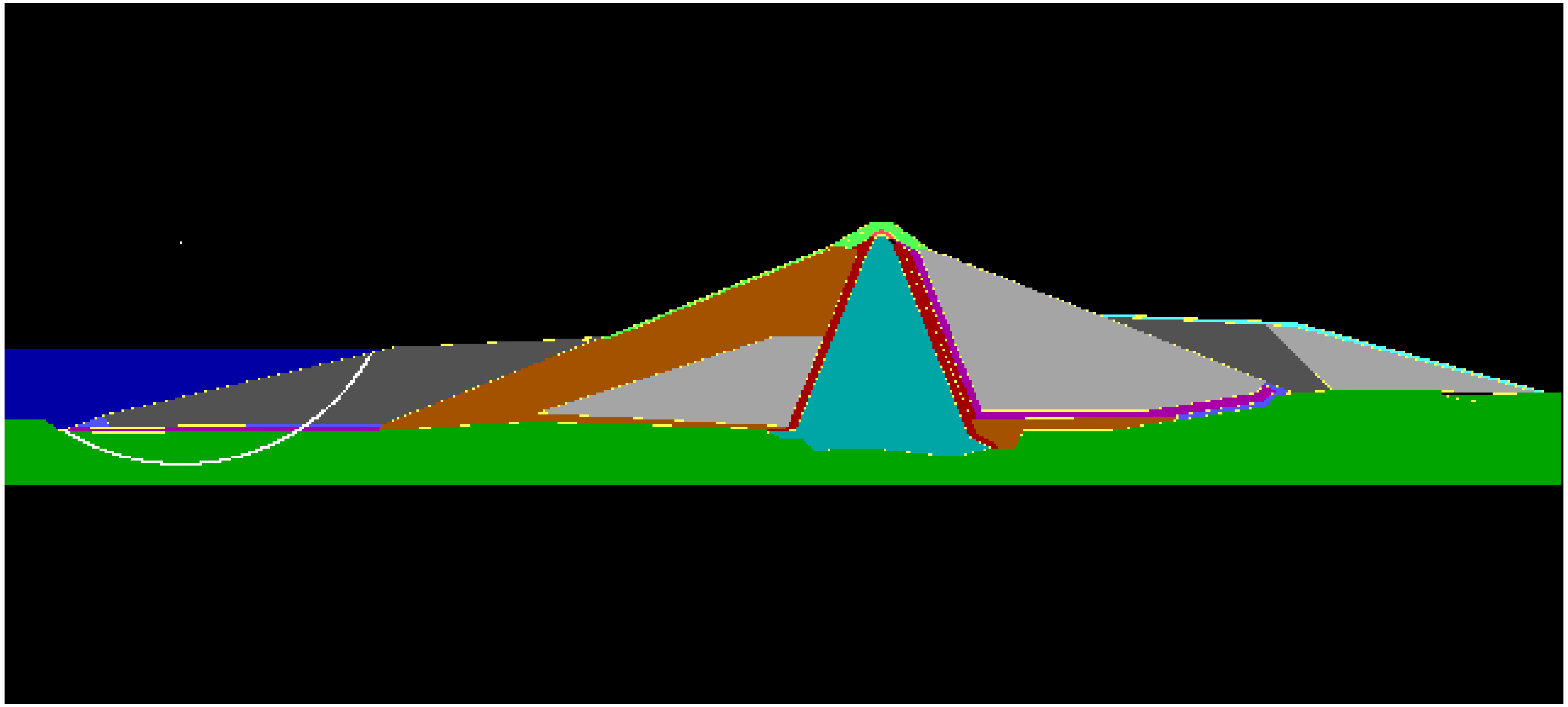
Ch 3200 reservoir full - upstream



Downstream



Reservoir empty - upstream



Soil and rock properties used in the analysis

Obtained from Dam documents (refer also to Suhail A.A. Khattab, 2008, Stability Analysis of Mosul Dam under Saturated and Unsturated Soil Conditions", Al-Rafidain Engineering)

Parameter	Unit	Shell	Filter	Core
Dry density	kN/m^3	19.5	19.5	17.88
Natural density	kN/m^3	20.5	20.5	21.3
L.L	-	-	-	38
Angle of internal friction	Deg.	37	37	29.5
Cohesion (c)	kN/m^2	0	0	26
Permeability	m/sec	$1.69*10^{-5}$	$1.69*10^{-3}$	$3.5*10^{-11}$
Poisson ratio	-	0.25	0.25	0.35
Modules of elasticity	kN/m^2	69000	69000	7616

As the dam body is the target of the study, for the bedrock, high strength parameters were used and permeability of 10^-7 assuming that the curtain wall efficiency is adequate

Results

For the four sections analyzed the minimum factors of safety were as follows

Case: upstream - full reservoir Trial circle x=300 y=0 R=50m Water level 330							
case		Static	Horizontal			vertical up	vertical down
k		0	0.1	0.15	0.25	0.1	0.1
kw	0	1.506	1.219	1.104	0.917		
		1.586	1.325	1.226	1.062		
	0.04		1.116	1.009	0.834		
			1.206	1.115	0.968		
	0.08		1.018	0.916	0.753	1.079	1.724
			1.089	1.008	0.873		

Case: upstream - full reservoir Trial circle x=300 y=0 R=50m Water level 325							
case		Static	Horizontal			vertical up	vertical down
k		0	0.1	0.15	0.25	0.1	0.1
kw	0	1.582	1.259	1.133	0.93		
		1.753	1.451	1.327	1.142		
	0.04		1.168	1.049	0.859		
			1.344	1.229	1.054		
	0.08		1.079	0.968	0.789		
			1.235	1.135	0.975		

Case: upstream - empty reservoir Water level 283										
Case		Failure Circle			Static	Horizontal			Vertical up	Vertical down
Chainage	Method	X	Y	R	k=0	k=0.1	k=0.15	k=0.25	k=0.1	k=0.1
3200	S	60	60	50	2.107	1.345	1.127	0.838	2.115	2.294
	B	80	80	10	3.172	2.156	1.852	1.433		
3000	S	130	130	50	1.95	1.269	1.068	0.796	1.803	2.068
	B	120	120	50	3.774	2.424	2.05	1.556		
2700	S	140	140	40	1.944	1.243	1.04	0.778	1.793	2.067
	B	130	130	40	2.963	1.993	1.706	1.313		
2400	S	150	150	30	2.614	1.474	1.187	0.832	2.591	2.643
	B	160	160	40	3.124	2.097	1.788	1.386		

Case: downstream Trial circle x=500 y=-80 R=120m Water level 256 Chainage 3200						
case	Static	Horizontal			vertical up	vertical down
k	0	0.1	0.15	0.25	0.1	0.1
Swedish Fs	2.635	2.179	1.996	1.693		

Conclusions from the first study

Static Conditions

- All cases studied revealed high factors of safety

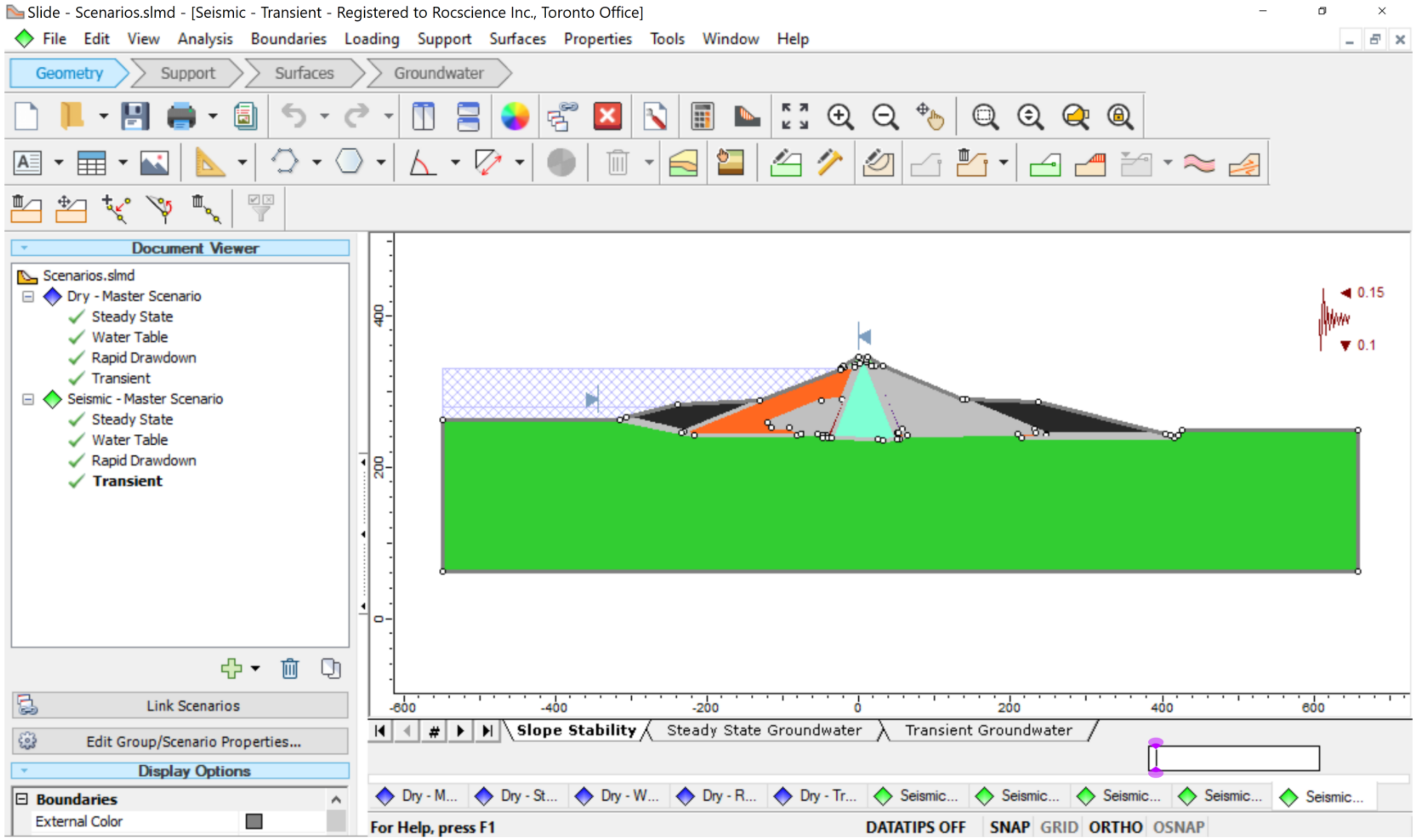
Pseudo dynamic analysis for seismic conditions

- Emptied reservoir cases had good factors of safety
- Vertical acceleration effect on stability was negligible
- Swedish circle method yielded low Fs values in full reservoir conditions for 330 and 325 water levels. Bishop method gave higher FS values but for kw=0.08 and peak acceleration of 0.25g both methods failed to show satisfactory FS values.

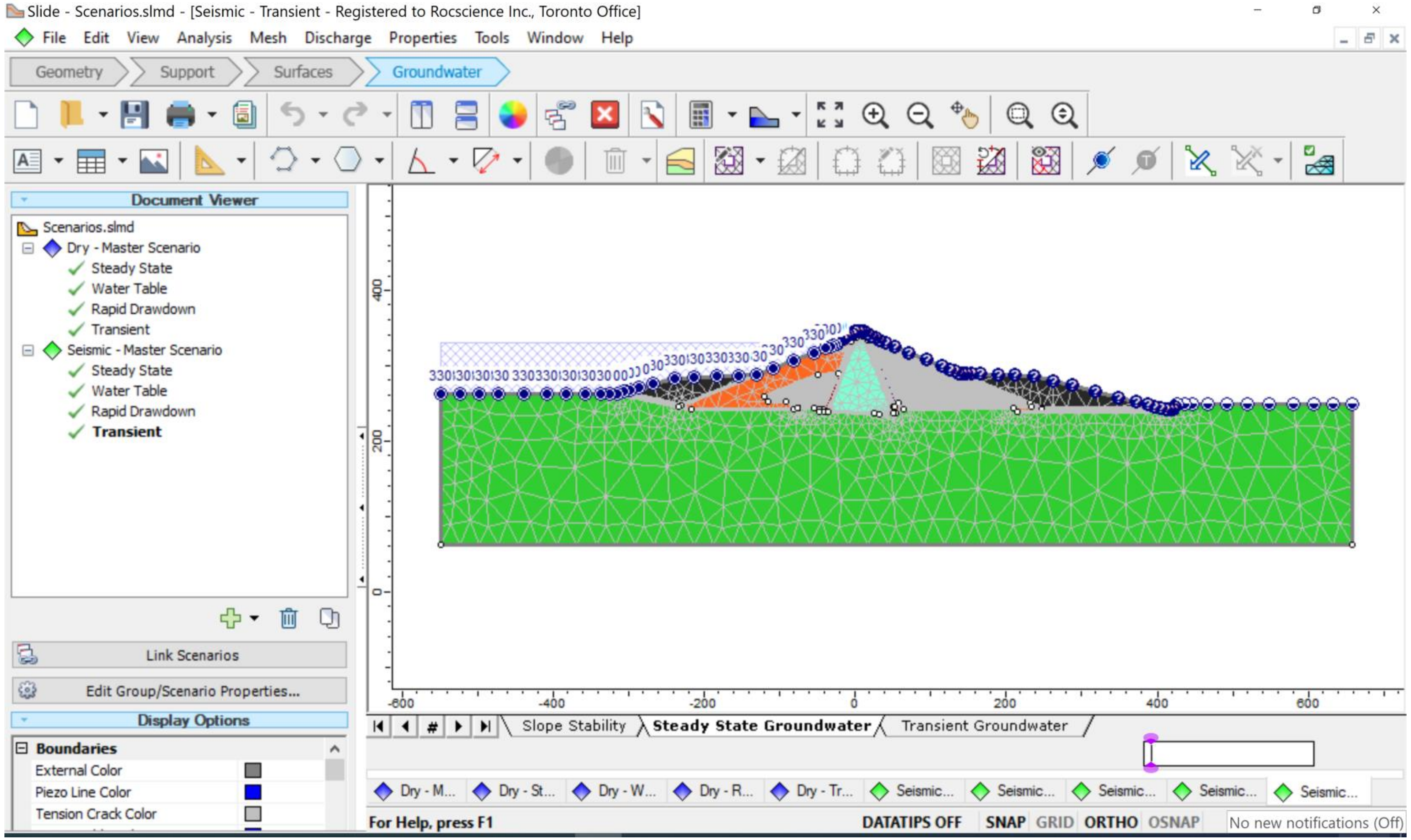
Recommended

- If acceleration of 0.25g is expected the reservoir should not get filled higher than 320. At acceleration values of 0.15 and lower the reservoir may be considered safe even at 330 W.L.
- The results of more comprehensive study using Slide2 software will give us a better idea.
- Comprehensive program to obtain updated soil properties is highly recommended and the testing should be carried out in all parts of the dam body and the foundation.
- New monitoring system records to be published or at least be available for researchers to calibrate their models.

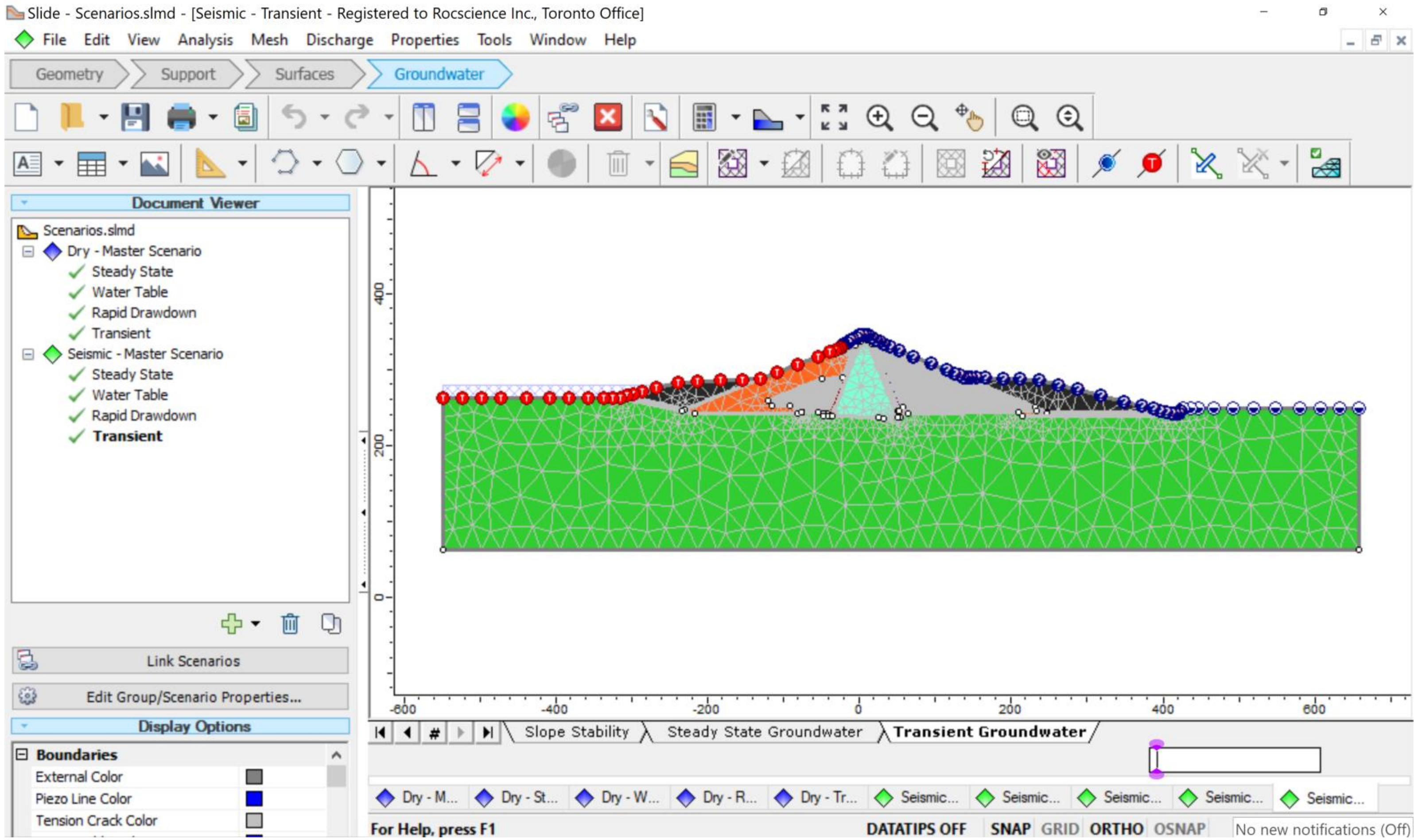
Application of *Slide2* software



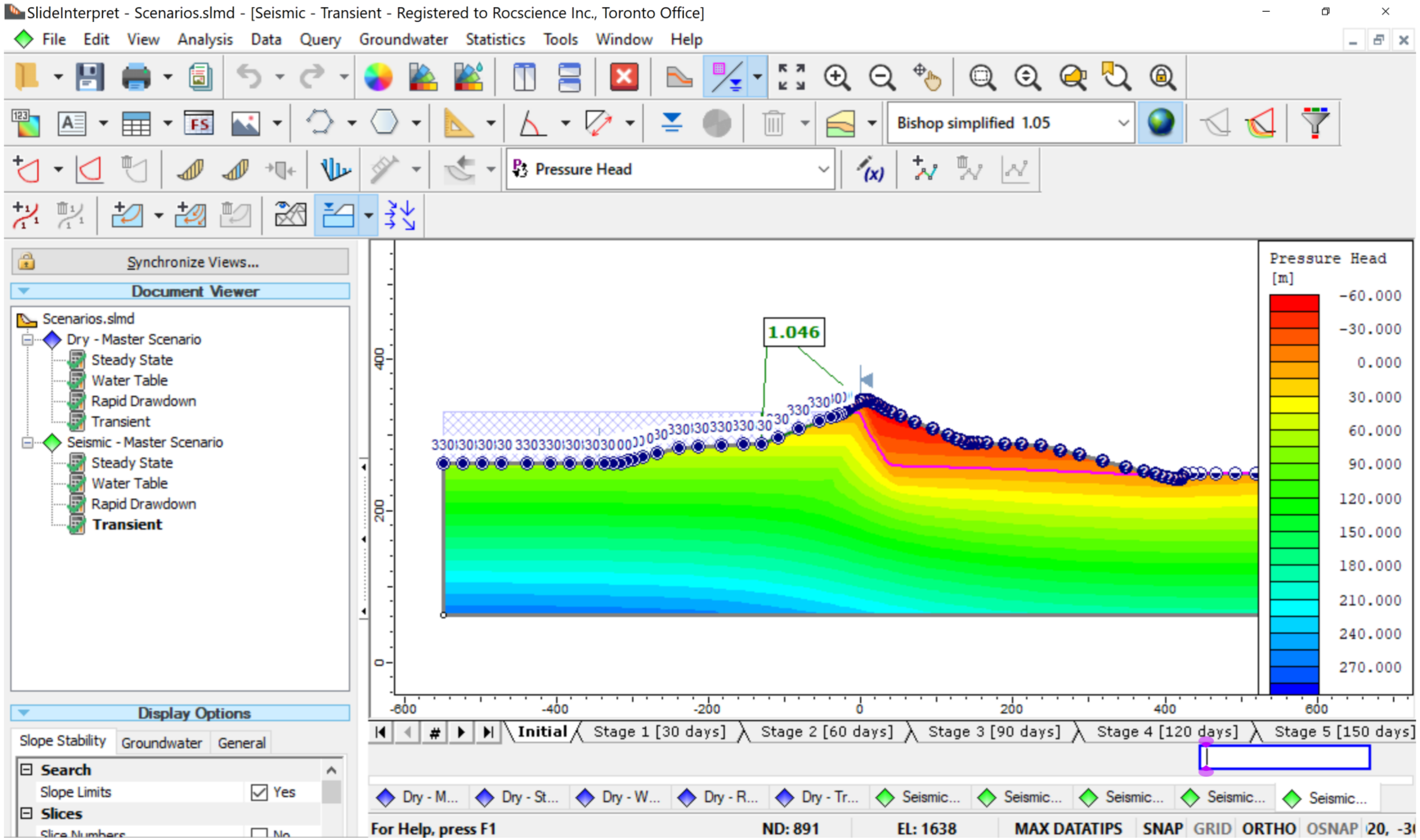
Seepage Analysis using FEM



Transient Groundwater Flow



Results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Multiple Methods and Multiple Senarios