QUAKE/W Tutorial – Getting Started

GEO-SLOPE International Ltd. | www.geo-slope.com

1200, 700 - 6th Ave SW, Calgary, AB, Canada T2P 0T8
Main: +1 403 269 2002 | Fax: +1 888 463 2239

Introduction

The prime purpose is to demonstrate to new QUAKE/W users how to get started, to introduce the usual type of data required to do a QUAKE/W analysis, and to illustrate what can be simulated with QUAKE/W. The problem is quite simple, so that it can be analyzed with the GeoStudio Student Edition.

Numerical Simulation

Figure 1 shows the problem configuration. It is an earth dam founded on an 8 m stratum of fairly loose, silty soil. The embankment is 5 m high with 2h:1v side slopes. The dam retains a reservoir with a full supply level (FSL) at El. 12 m. Other relevant dimensions are shown in the following sketch.

The dam has a granular under drain to control the seepage through the dam. The drain itself is actually not included in the analysis, but is considered when defining the phreatic surface. On the downstream side, the water table is at the ground surface.

For the analysis, the geometry can be represented by two GeoStudio regions; one region for the foundation and the second region for the embankment.

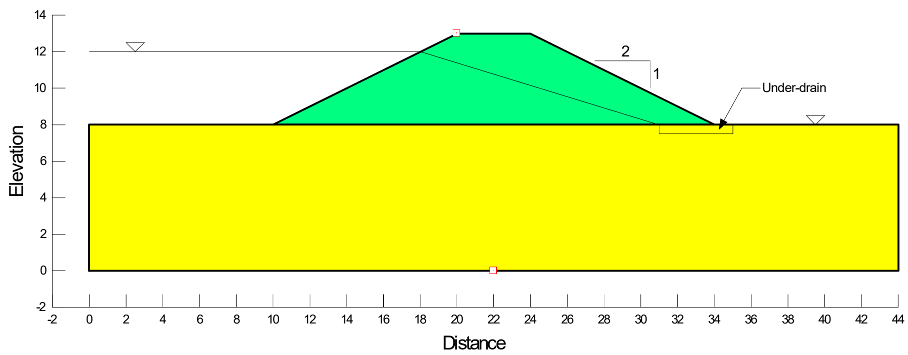

Figure 1. Tutorial problem configuration.

The objective of the analysis is to investigate the response of the ground and the structure when it is subjected to an earthquake, and to examine the possibility that there may be some generation of excess pore-water pressures, which in turn could lead to some liquefaction.

The structure will be subjected to earthquake shaking according to the time-history record shown in Figure 2. The peak acceleration is 0.12 g and the duration is 10 seconds.

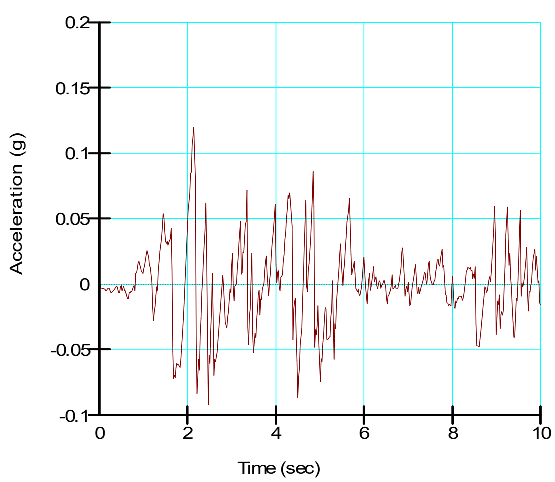

Figure 2. Earthquake time-history record.

The first step in any QUAKE/W analysis is to establish the *in situ* stress state conditions that exist before the earthquake occurs. Stated another way, it is necessary to establish the initial static stresses before subjecting the structure to the dynamic action.

In QUAKE/W the initial insitu static stress can be computed with the Initial Static analysis type. The two most important soil properties required for the Initial Static analysis is the total unit weight of the materials and Poisson's ratio (v).

Poisson's ratio is important because it influences K_o – the coefficient of earth pressure at rest. For a 2-D analysis like we are doing here, K_o is equal to $v/(1 - v)$. Poisson's ratio is specified as 0.334 (1/3) for this problem which represents a K_o condition equal to 0.5. The total unit weight for the foundation and the damn has been defined as 0.18 kN/m³ and 16 kN/m³, respectively.

Along the vertical ends of the problem, we must specify the equivalent of rollers. This is done by specifying a zero x-displacement condition along these edges. The ground is free to move in the vertical direction, but is fixed in the horizontal direction (Figure 3).

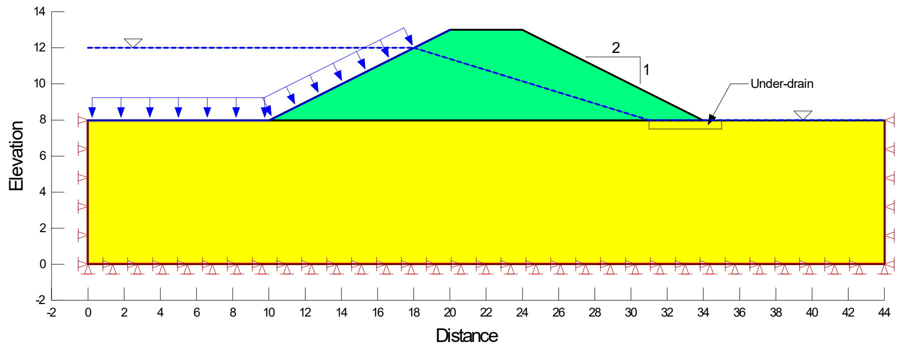

Figure 3. Boundary conditions for the Initial Static analysis.

The problem is fixed along the base. This is accomplished by specifying the displacement to be zero in both the horizontal (x) and vertical (y) directions.

To compute the correct total and effective stresses, it is necessary to apply the weight of the reservoir water as a boundary condition. The arrows perpendicular to the ground surface in Figure 3 graphically represent the water pressure. The water weight or pressure is specified with a Fluid Pressure type of boundary. With this type of boundary condition, it is necessary to specify the FSL elevation and the unit weight of the fluid (water in this case).

The initial pore-water pressures are defined by and computed from a specified water table. The water table goes along the reservoir water surface, as it naturally should, and then follows a straight line in the embankment from the FSL elevation to the upstream tip of the under drain, and then follows a horizontal line to the right end of the problem at the downstream ground surface elevation.

Once the problem has been completely defined with respect to the geometry, the boundary conditions and the material properties, it is necessary to check that the finite element mesh is appropriate for the analysis.

The mesh can be viewed and modified with the Draw Mesh Properties command. In this case, it was specified that the global element size should be about one 1 m. With this one and only user-specified criterion, the default mesh is as presented in Figure 4, which is deemed adequate for this particular analysis.

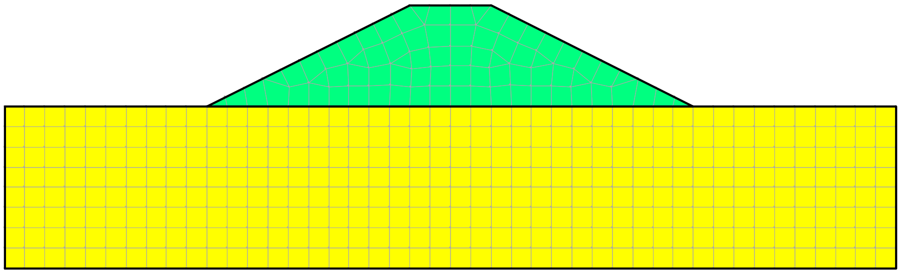

Figure 4. Finite element mesh.

Once the *in situ* static stresses have been established, the next step is to do the dynamic or shaking analysis.

With the Define Analyses command, a new QUAKE/W analysis is created where the "Parent" is the previous Initial Static analysis. Both the initial stress conditions and the pore-water pressure conditions come from the Parent (previous) analysis.

The Equivalent Linear Dynamic analysis type is used here.

The boundary conditions at the vertical ends of the problem have to be changed for the dynamic analysis. Now the vertical movement is fixed, but the ground is allowed to move laterally. Notice the different boundary condition symbols along the ends in Figure 5. These conditions allow the ground to sway from side to side when the horizontal earthquake accelerations are applied.

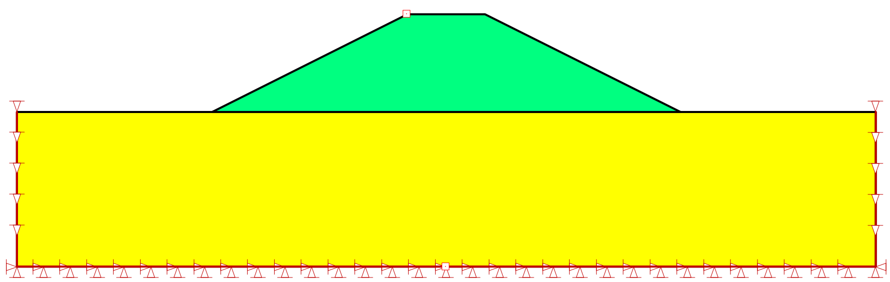

Figure 5. Boundary conditions for the dynamic analysis.

In QUAKE/W, selected points can be flagged where the results will be saved for each and every time step while integrating through the earthquake record. They are known as History Points. Two History Points have been defined here. They are the two small red squares shown in Figure 6.

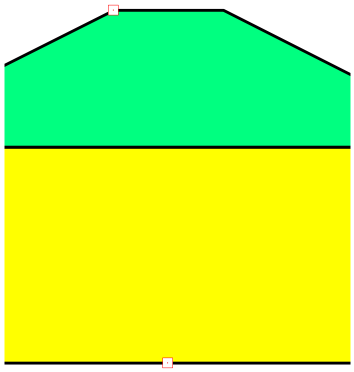

Figure 6. Locations of History Points.

The constitutive behavior of the soil will be treated as being linear elastic. The shear modulus G_{max} is 5000 kPa for both the foundation and embankment soil. The damping ratio is a constant 0.1 (10%).

To compute excess pore-water pressures that may arise due to the shaking, it is necessary as a minimum to define two functions. They are called the Pore-water pressure Ratio function and the Cyclic Number function. For this introductory example, we can use the sample functions shown in Figure 7 and Figure 8 (these sample functions are included with the software). The Cyclic Number function in Figure 8 is the sample function for loose sand.

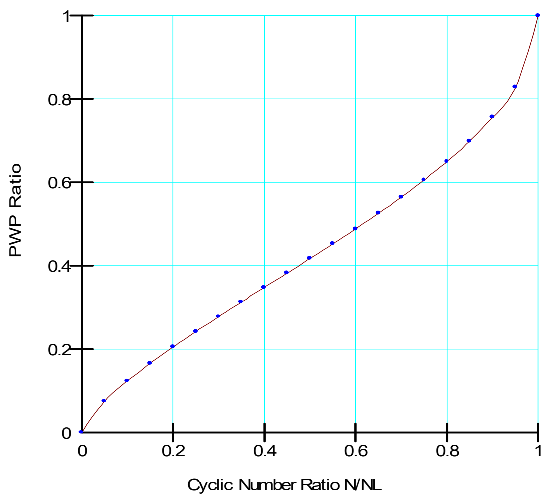

Figure 7. Pore-water pressure ratio function.

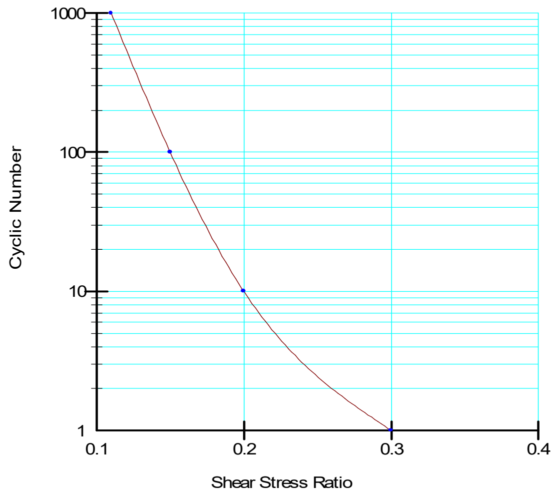

Figure 8. Cyclic number function.

The embankment material is deemed to be non-liquefiable soil, and so no pore-water pressure functions are specified for this material.

QUAKE/W is formulated on the basis of a time integration scheme. This means that QUAKE/W steps through the earthquake record at a specified time interval and does a finite element analysis for each time step. Usually, the time steps are equal to the time interval of the data points in the earthquake record.

In this analysis, the earthquake record data points have a time interval of 0.02 seconds, making a total of 500 data points for the 10-second duration. This means there will be 500 time steps, or 500 finite element analyses.

By default, QUAKE/W stores data at the 20 highest peaks in the earthquake record. In addition, it has been specified that the data should be saved every 10^{th} time step.

Results and Discussion

There are many different ways to examine the resulting *in situ* stresses of the initial static analysis. One typical way is to look at the total and effective vertical stress contours, as in Figure 9 and Figure 10. Notice how the total stress under the reservoir where the ground is horizontal is about 40 kPa. The corresponding effective stress contour is near zero, as it correctly should be.

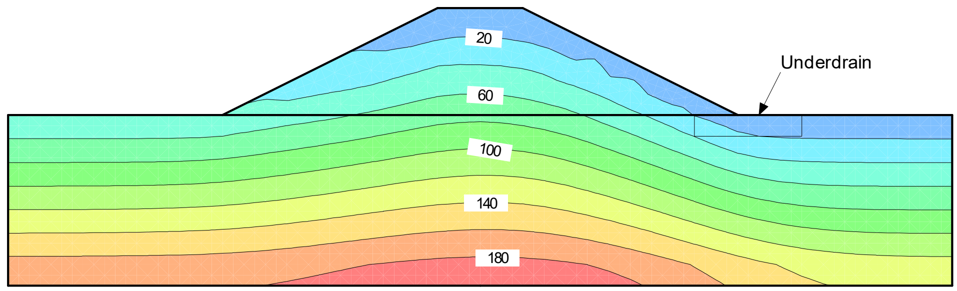

Figure 9. Total vertical stress contours.

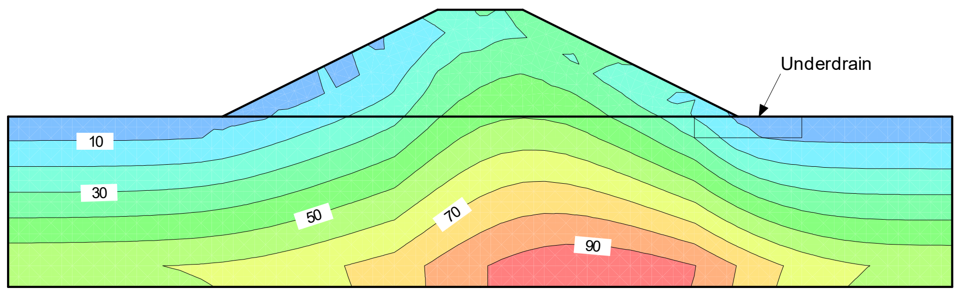

Figure 10. Effective vertical stress contours.

As noted earlier for the Static analysis, there are many ways of presenting and viewing the results, and this is particularly true the dynamic part of the analysis. Only a sampling of what can be done and is available will be presented here.

We had defined a History Point at the crest of the dam and at the base of the problem. With the Draw Graph command, we can create graphs specific to the History Points. It is possible, for example, to create graphs of x-accelerations versus time for the crest and the base and plot them together at the same time (Figure 11). The base values are a replication of the input; that is, the input earthquake record. Recall that the input record has a peak of 0.12 g. As is evident in Figure 11, the peak horizontal accelerations at the crest reach values greater than 0.3 g, indicating there is some amplification in the motion at the crest.

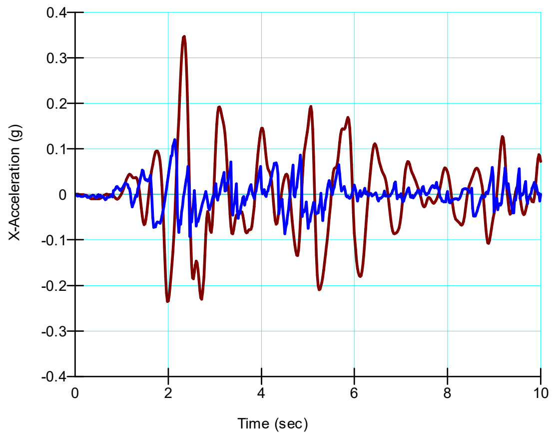

Figure 11. Horizontal accelerations at the crest compared with the base input.

Figure 12 and Figure 13 show lateral displacement profiles at the center-line of the dam. Figure 12 shows the total or absolute displacements. Absolute displacements include the solid body motion at the base of the problem, together with any additional movements relative to the base. Figure 13 shows the displacements relative to the fixed base.

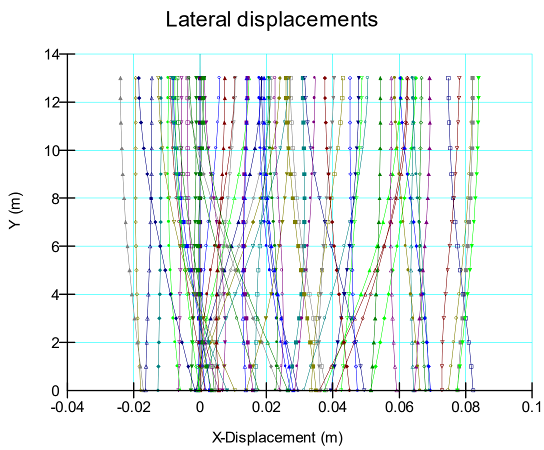

Figure 12. Absolute lateral displacement profiles at the center line of the dam.

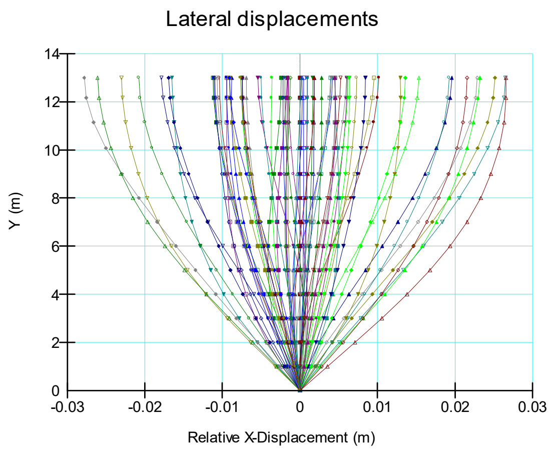

Figure 13. Relative lateral displacement profiles at the center line of the dam.

In a QUAKE/W analysis, it is very important to be mindful of the fact that only relative displacements create dynamic shear stresses and only dynamic shear stresses lead to the generation of excess pore-water pressures.

Figure 14 and Figure 15 show the relative displacements as a deformed mesh at two different times. These two diagrams illustrate the swaying of the ground during the earthquake.

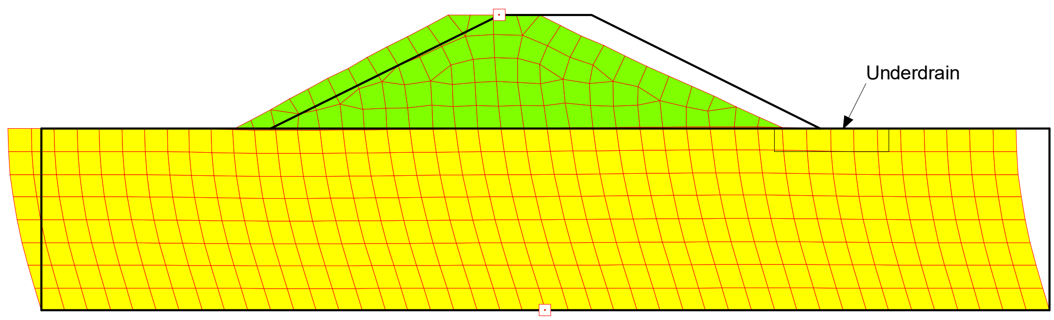

Figure 14. Relative displacements at 2.22 seconds into the shaking (100x exaggeration).

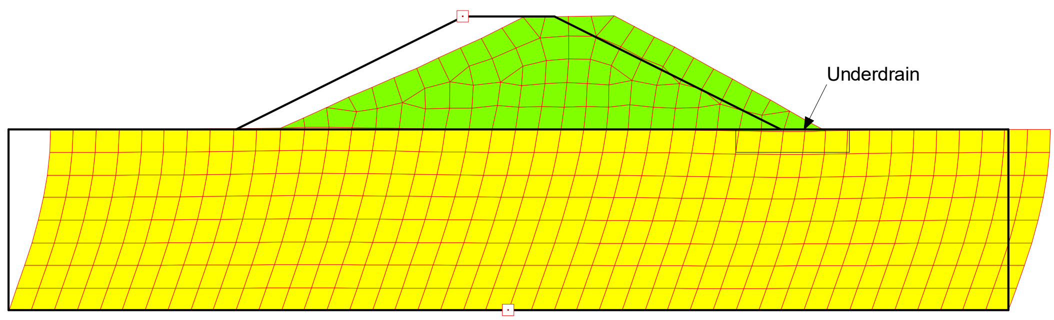

Figure 15. Relative displacements at 2.80 seconds into the shaking (100x exaggeration).

In an Equivalent Linear analysis, a key parameter obtained is the Cyclic Stress Ratio (CSR) (Figure 16). This number is used together with the Cyclic Number function discussed earlier (Figure 10) to indicate the possibility of liquefaction. Without going into much detail, generally the higher the CSR, the higher the possibility of liquefaction. In this example, CSR's greater than about 0.2 will indicate liquefaction is possible, as demonstrated in Figure 17.

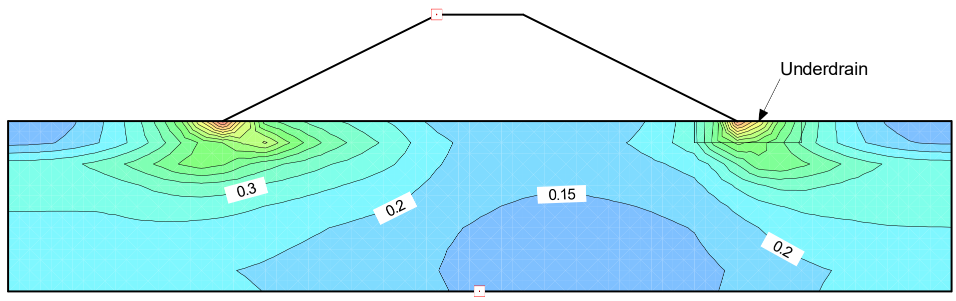

Figure 16. Cyclic Stress Ratio contours.

The potential liquefaction shading in Figure 17 is rather blotchy. This is because of the 4-node quadrilateral elements. The stresses in these elements are somewhat irregular. Using higher-order 8-nodes elements over comes this issue. In spite of the spotty shading, it nonetheless delineates zones where there is the potential for liquefaction.

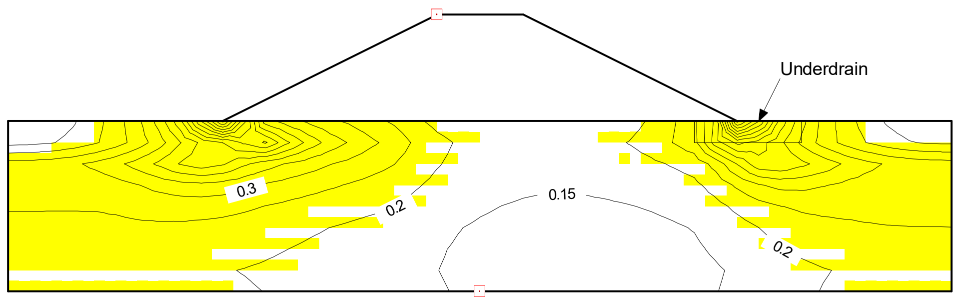

Figure 17. Zones of potential liquefaction.

The shear stress ratio (CSR) in QUAKE/W is defined as:

$$CSR = \frac{q_d}{2\sigma'_{v\,(static)}} * 0.65$$

Equation 1

The 0.65 constant is specified under the Define Analyses Advanced tab (Figure 18). It is called the Coefficient of Equivalent Shear Stress. It is used to view the irregular earthquake shaking in terms of equivalent uniform cycles.

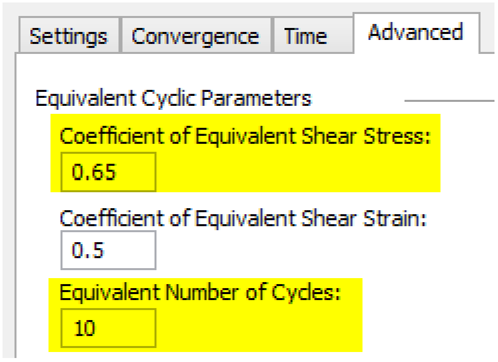

Figure 18. Equivalent Cyclic parameters.

The term q_d in the CSR equations is the Peak Dynamic deviatoric stress. The term $\sigma'_{v\,(static)}$ is the static vertical effective stress before the earthquake shaking (the initial static conditions or time = zero conditions).

Consider the Gauss Region in Figure 19 – it is below the upstream toe of the dam embankment.

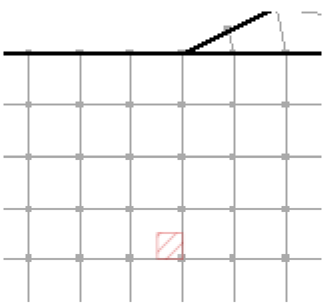

Figure 19. Gauss region.

At time zero the vertical effective stress is 30.285 kPa and at time equal 10 sec, the Peak Dynamic stress is 28.538 (Figure 20).

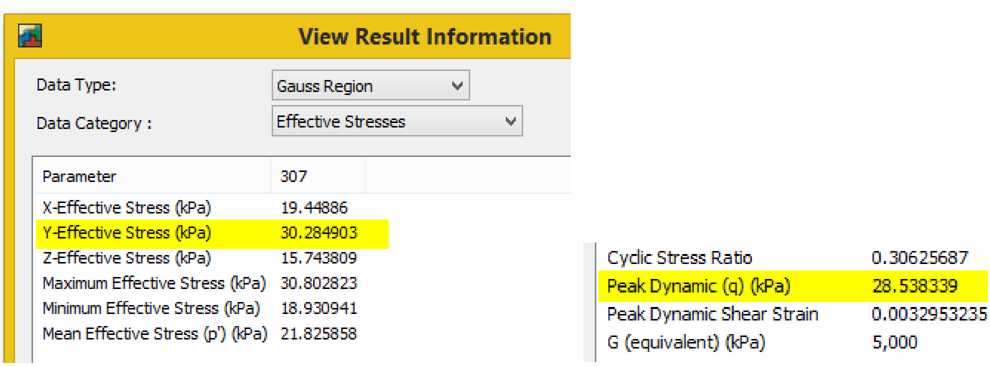

Figure 20. Detailed results for the selected Gauss region.

The cyclic stress ratio then is computed as follows:

$$CSR = \frac{28.538}{2 * 30.285} * 0.65 = 0.306 \quad \text{Equation 1}$$

This matches the value shown in the View Results Information dialog box (Figure 20).

As shown in Figure 18, the Equivalent number of Cycles is specified as 10. This means that the irregular earthquake shaking will produce 10 uniform cycles.

The graph in Figure 10 shows that at a Shear Stress Ratio equal 0.2, 10 cycles are required to produce liquefaction. If the CSR ratio is greater than 0.2, less than 10 cycles are required to produce liquefaction. But the earthquake will create 10 uniform cycles. Consequently, where the CSR is greater than 0.2, the soil will liquefy. Where the CSR is smaller than 0.2, some excess pore-water pressure will be generated but it will not be sufficient to cause liquefaction.

Consequently, in this illustrative example, there is a potential for liquefaction where the CSR is greater than 0.2, as is depicted in Figure 16 and Figure 17.

Another interesting piece of information is the generated excess pore-water pressures (Figure 21). Of interest are the pockets of high excess pore-water pressures where the excess pore-water pressures exceed 25 kPa. This is the pore-water pressure over and above the initial static pore-water pressure conditions.

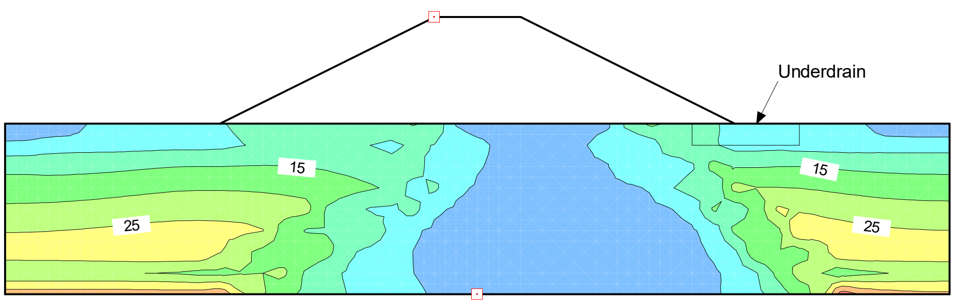

Figure 21. Contours of excess pore-water pressure.

Summary and Conclusions

This introductory example is rather simplistic and not all that realistic in some respects. It nonetheless illustrates the powerful features and capabilities available in QUAKE/W.

This introductory example only looks at liquefaction in the context of the Cyclic Stress Ratio. More advanced techniques are available in QUAKE/W. These advanced techniques are discussed in terms of what is known as soil-grain collapsible surface. These advanced techniques need to be used in actual field projects. The CSR approach alone is not adequate for actual field problems.