# Lab Practical   -   <u>Rock Support Interaction</u>

<u>Part A – Medium Support</u>

In this example, the Duncan Fama solution method will be used to determine the Ground Reaction Curve for a tunnel without support. Then support will be added, and a factor of safety for the support determined. Analysis will be Deterministic (i.e. all parameters assumed to be known). The Rocscience program ROCSUPPORT will be used.

The problem involves a 12 meter diameter tunnel, which is to be constructed at a depth of 60 meters in a rock mass whose strength is defined by the Hoek-Brown criterion with an intact rock strength $\sigma_{ci} = 7$ MPa, constant $m_i = 10$ and a Geological Strength Index = 20.
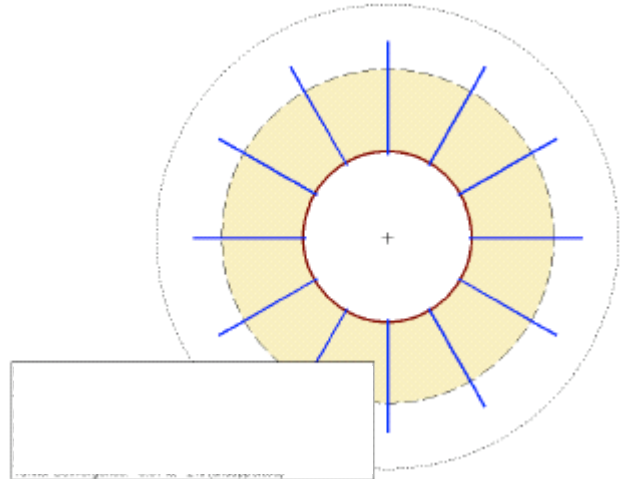
1) <u>GETTING STARTED</u>

To begin creating a new model:

Select: *File → New*

When a new file is created, the Ground Reaction View will initially be displayed. This will show the Ground Reaction Curve based on the default Tunnel and rock input data. To view a cross-sectional view of the model:

Select: *Analysis → Tunnel Section*

The Tunnel Section View displays:

- A cross-section of the tunnel diameter, and the plastic zone (shaded region). Note that the size of the plastic zone is drawn to scale with respect to the tunnel diameter.

- A Project Info Textbox with a summary of the main input and output parameters. Note that for a new file, the default Analysis Type is Deterministic, and NO support is added, so the analysis results are for an unsupported tunnel.

- If support is installed, this will be displayed on the Tunnel Section View and the plastic zone radius (with support) will be displayed.

2) <u>PROJECT SETTINGS</u>

For this example, we do not need to change any Project Settings.

3) TUNNEL AND ROCK PARAMETERS

The tunnel diameter, in-situ stress and rock parameters are defined with the Tunnel Parameters option, which you may select from the toolbar or the Analysis menu:

Select: *Analysis → Tunnel Parameters*

For a Deterministic analysis, the Tunnel and Rock Parameters dialog will appear.

Tunnel Radius

For this example, the tunnel diameter is 12 meters, so enter a tunnel radius of 6 meters under "General" section. NOTE that you must input the tunnel radius, and NOT the tunnel diameter.

In-Situ Stress

In the Tunnel and Rock Parameters dialog, you may input the hydrostatic in-situ stress directly, if it is known. However, as you will discover with other input data in RocSupport, whenever you see a "calculator" icon to the right of an input data edit box in a dialog, this means that the required input data may be estimated from other parameters. In the case of In-Situ Stress, this can be simply estimated from the tunnel depth, and the rock unit weight.

In the Tunnel and Rock Parameters dialog, select the Calculator icon to the right of the In-Situ Stress edit box. You will see the Estimate In-Situ Stress dialog.

Enter a tunnel depth of 60 meters. We will use the default value for Unit Weight of Rock (0.027 MN/m³). Note that the estimated in-situ stress (1.62 MPa) is displayed in the dialog. Select OK and the estimated value will be loaded into the Tunnel and Rock Parameters dialog.

To apply the new parameters you have just entered, select the Apply button. This will run the analysis, and all views of the current document will be updated with the latest results.
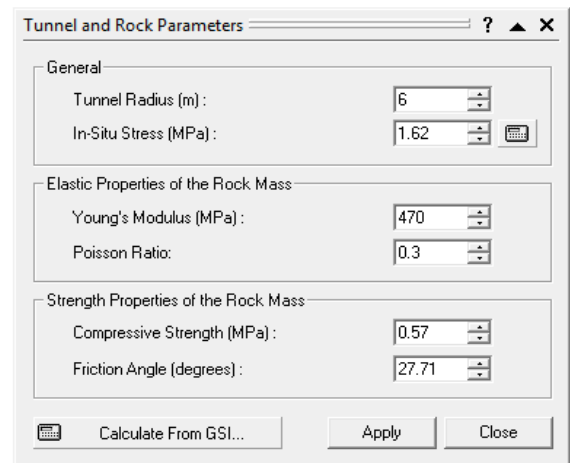
4) ROCK MASS PARAMETERS

Remember that the rock properties were given in terms of Hoek-Brown parameters. However, the *Duncan Fama solution method uses the Mohr-Coulomb failure criterion*, and requires a friction angle. For this purpose, the "Calculate from GSI" option is provided in the Tunnel and Rock Parameters dialog. This dialog allows you to obtain estimates for rock mass properties such as Young's Modulus, Compressive Strength and friction angle by entering Hoek-Brown parameters (GSI, mi, intact UCS, and D).

In the Tunnel and Rock Parameters dialog, select the Calculator icon on the lower left side of the window. You will see the Parameter Calculator dialog.

Enter, Intact UCS = 7, GSI = 20, Intact mi =10 and Disturbance Factor = 0.

Check the boxes besides Young Modulus, UCS of Rock Mass, and Friction Angle of Rock Mass to have them as output, under "output" section.
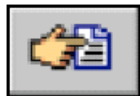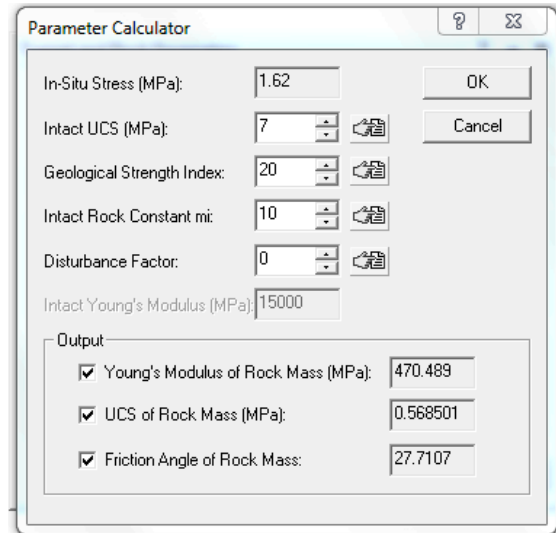
Before you select OK, notice that beside the GSI input edit box, is a "pick" icon, as shown in the margin. Whenever you see this icon displayed in a RocSupport dialog, this means that data can be selected from a table or chart.

For example, in the Parameter Calculator dialog, select the "pick" icon beside the GSI edit box. You will see the following GSI table, allowing you to determine a value for GSI based on the rock structure and surface conditions.

Note:
- As you move the mouse around the chart, the GSI value at that point will be displayed beside the cursor

- If you click the mouse at a point on the chart, the corresponding GSI value will be loaded into the edit box at the top of the GSI table

- You may then edit this value, if necessary

It should be emphasized that a parameter such as GSI should not be considered an exact value, and a range of possible values should always be considered in an analysis.
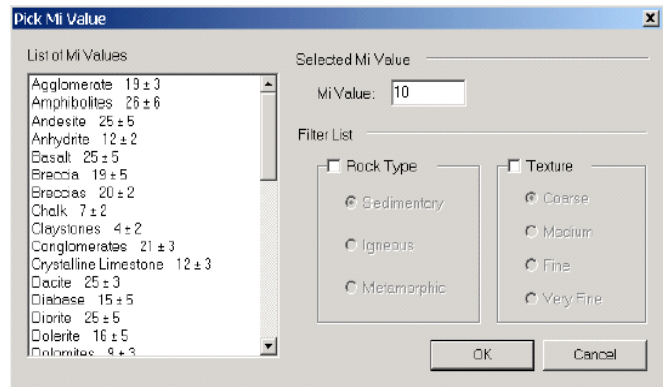
Since we have already decided on a value for GSI, just select Cancel in the GSI dialog.

Notice that beside the m_i input edit box is a "pick" icon. As discussed previously for the GSI table, select this icon, and you will see the following table, allowing you to select a value for m_i based on the rock type.

To use this dialog:

- Simply select a rock type from the list at the left of the dialog, and the corresponding mi value will be loaded into the edit box at the top of the dialog.

- You may filter the list, if desired, by selecting the Rock Type and / or Texture checkboxes, and then selecting the desired Rock Type and / or Texture. This will display only the requested subset in the list. You may want to experiment with this.

Since we have already decided on a value for mi, just select Cancel in the Pick m_i Value dialog.

> *Select OK in the Parameter Calculator dialog, to return to the Tunnel and Rock dialog.*

The computed values of modulus, compressive strength and friction angle are automatically entered in the Tunnel and Rock Parameters dialog.

Estimating Parameter Interdependency:

At this point, we will make the following important observations:

- When using the "pick" icons as described above, estimating one parameter can affect the value of another. For example, if GSI is modified in the Estimate Compressive Strength dialog, then Young's Modulus will be updated accordingly, and vice versa.

- The Friction Angle is also re-calculated, when Young's Modulus (GSI modified) or Compressive Strength (Hoek-Brown parameters only, GSI or m_i modified) are estimated.

- In general, it may be necessary for the user to manually reset a desired value (eg. Friction Angle) after estimating another value (eg. Young's Modulus).

Estimating Rock Mass Poisson's Ratio:

Poisson Ratio is utilized in both the Duncan Fama and Caranza-Torres solution methods. In this case we will accept the default value of 0.3. NOTE that the Poisson Ratio is NOT affected by the Estimate calculations, as described above for the Friction Angle.

5) APPLY

We are now finished entering all of the desired data in the Tunnel and Rock Parameters dialog. In order to save the newly entered parameters, and re-run the analysis, you must select the Apply button.

> *Select Apply in the Tunnel and Rock Parameters dialog. Now, close the dialog, by selecting either the Close button, or the X in the upper right corner of the dialog.*

Notice that the information in the Ground Reaction View and Tunnel Section View has been updated with the new results. REMEMBER that you MUST SELECT APPLY to save the data and re-run the analysis. If you select the Close button without FIRST selecting Apply, then this will cancel all new data entered, and the previous results will remain on the screen.

6) ANALYSIS RESULTS (NO SUPPORT)

In the Tunnel Section View, revise the summary provided in the Project Info Textbox.

On your answer sheet, record the values for the Plastic Zone radius (no support) and final Tunnel Convergence.

For the given amount of convergence calculated, use the table below and comment on the type of support that should be considered for the tunnel.

|	Strain ε %	Geotechnical issues	Support types
A	Less than 1	Few stability problems and very simple tunnel support design methods can be used. Tunnel support recommendations based upon rock mass classifications provide an adequate basis for design.	Very simple tunneling conditions, with rockbolts and shotcrete typically used for support.
B	1 to 2.5	Convergence confinement methods are used to predict the formation of a 'plastic' zone in the rock mass surrounding a tunnel and of the interaction between the progressive development of this zone and different types of support.	Minor squeezing problems which are generally dealt with by rockbolts and shotcrete; sometimes light steel sets or lattice girders are added for additional security.
C	2.5 to 5	Two-dimensional finite element analysis, incorporating support elements and excavation sequence, are normally used for this type of problem. Face stability is generally not a major problem.	Severe squeezing problems requiring rapid installation of support and careful control of construction quality. Heavy steel sets embedded in shotcrete are generally required.
D	5 to 10	The design of the tunnel is dominated by face stability issues and, while two-dimensional finite analyses are generally carried out, some estimates of the effects of forepoling and face reinforcement are required.	Very severe squeezing and face stability problems. Forepoling and face reinforcement with steel sets embedded in shotcrete are usually necessary.
E	More than 10	Severe face instability as well as squeezing of the tunnel make this an extremely difficult three-dimensional problem for which no effective design methods are currently available. Most solutions are based on experience	Extreme squeezing problems. Forepoling, face reinforcement are usually applied and yielding support may be required in extreme cases.

7) GROUND REACTION CURVE

To view the Ground Reaction Curve, select the Ground Reaction option from the toolbar or the Analysis menu.

Select: *Analysis → Ground Reaction*

By default, the X-axis of the Ground Reaction Curve is expressed as Tunnel Convergence (%).
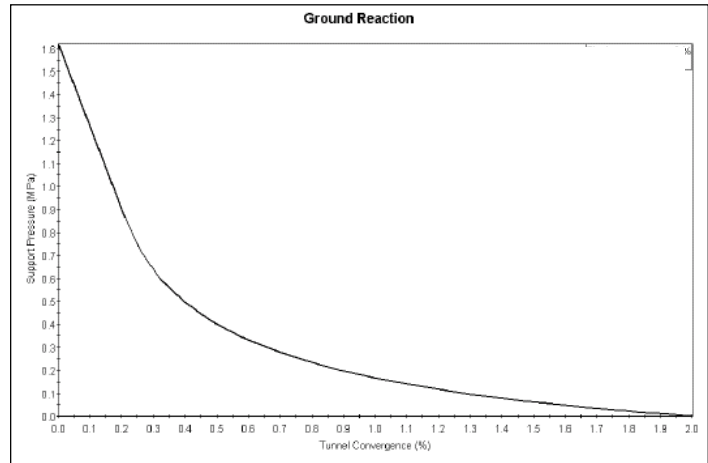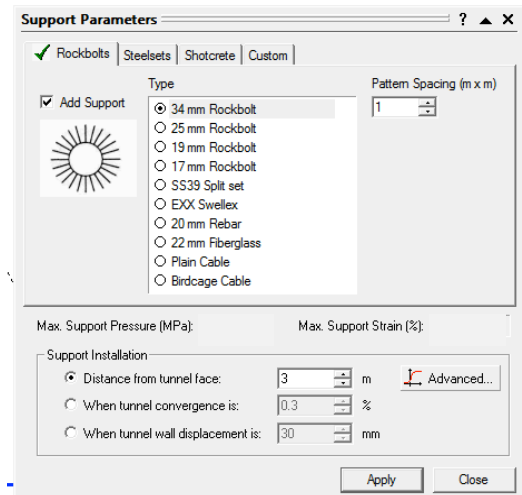

8) SUPPORT

Now let's add some rockbolt support, and see the effect on the tunnel behaviour. To add support, select the Support Parameters option from the toolbar or the Analysis menu.

Select: *Analysis → Support Parameters*

For this example, we will start by adding 34 mm rockbolt support, at 1 x 1 m pattern spacing. Support will be installed at a distance of 3 m from the face.

To add the rockbolt support:

1. Select the Add Support checkbox under the Rockbolts tab. Notice that a green checkmark now appears beside the Rockbolts tab, to indicate that rockbolt support will be in effect.

2. We will use 34 mm rockbolts, which is already selected by default in the Type list.

3. We will use the default Pattern Spacing = 1 x 1 meters.

4. Enter Distance from Tunnel Face = 3 m

Select the Apply button. This will save the support parameters you have entered, and re-run the analysis. All open views of the current document, will be updated with the latest analysis results.

Before closing the Support Parameters dialog, record on your answer sheet the Maximum Support Pressure and Maximum Support Strain, which are displayed at the middle section of the dialog.

Note that these parameters correspond to the properties of the support type chosen. For a given tunnel diameter:

- The Maximum Support Pressure depends on the type of support you have added, as well as the Out of Plane Spacing (for steel sets) or the Pattern Spacing (for rockbolts)

6

- The Maximum Average Strain depends only on the support type you have selected, and is not affected by Out of Plane Spacing or Pattern Spacing.

- If none of the pre-defined support types (Rockbolts, Steel Sets or Shotcrete), provide the required Support Pressure and Average Strain, then the user can simply define a Custom support type in the Support Parameters dialog.

- Different support types (eg. Rockbolts and Shotcrete) can be combined in the same analysis.

Now close the Support Parameters dialog (make sure you have selected Apply before you select Close), and we will examine the results of the analysis with support.

9) ANALYSIS RESULTS (WITH SUPPORT)

If the Tunnel Profile View is not currently active, then select the Tunnel Profile option from the toolbar or the Analysis menu to view the Tunnel Section and analysis summary.

Notice that there are now two boundaries displayed as dotted lines. The interior boundary shows the extents of the plastic zone (shaded region) around the tunnel when support is installed. The outer boundary depicts the plastic zone when the problem is analyzed without support.

> ***Using the Project Info textbox, record the following on your answer sheet: Radius of the plastic zone (with support and unsupported), Factor of Safety, Mobilized Support Pressure, and Tunnel Convergence.***

Note: Although bolt length does not enter into a RocSupport analysis (since support is modeled as an equivalent uniform internal pressure), the Plastic Zone Radius gives an indication of the required bolt lengths for effective support. For bolts to be effective, they must be anchored in unyielded rock. This means that they have to extend beyond the plastic zone.

10) ROCK SUPPORT INTERACTION

Now view the Ground Reaction and Support Reaction curves.

Select: *Analysis → Ground Reaction*

Note the following about the Support Reaction Curve:

- The origin of the Support Reaction Curve, on the horizontal (Tunnel Convergence) axis, is determined from the Distance from Tunnel Face in conjunction with the Longitudinal Deformation Profile.

- The slope of the elastic portion of the Support Reaction curve, is equal to the Maximum Support Pressure divided by the Maximum Average Strain.

- The intersection of the Support Reaction with the Ground Reaction, determines the mobilized support pressure, final tunnel convergence (with support) and plastic zone radius, listed in the Tunnel Section View. If the Ground Reaction Curve intersects the Support Reaction Curve in the elastic region, as in this example, then the mobilized Support Pressure and Tunnel Convergence are considered EQUILIBRIUM values.

11) <u>COMBINING SUPPORT TYPES</u>

As previously noted, the Support Parameters dialog allows multiple support types to be added for a given model. For example, Rockbolts and Shotcrete could be added to the same model, simply by selecting the Add Support checkbox for both Rockbolts and Shotcrete, and entering the desired parameters for each.

When multiple support types are used for a single model, the following rules apply to the Maximum Support Pressure and Average Strain:

  • The Maximum Support Pressure is cumulative, and is ADDED for all applied support types.
  • The Maximum Support Strain is the MAXIMUM value for all applied support types.

These simplistic assumptions are of course not intended to model the actual, complex interaction of multiple support systems, but are an idealized approximation.

For our current example, let's add some shotcrete support to the rockbolt support, and see the effect on the analysis results.

     Select: *Analysis → Support Parameters*

In the Support Parameters dialog:

1. Select the Shotcrete tab.

2. Select the Add Support checkbox. Notice that green checkmarks now appear on BOTH the Rockbolts tab and the Shotcrete tab, indicating that both rockbolt and shotcrete support will be in effect.

3. Select the 50 mm thickness, 28-day age shotcrete type from the Properties list.

4. Select the Apply button, to save the shotcrete parameters and re-run the analysis. All open views of the current document, will be updated with the latest analysis results.
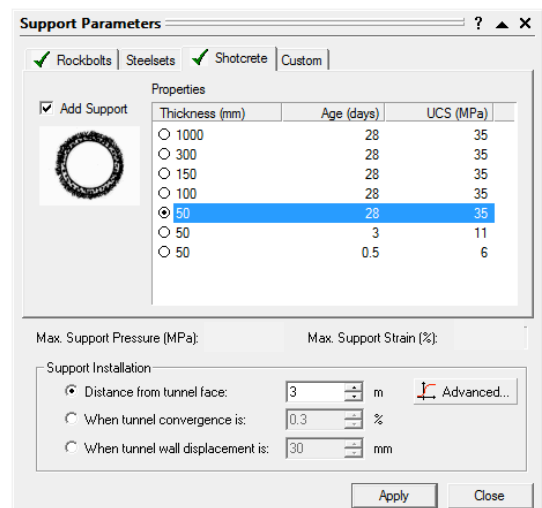
> ***Before closing the Support Parameters dialog, record on your answer sheet the Maximum Support Pressure and Maximum Support Strain, which are displayed in the middle section of the dialog.***

Remember, as noted above:

• The (combined) Maximum Support Pressure is the SUM of the 34 mm rockbolt support pressure and the 50 mm shotcrete support pressure.

• The (combined) Maximum Support Strain is the maximum of the rockbolt and shotcrete values.

Now close the dialog and observe the new analysis results.

Note that the thickness of shotcrete (or steel set) support is not drawn to scale.

12) ANALYSIS RESULTS (WITH COMBINED SUPPORT)

As we did after adding rock bolt support, examine the information in the Tunnel Section View and the Ground Reaction / Support Reaction View.

> ***Using the Project Info textbox, complete the Table given in your answer sheet.***

It can be seen that the addition of shotcrete support did not have a great effect on the plastic zone radius, tunnel convergence or mobilized support pressure, compared to the rockbolt support alone. This is because the additional support capacity, in this case, has not significantly changed the intersection point of the Ground Reaction and Support Reaction curves, which determines these values.

Also note that we used the 28-day shotcrete strength. The support pressure provided by the shotcrete at early ages is much less than the 28-day strength, and this must be taken into consideration when considering the actual combined safety factor, at different stages of the shotcrete curing. (Note that 3-day and 0.5-day 50 mm shotcrete support is also available in the Support Parameters dialog).

Finally, let's look at the Info Viewer option. The Info Viewer option provides a well-formatted summary of all input and output data.

> Select: *Analysis → Info Viewer*

Notice that the Support Parameters information lists the Total Combined (Maximum Support Pressure and Maximum Support Strain), as well as the contributions from each individual support type used in the model (in this case, rockbolts and shotcrete).

Part B – Heavy Support

In this example, we will model a tunnel with much more serious stability problems than in Part A, requiring heavier support. The Caranza-Torres solution method will be used to determine the Ground Reaction Curve. Analysis will be Deterministic (i.e. all parameters assumed to be known).

The problem involves a 10 meter diameter tunnel to be constructed at a depth of 75 meters in a rock mass whose strength is defined by the Hoek-Brown criterion with an intact rock strength σ_{ci} = 3 MPa, constant m_i = 15 and a Geological Strength Index = 10.

Project Title: ROCSUPPORT Example 2
Project Settings: Deterministic Analysis, Carranza-Torres Solution
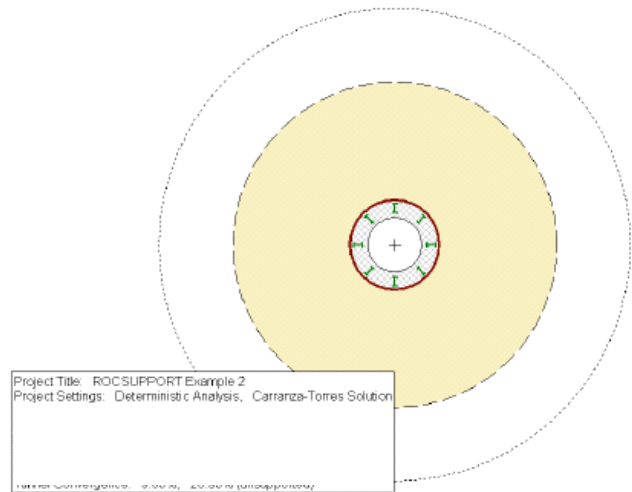
1) GETTING STARTED

If you have not already done so, create a new file to begin working with:

Select: *File → New*

If necessary, maximize the Tunnel Section View by selecting the Maximize button in the upper right corner of the view.

2) PROJECT SETTINGS

For this example, we will use the Carranza-Torres solution method, which must be selected in the Project Settings dialog:

Select: *Analysis → Project Settings*

In the Project Settings dialog, select the Carranza-Torres Solution Method.

Immediately, the Tunnel and Rock Parameters dialog comes up. Anytime you change from one solution method to the other this dialog is automatically invoked. This is because the input rock parameters for the two methods differ, making it necessary for you to verify that you are using the right values for analysis.

Remember that:

- The Carranza-Torres solution method uses the Hoek-Brown failure criterion, to determine the Ground Reaction Curve and plastic zone radius.

- The Duncan-Fama solution method uses the Mohr-Coulomb failure criterion, to determine the Ground Reaction Curve and plastic zone radius.

3) TUNNEL & ROCK PARAMETERS

Our tunnel diameter is 10 meters, so the default Tunnel Radius of 5 meters is already correct and does not need to be changed under the "General" section of "Tunnel and Rock Parameters" dialog.

In-Situ Stress:

The In-Situ Stress can be estimated from the Tunnel Depth.

1. Select the Estimate button beside the In-Situ Stress edit box.
2. Enter Tunnel Depth = 75 meters. Select OK in the Estimate In-Situ Stress dialog.
3. The estimated In-Situ Stress is 2.025 MPa.

Rock Parameters:

Under the "Peak Strength Properties", enter:

Compressive Strength of Intact Rock σ_{ci} = 3, GSI = 10, and Intact Rock Constant m_i = 15. Leave all the other default values as they are.

Young's Modulus:

You will notice that there is a calculator button beside the Young's Modulus edit box. If you select this button, the rock mass Young's Modulus will be automatically calculated according to the Modulus Estimation Method specified in the Project Settings dialog.

Now select Apply to save the Tunnel and Rock Parameters you have entered, and run the analysis with the new parameters. Then select Close.

4) ANALYSIS RESULTS (NO SUPPORT)

In the Tunnel Section View, examine the summary provided in the Project Info Textbox:

> ***On your answer sheet, record the values for the Plastic Zone radius (no support) and final Tunnel Convergence.***
>
> ***For the given amount of convergence calculated, use the table given in the previous exercise and comment on the type of support that should be considered for the tunnel.***

The resulting value of Tunnel Convergence is very high. A tunnel with these input parameters would have very serious stability problems. Very heavy support, installed as close as possible to the advancing face, would be necessary.

5) GROUND REACTION CURVE

To view the Ground Reaction Curve, select the Ground Reaction option from the toolbar or the Analysis menu.

Select: *Analysis → Ground Reaction*

By default, the X-axis of the Ground Reaction Curve is expressed as Tunnel Convergence (%).

6) SUPPORT

For support, let's start with I section steel sets (254 mm depth, 203 mm width, weighing 82 kg/m), spaced at 1.5 m, and installed at a distance of 3 m from the face.

Select: *Analysis → Support Parameters*

In the Support Parameters dialog:

1. Select the Steel Sets tab, and select the Add Support checkbox.

2. Select I section rib from the Type drop-down list. We will use the default selection 203 mm Flange Width.

3. Enter Out of Plane spacing = 1.5, and Distance from Tunnel Face = 3.

4. Select Apply to save the support parameters you have entered and re-run the analysis.

   Before closing the Support Parameters dialog, record on your answer sheet the Maximum Support Pressure and Maximum Support Strain.

   Close the dialog*.*

7) ANALYSIS RESULTS (WITH SUPPORT)

Examine the Ground Reaction and Support Reaction curves.

Select: *Analysis → Ground Reaction*

After, select the Tunnel Profile option, and view the analysis summary in the Project Info Textbox.

Select: Analysis → *Tunnel Profile*

Compare the unsupported results to those with the steel set support.

On your answer sheet, record the Radius of the plastic zone (with support and unsupported), Factor of Safety, Mobilized Support Pressure, and Tunnel Convergence.

Even with support, the tunnel is still surrounded by a large plastic zone radius, and final convergence is still very high. However, the Factor of Safety for the Steel Sets indicates that the loading is well within the support capacity.

8) ADDITIONAL SUPPORT

Let's now see the effect of adding a layer of shotcrete in addition to the steel set support.

Select: Analysis → *Support Parameters*

In the Support Parameters dialog:
1. Select the Shotcrete tab
2. Select the Add Support checkbox
3. Select 100 mm thickness shotcrete
4. Select Apply

Before closing the Support Parameters dialog, record on your answer sheet the Maximum Support Pressure and Maximum Support Strain of the combined steel sets with shotcrete.

Close the dialog and observe the new analysis results.

9) ANALYSIS RESULTS (WITH COMBINED SUPPORT)

As we did after adding the steel set support, examine the information in the Tunnel Section View and the Ground Reaction / Support Reaction View.

Using the Project Info textbox, complete the Table given in your answer sheet.

As before, the addition of shotcrete support has had a significant effect on the Factor of Safety, but not on the plastic zone radius, tunnel convergence or mobilized support pressure, compared to the steel set support alone. If we compare the combined Support Reaction curve to the curve for the Steel Sets alone, you will note the following:

• The additional shotcrete support, has approximately doubled the Maximum Support Pressure, hence the increase in the Factor of Safety.

• However, the intersection point of the Ground Reaction and Support Reaction curve, has not changed significantly, hence there is no significant change in the final Tunnel Convergence or Plastic Zone radius.

The intersection of the Ground Reaction and Support Reaction is affected primarily by the Distance From Face (entered in the Support Parameters dialog). We did not change this value when we added the shotcrete support.

As a final optional exercise, enter different values for the Distance from Face in the Support Parameters dialog (eg. 2 meters, 1 meter etc), and select Apply to re-calculate and view the results. Notice that changing the Distance from Face shifts the origin of the Support Reaction curve. This DOES have an effect on final Tunnel Convergence, Plastic Zone Radius, and Factor of Safety for the Support. The Factor of Safety

decreases as the Distance From Face decreases, because the Support takes a greater load as it is installed closer to the face.

In performing such analyses, the user is encouraged to experiment with the Support Parameters input. Parametric analyses can be performed very quickly by: adding or removing support, changing support parameters, selecting Apply to re-calculate the results and observing the effects on the Support Reaction Curve.
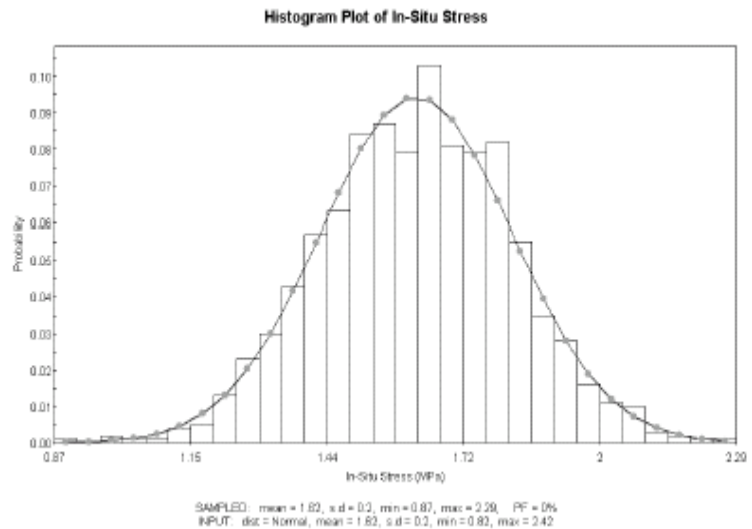
Lastly, note that a tunnel with the input parameters used for this example, would certainly require very detailed final support design, which would include numerical analysis such as finite element. A rock support interaction analysis of such a tunnel, as demonstrated here using ROCSUPPORT, would certainly not be considered adequate for final design purposes.

Nonetheless, valuable insight into the tunnel behaviour can be gained from the use of ROCSUPPORT even in such cases. Quick parametric analysis is very easy to perform using such tools, allowing the user to vary all input parameters, and view the effect on the results.

Part C – Probabilistic Analysis

This exercise will demonstrate how to carry out a Probabilistic analysis with RocSupport. For a given tunnelling problem, many of the input parameters are not known with accuracy, particularly those describing the rock mass characteristics. Therefore it is very useful to be able to input statistical distributions for input parameters, in order to obtain statistical distributions of the analysis results.

This example will be based on the problem given in Part A, with statistical distributions entered for some of the input variables.

Histogram Plot of In-Situ Stress

SAMPLED: mean = 1.82, s.d = 0.2, min = 0.87, max = 2.29, PF = 0%
INPUT: dist = Normal, mean = 1.82, s.d = 0.2, min = 0.83, max = 2.42

1) GETTING STARTED

   Start a new analysis, referring to the settings used (e.g. tunnel dimensions and rock mass properties only) in Part A. We will be using a different support type for this exercise.
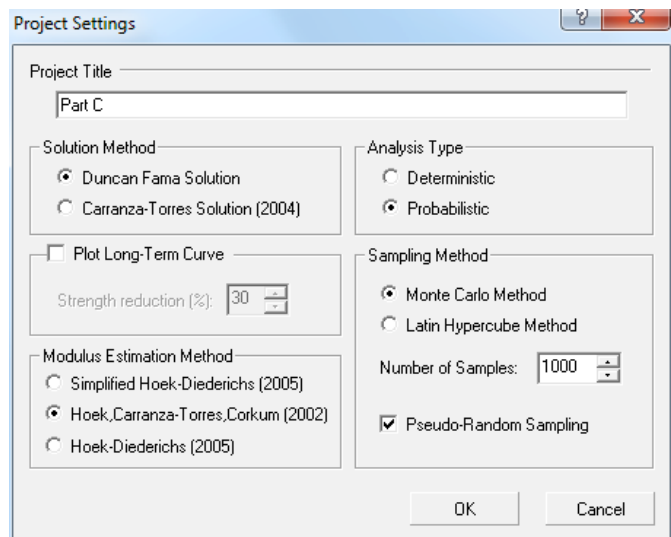
2) PROJECT SETTINGS

   First we need to change the Analysis Type in the Project Settings dialog from Deterministic to Probabilistic:

   Select: *Analysis → Project Settings*

   In the Project Settings dialog:
   1. Select the Duncan-Fama Solution Method
   2. Change the Analysis Type to Probabilistic
   3. Select the Pseudo-Random Sampling option and click OK.

3) TUNNEL & ROCKMASS PARAMETERS

   Now select Tunnel Parameters from the toolbar or the Analysis menu.

   Select: *Analysis → Tunnel Parameters*

   Notice that the Tunnel and Rock Parameters dialog is presented in a grid format for a Probabilistic analysis. This simplifies the input of statistical parameters, and allows you to easily define random variables and keep track of which variables have been assigned statistical distributions.
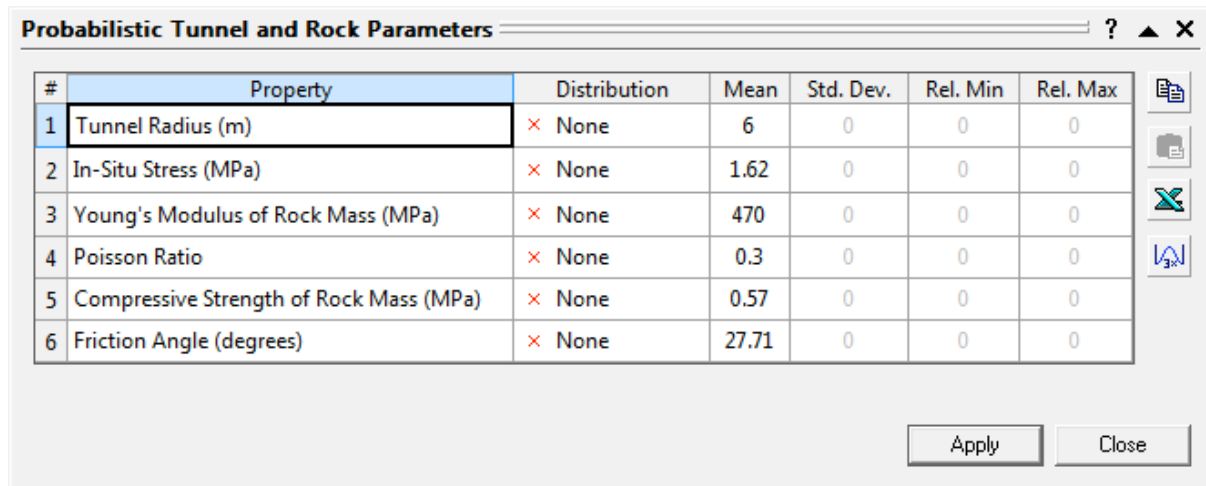
Note that:

- The basic input variables for all Tunnel and Rock Parameters are the same as requested for a Deterministic analysis.

- A statistical distribution cannot be defined for Tunnel Radius (which is always specified exactly, even for a Probabilistic analysis).

For this exercise, we will define the In-situ stress, young's modulus, compressive strength and friction angle as random. To define a random variable, first select a statistical distribution for the variable (e.g. Normal) in the Tunnel and Rock Parameters dialog. Then enter the mean, standard deviation and relative minimum and maximum values, which define the statistical distribution for the variable. For this exercise, enter the following parameters:

Property	Distribution	Mean	Std. Dev.	Rel. Min.	Rel. Max
In-Situ Stress	Normal	1.62	0.2	0.6	0.6
Young's Modulus	Normal	470	50	150	150
Compressive Strength	Normal	0.57	0.1	0.3	0.3
Friction Angle	Normal	27.71	2	6	6

Note that the Minimum and Maximum values are specified as RELATIVE distances from the mean, rather than as absolute values. This simplifies the data input for the user. See the ROCSUPPORT Help system, for details about the various statistical distributions, which are used in ROCSUPPORT, and the significance of the input parameters for each distribution.

The Tunnel and Rock Parameters dialog should appear as follows:

You may have noticed that the relative minimum and maximum values we entered for each variable, was 3 times the standard deviation. For a Normal distribution, this ensures that a complete distribution is defined (i.e. since 99.7% of all samples fall within 3 standard deviations of the mean, for a normally distributed random variable).

> *Now select Apply.*

This will save the parameters you have just entered, and run the ROCSUPPORT Probabilistic analysis. The analysis should only take a few seconds or less (remember that we used the default Number of Samples = 1000 in the Project Settings dialog). Close the Tunnel and Rock Parameters dialog, and we will modify the support type used.

NOTE: because we selected Pseudo-Random sampling, the Probabilistic analysis will always generate exactly the same results, for a given set of input parameters. To generate true random sampling, we would have to de-select the Pseudo-Random Sampling option.

4) SUPPORT

In the Support Parameters dialog:
1. Add rock bolt support.
2. Select the 20 mm rebar as the support type.
3. Select Apply.

> ***Before closing the Support Parameters dialog, record on your answer sheet the Maximum Support Pressure and Maximum Strain of the rebar support.***

5) ANALYSIS RESULTS

The Tunnel SectionView, for a Probabilistic analysis, appears the same as for a Deterministic analysis. However, in the analysis summary provided in the Project Info Textbox, note that:

- The results are the MEAN values from the statistical analysis. In general, these MEAN values will NOT NECESSARILY be the same as the Deterministic analysis results, based on the mean input data.

- A Probability of Failure, for the support, is listed, as well as the MEAN safety factor. The Probability of Failure represents the number of analyses, in which the Factor of Safety for the support was less than 1, divided by the total number of analyses (1000 in this case).

On your answer sheet, record the Probability of Failure, and mean Factor of Safety, Mobilized Support Pressure, Radius of Plastic Zone, and Tunnel Convergence.

6) STATISTICS

After a Probabilistic analysis, the user can plot the results in the form of Histograms or Cumulative Distributions, of input and output variables.

Histograms:
To create a Histogram plot, select Histogram Plot from the toolbar or the Statistics menu.

> Select: *Statistics → Histogram Plot*

Plot a histogram of Factor of Safety. Since this is the default selection in the Plot Histogram dialog, just select OK to generate the plot.

Note that:
- The Input Distribution is the distribution defined by the input data you have entered in the Tunnel and Rock Parameters dialog.

- The Sampled data statistics are derived from the raw data generated by the statistical sampling (Monte Carlo method in this case) of the Input Distribution you have defined. This explains why the SAMPLED and INPUT statistical parameters listed at the bottom of an input variable histogram, will in general differ slightly.

Select Show Failed Bars from the Statistics menu (or the right-click menu). The percentage of each bar of the histogram, corresponding to analyses with Factor of Safety less than 1, is now highlighted in RED.

Cumulative Plots:
A cumulative distribution is, mathematically speaking, the integral of the normalized probability density function. Practically speaking, a point on a cumulative distribution gives the probability that a random variable will be LESS THAN OR EQUAL TO a specified value. To generate a Cumulative distribution, select Cumulative Plot from the toolbar or the Statistics menu.

> Select: *Statistics → Cumulative Plot*

Note that the list of Variables to plot is exactly the same in both the Plot Histogram and Plot Cumulative dialogs. Let's plot the Factor of Safety cumulative distribution. Since this is the default selection in the Plot Cumulative dialog, just select OK to generate the plot.

7) SENSITIVITY

You can repeat the previous steps for other input or output variables. Notice the distribution of failed analyses, with respect to the overall distribution of the variable. The Show Failed Bars option allows the user to examine the relationship of any given input or output variable, to the failure of the support system.