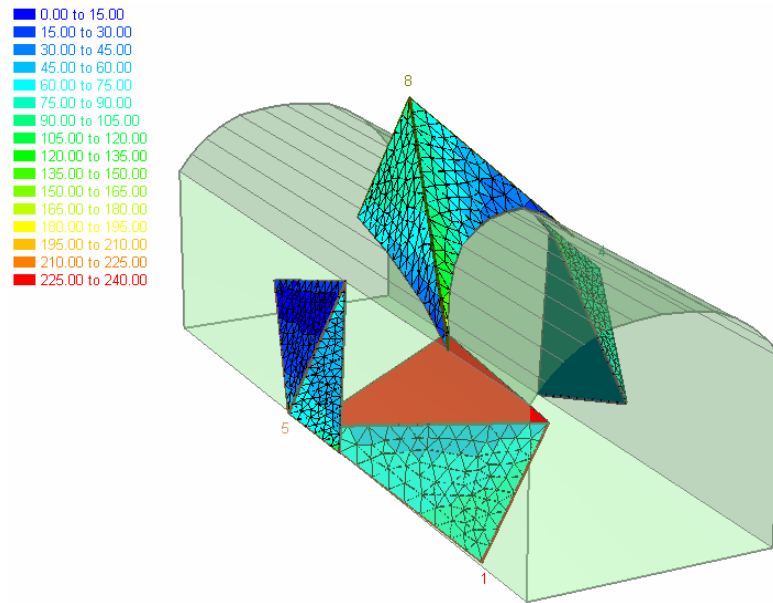


Field Stress Tutorial



Maximum Normal Stress: 180.22 t/m²
 Minimum Normal Stress: 12.85 t/m²

The default *Unwedge* analysis is based upon the assumption that the wedges are subjected to gravitational loading only (i.e. self-weight of the wedges). The actual stress field in the rock mass surrounding the excavation is not taken into account. While this assumption leads to some inaccuracy in the analysis, the error is generally conservative, leading to a lower factor of safety.

The **Field Stress** option in *Unwedge* allows you to include the effect of in-situ stress (clamping stress) on the wedge safety factor. In general, this has a tendency to increase wedge safety factor, although this depends on the wedge geometry and field stress orientation.

By default, the reported factor of safety (with Field Stress) will always be greater than (or equal to) the factor of safety without considering Field Stress.

Topics Covered

- Stress analysis overview
- Defining field stress
- Safety factor with field stress
- Viewing stress contours
- Stress contour data tips
- Advanced stress options

Stress Analysis Overview

When the **Field Stress** option is applied in *Unwedge*, a boundary element stress analysis is automatically performed prior to the wedge stability calculation. This determines the elastic stress distribution around the excavation, which is used to compute the actual stress distribution on each wedge plane. The general features of the stress analysis implementation are as follows:

1. The field stress orientation and magnitude is defined in the **Field Stress** dialog. You may choose either a constant or gravitational far field stress.
2. Based on the field stress parameters, *Unwedge* will carry out a boundary element stress analysis around the excavation. The boundary element method assumes linear elastic behaviour (i.e. plasticity and localized failure is not accounted for in this type of analysis).
3. The boundary element stress analysis used in *Unwedge* is based on the analysis engine used in the Rocscience program *Examine2D*. For more information about *Examine2D*, see:
<http://www.rocscience.com/products/Examine2D.asp>
4. The boundary element stress analysis in *Unwedge* uses the **Complete Plane Strain** formulation. This means that the principal stress orientations do not have to be aligned with the excavation axis. Although the excavation model is 2-dimensional, the defined Field Stress and the stress analysis results are 3-dimensional.
5. The stress analysis determines the distribution of stresses around the Opening Section assuming an infinitely long excavation in the axis direction.
6. The stress analysis DOES NOT analyze the stress distribution around the ends of the excavation. Therefore, the results of using **Field Stress** can only be applied to the Perimeter Wedges, and does not apply to the End Wedges.
7. Based on the results of the stress analysis, *Unwedge* determines the actual distribution of stress on each wedge face (Perimeter Wedges only), and includes this stress in the stability calculations.

For further information see the Theory > Safety Factor section in the *Unwedge* help system. See sections 9 and 10 in the Safety Factor document for details about the Field Stress calculations.

Model

To begin this tutorial, read in the file **Tutorial 05 Field Stress.weg** which you will find in the Examples > Tutorials folder in your *Unwedge* installation folder. You should see the following model:

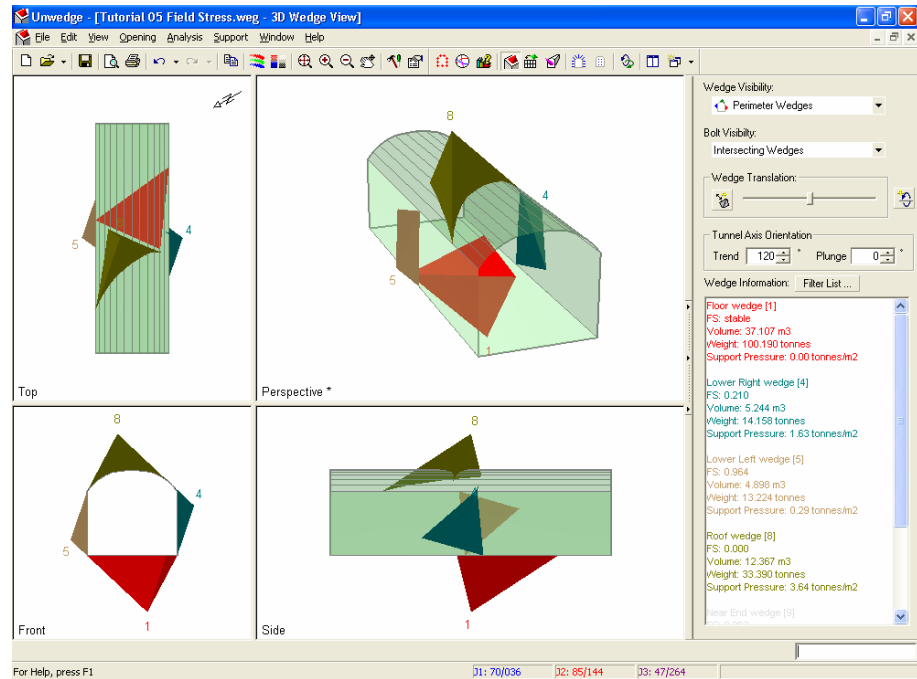


Figure 1: Unwedge model for field stress tutorial.

The model represents a horizontal tunnel with an axis orientation of Trend = 120, Plunge = 0. Notice the four perimeter wedges, and the values of safety factor:

- Lower Right Wedge (FS = 0.210)
- Lower Left Wedge (FS = 0.964)
- Roof Wedge (FS = zero)
- Floor Wedge (stable)

The model currently does NOT have Field Stress defined, therefore the wedges are subjected to gravitational loading only, due to the self-weight of each wedge.

We will now define Field Stress and observe the effect on the wedge safety factors.

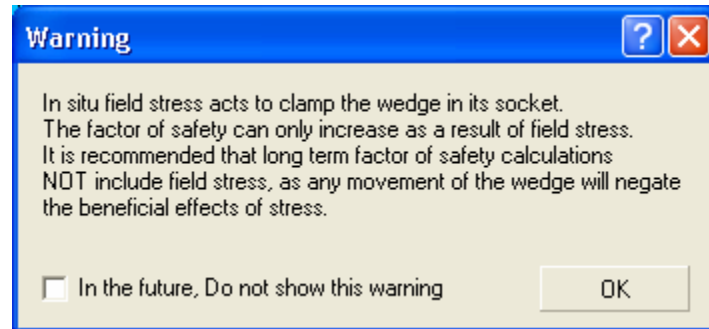
Field Stress

To define Field Stress, select the **Field Stress** option from the **Analysis** menu.



Select: Analysis → Field Stress

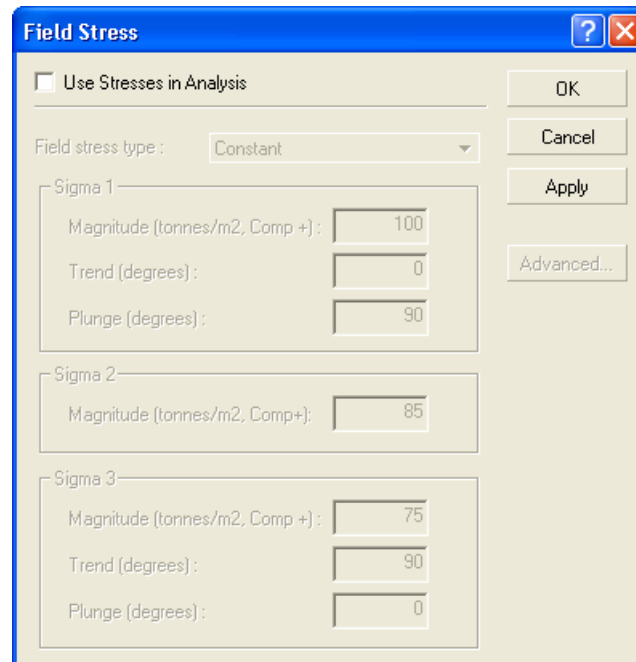
You may first see the following warning dialog.



If you see this dialog, read the message and select OK.

The dialog message is a reminder that the Field Stress option in *Unwedge* should always be considered an advanced user option, and results should be carefully evaluated. For conservative design purposes, it is best to design on the basis of NO field stress effect.

You will now see the Field Stress dialog.



1. To enable Field Stress, select the **Use Stresses in Analysis** checkbox in the Field Stress dialog. This enables the Field Stress option and allows you to define the Field Stress parameters.
2. We will use Field Stress Type = **Constant** (i.e. assume that the initial in-situ stress does not vary with depth or location).
3. Enter the following magnitudes and orientations for the major, intermediate and minor principal far field stress:
 - Sigma 1: Magnitude = 100, Trend = 0, Plunge = 90
 - Sigma 2: Magnitude = 85 tonnes/m²
 - Sigma 3: Magnitude = 75, Trend = 90, Plunge = 0
4. Note: the Sigma 1 and Sigma 3 orientations must be orthogonal to each other (i.e. the direction vectors must differ by 90 degrees). The orientation of Sigma 2 is automatically determined to be orthogonal to both Sigma 1 and Sigma 3.
5. Select OK.

The screenshot shows the 'Field Stress' dialog box with the following settings:

- Use Stresses in Analysis
- Field stress type: Constant
- Sigma 1**
 - Magnitude (tonnes/m², Comp +): 100
 - Trend (degrees): 0
 - Plunge (degrees): 90
- Sigma 2**
 - Magnitude (tonnes/m², Comp+): 85
- Sigma 3**
 - Magnitude (tonnes/m², Comp +): 75
 - Trend (degrees): 90
 - Plunge (degrees): 0

Buttons on the right: OK, Cancel, Apply, Advanced...

Safety Factor with Field Stress

Now observe the wedge safety factors displayed in the Wedge Information panel. The following table summarizes the wedge safety factor values before and after applying the Field Stress.

Wedge	Factor of Safety (No Field Stress)	Factor of Safety (With Field Stress)
Lower Right Wedge	0.210	0.729
Lower Left Wedge	0.964	0.964
Roof Wedge	0	1.165
Floor Wedge	Stable	Stable

Lower Right Wedge and Roof Wedge

The “clamping effect” of the Field Stress has significantly increased the Factor of Safety for the Lower Right Wedge (0.210 to 0.729) and for the Roof Wedge (0 to 1.165).

Lower Left Wedge

For the Lower Left Wedge, the application of Field Stress did not change the reported Factor of Safety (0.964). In this case, the inclusion of Field Stress in the stability calculations actually results in a LOWER Factor of Safety for the wedge. When this occurs, the Factor of Safety which is reported is the original Factor of Safety, without Field Stress.

Unwedge always compares the stressed and unstressed values of safety factor, and by default, reports the HIGHER of the two values. The logic behind this reasoning is as follows:

- If the actual stress distribution in the rock mass has a tendency to “push” the wedge into the excavation, then in effect, the wedge reverts to an unstressed state. The safety factor then reverts to the original safety factor, due to the self-weight of the wedge.
- Notice that the Lower Left Wedge is a relatively “flat” wedge. The geometry of this wedge is such that the Field Stress has a greater tendency to dislodge the wedge, rather than clamp the wedge in place.

NOTE: when the Factor of Safety (with Field Stress) is less than the unstressed value, it is possible to obtain the stressed Factor of Safety. See the **Advanced Stress Options** section later in this tutorial for details.

Viewing Stress Contours

When you are using the **Field Stress** option in *Unwedge*, you can view the actual stresses computed on the wedge planes as follows:

1. Right-click directly on any perimeter wedge in the 3D Wedge View.
2. In the popup menu, you will see a **Field Stress Visualization** sub-menu.
3. From this sub-menu you can choose to view contours of:
 - Normal Stress
 - Shear Stress
 - Sigma 1
 - Sigma 3
 - Sigma X
 - Sigma Y
 - Tau XY

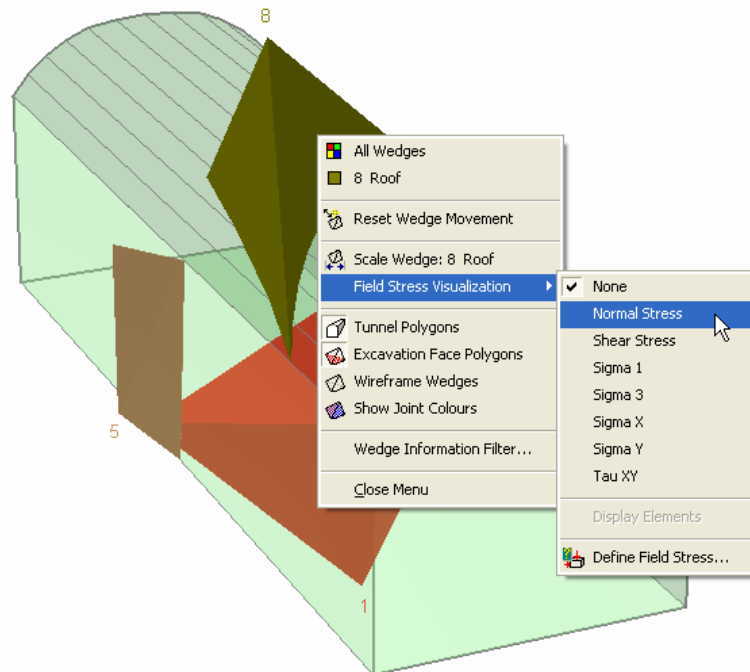


Figure 2: Right click menu for field stress visualization.

4. Select a data type from the list (e.g. Normal Stress), and the joint planes of all wedges will immediately display contours of the selected data type. A Field Stress Legend will also be displayed, so you can determine the values of the contours, as shown in the following figure.

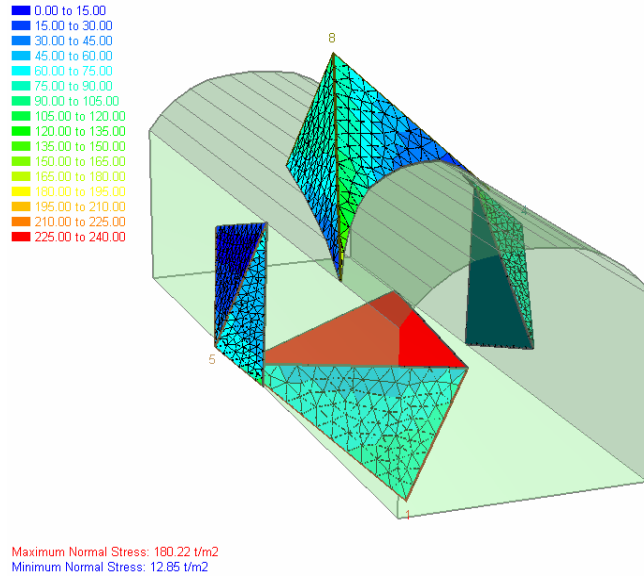


Figure 3: Contours of normal stress displayed on wedge planes.

Display Elements

If you see a mesh of triangular elements displayed on the wedge faces (see Figure 3), the nodes of the mesh are the locations at which the stress is calculated on each wedge face. The stress contours are generated from these values. To show (or hide) the mesh, right click on any wedge, and from the **Field Stress Visualization** sub-menu in the right-click menu, toggle the **Display Elements** option on (or off).

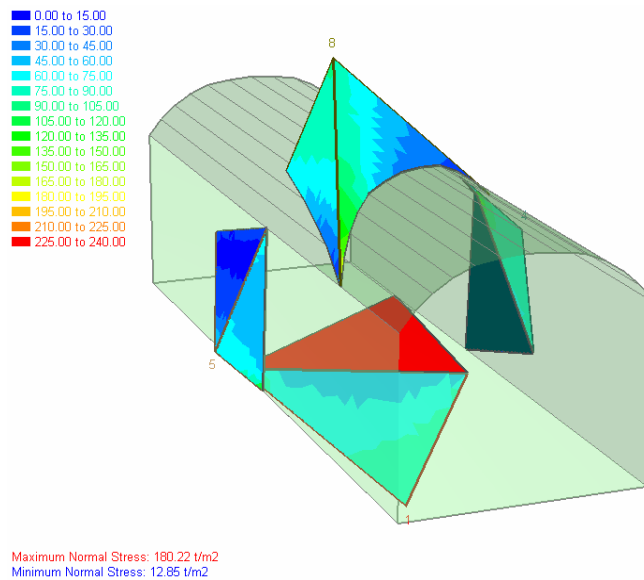


Figure 4: Stress contours on wedge faces, mesh display turned off.

Data Tips

When stress contours are displayed on the wedge planes, if you hover the mouse over any contoured wedge plane, a popup data tip will display the value of the stress at that location. This is shown in the following figure.

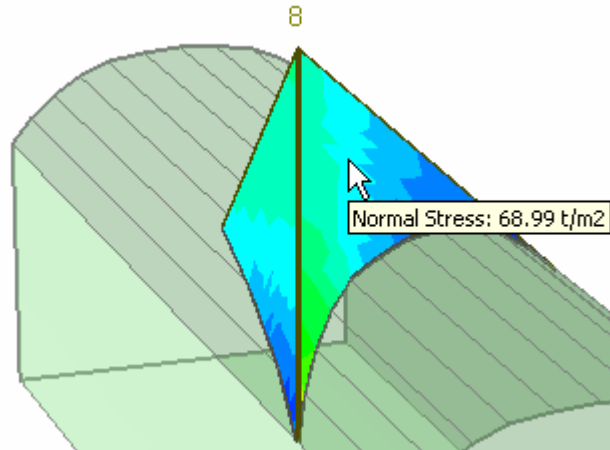


Figure 5: Data tip display of normal stress on wedge plane.

Note: if you do not see any data tips, go to the **View** menu and set the **Data Tips** option to **Maximum**.

Notice that the value of stress displayed in the data tip, corresponds to the stress contour values displayed in the Legend. Experiment with viewing different stress contours (e.g. Shear Stress).

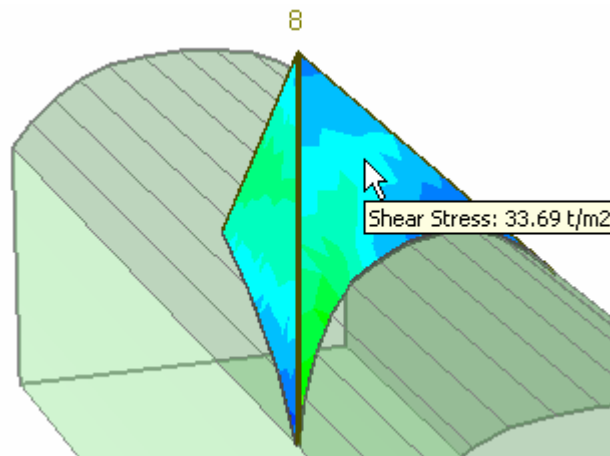


Figure 6: Data tip display of shear stress on wedge plane.

Advanced Field Stress Options

The boundary element stress analysis in *Unwedge* is not a “black box” – advanced users who wish to configure the settings of the analysis can do so with the Advanced Stress Settings dialog. To access this dialog:



1. Select the **Field Stress** option from the **Analysis** menu.
2. Select the **Advanced** button in the Field Stress dialog.
3. You will see the following dialog, which allows you to configure the rock mass elastic parameters, boundary element discretization, solver type and other parameters related to the stress analysis and display of results.

Advanced Settings For Stresses

Rock mass Young's Modulus (tonnes/m2)

Rock mass Poisson ratio:

Matrix solution technique :

Element type :

Number of elements :

Number of joint sample points :

Data to contour on joint planes:

Number of Intervals for contours:

Apply pressures on excavation boundary as boundary conditions in stress analysis

Report only the stressed factor of safety (do not check against the unstressed)

For more information about the Advanced Stress Setting parameters, see the *Unwedge* help system.

Before you close the dialog:

1. Select the checkbox at the bottom of the dialog – “Report only the stressed factor of safety”.

Report only the stressed factor of safety (do not check against the unstressed)

2. Select OK in the Advanced Stress Settings dialog, and select OK in the Field Stress dialog.

3. Now look at the wedge safety factors displayed in the sidebar. In particular, look at the factor of safety for the Lower Left Wedge and the Floor Wedge (these are highlighted in the following table).

Wedge	Factor of Safety (No Field Stress)	Factor of Safety (With Field Stress)
Lower Right Wedge	0.210	0.729
Lower Left Wedge	0.964	0.746
Roof Wedge	0	1.165
Floor Wedge	Stable	1.337

NOTE:

- The Factor of Safety (with Field Stress) for the Lower Left Wedge is now LESS THAN the factor of safety without field stress.
- The Factor of Safety (with Field Stress) for the Floor Wedge is now a finite value, compared to the Stable result (without Field Stress).

As discussed earlier in this tutorial, by default *Unwedge* does NOT report Factor of Safety values (with Field Stress) when the values are LESS THAN the Factor of Safety (without Field Stress). The reasons for this have already been discussed. However, if you do wish to see the Factor of Safety (with Field Stress), regardless of the value, then you can select the checkbox in the **Advanced Stress Settings** dialog, as we have shown here. These values are provided for academic interest, but it is not recommended that they be used for any design purposes.

Speed of Calculations when using Field Stress

If you use the **Field Stress** option, this can noticeably affect the speed of the *Unwedge* calculations. This is because the boundary element stress analysis must be carried out first, before the limit equilibrium calculations. If the tunnel axis orientation is changed, the stress analysis must be re-computed. If joint orientations are changed, the stresses must be re-computed on each wedge face.

You may not notice any difference in speed for a simple analysis of a single tunnel orientation. However, if you are using the **Tunnel Axis Plot** option (for example), the plot generation may take some time if you are using Field Stress, because the entire boundary element analysis has to be re-computed for each tunnel orientation. For information about the Tunnel Axis plot see the *Unwedge* help system.

End Wedges and Field Stress

The stress analysis which is performed in conjunction with the **Field Stress** option in *Unwedge* is a plane strain analysis. It is assumed that the excavation is of infinite length. The stress distribution at the ends of the excavation is NOT computed. Therefore, the Field Stress option is only applicable for perimeter wedges in *Unwedge*, and cannot be applied to the End Wedges.

In order to apply Field Stress to End Wedges, a full 3D stress analysis of the excavation would be required. This is not within the current capabilities of *Unwedge*.

Conclusion

The **Field Stress** option in *Unwedge* is an interesting analytical tool which allows you to see the potential effects of including the actual rock mass stress in the wedge stability calculations.

However, the Field Stress option should be used with caution, and engineering judgment must be used when interpreting the results. If long term behaviour is being considered, then the inclusion of Field Stress is NOT recommended, so that the analysis and design of support is conservative.