Model calibration for prediction of structurally controlled over-break - V377 example

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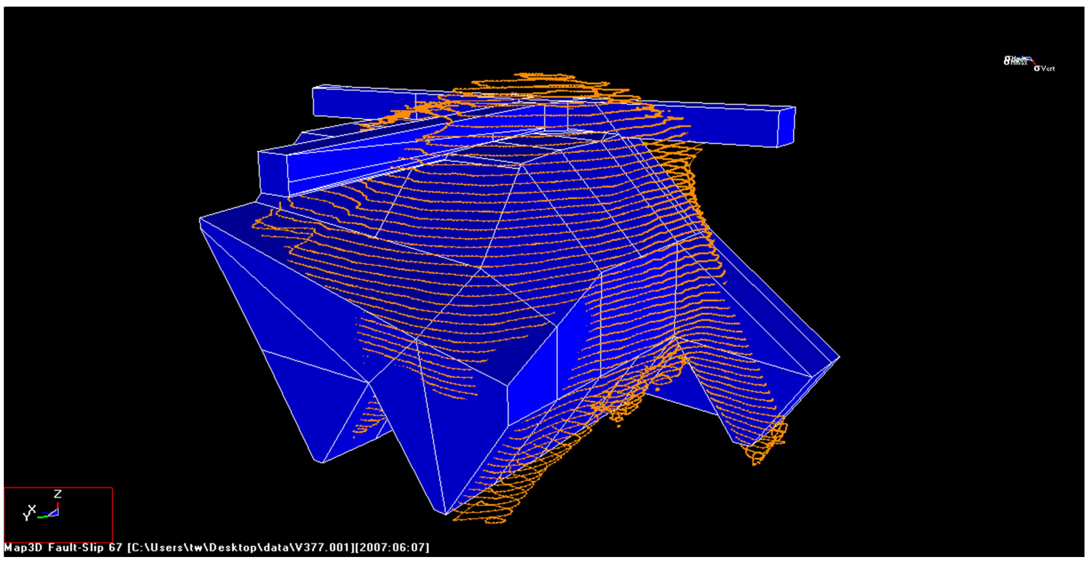
Files required:

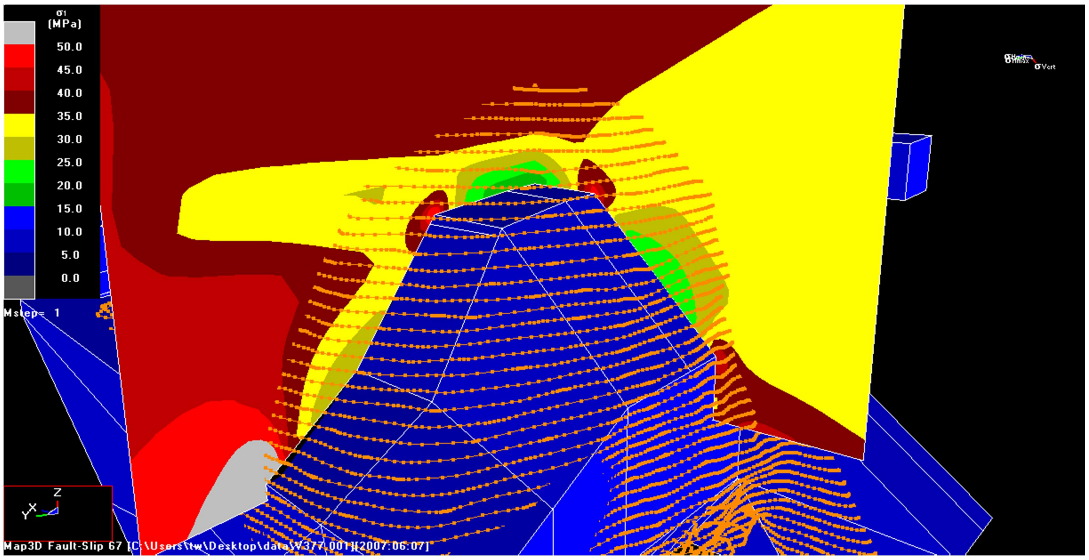
- V377.001
- V377.dxf

The stope was modelled according to the designed shape shown in blue "Map3D > File > Results View > V377.001". The cavity survey shown in orange ("Map3D > File > Open Construction Lines > V377.dxf") illustrates the over-break. The objective here is to find a failure criterion that provides the best estimate of the over-break.



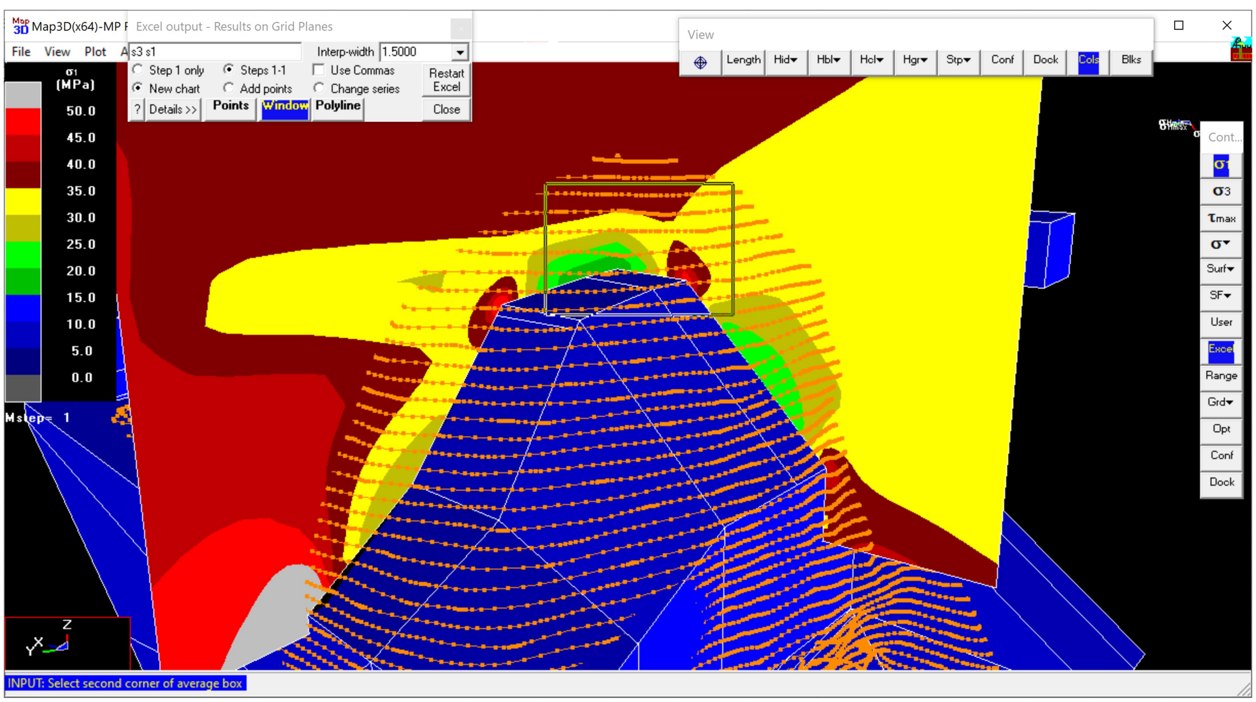
Rock Mass Failure

First let's present the stresses in a useful format. Plot the major principal stress σ_1 using "Map3D > Plot > Stress > σ_1".

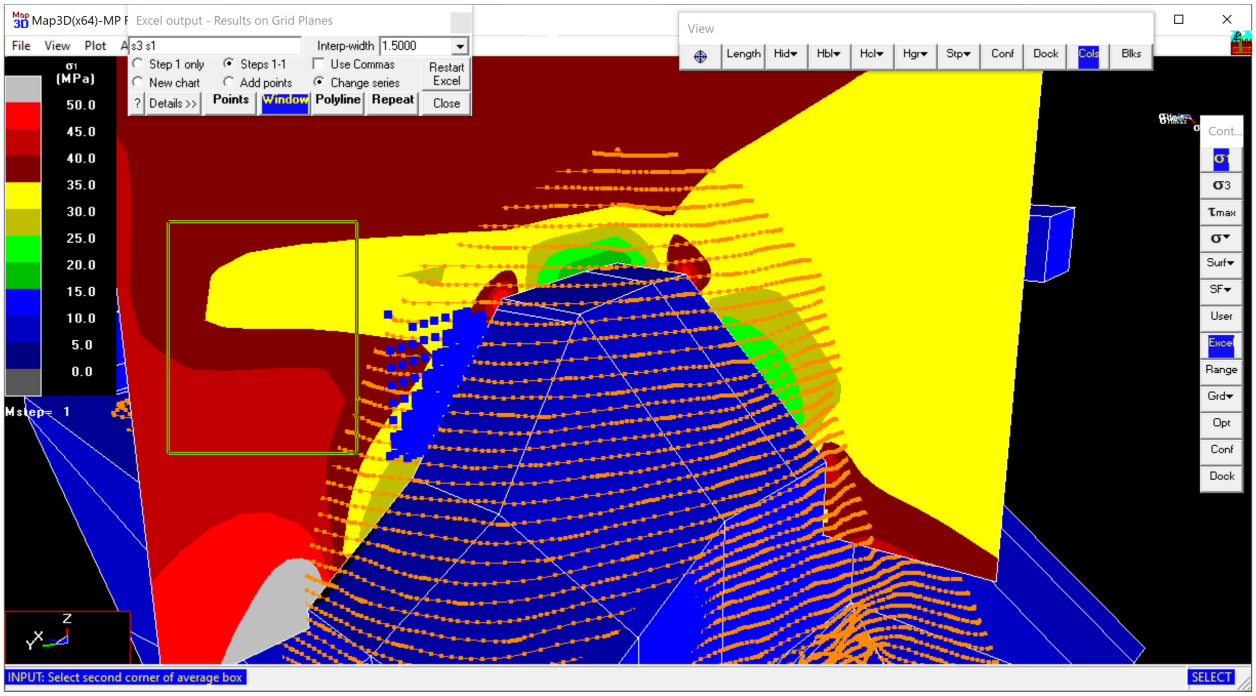


Using Excel, I now collect stresses for points inside and outside the over-break zone, as well as along the indicated depth of failure. In this case I will use “s3 s1” as the arguments for the “Map3D > Plot > Excel” function. Here “s3 s1” represent respectively σ_3 and σ_1 such that σ_3 will be the x-axis (abscissa) and σ_1 will be the y-axis (ordinate).

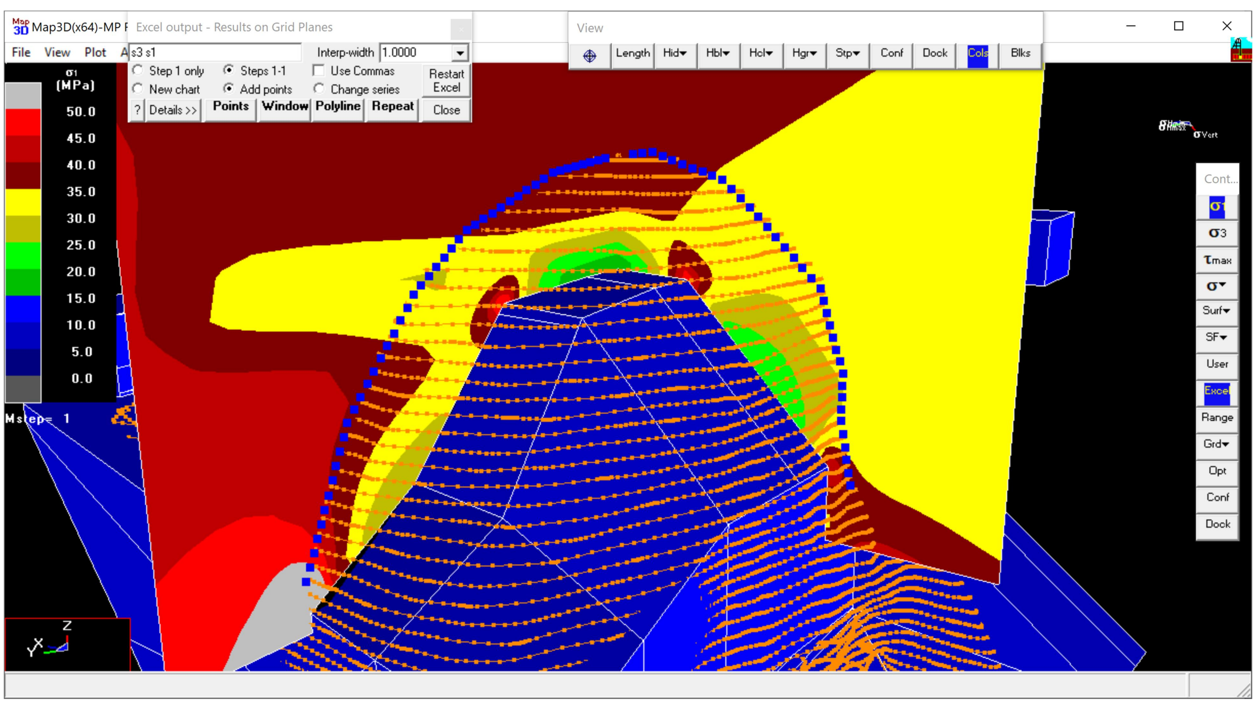
Using the “Map3D > Plot > Excel > Window” function, multiple sets of data inside the failed zone can be dumped to Excel.



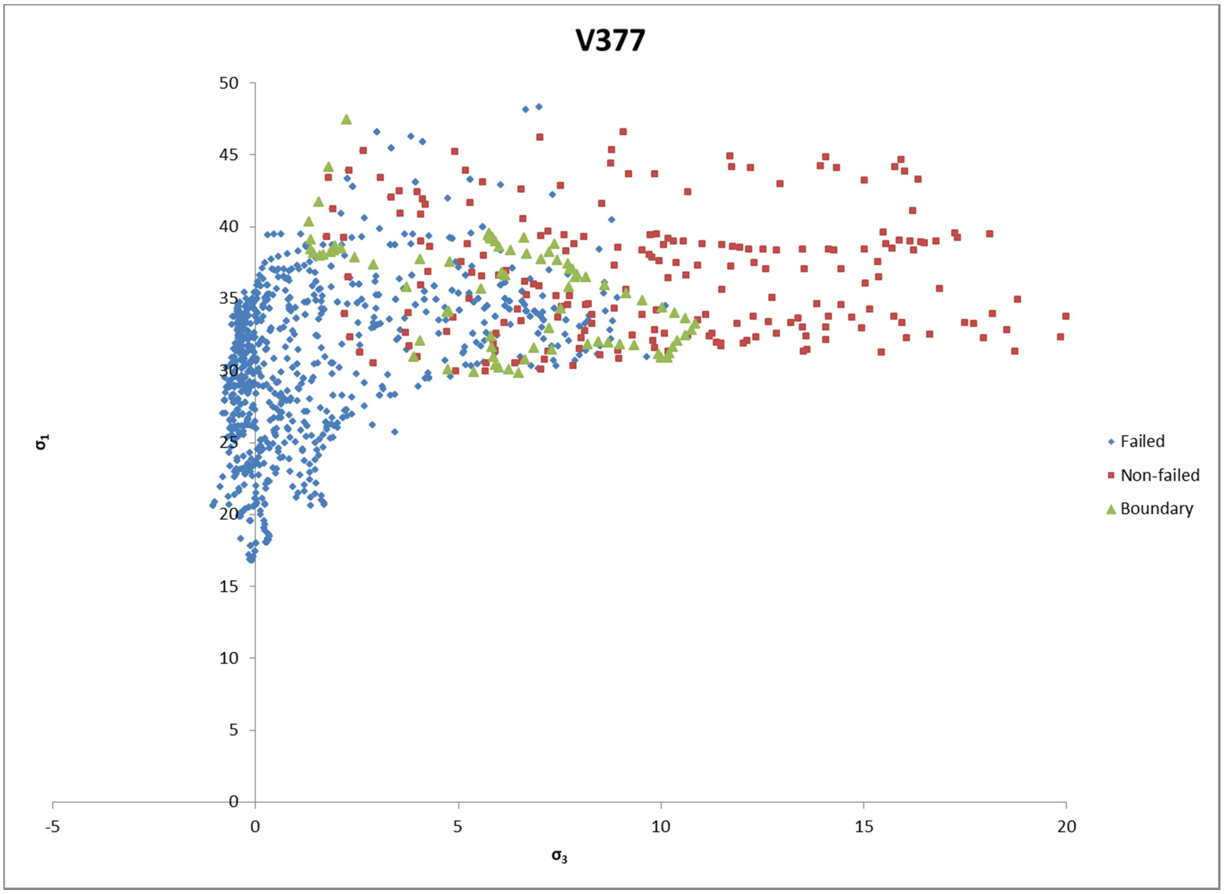
Now I will select “Map3D > Plot > Excel > Change Series” function then select several windows outside the failed zone.



Finally, I will set the “Interp-Width” to 1 m, select “Change Series”, then start the “Map3D > Plot > Excel > Polyline” function. Note that you must hold down the shift key in order to select multiple points along the indicated depth of failure.



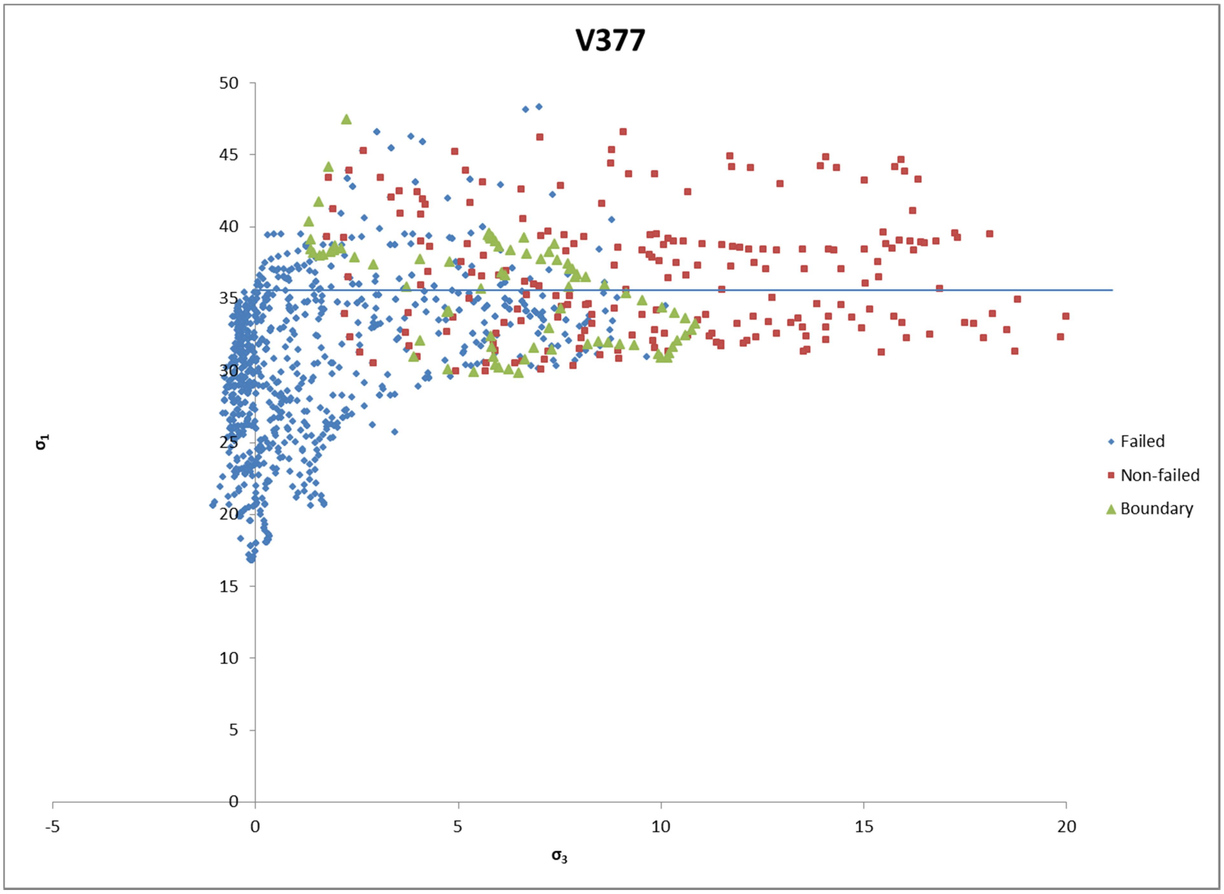
The stress plot appears as follows.



The objective is to find a failure criterion line that neatly divides the failed (blue diamonds) and non-failed (red squares) stresses, and also is centred on the points at the indicated depth of failure (green triangles).

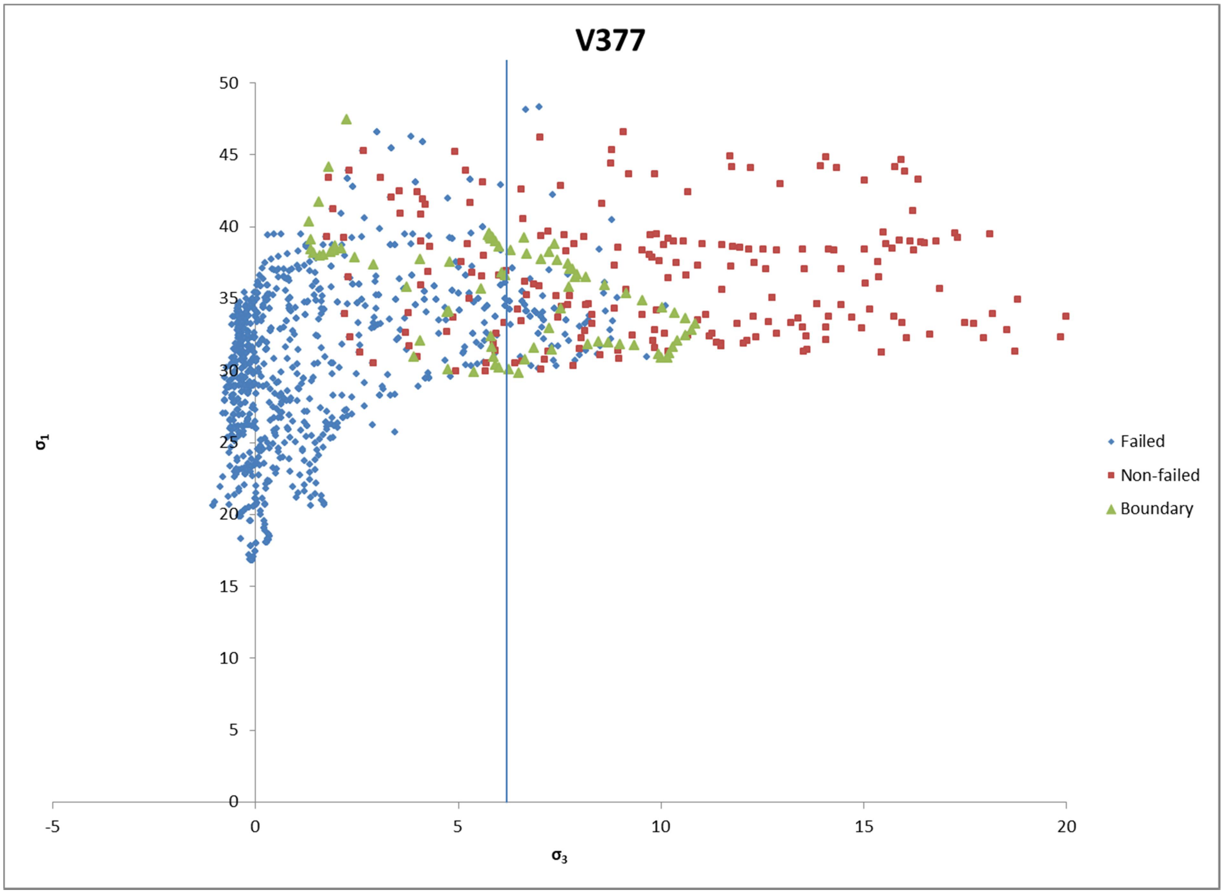
1) σ_1 = constant

First let's try σ_1 = constant as a failure criterion. At first glance it would appear that σ_1 = 35.5 MPa (the average value of σ_1 for the green triangles) would provide an over-break prediction, although a poor one. However more careful observation shows that this cannot be correct since $\sigma_1 < 35$ represents the zone nearest the excavation (i.e. the non-failed zone). Whereas $\sigma_1 > 35$ represents the zone farther from the excavation (i.e. the failed zone). This is completely backwards.



2) σ_3 = constant

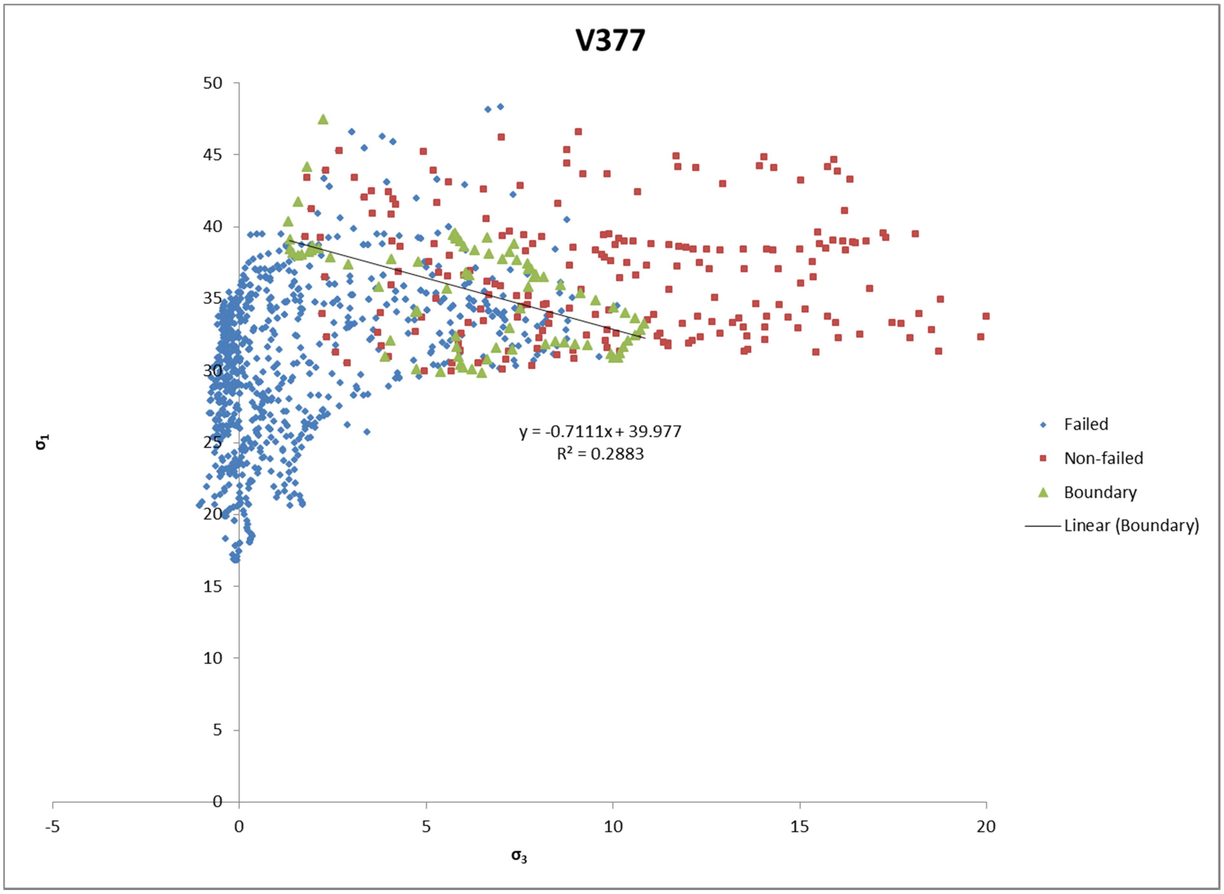
Some user's have suggesting using σ_3 = constant as a failure criterion. At first glance it would appear that σ_3 = 6.3 MPa (the average value of σ_3 for the green triangles) would provide an over-break prediction. The stresses in the failed zone lie predominately at values $\sigma_3 < 6.3$ MPa, and a large number of the non-failed stresses lie at values $\sigma_3 > 6.3$ MPa, which is an improvement. However, I am not aware of any kind of failure mechanism to support such a choice. I think this criterion appears to work simply because by definition, σ_3 does have smaller values near excavation surfaces simply because $\sigma_3 = 0$ at the excavation surface.



3) $\sigma_1 = UCS + q \times \sigma_3$

Now let's try $\sigma_1 = UCS + q \times \sigma_3$ where *UCS* and *q* represent respectively the intercept and slope of the failure criterion on a σ_1 versus σ_3 plot.

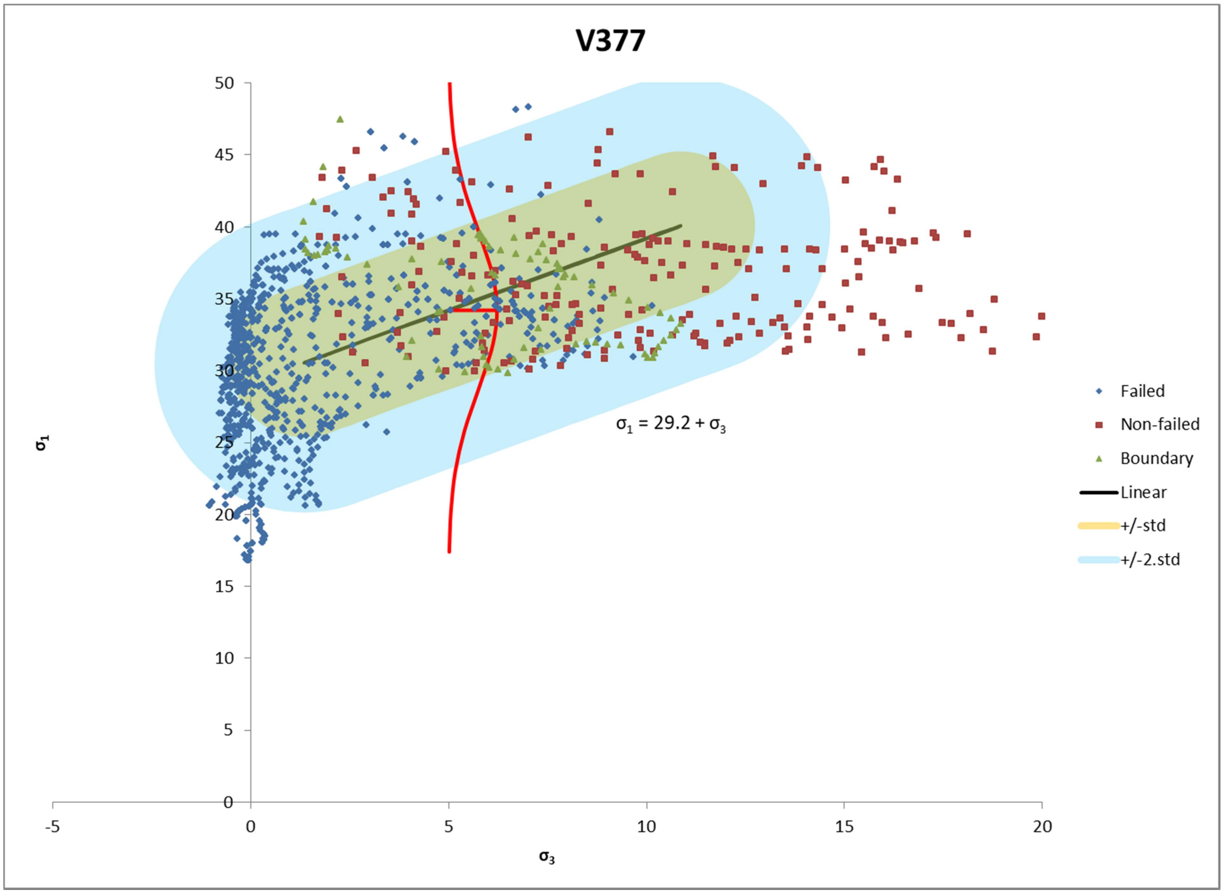
The best choice for such a line is one that intercepts the σ_1-axis at around *UCS* = 40 MPa and has a slope *q* = -0.71 as shown below (the best fit line though the green triangles). In spite of this being a best-fit line, the green triangles are not well biased towards correlation with an R^2 value of only 0.29 In addition, this is not an allowable choice since negative slope values are not permitted, and in fact the slope must be at least +1 or larger. This is because the slope *q* can be related to friction angle as $q = \{1 + sin(\varphi)\}/\{1 - sin(\varphi)\}$ where φ represents the friction angle. Values of $q < +1$ would imply negative friction, clearly impossible.



Let's now find the best fit straight line for the case where $q = 1$ (i.e. $\varphi = 0$). This line will pass through the mean value of σ_1 and σ_3 for the green triangles. These are calculated respectively as 35.50 MPa and 6.30 MPa. The intercept, *UCS*, for this line can be calculated from $35.5 = UCS + q\ 6.3$ with $q = 1$ and gives *UCS* = 29.2 MPa.

The scatter around the best fit line with the $q = 1$, can be determined as the standard deviation calculated using the σ_1 difference between the line and the boundary points (the green triangles) as ±5.6 MPa.

It can be observed that this line does not in any way divide the failed points (blue diamonds) from the non-failed points (red squares). The poor representation of the observed data with this choice is reflected in the wide zones of uncertainty, and the very broad normal distribution (shown in red).

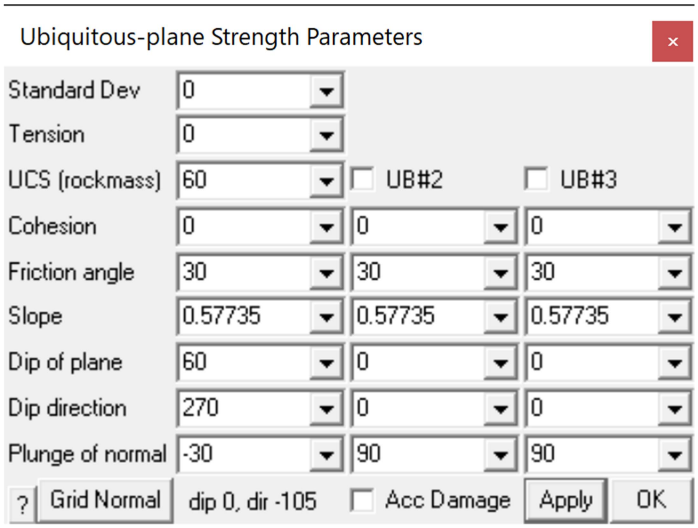


It is apparent that there is no sensible σ_1 versus σ_3 relationship that can define a failure criterion here. Certainly there is no Hoek-Brown shape would work here either.

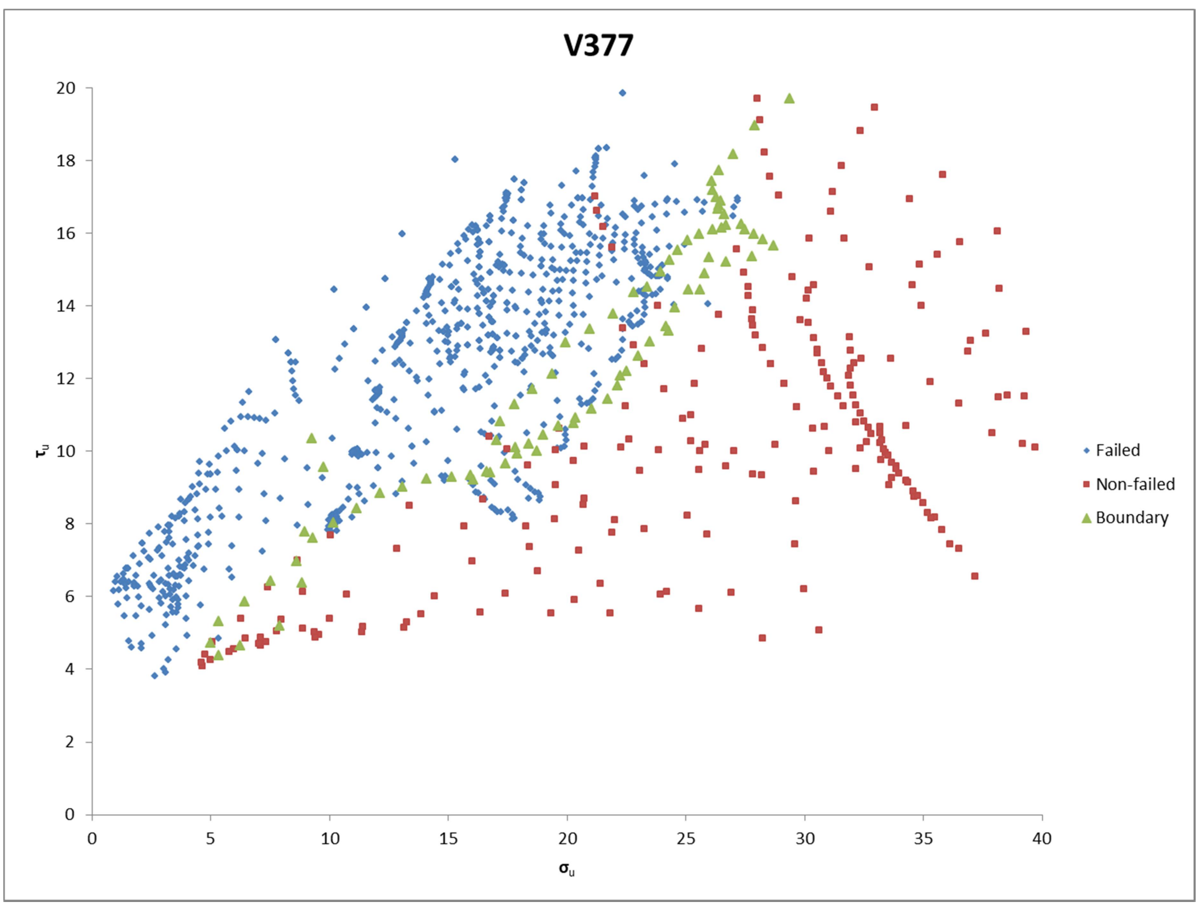
Structurally controlled - oriented failure criterion

It does not appear that there is any realistic σ_1 versus σ_3 rock mass type failure criterion that is able to predict the over-break. This suggests that failure of the rock mass is not the failure mechanism. In this case, there is a bedding plane that dips at 60° with a dip direction of 270°. Let's try $\tau_{ub} = Coh + tan(\varphi) \times \sigma_{ub}$ where τ_{ub} and σ_{ub} represent respectively the shear and normal stresses acting at the orientation of the bedding plane. *Coh* and *tan*(*φ)* represents respectively the intercept and slope of the failure criterion on a τ_{ub} versus σ_{ub} plot.

Let's present the stresses in a useful format. First we need to set the bedding plane orientation using "Plot > Strength Factors > UB_{mod}".

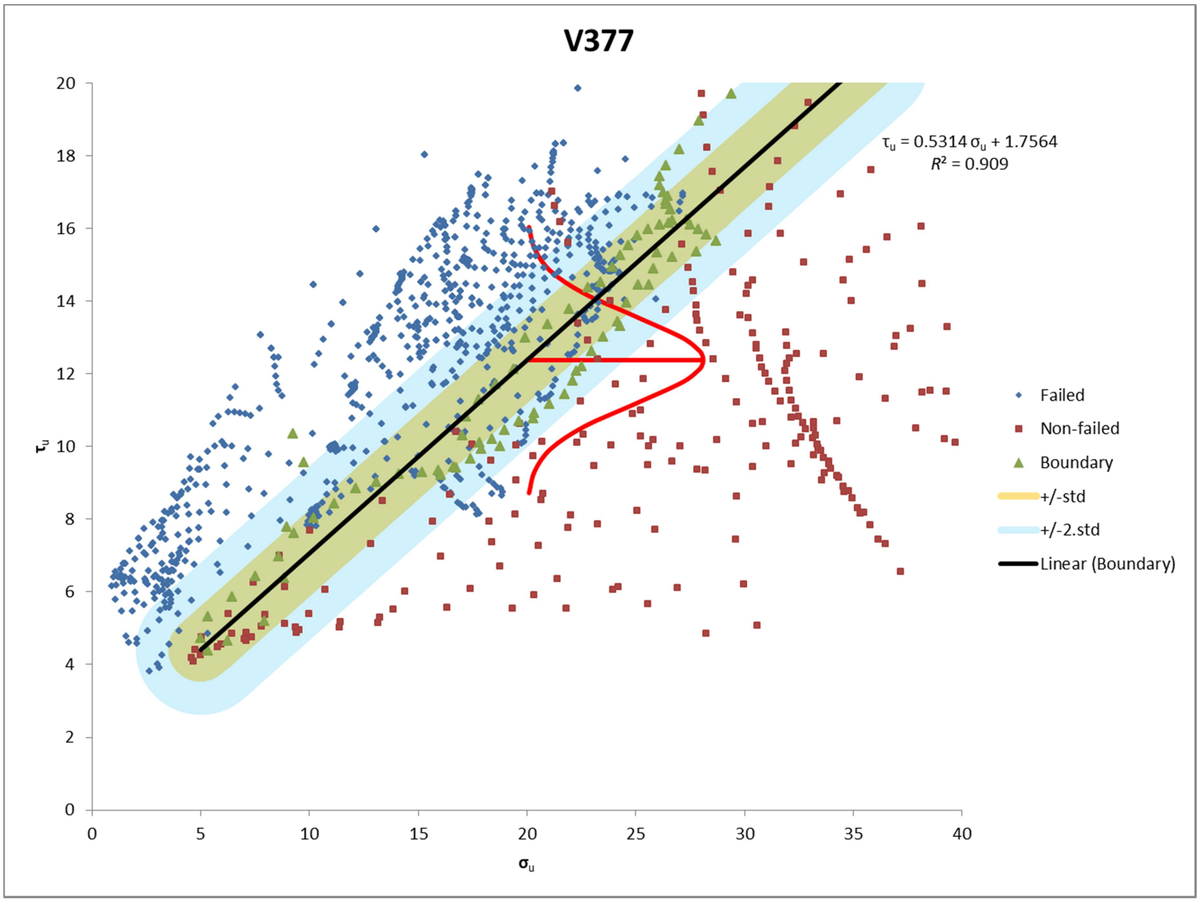


Using Excel as above, I now collect stresses for points inside and outside the over-break zone, as well as along the indicated depth of failure. In this case I will use “su tu” as the arguments for the “Map3D > Plot > Excel” function. Here “su tu” represent respectively σ_{ub} and τ_{ub} such that σ_{ub} will be the x-axis (abscissa) and τ_{ub} will be the y-axis (ordinate). The stress plot appears as follows.



4) $\tau_{ub} = Coh + tan(\varphi) \times \sigma_{ub}$

As before, the objective is to find a failure criterion line that neatly divides the failed (blue diamonds) and non-failed (red squares) stresses, and also is centred on the points at the indicated depth of failure (green triangles). The best choice for such a line is one that intercepts the τ_{ub}-axis at around *Coh* = 1.76 MPa and has a slope *tan*(φ) = 0.531 ($\varphi = 28°$) as shown below (the best fit line though the green triangles).



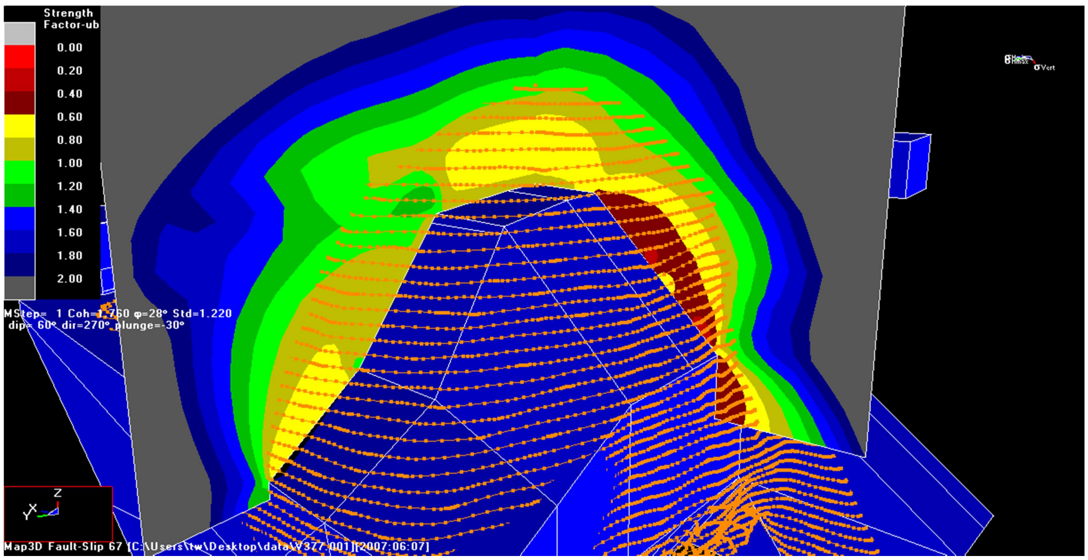
The stresses in the failed zone lie predominately at values $\tau_{ub} > Coh + tan(\varphi) \times \sigma_{ub}$, and stresses in the non-failed zone lie predominately at values $\tau_{ub} < Coh + tan(\varphi) \times \sigma_{ub}$. The stresses along the boundary between the failed and non-failed zones (green triangles) are obviously well correlated with an R^2 value of 0.91

The scatter around the best fit line can be determined as standard deviation using Excel STEYX function, and found to be equal to ±1.22 MPa. The normal distribution is shown in red. Now, dividing this by the average value of τ_{ub} (the average of τ_{ub} values for the green triangles), the coefficient of variation can be determined as ±9.8%, a very good fit.

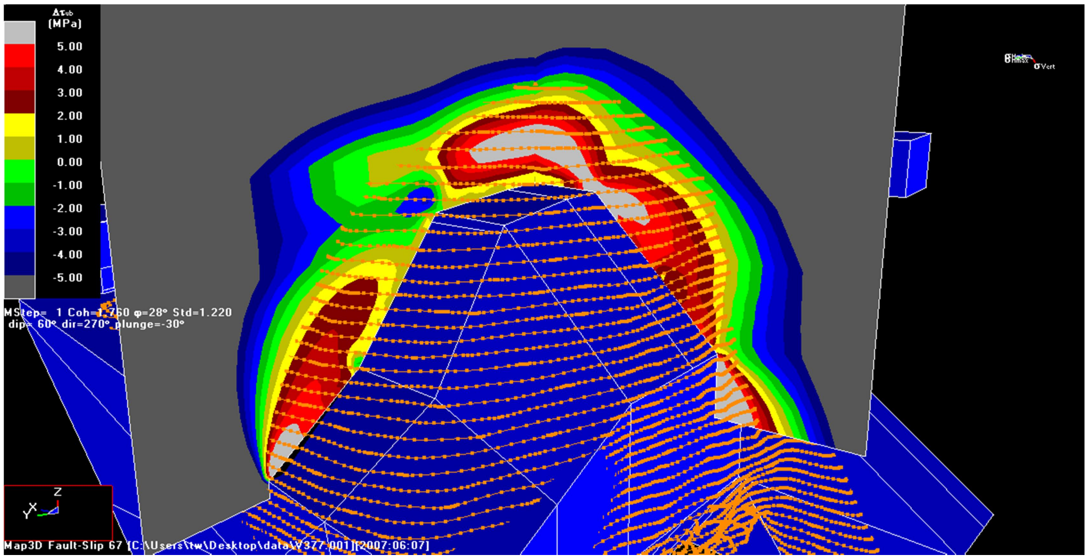
It can be observed that most of the failed points (blue diamonds) fall above this line, and most of the non-failed points (red squares) fall below this line, which is good. The high quality representation of the observed data with this choice is reflected in the narrow zones of uncertainty.

This suggests that the bedding plane represents a structurally oriented weakness resulting in the observed over-break. This provides further confirmation that this is not a σ_1 versus σ_3 rock mass type failure.

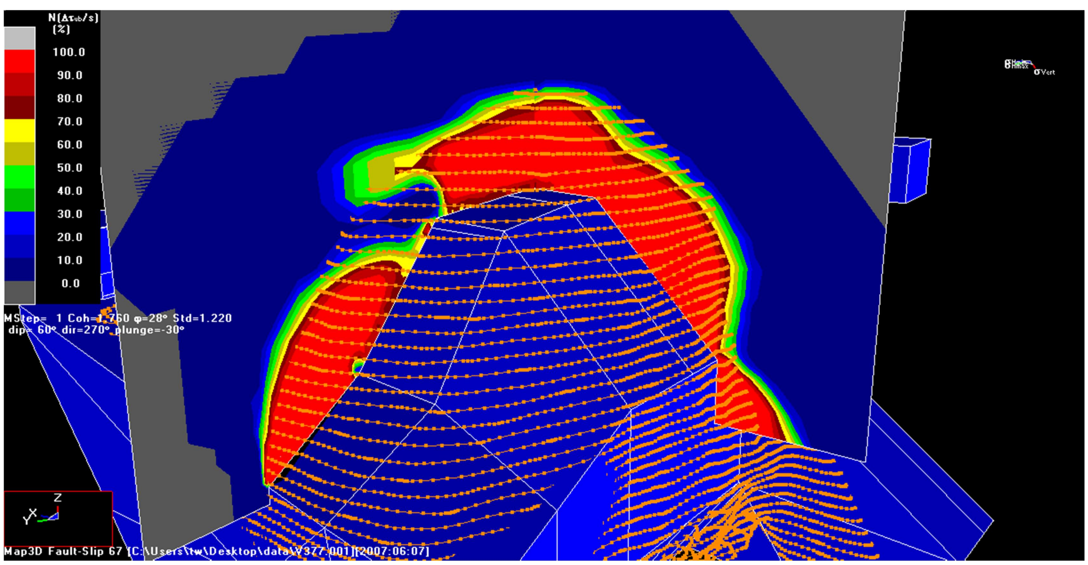
This failure criterion can now be presented in Map3D by substituting the values for the best fit line (*Coh* = 1.76 MPa and *tan*(φ) = 0.531). Below this is presented as strength factor defined as $\{Coh + \tan(\varphi) \times \sigma_{ub}\} / \tau_{ub}$ In this case the predicted failed zone is shown in yellow and red.



This can also be presented as excess stress defined as $\Delta\tau_{ub} = \tau_{ub} - \{Coh + \tan(\varphi) \times \sigma_{ub}\}$. Again, the predicted failed zone is shown in yellow and red.



Finally, the uncertainty in this prediction can be presented as probability of failure defined as $N(\Delta\tau_{ub} / std)$ where the function *N* represents the normal distribution and the symbol *std* represents the standard deviation for the scatter around the best fit line found as ±1.22 MPa above. Here, the zone of uncertainty is shown as the variation between dark blue and bright red. This zone represents the scatter of the stresses around the best fit line (green triangles in the τ_{ub} versus σ_{ub} plot above).



While further verification of this criterion should be undertaken for additional stopes, it would appear that a useful predictor has been found.