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Building useful geotechnical models

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Abstract

The success of any geotechnical design is dependent on the geotechnical model used in the design assessments. No matter the methodology adopted, the budget allocated, or the expertise assembled for the design analyses, an unsuitable geotechnical model will result in a sub-optimal outcome or misleading results. The nature of any geotechnical model must be dependent on the type, amount, and spatial distribution of the information available and the purpose for which the model is constructed. A geotechnical model for an open pit must allow for the generation of slope design parameters that are most appropriate for the geotechnical environment, taking into account the dominant mode/s of failure, the level of confidence in the data and acceptable levels of risk. It may require a significant amount of evaluation, interpretation, and judgement to develop a model that is fit-for-purpose, even for one that appears simple. It is better for it to be approximately 'right' than precisely 'wrong'!

This paper discusses the conception and development of appropriate geotechnical models for slope design. It considers the types of information available, the level of study, the shape of the excavation, controlling failure mechanisms, and uncertainties. It discusses how a model can be spatially defined and how the data can be best used to characterise each zone. The lithology, alteration, structural and hydrogeology models that contribute to the geotechnical model, and the likely slope failure mechanisms are important in selecting appropriate software or analysis methods that should be employed for slope design analyses. In this context, typical pitfalls in geotechnical models are examined.

Keywords: *geotechnical model, numerical model, characterisation, stability analysis, slope design*

1 Introduction

The success of any geotechnical open pit slope design is dependent on the geotechnical model developed for the design assessments. It is rare that site conditions and the intended mining are of such a nature that the mine design is not sensitive to the representation of the geotechnical conditions. The nature of the model is strongly dictated by the type, density, and spatial distribution of the information available, but must also be developed to facilitate the purpose for which the model is constructed. A geotechnical model for an open pit must allow for the generation of slope design parameters that are most appropriate for the geotechnical environment, taking into account the dominant mode/s of failure, the level of confidence in the data, and acceptable levels of risk. It may require a significant amount of evaluation, interpretation, and judgement to develop a model that is fit-for-purpose. In most cases, an unsuitable geotechnical model will result in a sub-optimal design outcome or a greater risk of instability than is intended.

2 Nature of a model

What is a geotechnical model? In simple terms, a geotechnical model can be defined as the delineation of regions of the ground (rock or soil mass) in which geotechnical conditions are expected to be broadly similar from a performance perspective, with the identification of parameters that suitably describe the conditions within each delineated area.

Domains are typically defined by a combination of the factors below, depending on what is most important at the site:

- Geology (rock type and/or alteration).

- Weathering.
- Intact rock strength.
- Frequency and/or condition of fractures.
- Overall rock mass quality (as defined by rock mass classification systems, incorporating intact strength and density and condition of fractures).
- Nature and orientation of structural fabric.
- Pit sectors, based on pit wall orientation.
- Likely slope failure modes (common modes are illustrated in Figure 1).

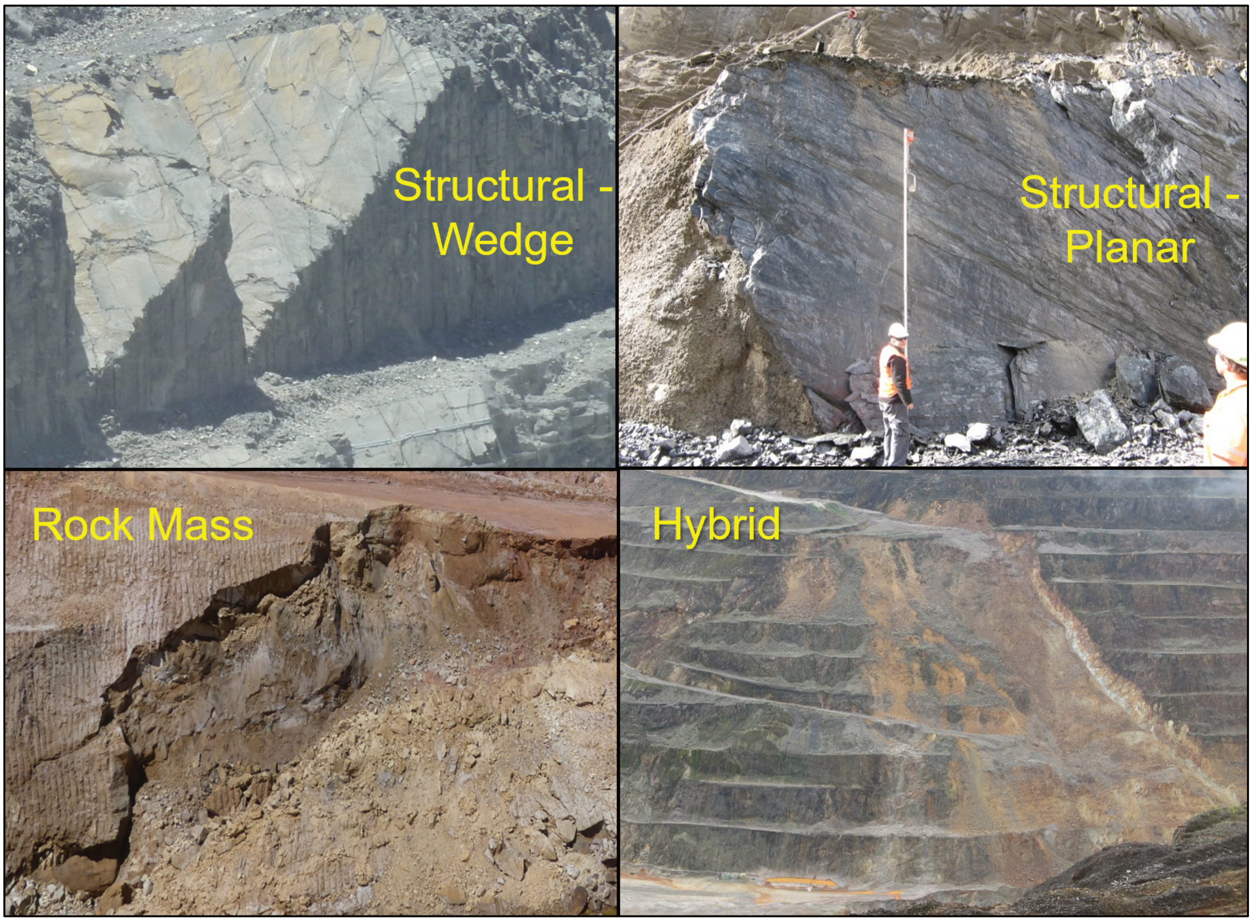


Figure 1 Examples of some of the common slope failure modes (toppling failure not shown)

The geotechnical model should consist of:

- A means of delineating the boundaries of the domains/sectors: these could include 3D surfaces or solids (wireframes) or 3D blocks (as in a block model).
- Key parameters for each domain/sector/cell that are required to fulfil the purpose of the models. These may include raw data values/descriptions and calculated/interpreted values or classifications.
- A means of identifying the spatial variation within the domains, by means of:
  - Statistical distributions identified for each domain.
  - Explicit inputs generated in a probabilistic manner (using the statistics).

    - Automated extrapolation of values from spatial investigation data into a grid (as for a block model).

  If variations within a domain are very large or can practically be sub-delineated, then it would be more appropriate to re-define the domains.

- A means of representing the structure within the domains or pit sectors, where necessary.

3 Purpose of a model

The first step in constructing a geotechnical model is identifying clearly who will use it and the purpose for which it is intended. Some geotechnical models need to be complex and multi-faceted. Others need to be very simple and easy to understand at a glance.

A geotechnical model could be one or all of the following:

- An appropriate tool to use in evaluations/stability analyses for optimisation of mine design:
    - Kinematic.
    - Numerical.
    - Empirical.

  The model will need to be developed in order to be suitable for use in the analysis methodology/software that will be used, so this should at least be considered at the outset.

- A basis for identifying the likelihood of different slope failure mechanisms around a pit.
- A basis for a hydro-geotechnical model (a model of pore pressure distributions in the near-pit environment, to be used as input for stability analyses).
- A basis for drill and blast assessment and design.
- A basis for hazard and risk identification.
- A basis for operation slope management and monitoring programs.

A geotechnical model should seldom attempt to be a precise representation of reality. The idea that a model, no matter how detailed and high quality the data, is a precise representation of reality will result in over confidence in the outcomes of the design analyses and an underestimation of risk. Were a precise representation of reality even possible, it is very likely to be counterproductive to try to incorporate it into design analyses, unless at a very small scale. Models that are overly complex are likely to be difficult to incorporate into numerical analysis models, very time consuming to run, require very large amounts of processing power, and have a high risk of experiencing difficulties whilst running. This can be particularly problematic where multiple sensitivity analyses are necessary.

Paradoxically, in some cases a geotechnical model should not attempt to be even a precise representation of the data. The reliability/certainty of data can be misleading; and the design process may need to recognise and account for 'known unknowns', imperfect classification and characterisation systems, and imperfect shear strength models. The models will need to be developed to still be effective within these limitations.

4 Types of models

The type of model to be developed depends on its purpose. Common types of geotechnical models are geotechnical domain models and geotechnical block models. Geotechnical domain models are often subsequently used as the basis for geotechnical stability analysis (numerical) models.

4.1 Geotechnical domain models

If the requirement is to delineate geotechnical domains for inclusion in 2D stability analyses, then a model could consist of a typical or indicative cross-section for each domain. More commonly these days, the model would be 3D, with domains defined by wireframe surfaces or solids. 3D models allow for several somewhat different sections to be cut through any given domain; and could be incorporated directly into a 3D stability analysis numerical model. Typical sets of representative rock mass and/or structural properties would be identified for each domain/zone, with definition of variability for carrying out sensitivity deterministic analyses or statistics for carrying out probabilistic analyses. An example of a geotechnical domain model is shown in Figure 2.

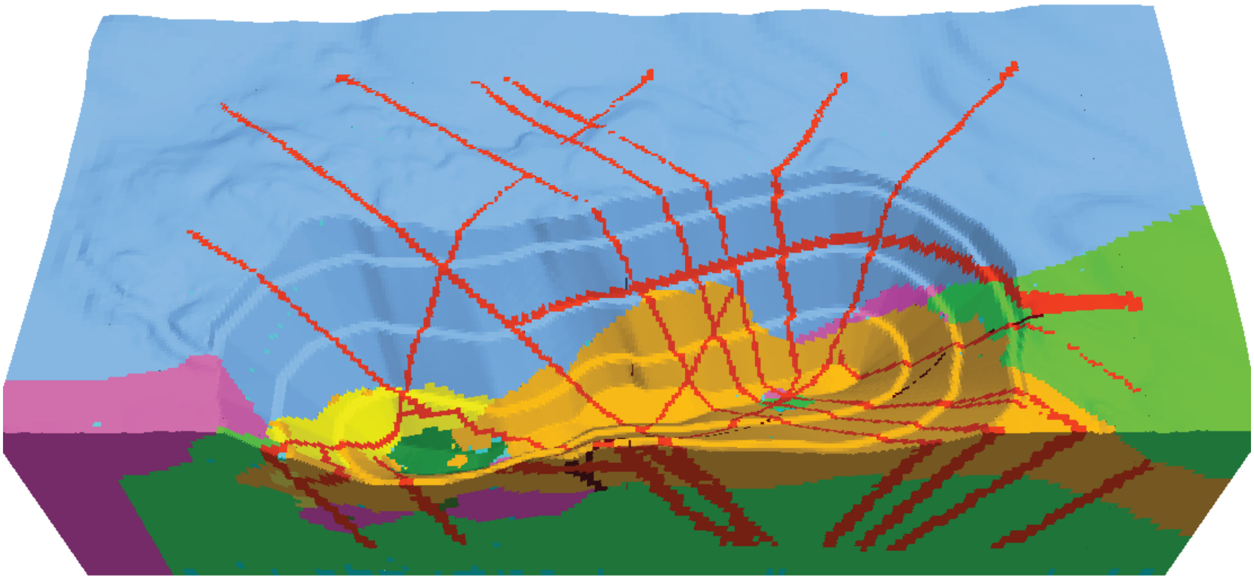


Figure 2 Cutaway isometric view of a geotechnical domain model for an open pit, showing domains based on rock types and geotechnical conditions, and including major structures (red)

4.2 Geotechnical block models

Block models are a very different type of model in which raw data or calculated/interpreted values are defined for each 3D cell (block) of regular shape (square or rectangular). Each cell is usually much smaller than an individual domain and the intent is less to interpret larger domains of broadly similar conditions and more to let the data 'speak for itself' in each small cell (typically between 5 and 30 m in dimension). The assignment of values for each parameter within each cell is usually automated by the mining software package used. The data can be assigned to the cell volumes or can be produced as a point cloud with the points defining the centroids of the cells.

The data sources used as input are typically drillhole logs, mapping traverses or point data from mapping or testing, and values are usually assigned to individual cells using nearest neighbour, inverse distance, or kriging methods. The extrapolation/interpolation of data is often guided by geology model shapes (rock type, weathering, alteration, large structures). An examples of a geotechnical block model is shown in Figure 3.

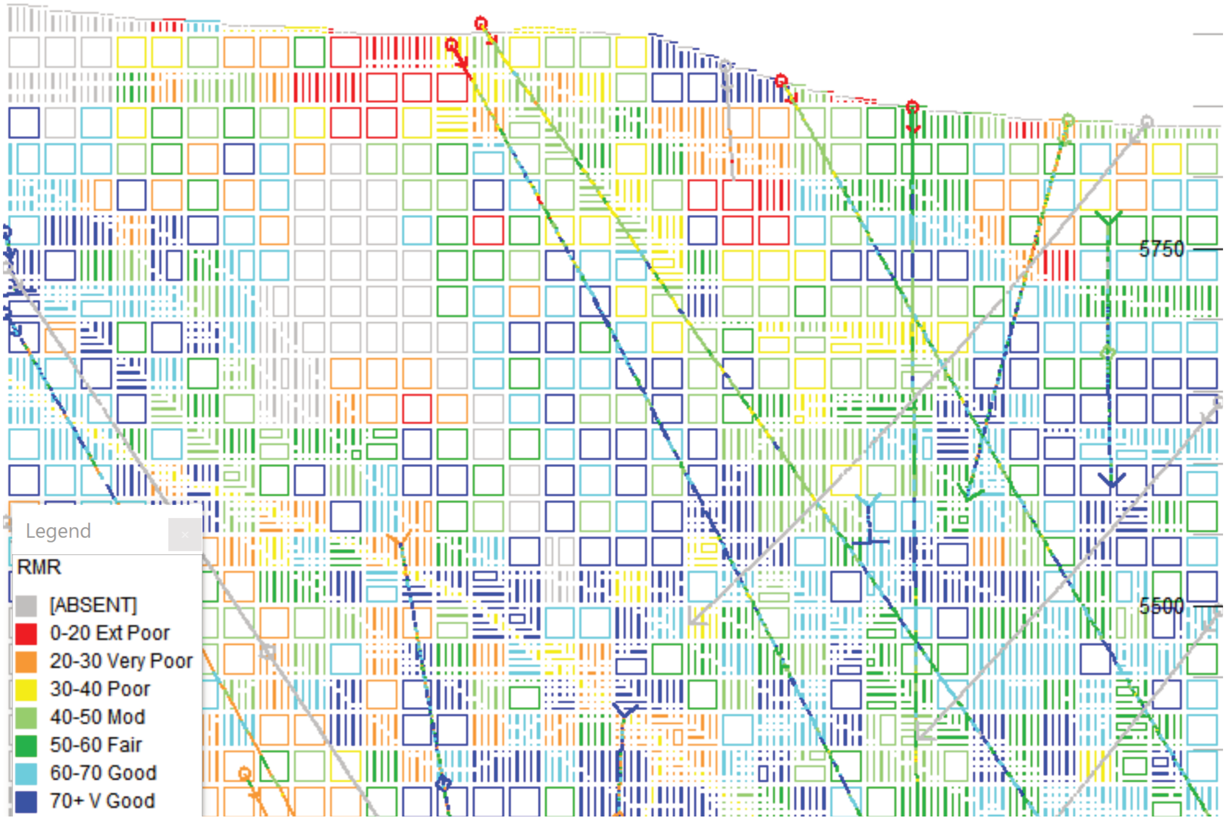


Figure 3 Section through a 3D geotechnical block model (25 m cells, 5 m sub-cells), showing drillhole data

For block models to be possible and valuable, the density of available data needs to be relatively high. If it is not sufficiently dense, over-extrapolation will result in cell values of low confidence and there will be large areas in the model with cells that have no values assigned otherwise.

Block models are very seldom incorporated directly into numerical stability analyses models, though it is becoming possible for point clouds to be imported into numerical models to generate fields of spatial variability. Rather, they are typically used for visualisation of geotechnical conditions and their variability: for risk assessment, for design, and for planning during ongoing operations. However, the patterns indicated by block models can help to interpret domain models where these are necessary.

5 2D models versus 3D models

Generally, geotechnical models are constructed for the entire mining environment of a project, be it a proposed (greenfields) project, an operating mine, or a proposed significant extension to an existing mine. It is therefore usually necessary to generate 3D models that include the rock mass volumes under consideration. It is possible (in fact likely) that due to variability in data density/type across the rock mass volume, different zones of the model will be of different resolution and/or confidence, and that this will change with time as the models are progressively developed. These 3D models can be directly imported into numerical models or simply used for characterisation of the rock mass for empirically based mine design and mine planning.

In order to perform 2D design stability analyses or to address localised issues (such as the risk to in-pit infrastructure or the mitigation of localised instability), 2D slices through the 3D model may be taken. These will initially be at the level of detail that is available in the greater 3D model, however, a 2D section (effectively a 2D model), is far simpler and easier to modify in order to:

- Include additional detail that is difficult or impractical to include in a 3D model, such as overprinted geology (alteration of localised shear fabric).

- Incorporate specific data/detail along a section line (such as a mapping traverse or a 'fence' of drillholes) that is very difficult to meaningfully extrapolate in 3D.
- Make modifications to geology/structure boundaries, groundwater level (phreatic surface) or excavation profiles in order to perform sensitivity analyses quickly and efficiently.

Localised 2D models can therefore be very useful. As an extension of the 2D model concept, quasi-3D models can be created (sometimes referred to as 2.5D models). Such models are actually 3D, but the inherent model detail does not vary in the third dimension; for example, a section is extrapolated ('extruded' in the third dimension) to form a 3D shape. Such models are not true 3D models in the sense that they do not present true variability in all dimensions, and they are often of limited extent in the third (extrapolated) dimension. However, they may be very useful because:

- They are relatively quick and simple to generate, resulting in models that are less complex and therefore quicker to run.
- They extend model boundaries away from the 2D section under focus, thus allowing for some degree of 3D influence to be incorporated into the relatively narrow area of focus around the original section. Examples of this are the 3D stress/strain environment (i.e. including the effects of stress/strain development in the extrapolated dimension) or the porewater pressure environment (i.e. including lateral flow or recharge).
- They allow for a generic or indicative 3D assessment to be made in limited zones that are considered to be reasonably homogeneous. An example of this would be seepage analyses for assessing lateral drainhole spacing within a geotechnical domain or slope sector.

6 Building the model

The development of geotechnical domain models usually requires significant engineering geological judgement. It is very advantageous for the principal developer of the geotechnical model to have closely observed the site conditions, to have mapped at the site or logged drillcore, or to have at least closely observed the core, in order to effectively visualise and judge:

- The nature of the rock and the variability in conditions.
- Whether the data collected provides a suitable representation of the site conditions.
- Whether the intended rock classification indices or strength calculations will suitably represent reality.
- What adjustments may need to be made to account for rock masses that are marginal for the classification method, are anisotropic or are highly variable.

Working only with the raw investigation data often hampers this judgement.

6.1 Inclusion of geology

An understanding of the nature and distribution of the geological units present at the site, and the geological processes that have resulted in the current site geology, are very important. This understanding will help to identify what level of detail and complexity it is possible and necessary to incorporate, and to evaluate how it best be represented in the 3D model, depending on the purpose of the model.

Geology is usually included in a geotechnical domain model using the available 3D lithological (rock type) models in the form of enclosed shapes or surfaces. Weathering horizons (usually defined as surfaces) will crosscut the upper parts of some or all lithologies, resulting in additional domains. The effects of overprinting alteration halos may necessitate further sub-domaining. In some cases, geotechnical properties (and thus domaining) may not be heavily dependent on lithology. However, it is more common that lithologies will form a strong basis for domaining and may need to be sub-domained due to internal variation in geotechnical properties.

Understanding the geological history is helpful in conceptualising the rock mass variability and how the rock mass behaviour might develop over time. It is useful for the model developer to have at least a basic understanding of the common models of formation and the geology/alteration/structure related to typical deposit types of various commodities. Discussion with the project geologists is usually very beneficial in this regard.

Engineering geological judgement is usually less important in the development of geotechnical block models, which are based more on automated processes. However, the selection of the geological shapes that will be used in guiding/constraining the block model development is important, as are the considerations for rock mass properties that are to be calculated from the raw data.

6.2 Key geotechnical properties of the rock mass

The geotechnical properties that need to be included in a model are very much dependent on the purpose/s of the model. It is not useful to try and exhaustively define all of these, however, key properties commonly include:

- Descriptive inputs (alphanumeric):
  - Weathering grade.
  - Rock type.
  - Alteration type.
  - Type of structural zone (if applicable).
  - Discontinuity set roughness.
  - Discontinuity set infill.
- Measured/ assessed values:
  - Intact rock strength.
  - Intact rock density.
  - Young’s modulus.
  - Poisson’s ratio.
  - Rock quality designation.
  - Number of discontinuity sets.
  - Discontinuity frequency or spacing.
  - Orientation of discontinuity sets (dip and dip direction).
  - Rating values for individual components of rock mass classification schemes.
- Calculated values:
  - Rock mass classification indices (examples rock mass rating, Q, Q’, GSI).
  - Key parameter values.
  - Rock mass shear strength inputs.
  - Rock mass modulus.

6.3 Inclusion of structure

Structure can be included in one or all of the following ways, depending on what is required to assess the expected failure modes:

- Explicitly-defined planes, that have been generated by:
  - An attempt at precise delineation. Major structures such as faults or shears are usually defined this way, independent of domain boundaries or forming domain boundaries. Major structures may be represented a planes or zones, whilst other rock mass fabric is usually represented as planes.
  - Probabilistic representation of statistically characterised discontinuity sets (Figure 4).

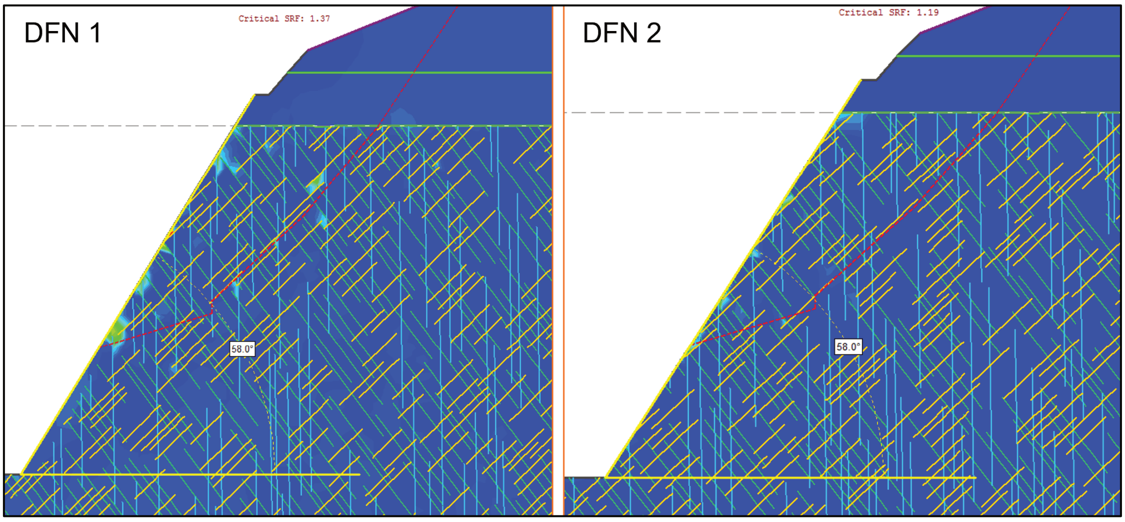


Figure 4 2D analysis sections showing two different probabilistic discrete fracture networks (DFN) generated from statistically characterised discontinuity sets

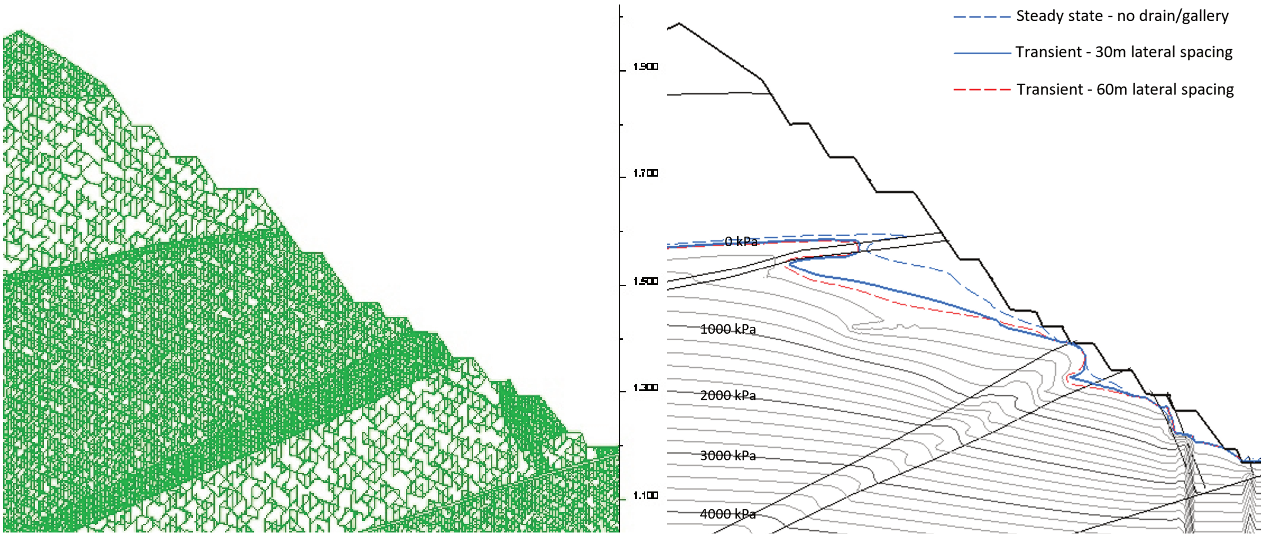
- Ubiquitous fabric.
- Rock mass strength anisotropy function.
- Characterisation of domains/sectors by means of stereographic representation and characterisation of individual structural sets, allowing for kinematic stability analyses to be carried out but with no explicit inclusion of structure in numerical analysis models.

6.4 Inclusion of groundwater

Groundwater is not usually included in a geotechnical domain model; a separate conceptual hydrogeological model is commonly developed. However, inclusion of groundwater in geotechnical slope stability analyses is often necessary. The distribution of porewater pressure within a pit slope can have a strong controlling factor on stability and it is therefore always necessary to:

- Use the conceptual hydrogeological model to assess/predict the likely groundwater regime within the pit slopes at various stages of excavation.
- Assess if/at what point in time groundwater is likely to be a factor in stability (depending on the nature of the soil or rock mass in which excavation is occurring).
- Develop appropriate hydrogeological inputs for the stability analysis models:
  - 2D or 3D representations of the phreatic surface, below which porewater pressures are expected to be hydrostatic.
  - 2D or 3D porewater pressure distributions.

The compatibility of the geotechnical and hydrogeological models is important so that porewater pressures obtained from seepage modelling can be accurately inputted into geotechnical stability analysis models. For this to be possible, the same base geological/geotechnical domain model used in the geotechnical stability model must be used in the seepage analysis model. Failure to do so may result in zones of pore pressure that are not representative of the geotechnical domains, particularly in complex models and/or models where groundwater is compartmentalised. An example of compatible geotechnical and hydrogeological models is shown in Figure 5.



(a) (b)

Figure 5 Sections through compatible models: (a) Geotechnical model with domains showing rock mass fabric; (b) Corresponding hydrogeological model showing porewater pressure contours

Depressurisation of pit walls can be very important for achieving a target pit slope design or for allowing slopes to be steepened. The key variables in achieving slope design acceptance criteria, in terms of calculated Factor of Safety, probability of failure or maximum allowable strain, are the slope angles and porewater pressures within the pit walls. If predicted slope stability is below the acceptance criterion, the focus can be on implementation of depressurisation measures, reduction in slope angles, or a combination of both measures, depending on what is possible, practical, or most cost-effective for the project. The design process will often need to be iterative for an optimal solution to be identified.

The evaluation of depressurisation requirements necessary to maintain stability of slopes can be carried out using 2D and/or 3D seepage analyses conducted to identify the drainage measures necessary to achieve this depressurisation during the various stages of cutback development. It is not only the magnitude and distribution of depressurisation that is important; the timing of depressurisation is often critical for each stage of pit excavation. Significant failures of interim, stage or final pit walls can occur if timely depressurisation is not achieved.

6.5 Data variability

Capturing the variability of geotechnical conditions or of individual key parameters within a geotechnical model is important. Where a high degree of variability exists across the mining area, delineation of domains can be difficult. An attempt must be made to identify general/broad patterns, even if these are relatively weak. Where patterns are weak, each domain will likely have high variability, with significant overlap of data distributions when comparing domains. The domain delineation will still be useful, and a geotechnical block model (if available) can be very useful to assist in the identification of domains for the domain model.

Where patterns of variability allow, the domains must be refined as much as possible to create the least degree of variability within each domain. If in fact the spatial variability can be lessened by sub-domaining, then this should be done. It is not just the variability in the 'magnitude' of the data that is important, but also the 'spatial' variability of the data. It can be argued that probabilistic analysis is most beneficial when it takes this spatial variability into account. It is common to perform thousands of analyses with various probabilistically generated combinations of values for various parameters, however, this assumes that each parameter has only a single value in that domain during each analysis. This is never actually the case; only slope design parameters (such as batter face angle or berm width, for instance) actually vary in this 'only one value or another' manner. In reality, the variability is spatial and therefore, probabilistic generation of the spatial variability should ideally be taken into account. The stability of a slope is controlled by the total shear resistance along the critical failure surface/s, rather than the shear resistance at any one individual location (such as a point of data). Therefore, for probabilistic slope analysis, it is appropriate to determine the variance of the rock mass strength over the entire potential zone of failure (Cylwik et al. 2018). This will require selection of methodology/software that can effect this. This methodology has been seen in many studies to significantly reduce the range of failure probabilities, by eliminating the tails of the range (i.e. where values are all 'very good' or 'very poor').

7 Progressive model development

The limitations of the available geological model and geotechnical data define the geotechnical model at various levels of study. It is not within the scope of this paper to define and discuss study levels in detail; this has been done in numerous other publications. However, the following paragraphs present a general overview of the likely status at various study levels.

For scoping and conceptual level studies, the rock type and weathering zone boundaries, and pit slope sectorisation based on wall orientation, may be the only means of delineating domains. Data may be basic, and significant inference, extrapolation and engineering geological judgement is usually required to identify suitable representative geotechnical input properties. The type of data available is usually limited, and data is seldom dense enough that statistically valid properties can be determined. Limited sensitivity analyses are likely to be required for design.

At pre-feasibility level, it is necessary to collect dedicated geotechnical data (i.e. by means of detailed geotechnical logging and/or mapping) with calculation of key rock mass classification indices and shear strength parameters. Whilst the type of data available is likely to be more geotechnically-focused, the density of data is unlikely to be optimal, with significant spatial gaps and uncertainties in variability. The data is likely to allow for some domaining based purely on the geotechnical data (i.e. sub-domaining of the geology model). The development of statistical parameters for sensitivity analyses is important.

At feasibility level, both the types and density of data should be optimal. Key gaps and uncertainties should have been identified from the pre-feasibility study and addressed in the feasibility study. Domaining should be refined as much as possible, with the most detailed and complex sub-domaining possible. The data should be of sufficient density and quality that probability of failure analyses can be conducted if necessary.

8 Application in stability modelling

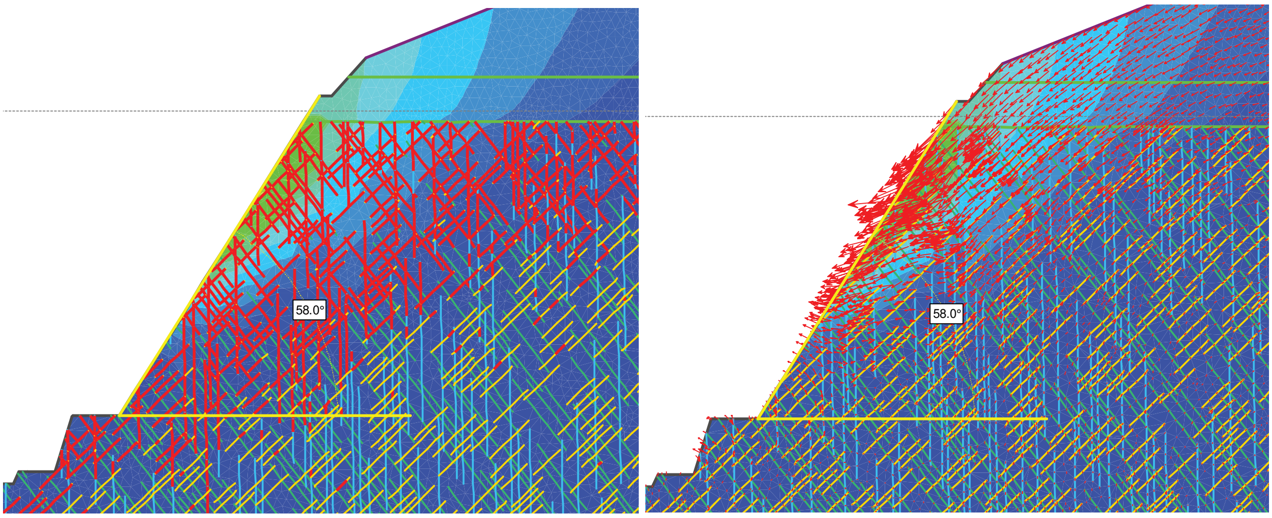
A geotechnical domain model should always be as detailed as possible for the data available and the variability thereof, expressing the greatest degree of refinement practical. This will allow for the best application of the model. However, it may very well be beneficial or necessary to then simplify the model for the individual uses to which it is applied. For instance, it may be necessary to simplify a complex 3D domain model to allow it to be incorporated into a 3D numerical stability analysis model. Incorporating the model in its full complexity may result in a numerical model that is too time-consuming or difficult to construct, too time-consuming to run, or difficult on which to perform sensitivity, probability of failure or strength reduction analyses. It is better to have constructed a domain model for which the complexities are initially represented and understood and then simplify it to make it practical for a purpose, than to generate a simpler domain model that does not represent (and therefore explain) the key complexities and issues.

The level of detail, types of information available, and confidence levels in the information in a geotechnical model can be a controlling factor in the stability analysis method that can be most effectively utilised. It is very important that the numerical analysis method that will best represent the likely failure mechanism/s for the rock mass conditions in each domain is selected and utilised. Therefore, this needs to be considered fairly early in the data collection and model development process so that the right information to build the most appropriate model for the necessary analyses is identified and collected.

Pit slope design is controlled by the results of the numerical stability analyses and by the level of confidence in these results. It is therefore very important that the appropriate method and software is selected and utilised. Key considerations are:

- Uncertainty – is the uncertainty in the model due to stochastic variability (uncertainty due to random variation, which can be dealt with using probabilistic models) or the absence of information (which must be accounted for largely by experience/judgement)?
- Homogeneity of the rock/soil mass – can it be represented as a continuum?
- Anisotropy in a rock mass – is this consistent and can it be represented by a strength anisotropy function or by ubiquitous structural fabric within the model?
- Is structure likely to play a strong role in the failure mechanisms? For blocky rock masses with numerous strong joint sets structure may need to be explicitly represented in the model to:
  - Capture step-path or combination structure and rock mass failure (hybrid) mechanisms.
  - Assess the ongoing behaviour of the rock mass with time and under large strain, where gradual dilation can be an issue (large, complex toppling failures are an example of this). Can the structural fabric be probabilistically generated or can an explicit fabric be directly imported?

  Simple analysis methods or those without the inclusion of explicit structure would assume a pseudo-rotational rock mass failure mechanism through a continuum. Such analysis is likely to overestimate the stability of the slope as it would not be able to assess the potential for structure to affect the failure mechanism, particularly in near proximity to the slope face (Figure 6).

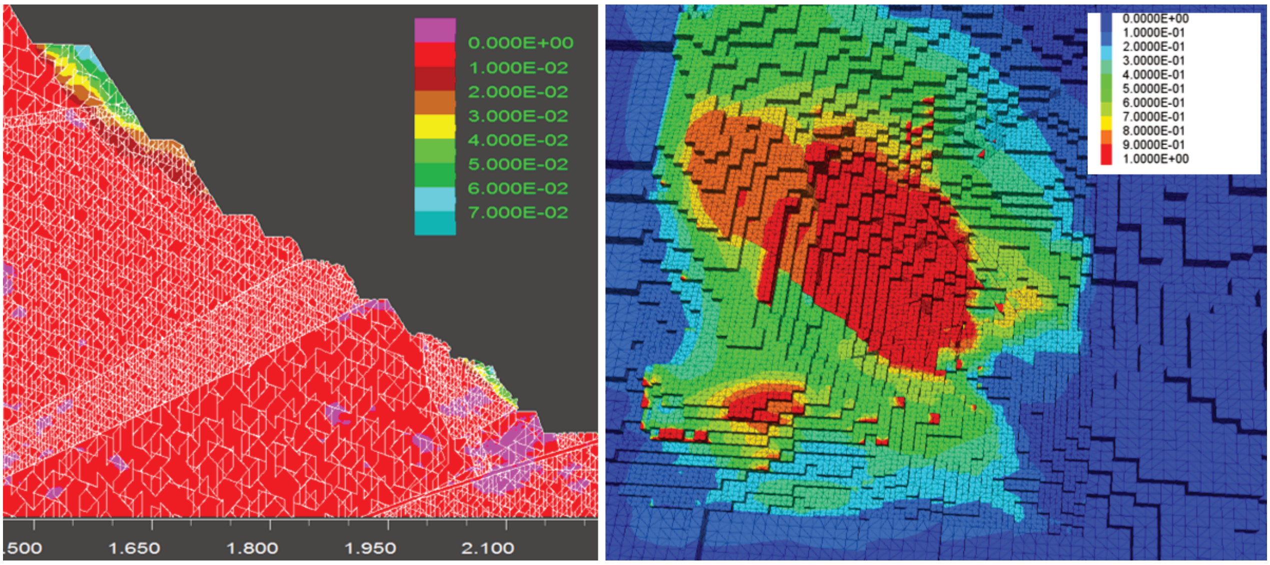


(a) (b)

Figure 6 2D finite element stability model sections showing the effects of rock structural fabric on slope stability: (a) Displacement magnitude; (b) Displacement vector

In order to limit the size of a numerical model, it may be necessary to represent structure at a far greater spacing than the actual spacing. Doing so will allow for the appropriate failure mechanism to still be predicted by the model, whilst the rock mass between the structures can still be represented by a rock mass shear strength model. If the spacing increase is relatively small (i.e. only two or three times the actual spacing), then some upward adjustment of the discontinuity spacing parameter/s in the rock mass shear strength model may need to be made to avoid 'double counting' the effect of structure in the model.

- Does large, time-dependent strain need to be analysed?
  - Can failure slowly develop over time that would not be predicted by some analysis methods?
  - Is there a practical limit to the amount of deformation that can be tolerated, even though outright failure may not have occurred?
- Should 2D or 3D analyses be conducted? This will depend on:
  - The level of study. Early studies will seldom support of require the rigour of 3D analyses.
  - Software availability, time, and budget – constraints may necessitate 2D analyses.
  - The geometry of the pit slopes, geology, and structure in the area of focus – in some cases 2D analyses may not be able to sufficiently replicate reality.
  - What will provide the most useful, reliable results? Although it might seem that 3D analyses would always be better than 2D analyses, this is not always the case. The nature of the geotechnical model and the type and detail of the information available may not adequately support 3D analyses. The interpretation of the results of 3D analyses is sometimes more difficult, and some mechanism types or smaller scale failures mechanisms may be masked by others. 2D analyses are more agile and can be more efficiently used to perform sensitivity analyses. This is illustrated in Figure 7.



(a) (b)

Figure 7 Distinct element stability models: (a) 2D model incorporating greater structural detail and more easily identifying small yet significant instability zones/mechanisms; (b) 3D model more accurately representing 3D instability over the large-scale in a curved pit wall

- What requirements might there need to be in a geotechnical model for it to be compatible with a hydrogeological seepage analysis model required to provide porewater pressure inputs for the stability analysis model?

Interpretation of the results of numerical analyses should be done with great care. This is a complex subject on its own and is not the focus of this paper. However, it must be emphasised that a 'sanity check' is important to make sure that the model has run correctly, has reproduced the expected failure mechanisms, or has predicted ones that are plausible. Applying these results in the understanding of key risks and the formulation of appropriate slope design requires judgement based on experience and understanding of the geotechnical conditions.

9 Conclusions

9.1 Key considerations for geotechnical models

A geotechnical model can be simply defined as the delineation of regions of the rock or soil mass in which geotechnical conditions are expected to be broadly similar from a performance perspective, with the identification of parameters that suitably describe the conditions within each delineated area. Key considerations for geotechnical models include the following:

- It should be clearly identified who will use the geotechnical model and the purpose for which it is intended.
- A geotechnical model is not a precise representation of reality. The model must be developed to still be fit-for-purpose within the limitations of unknowns, imperfect classification and characterisation systems, and imperfect shear strength models.
- It is usually necessary to generate 3D geotechnical domain models for the mining project environment, which can be directly used for 2D or 3D stability analysis models or simply used for characterisation of the rock mass for empirically based mine design and mine planning. 2D models can be very useful for the ease in which modifications to geology, structure, groundwater levels or excavation profiles can be made in order to perform sensitivity analyses quickly and efficiently. Quasi-3D models allow for indicative 3D assessment to be made in limited zones that are considered to be reasonably homogeneous in the third dimension.
- The development of geotechnical domain models usually requires significant engineering geological judgement. An understanding of the nature and distribution of the geological units present at the site, and the geological processes that have resulted in the site geology, are therefore important.
- Careful consideration should be given to the need for inclusion of structure in the geotechnical model and the manner in which it is represented in the stability analysis model, depending on what is required to assess the expected slope failure modes.
- Capturing the variability of parameters within a geotechnical model is important. Both the variability in magnitude and the spatial variability of the data should be considered.
- The compatibility of the geotechnical and hydrogeological models is important so that porewater pressures obtained from seepage modelling can be accurately inputted into geotechnical stability analysis models. For this to be possible, the same base geological/geotechnical domain model used in the geotechnical stability analysis model must be used in the seepage analysis model.
- The level of detail, types of information available and confidence levels in the information in a geotechnical model can be a controlling factor in the stability analysis method that can be most effectively used for slope design. It is very important that the numerical analysis method that will best represent the likely failure mechanism/s for the rock mass conditions in each domain is selected and utilised. This needs to be considered fairly early in the data collection and model development process.

9.2 Common problems and pitfalls

Some common problems to avoid in the development and use of geotechnical models are described as follows:

- If the principal developer of the geotechnical model has not had the opportunity to closely observe the site conditions, it is difficult for them to effectively visualise the nature of the rock and the variability in conditions. It may therefore be difficult for them to judge whether the data collected provides a suitable representation of the site conditions, whether the intended rock classification indices or strength calculations will suitably represent reality, and what adjustments may need to be made to account for rock masses that are marginal for the classification method, are anisotropic, or are highly variable.

- If the same base geological/geotechnical domain model used in the geotechnical stability model is not used for the hydrogeological seepage analysis model, zones of pore pressure may be predicted that are not representative of the geotechnical domains, particularly in complex models and/or models where groundwater is compartmentalised. This results in problematic runs or inaccurate predictions during the geotechnical stability analyses.
- Building overly complex numerical analysis models is likely to render them very time-consuming to run, requiring very large amounts of processing power, and having a high risk of experiencing difficulties whilst running. This can be particularly problematic where multiple sensitivity analyses are necessary. 3D analyses are sometimes necessary, however, due to potential limitations in the model detail or modelling method, it must be understood they do not always provide more accurate or more representative results.
- In rock masses where structure is likely to play a strong role in the medium to large-scale failure mechanisms (for instance, blocky rock masses with numerous strong joint sets), selection of a numerical stability analysis method that does not allow for the potential failure mechanism to be suitably assessed/predicted will likely lead to an over-estimation of slope stability and an under-prediction of risk. Simple analysis methods or those without an appropriate representation of structure would assume a pseudo-rotational rock mass failure mechanism through a continuum. Such analysis is likely to overestimate the stability of the slope as it would not be able to assess the potential for structure to contribute to the failure mechanism, particularly in near proximity to the slope face. This will in turn likely result in an inappropriate slope design.

References

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