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An introduction to StopeX – a plug-in to simplify and fast-track *FLAC3D* numerical modelling for mining applications

A. Vakili[1,2], B. Abedian[2] & B. Cosgriff[2]
[1] *Mining One Consultants PTY LTD, Melbourne, VIC, Australia*
[2] *Cavroc PTY LTD., Melbourne, VIC, Australia*

1 INTRODUCTION

Numerical modelling is increasingly employed in the mining industry to predict the response of the rock mass to various mining activities. With mines going deeper and dealing with more complex geological conditions, the traditional state-of-practice analysis, such as boundary element and limit equilibrium methods, are not able to capture more complex rock mass behaviors. Vakili et al. (2014) and Andrieux (2011) showed some of the limitations of the state-of-practice methods for analyzing the rock mass response in more challenging ground conditions.

On the other hand, the state-of-art finite element and finite difference numerical modelling often requires significant experience and expertise and therefore is rarely applied by mining geotechnical practitioners. This state-of-art numerical modelling can help mining companies and consultants to predict rock mass behavior, understand and predict rock damage, and appreciate the interactions between neighboring excavations. Advanced modelling techniques have been used to improve mine performance through optimizing various aspects of an underground or open pit mine such as pillar and stope sizes, mining sequence, dilution, mining induced seismicity and pit slope angles. However, numerical modelling is often considered 'too difficult' or 'time consuming' and is therefore generally left to specialist consultants with many years of modelling experience. This created the impetus for StopeExamine (StopeX).

StopeX was primarily developed as a plug-in to *FLAC3D* (Itasca 2017) which helps to lessen difficulty and time taken in numerical modelling for beginner and intermediate users. This plug-in is a collection of several routines, macros and algorithms that automate *FLAC3D* modelling for underground mining applications and hence require considerably less expertise to learn and apply. Figure 1 shows a conceptual flow chart comparing the conventional *FLAC3D* numerical modelling process and the StopeX process.

The software boasts a sleek and easy-to-navigate user interface with real time helps. The primary advantage of the plug-in over using unsupported *FLAC3D*, or any other numerical modelling package, is that model construction time is generally reduced significantly. The plug-in also uses the built-in constitutive model IUCM, a unique and accurate material model developed specifically for rock. This model was implemented to be detailed and versatile and has been calibrated and verified against over 100 mining cases worldwide.

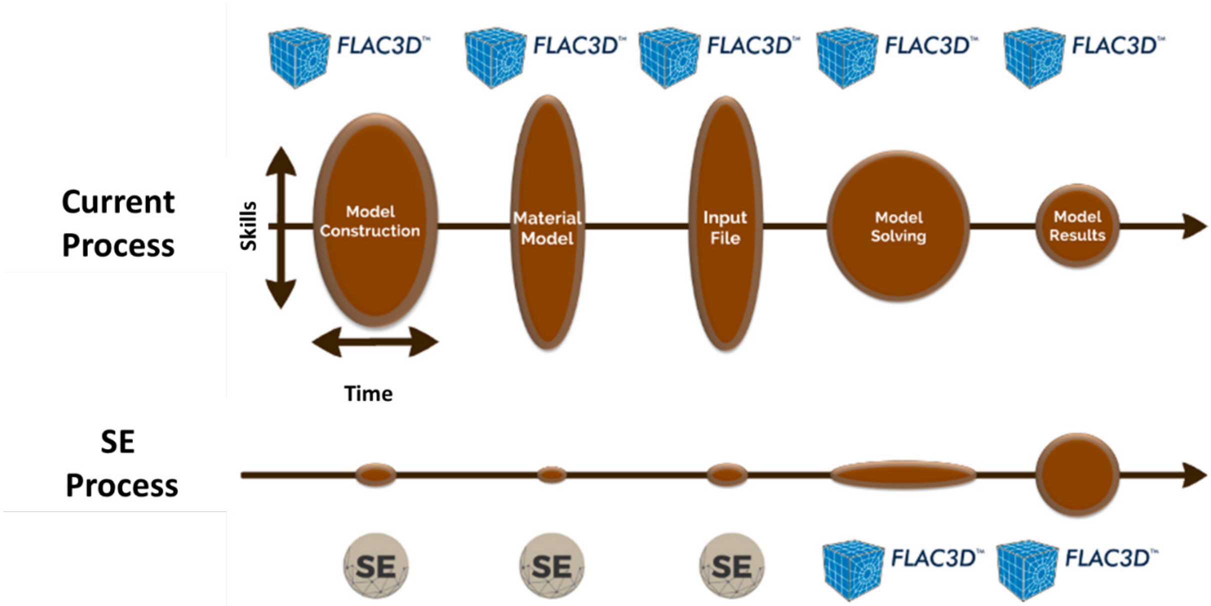

Figure 1. Comparison between conventional *FLAC3D* modelling process and StopeX process.

2 CORE ALGORITHMS

StopeX is a collection of several algorithms implemented in the *FISH* scripting interface of the *FLAC3D* software. The plug-in is primarily designed for geotechnical analysis of underground stoping operations. However, the application can be used for other analyses such as underground infrastructure, room and pillar mining, surface subsidence induced by underground workings, interaction between open pit and underground mining and shaft stability assessment. StopeX's main built-in *FISH* algorithms are described in the following paragraphs.

- **Model set up** – This function allows the user to import several geometrical components into the model including stopes, development, topography, area of interest and historical mining. Except for stopes, all the other components are optional. Geometries imported for the stope component will be treated as the main excavations in the model and can be other mining excavations such as a crusher chamber. Area of interest is designed to give the user the additional controls for meshing and plotting of a particular geometry in the model such as a single stope, a portion of development, key infrastructure or geological feature like faults and shear zones.
- **Automatic octree meshing** – Meshing is often one of the most time consuming and difficult tasks in finite element and finite difference modelling. StopeX has built-in routine which streamlines the octree meshing process in *FLAC3D*. This functionality can generate an optimized model mesh using an iterative process where zone sizes increase or decrease in an attempt to find the best model mesh which has sufficient resolution for accurate analysis but also does not exceed a user defined maximum computer RAM limit. During the *FLAC3D* run, if the iteration process was not able to meet both user defined inputs (required resolution and computer RAM), a message box will appear and will suggest few alternatives to adjust the required mesh characteristics.
- **MAP3D import option** – Given the popularity of MAP3D software amongst the mining geotechnical practitioners, this functionality allows the user to import the key model geometries such as stope and development as well as the mining sequence from a MAP3D input file. This facilitates a simple method to transition from MAP3D modelling to *FLAC3D*.
- **Improved Unified Constitutive Model (IUCM)** – IUCM serves as the built-in constitutive model for StopeX. This model is applicable to a wide range of rock mass conditions and failure mechanisms while still being simple to understand by most geotechnical practitioners. A detailed and transparent description of all the model's components are presented by Vakili (2016). This includes step by step instructions on the procedures that were implemented in each of the model's algorithms. There is also a detailed guideline for selection of input parameters. In addition to IUCM, users can also run the model entirely in Elastic mode.

- **Energy Release outputs** – For seismic hazard assessment, StopeX include an Energy Release calculation routine which is discussed in more details by Vakili et al. (2018).
- **Pre-mining stress set up** – This function assigns the insitu stresses in the model according to principal stress gradients provided by the user. The interface allows the user to also include a locked stress for each principal stress component which will add a constant stress value at ground level elevation. This algorithm assigns the stresses differently if topography is included in the model or not. In case of having a topography, stresses will be calculated by using the stress gradients and distance from each face in the topography. This allows a uniform distribution of stresses that follows the different elevations of the topography in mountainous areas. If no topography is included by the user, stresses will be calculated from a give RL for the ground surface elevation that user provides.
- **Boundary conditions** – This function automatically assigns the appropriate boundary conditions in the model without any major user action. The code first extends the outer boundaries of the model by an offset value provided by the user. The offset value is added to the maximum and minimum extent of the geometries in east, west, north, south, up and down directions which is calculated automatically in this function. If topography is included, no fixed conditions will be applied to the topography (top) boundary but in case of no topography, the top boundary will be fixed. Also, if ground surface elevation (when no topography is included) is below the top boundary of the model, all zones above the ground surface will be deleted and the top boundary will be free to displace (no fixed boundary conditions).
- **Model sequence** – The extraction sequence in the model is assigned by using the geometries associated with each mining step (imported by the user). This function assigns the relevant group names in the model. The sequence of solving in *FLAC3D* involves extracting each mining step, backfilling the excavations from the previous mining step (if backfill option is selected), solving to convergence without allowing material yield (elastic mode) and finally solving to convergence allowing material yield and softening.
- **Backfill** – The backfill functionality allows the user to fill the previously mined stopes. Excavation geometries that will need filling should be provided by the user. The properties of the backfill can be assigned separately using perfectly plastic Mohr-Coulomb model or Elastic material model.
- **Rock mass assignments** – The geotechnical domains and associated properties are assigned through this functionality. Users can import the geometries that define each geotechnical domain (closed volumes or surfaces defining the base of the geological units) and then assign the properties associated with each domain. The compulsory properties required for the model are all readily available from common laboratory tests and rock mass characterization (e.g. UCS, Ei, GSI, etc.).
- **Historical Mining** – The zones in the model that are associated with geometries imported by the user for the Historical Mining component are treated differently during model solving. For these zones, if backfilling option is selected, they will not be excavated to void before filling and instead stresses for zones inside the geometries will be gradually reduced to zero and then replaced with backfill material (or void if backfill is not selected). This alternative solving process is designed for mining excavations that are far from the area under study but that can impact the regional stress redistribution around the area of interest. This process allows the user to process all those historical mining geometries in one initial mining stages without detailed sequencing and hence reducing the run time.
- **Future improvements** - There are several future functionalities that are under development and will be added to future versions of StopeX. These include:
    - More flexibility with the backfill option so that users can have different backfill rules for different stopes including the stage of filling and different fill materials.
    - Automatic adaptive re-meshing algorithm for more accurate and computer efficient modelling.
    - Assignment of ubiquitous joint orientations for anisotropic materials according to provided geological wireframes to include the effect of folding and faulting.

3 GRAPHICAL USER INTERFACE

StopeX's user interface (UI) is a desktop app that guides the user to construct a *FLAC3D* model through the StopeX platform. The app assists the user to assign the model parameter, upload required geometry files, and control different settings. Input validations and parameter dependencies are built in the UI, which can assist the users to avoid falling in the common pitfalls of setting a model up.

The user journey is designed according to the industry's state-of-art numerical modelling practices which brings about more than 15 years' experience and more than 100 numerical modelling studies for mines around the world. The UI design process went through multiple design iterations to address shortfalls that were reported by the users during the usability test process. Figure 2 shows two snapshots of StopeX's UI.

The UI app is built with the latest web technologies (React and Node .js), which can be ran as standalone desktop apps on major operating systems but also facilitate easy transition to cloud-based model processing in the future. This approach was chosen to ensure that the app can be installed on a local desktop for users in remote areas with limited or no internet access.

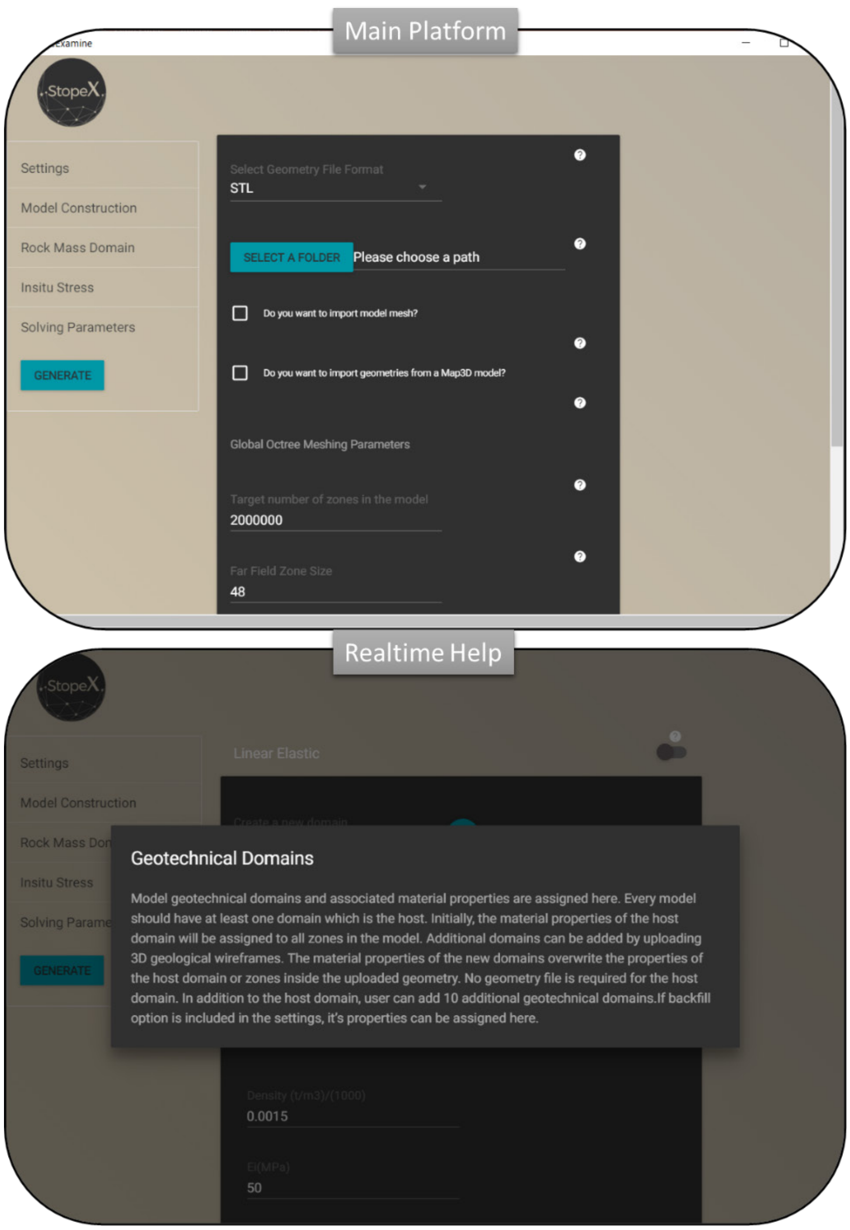

Figure 2. StopeX's Graphical User Interface.

4 CONCLUSIONS

This paper described the key functionalities and processes developed for StopeX, which is a plug-in to *FLAC3D*. StopeX was developed with the intention to narrow the gap between state-of-art and state-of-practice numerical modelling practices for mining application

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