Caving 2022 - Y Potvin (ed.)

doi:10.36487/ACG_repo/2205_96

Material flow simulation using marker mixing

F Khodayari *Dassault Systèmes, Canada*

T Diering *Dassault Systèmes, Canada*

Abstract

Material mixing and its impact on the block cave operations is one of the main aspects for evaluating and operating any caving project. Initial modelling with limited geotechnical data and calibration using the actual data are the two main phases to build the flow model. Challenges on the way are inevitable; how to predict the flow in the first place, and how to calibrate even when such data is available. In order to achieve realistic results, the right tools are a necessity to be able to mimic the actual cave. Vertical Mixing (VM), Template Mixing (TM), and CA3D tools in GEOVIA PCBC have been extensively used for more than two decades by many users across the globe; very useful tools but slow and limited on graphics. To overcome these challenges, Marker Mixing (MM) was introduced in 2021; a powerful material flow simulator with unique graphical capabilities and much higher speed compared to other existing tools. The stand-alone feature in MMIX provides the option to run a mixing model without even running a productions schedule. Implementing cave back and other geotechnical and operational constraints are easier and visually assessable, increasing the transparency while making it possible to improve the caving model in a more efficient approach. Markers simulate the material movements from their original location to extraction (from drawpoints) within the cave. Simulation is done step by step with vertical and horizontal movements, toppling, riling, erosion and frozen concepts all captured and visualised in the new MMIX tool. The theory and experience behind MMIX can help define the initial flow model, then in the next step, actual production data can be used to calibrate the parameters. In addition, information gathered from Beacons (smart markers) installed in the cave zone can be visualised, interpreted, and implemented using the MMIX play back tool. This feature can significantly improve the calibration process for achieving more precise models by mimicking the actual flow in the cave. The residual block model can also be generated using MMIX much faster and with better visual checks compared to CA3D. This paper introduces Marker Mixing tool, its features, and capabilities, with comparisons to existing Vertical Mixing, Template Mixing, and CA3D tools in PCBC.

Keywords: *block caving, material flow, marker mixing, production schedule, PCBC*

1 Introduction

The existing material flow analysis in block caving can be divided into three categories: numerical models, pilot tests, and full-scale experiments (Khodayari & Pourrahimian 2019). Pilot tests and full-scale experiments can be very expensive to implement while not easy to calibrate based on the actual data for specific projects. Many of numerical models are computationally intensive with limitations for implementation in large-scale block cave operations (Diering 2007). Incorporation of material flow within the production schedule is critical for achieving more accurate mine plans and reducing grade and tonnage uncertainties. This paper looks at existing material flow simulation tools in GEOVIA PCBC and then introduces Marker Mixing as the latest advancement in this area.

2 Existing mixing tools in PCBC

During the past few decades, different mixing tools have been developed in GEOVIA PCBC and implemented by mining engineers across the globe: from pre-vertical mixing which imitates the mixing that occurs among slices within the same draw column (Figure 1) to template mixing which is able to model a variety of mixing possibilities such as vertical and horizontal mixing, frozen and erosion, and toppling.

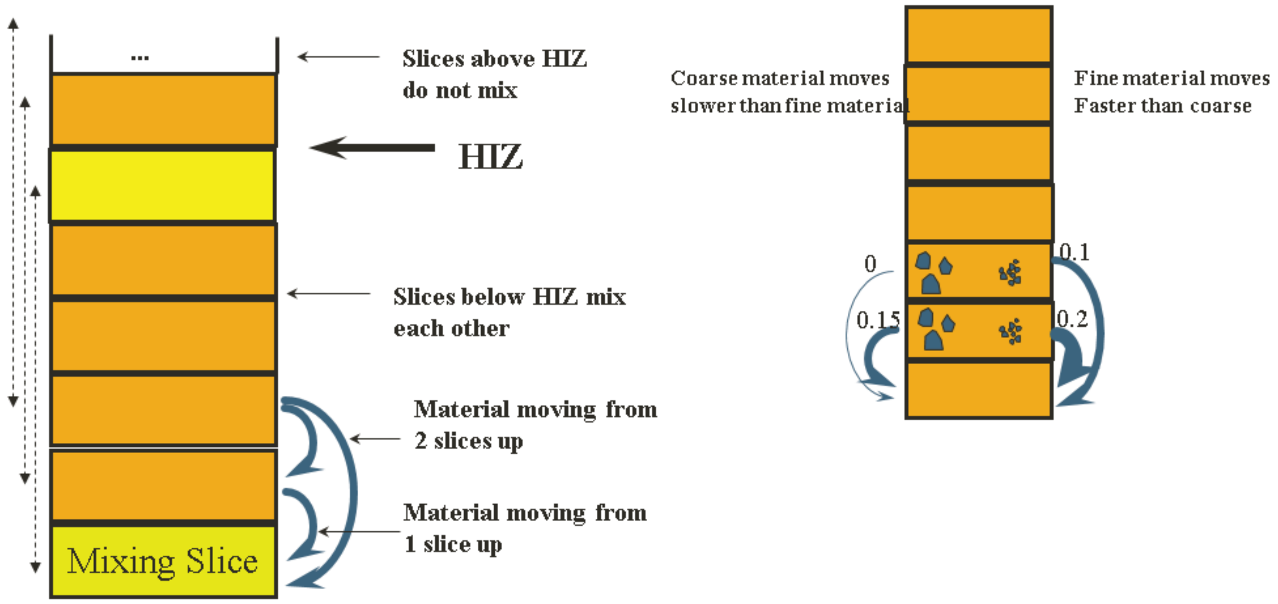

Figure 1 Vertical mixing in PCBC

Table 1 presents a summary of mixing tools in PCBC. Existing tools have been widely used and been effective for the material flow simulation; however, lack of advanced graphical interface and visualisation for mixing and material flow while depleting from drawpoints has always been a concern. Also, some of these tools such as CA3D and Template Mixing would require a lot of computational power and time to run, especially if wanted to use for calibration purposes or larger projects. Marker Mixing is a new tool developed in PCBC for mixing and material flow simulation which is much faster and more flexible compared to other tools while offering useful graphical features in to block cave planning.

Table 1 Material simulation tools in PCBC

Method	Ease of use	Non-linear?	Slice file/block model	Comment
No mixing	Easy	No	Slice file	No mixing base case (in situ)
Pre-vertical mixing	Easy	No	Slice file	PCBC 'default' (includes pre-erosion)
Template mixing	Harder	Yes	Slice file/block model	Flexible option available
Cellular automaton (CA3D)	Harder	Yes	Block model	Multiple flow and domain control
Marker mixing	Moderate	Yes	Slice file/block model	Powerful, fast, and visual capabilities

3 Marker Mixing

Marker Mixing (or fully Template Mixing using markers) is a new flow model both within PCBC and within the caving industry. MMIX (Marker Mixing) uses the same basic concepts for flow modelling as a depletion engine within the PCBC Production Scheduler (Diering 2022). However, instead of working with fractions of material which mix with each other during the flow process, MMIX uses discrete markers whose movement is tracked within each draw column.

3.1 MMIX features

Currently, the following features of the tool have been realised (Diering 2022):

- **Flexibility:** to be calibrated to a wide variety of flow situations.
- **Speed**: In stand-alone mode, MMIX will run much faster than Template Mixing (up to 10 times faster depending on the case study). Even within the Scheduler, the performance will be improved.
- **5 Modes** to run (scheduler, stand-alone, batch, evaluate, and residual model):
  - Within the existing **scheduler** tool to carry a full mine plan while implementing MMIX.
  - **Stand-alone mode**: this is the most effective way to use the tool if running for calibration purposes where the tons to be extracted are known in advance.
  - **Batch mode (automation)**: allowing several advanced profiles to be evaluated in a single run.
  - **Evaluate mode**: this will allow a different slice file to be evaluated using the markers extracted from a previous (saved) run.
  - **Residual block model**: partially depleted orebody can be modelled and used for lower lifts.
- **Seamless integration:** works same as TM and can easily be accessed from the production scheduler.
- Improved **graphical display**: Display is enhanced for selected drawpoints.
- Option to **evaluate** multiple Slice files (or block models) from a single run. Once a complete run has been done, it is then possible to change the slice file and evaluate that using the markers already extracted.
- **Multi-Lift** support: links between slices are based on:
  - The position of the slice within the draw column.
  - The absolute 3D position of the slice. The second option means that if slices from a lower lift are in close proximity to the base of draw columns from a higher lift, the material from the higher lift can move seamlessly into the lower lift.
- **External material** support: this allows for easy addition of external material into the flow domain. This concept has been widely and successfully used in PCSLC and has also been used within Template Mixing.
- Clean **riling and toppling**: In the Template Mixing algorithm, fractions of fractions of fractions of a slice are calculated leading to some slices having very small tonnages remaining which in turn lead to bits remaining in some slices which appeared to be floating in air. With the Marker Mixing however, the tracking of material is much simpler since each marker represents a distinct positive tonnage of material which can be better tracked.
- **Fines migration**: Fines migration is an important flow mechanism, it is achieved by preferentially moving fines designated markers in preference to coarse designated markers.
- More controls on **vertical mixing**: Vertical mixing (both above and below the mixing horizon) can be managed via a variety of keywords and bucket input values.
- Variable **cave back** and variable cave back thickness: The cave back can be simulated to be modified on a drawpoint by drawpoint and also by a period by period basis for maximum flexibility.
- Variable **marker size** can be implemented (but flow is not dependent on this). Marker size does not have to be related to block size.
- Simulation of **frozen and erosion** material.
- Input **fines** via grade element, not external model needed.

- Ability to update a **residual model**: Residual block model can be calculated by simulating the flow using mine plan or historical tonnages from a previous operation.

3.2 Proof of concept and results

In this part of the paper, examples are presented to show step by step depletion of material from the bottom of a single drawpoint. The examples are set up to show the various mixing mechanisms. Later, more than one drawpoint is used to analyse more complex scenarios.

Vertical mixing is where material mix within the same draw column as moving down; depletion steps are shown for one drawpoint when simulating vertical mixing using Marker Mixing (Figure 2):

1. Start of depletion.
2. Cave back (swelled material) reaches top of column.
3. Top of column moves down (no external material added).
4. Black and Blue zones largely mined.
5. End of run.

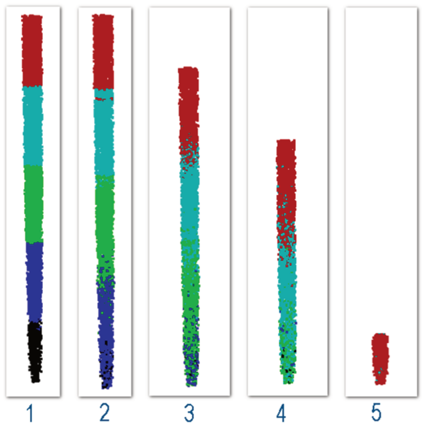

Figure 2 Vertical mixing simulated for one drawpoint using Marker Mixing

Swell factor is one of the critical parameters when simulating a caving flow; in the same condition, the higher the swell factor the slower the flow would be when caved material moving down through a draw column (Figure 3).

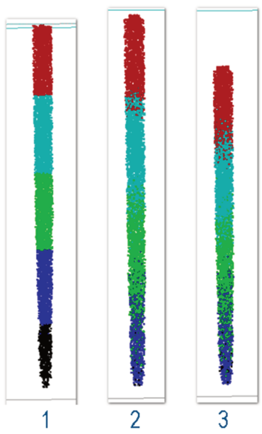

Figure 3 Impact of swell factor simulated in Marker Mixing: 1. Start, 2. Period 33 (with 1.2 swell factor), 3. Period 33 with minimal swell

External material can be introduced as source of replacing the depleted portion entering from top of the draw column and moving down contributing to the dilution, an old open pit on top of the cave would be an example of using this option. Figure 4 presents an example of implementation of external material and how it gradually becomes part of the depletion and mixing:

1. Start.
2. First external enter on top.
3. External midway to base (and mixed).
4. Last step.

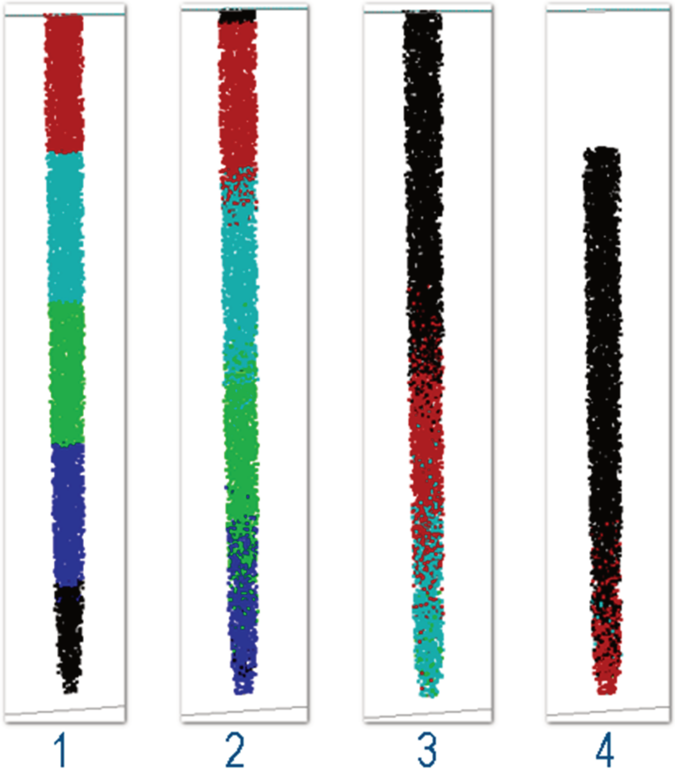

Figure 4 Implementation of external material in Marker Mixing

Fine material moves faster compared to coarse material within the cave and this can impact the depletion grade, especially when grade is significantly different between zones with different percentages of fines (Figure 5):

a) Fines probability at 0.7 (this parameter can be modified by user):
   1. Top = 70%, bottom = 30% fines.
   2. Fines (grey markers) movement only starts when swell allows.
   3. Start of coarse (grey markers) ‘cap’ at top of column.
   4. Distinct ‘cap’; at top.
   5. Almost all fines are mined.
   6. Only coarse left at end.

b) No fines preference:
   1. Fines and coarse move down with the same speed.
   2. Both fines and coarse material are depleted with the same rate.

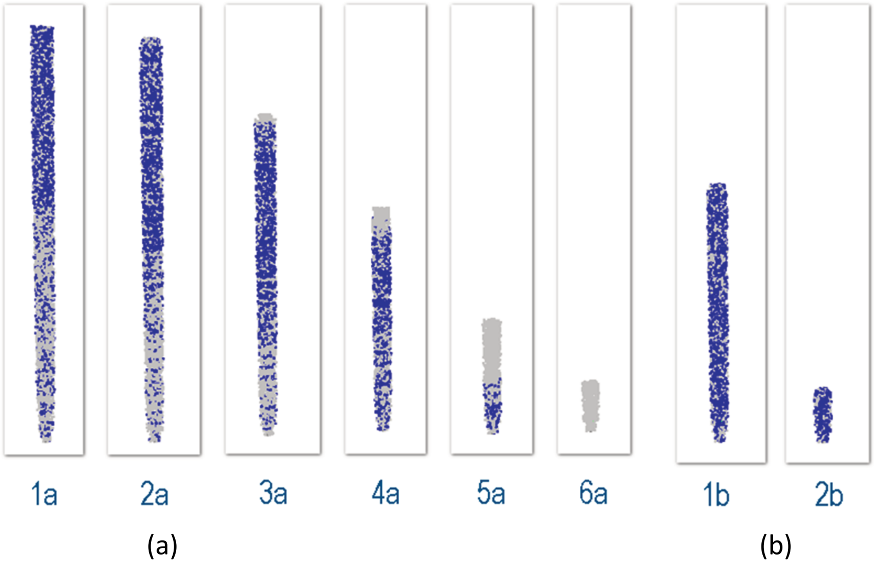

Figure 5 Fines and coarse material in Marker Mixing, 'blue markers' represent fines and 'grey markers' represents coarse material: a) Fines movement at 0.7 and b) No fines preference

Multi-lift draw can be simulated using MMIX where extraction starts from lift one on top and then continues through the second lift located at a lower elevation in the orebody. This feature facilitates multi-lift analysis as building a separate residual model for the first lift is not necessarily needed anymore, when looking at both lifts at the same time. Figure 6 presents a multi-lift situation with one drawpoint on each lift:

1. Start mining top lift (Lift 1).
2. External material entry at Lift 1.
3. Finish mining at Lift 1.
4. Cave back from bottom lift (Lift 2) reaches to top and first markers cross over.
5. Cross movement of external material.
6. No more external going into Lift 1.
7. End of run.

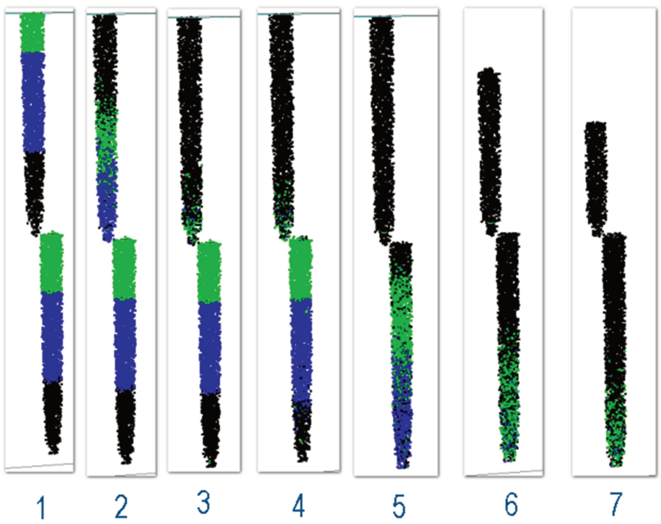

Figure 6 Multi-lift simulation using Marker Mixing

Frozen and erosion simulation in MMIX is more transparent and precise compared to previous tools, markers are frozen according to the estimated frozen factor and they erode (based on the erosion factor) and contribute to the flow as drawpoint matures during its extraction life (Figure 7):

1. Two lift drawpoints.
2. Step 1 showing only frozen material up to height of 120 m.
3. Most of frozen material eroded when top drawpoint is mined.
4. All of top is eroded and much of bottom.
5. End of run. Nearly all eroded.

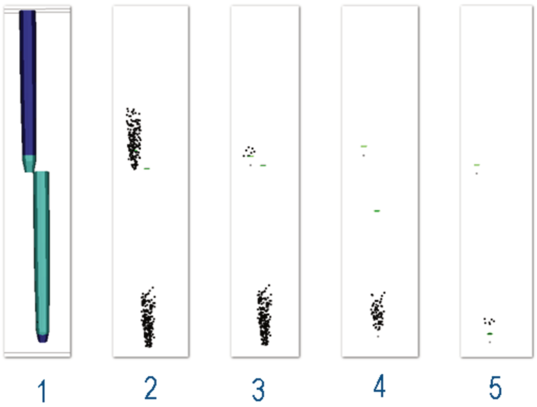

Figure 7 Frozen and erosion visualisation for a multi-lift project in MMIX

Beacon data is used for calibration purposes in a caving operation, MMIX can make this process much easier; this feature of MMIX allows users to select specific slices and see where the markers which originate from that slice move to. Users can then use the recorded positions for physical markers of beacons, comparison of two is significantly helpful for calibration of mixing parameters. A simulated example is shown in Figure 8 where the beacons or physical markers are shown as small spheres and the model markers as dots. For the two right side slices/drawpoints, the physical beacons are shown not to move. This could easily represent a situation where the physical beacons are above the cave back and the model does not have a cave back. So a further iteration could be done modifying the cave back surface. Also, this example shows a small amount of cross drawpoint movement of markers, this is set using the horizontal mixing parameter in MMIX.

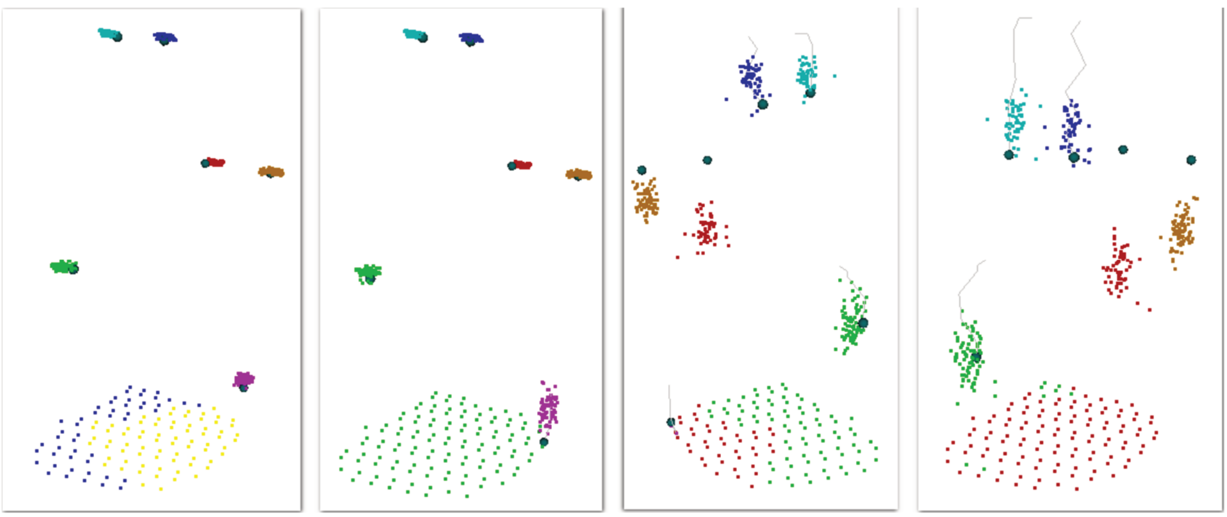

Figure 8 Using beacon data for calibration in MMIX

Figure 9 presents a normal MMIX run for multiple drawpoints from intact rock to full depletion (left to right) with no constraints; materials are mixed and moved down within the cave.

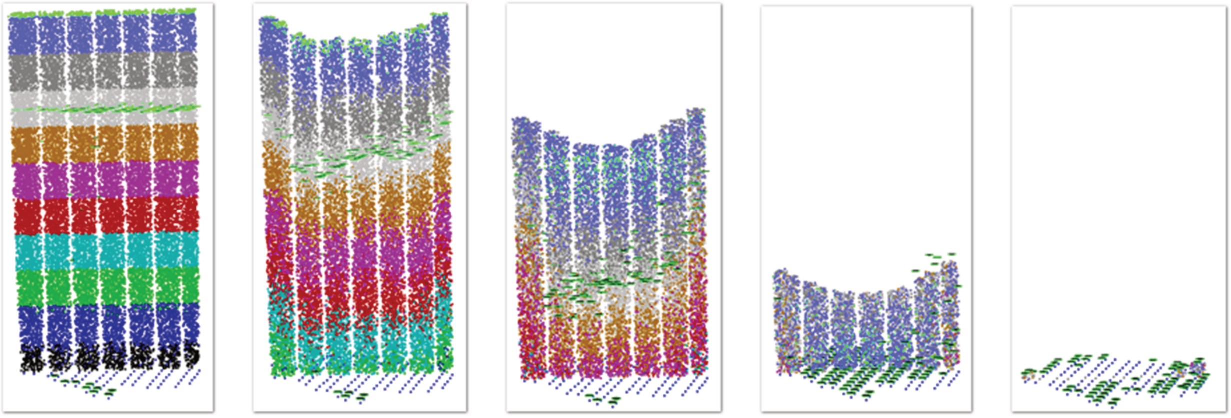

Figure 9 A normal run for multiple drawpoints without any constraints in MMIX

Figure 10 however, is when implementing a cave back shape in multiple steps, the caved portion is depleted while the intact rock (not broken or swelled) is hanging in its original place according to the defined cave back shape. Riling also occurs in this case from top right to bottom left.

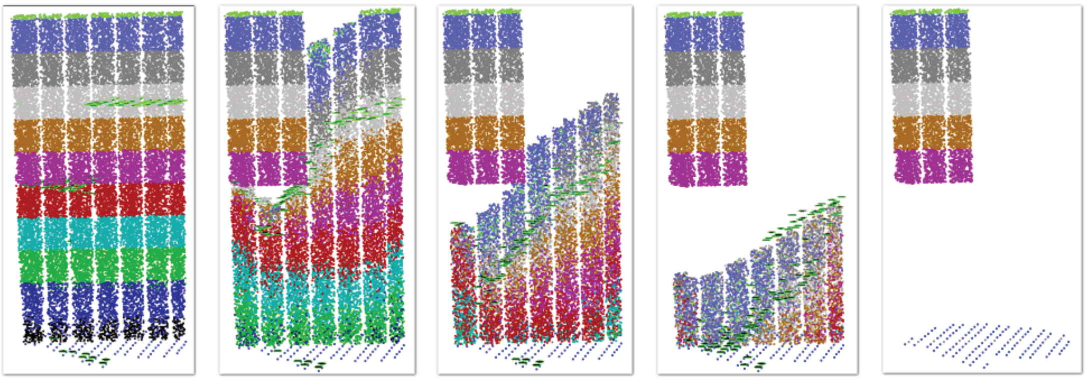

Figure 10 Using cave back constraint in MMIX

Figure 11 simulates the same case (as Figure 10) but releasing the material above cave back after some time (periods), material are released and become part of flow until the next cave back (above the first one) is implemented, where the rest of material above that remains in situ.

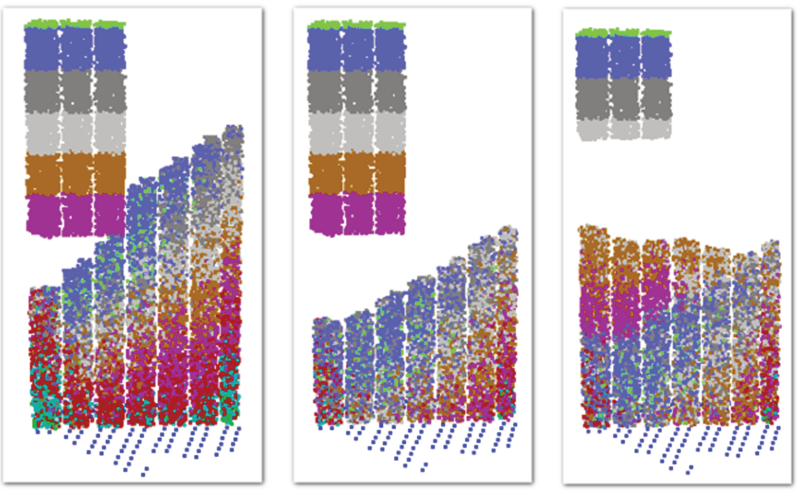

Figure 11 Using cave back in MMIX and releasing it after some time (after a certain period in the plan)

For the same scenario (as Figure 11), toppling is also permitted in Figure 12; in the second step till end, toppling from the top of the cave back starts to contribute to the cave flow, a combination of toppling, riling, and side erosion fill the void below the cave back.

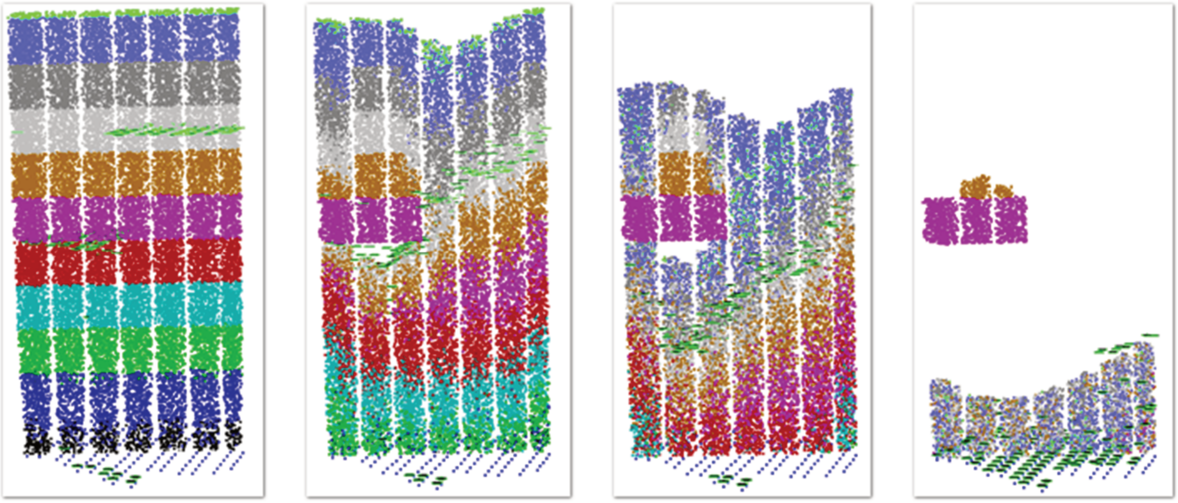

Figure 12 Using cave back and implementing toppling in MMIX

In a more complex situation, external materials are added from the top, where they mix and rill with the rest of materials while the cave back is in place (Figure 13).

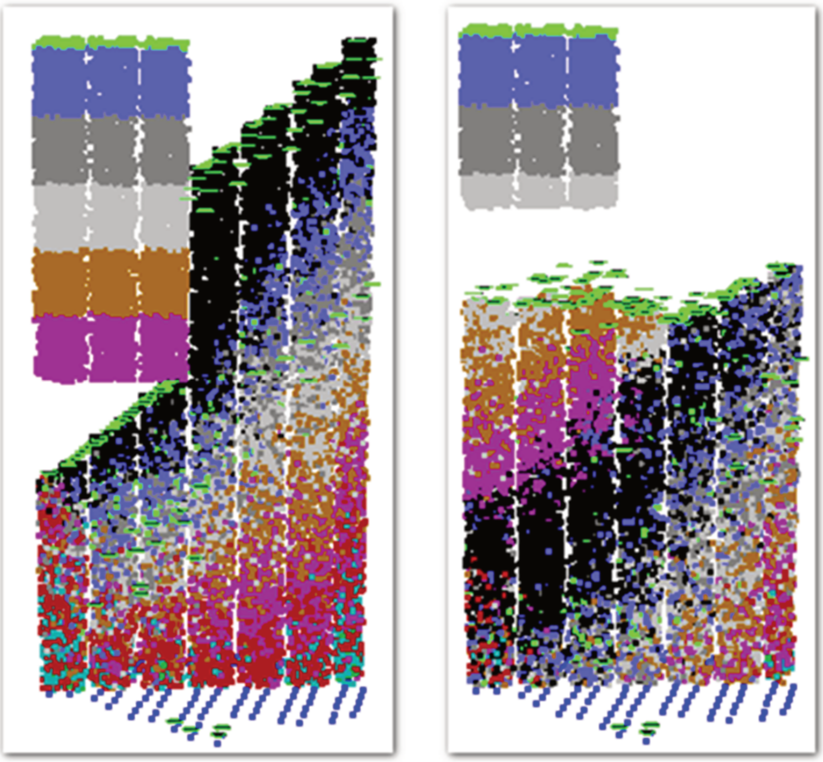

Figure 13 Using cave back, release, and adding external material from top in MMIX

4 Discussion

Today’s computational capabilities have helped mining engineers to study, analyse, predict, and visualise cave flow and material mixing faster and more precise than ever. As one of the software leaders in the caving industry, GEOVIA PCBC has been developing and upgrading its caving solutions according to the needs of mining projects across the globe. Marker Mixing brings more than 30 years of experience in cave mining, aiming to capture and implement impacting parameters to properly model a caving flow during the life of the mine. While the previous tools are still available to use by clients, as presented in this paper, MMIX is very promising as the next generation of caving flow analysis within the industry; it can pave the road for more sustainable caving projects bringing higher confidence to mine plans.

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