DOI: https://doi.org/10.68732/cc0fcefbeb6d9dd6

ISBN: 978-9989-2053-6-1

Integrated Workflow for Bench-Berm Design Optimisation and Reconciliation

F. Sanz
SRK Consulting (UK) Limited, Cardiff, UK
fsanz@srk.co.uk
0009-0003-0254-7325

Abstract

Bench-scale performance represents a critical component of geotechnical risk management in open-pit mining because structurally controlled backbreak and operational overbreak directly influence effective berm retention, rockfall containment capacity, and operational safety. However, uncertainty commonly exists between intended bench geometries and actual as-built conditions due to limitations in structural interpretation, persistence estimation, and blasting disturbance characterization, particularly during early project stages.

This paper presents an integrated and iterative workflow for progressively refining bench-scale engineering interpretation through reconciliation between structural characterization, block formation simulation, and observed operational performance. The workflow was applied across multiple open pit projects and different stages of pit development, ranging from conceptual greenfield studies to operational final wall conditions. The methodology integrates geological interpretation, borehole data, surface structural mapping, laboratory testing, bench-scale block formation simulation, and photogrammetry-based reconciliation of as-built bench performance.

The study demonstrates that representative engineering persistence and operational blasting conditions exert dominant controls on structurally controlled backbreak and effective berm performance. Comparison between simulated and observed bench conditions provided a practical basis for refining engineering assumptions, distinguishing structurally controlled instability from operationally induced overbreak, and progressively reducing uncertainty throughout pit development.

The proposed workflow provides a practical framework for improving confidence in bench-scale design optimisation and supporting risk-informed geotechnical decision-making through continuous operational reconciliation and iterative refinement of engineering interpretation.

Keywords

Integrated workflow, Design optimisation, Bench-scale performance, Operational reconciliation.

1 Introduction

Bench-scale performance is a critical component of geotechnical risk management in open-pit mining because local bench behaviour directly controls effective berm retention, rockfall containment capacity, and operational safety. While slope-scale analyses are commonly used to define overall pit geometries, bench-scale performance is frequently governed by the interaction between structural persistence, blasting disturbance, wall orientation, and operational practices, which together control and balance practical bench–berm configuration and backbreak behaviour (Gibson et al., 2006).

Traditional bench-scale design approaches commonly rely on simplified structural interpretations and limited reconciliation with observed pit performance. Although appropriate during early project stages, these approaches may not adequately capture the variability associated with structurally controlled backbreak and operationally induced overbreak mechanisms. Consequently, uncertainty commonly arises between intended design geometries and actual as-built slope conditions, particularly in structurally complex rock masses.

This paper discusses the application of an integrated and iterative workflow across multiple open pit projects and project stages to progressively refine structural interpretation, improve understanding of bench-scale behaviour, and support risk-informed bench–berm design optimisation. The workflow integrates geological interpretation, borehole data, surface structural mapping, operational observations, laboratory testing, bench-scale block formation simulation, and reconciliation with observed as-built performance.

Fig. 1presents the proposed workflow and its progressive application throughout different stages of pit development, from conceptual greenfield studies to operational final wall conditions. Operational reconciliation represents the central component of the methodology by linking simulated behaviour with observed bench performance to refine engineering assumptions, improve confidence in representative persistence and shear strength interpretation, and progressively reduce uncertainty throughout pit development.

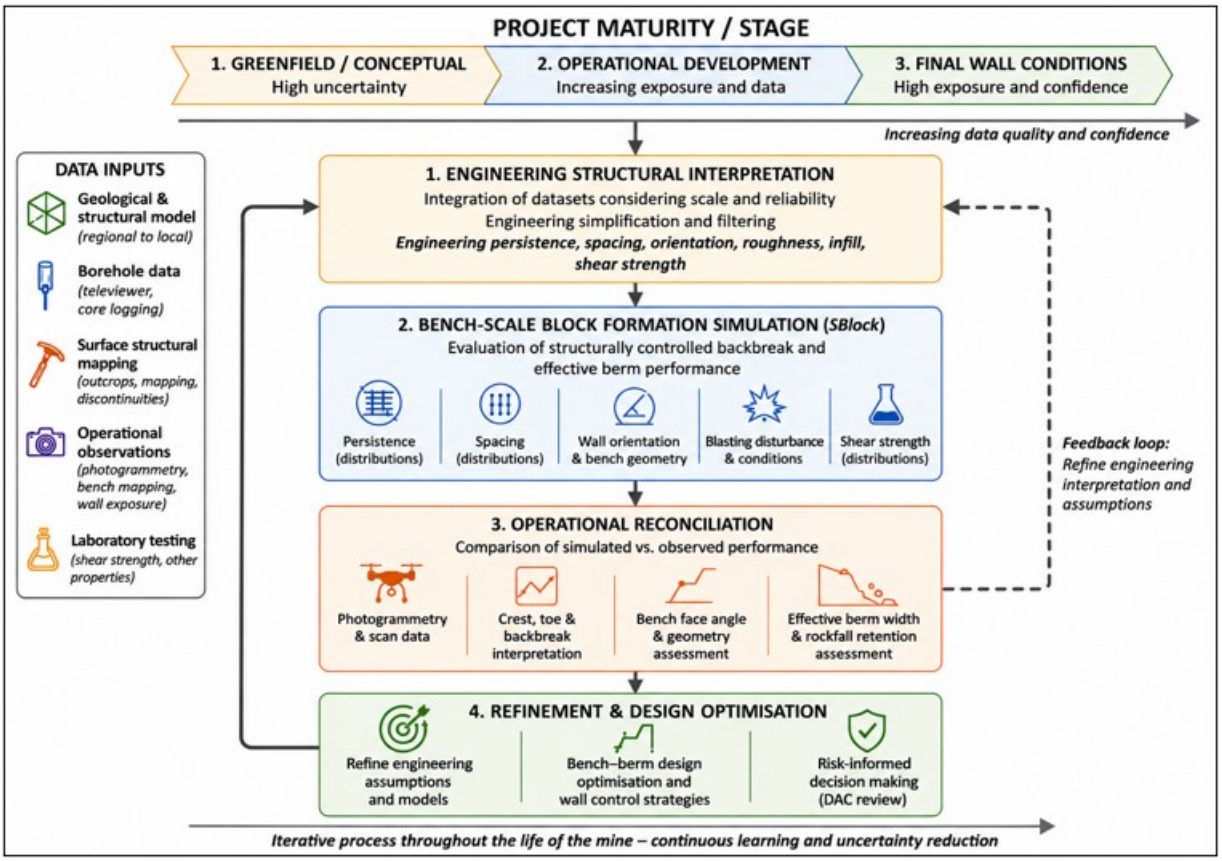


Fig. 1 Integrated workflow for bench-scale modelling, reconciliation, and design optimisation throughout pit development.

2 Structural Interpretation and Engineering Representation

Structural interpretation integrated large-scale geological understanding, borehole-based datasets, surface mapping, laboratory testing, and operational observations to define representative engineering joint sets suitable for bench-scale analysis. The availability and quality of these datasets evolved significantly throughout the project lifecycle, from conceptual greenfield interpretation based primarily on drilling information to operational reconciliation supported by high-resolution photogrammetry and exposed bench mapping.

During early project stages, borehole datasets provided the primary source of information regarding structural orientation, spacing, and geotechnical characteristics. However, persistence remained difficult to constrain reliably using borehole data alone (Shang et al., 2018). As additional operational exposure became available, surface mapping and photogrammetric interpretation provided direct observations of persistence, block formation mechanisms, blasting disturbance, and bench performance (Sturzenegger and Stead, 2009).

Table 1 summarizes the main information and reliability provided by each dataset considered in this work.

Table 1. Summary of information provided by each dataset.

Dataset	Joint Orientation	Joint Persistence	Joint Spacing	Joint Roughness / Infill (other characteristics)	Operational Exposure of Joints
Large-Scale Geological & Structural model	Limited (Interpreted)	Limited (Interpreted)	None	None	None
Televiewer	Excellent	None	Excellent	None/Limited	None
Core Logging	Moderate	None	Excellent	Excellent	None
Surface Mapping	Excellent	Excellent	Moderate	Limited	Excellent
Laboratory Testing	None	None	None	Moderate (Lab-scale strength)	None
Individual Block Back-Analysis	Limited (Local)	Limited (Local)	None	Excellent (Bench-scale strength)	Limited (Local)

A key aspect of the workflow involved distinguishing between geological persistence and engineering persistence, since engineering persistence was intended to reproduce practical block formation mechanisms relevant for bench-scale behaviour rather than actual discontinuity continuity. Consequently, structural simplification and filtering were required to isolate discontinuities capable of generating operationally significant instability mechanisms.

Representative bench-scale shear strength parameters were derived using laboratory testing, engineering judgement, and Barton-Bandis interpretations (Barton, 1973; Barton and Choubey, 1977) adjusted for disturbed operational conditions associated with blasting and excavation.

Table 2 presents a representative example modelling inputs considered for the block simulation.

Table 2: Example summary of engineering joint set characteristics used for block simulation.

Geotechnical Unit 01	Orientation	Geometrical Characteristics: Median [min-max]			Strength (average) Friction Angle (°)	
Joint set	Dip / Dip direction (°)	Spacing (m) [Min-Max]	Persistence (m)			
			Base Case	Sensitivity Case	Base Case	Sensitivity Case
1	75/120	2.8 [0.9 - 8.4]	12.0 [4.0 - 36.0]	18.0 [4.0 – 54.0]	35	30
2	85/245	1.7 [0.6 – 5.1]	8.3 [2.8 – 25.0]	12.5 [2.8 – 37.5]	40	35
3	50/235	2.9 [0.5 – 8.7]	7.2 [2.4 – 22.0]	10.8 [2.4 – 32.4]	40	35
4	45/290	3.4 [0.5 – 10.2]	7.3 [2.4 – 22.0]	11.0 [2.4 – 33.0]	40	35

3 Bench-Scale Modelling and Reconciliation

Representative engineering joint sets were developed using integrated interpretation of structural mapping, borehole datasets, laboratory testing, and operational observations. Block formation analyses were performed using SBlock (Esterhuizen, 2025; Hormazabal 2013) to evaluate structurally controlled backbreak and effective berm performance under varying wall orientations and bench geometries. Modelling assumptions incorporated simplified persistence and spacing distributions, representative friction angles, and disturbed structural conditions associated with blasting and excavation.

Sensitivity analyses demonstrated that persistence exerted the strongest influence on simulated backbreak behaviour, whereas spacing and friction angle generally exhibited comparatively lower influence. Relatively small increases in persistence commonly produced larger backbreak magnitudes and broader distributions of affected wall orientations.

The reconciliation process represented the central component of the workflow because it provided the link between conceptual engineering interpretation and observed operational performance. High-resolution photogrammetry and scan interpretation were used to extract crest lines, toe lines, and backbreak geometries using PointModeller (Maptek, 2025). These interpretations allowed comparison between observed as-built conditions and intended bench geometries, supporting estimation of backbreak magnitude, effective berm width, and bench face angle variability (Pratt et al., 2022).

Fig. 2 presents an example of as-built bench interpretation using photogrammetric scan data and comparison against the intended bench geometry. Crest lines, toe lines, and backbreak geometries were interpreted to estimate effective berm width, bench face angle variability, and structurally controlled backbreak magnitude. In this example, toe flare conditions were observed along sections of the final wall benches, indicating local reduction of catch berm capacity and increased rockfall risk associated with blasting disturbance and bench clean-up practices (Marklund et al., 2007).

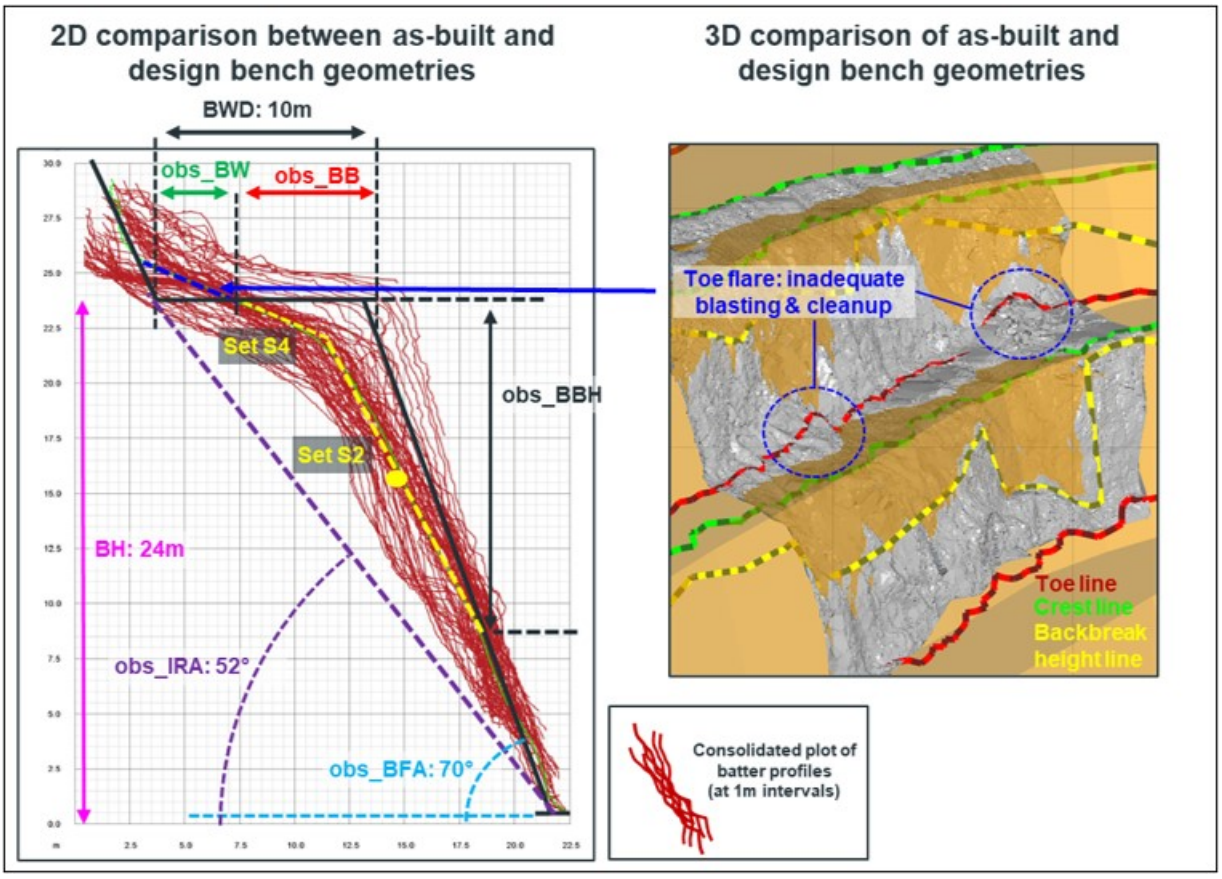


Fig. 2 Integrated reconciliation of bench-scale performance combining field observations, stereographic interpretation, and as-built geometry analysis to quantify structurally controlled backbreak and effective berm performance.

Comparison between simulated and observed bench performance provided a practical basis for refining engineering assumptions and distinguishing between structurally controlled instability and operationally induced overbreak associated with blasting practices.

Fig. 3 presents an example comparison between simulated block formation behaviour and observed as-built performance for an operational final wall condition. The comparison was used to evaluate whether the interpreted structural parameters remained representative under operational conditions and whether refinement of persistence assumptions or blasting practices was required.

Confidence associated with the engineering interpretation increased significantly as operational exposure and reconciliation opportunities became available throughout pit development.

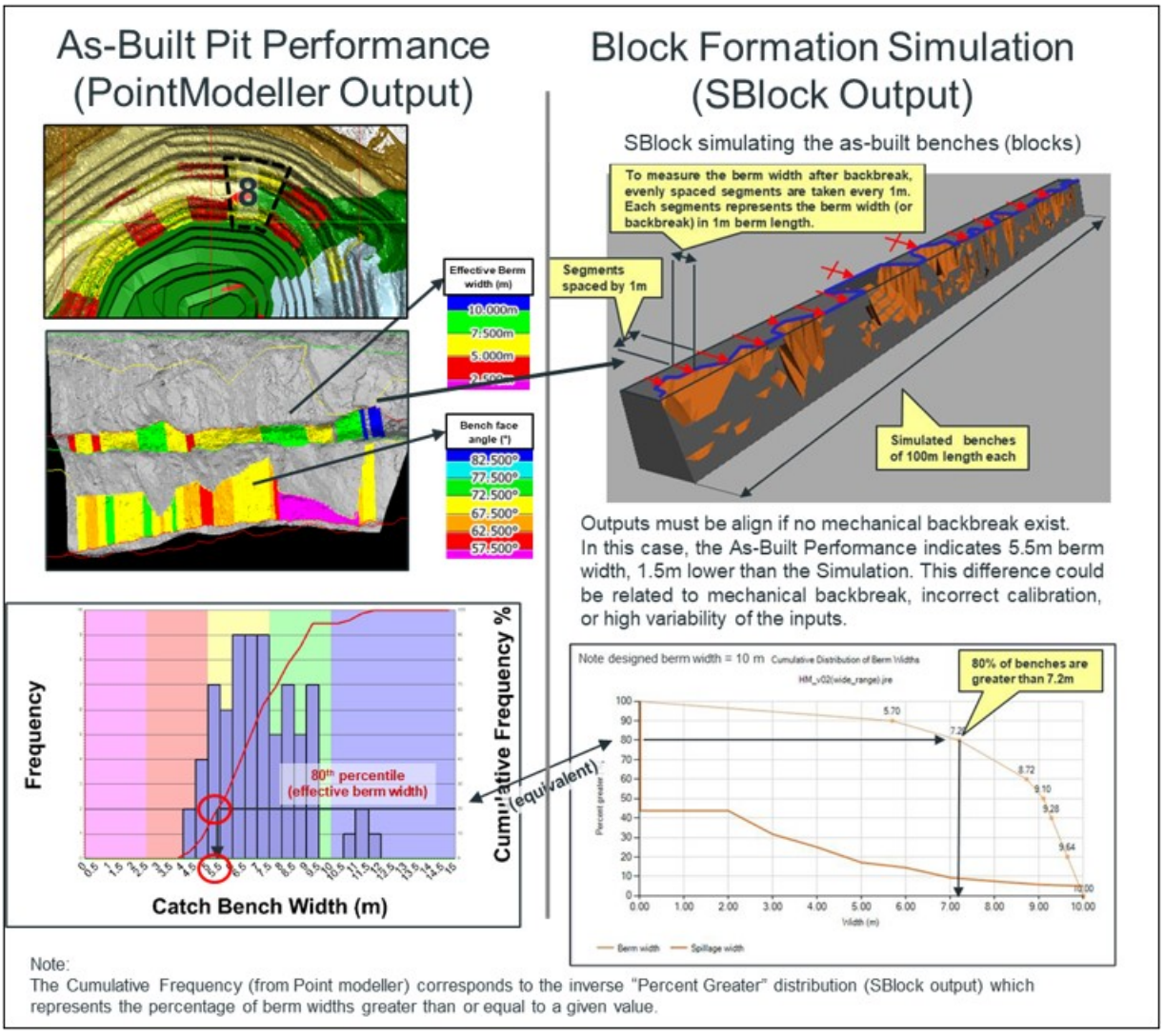


Fig. 3 Example of reconciliation of the bench performance (using PointModeller) and the simulation (in SBlock) for a final pit wall stage.

4 Engineering Implications and Conclusions

Application of the workflow demonstrated generally consistent agreement between simulated and observed bench performance when representative engineering persistence and disturbed structural conditions were incorporated into the modelling process.

The reconciliation process highlighted the importance of distinguishing between structurally controlled backbreak and mechanically induced overbreak associated with blasting practices. In several cases, operational blasting performance exerted a stronger influence on bench performance

than modifications to bench geometry itself, reinforcing the importance of integrating operational observations into bench-scale interpretation and optimisation.

These observations reinforce the need to treat bench-scale design as an iterative process in which excavation control, blasting performance, survey reconciliation, and operational observations are used to update engineering assumptions and manage uncertainty throughout pit development (Simmons, 2013; Graf and Sullivan, 2016).

From a risk management perspective, the workflow supported identification of slope sectors where uncertainty associated with structural persistence, blasting disturbance, or operational practices could significantly influence effective berm performance and rockfall retention capacity. The evaluated projects also demonstrated that acceptable bench performance and Design Acceptance Criteria (DAC) remain inherently project-specific and dependent on operational exposure, mining phase, and operational risk tolerance.

The proposed workflow provides a practical framework for refining structural interpretation, validating modelling assumptions, and improving confidence in bench-scale decision-making throughout pit development through continuous reconciliation with operational performance observations.

References

Barton, N. (1973). Review of a new shear strength criterion for rock joints. Engineering Geology, 7(4), 287–332.

Barton, N., and Choubey, V. (1977). The shear strength of rock joints in theory and practice. Rock Mechanics, 10, 1–54.

Esterhuizen, G. (2025). SBlock v3.01: User guide and reference manual. Computer software/manual.

Gibson, W.H., de Bruyn, I.A., and Walker, D.J.H. (2006). Considerations in the optimisation of bench face angle and berm width geometries for open pit mines. Proceedings of the International Symposium on Stability of Rock Slopes in Open Pit Mining and Civil Engineering, SAIMM, Johannesburg, pp. 557–578.

Graf, C.C., and Sullivan, R. (2016). A journey of wall control improvement at Boddington Gold. APSSIM 2016, Australian Centre for Geomechanics, Perth.

Hormazabal, E. (2013). Bench berm design using probabilistic key block analysis. Slope Stability 2013, Australian Centre for Geomechanics, Perth, pp. 227–236.

Maptek (2025). PointModeller Help Documentation. Maptek Pty Ltd.

Marklund, P-I., Sjöberg, J., Ouchterlony, F., and Nilsson, N. (2007). Improved blasting and bench slope design at the Aitik Mine. Slope Stability 2007, Australian Centre for Geomechanics, Perth.

Pratt, R.W., Conley, M.C., Childs, D.W., McNabb, J.C., and Schmelter, S.C. (2022). Slope auditing for assessment of bench-scale pit slope design utilizing drone photogrammetry.

Shang, J., West, L.J., Hencher, S.R., and Zhao, Z. (2018). Geological discontinuity persistence: Implications and quantification. Engineering Geology, 241, pp. 41–54.

Simmons, J.V. (2013). Excavation control, management of blast damage, and quality control. Slope Stability 2013, Australian Centre for Geomechanics, Perth.

Sturzenegger, M., and Stead, D. (2009). Quantifying discontinuity orientation and persistence on high mountain rock slopes and large landslides using terrestrial remote sensing techniques. Natural Hazards and Earth System Sciences, 9, pp. 267–287.