Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)

doi:10.36487/ACG_repo/2315_043

Repurposing Autodesk Civil 3D grading tools for natural landform closure design

C Buechler *SRK Consulting (U.S.), Inc., USA*

D Ludwick *SRK Consulting (U.S.), Inc., USA*

JD Pelletier *University of Arizona, USA*

N Abramson *University of Arizona, USA*

S Chataut *BHP Copper, Inc. USA*

Abstract

In mine closure projects, the term landform typically refers to the shape of a facility that is intended to mimic the natural forms of the surrounding stable topography. In arid climates, natural landform shapes may be chosen to increase the erosional stability of the final design. Closure of mine facilities can result in long slope lengths (>240 m) that are exceptionally prone to erosional damage from rainfall. Structural closure strategies of the past have utilized systems of benches and channels to break up long slope lengths, which may pose a long-term risk in some settings. Instead, a convex-concave slope can be utilized to mitigate the erosional risks of long slope lengths through gradual grade changes. To apply these principles to the closure of a tailings dam, this study selected a convex-concave profile to create a three-dimensional (3D) landform that protects an exposed dam face from degradation. However, designing natural landform shapes using typical 3D drafting tools can be a challenge. Traditional grading tools used in 3D drafting software are well-suited for creating straight lines, constant slope gradients, and angular corners. These linear tools can be at odds with evolving thinking in mine closure that is trending toward more natural and geomorphic shapes. Here we describe the methods used to create a 3D landform design surface in Autodesk Civil 3D (Civil 3D). Corridors in Civil 3D typically follow similar rules, utilizing linear slopes and sharp grade changes within subassemblies to create corridor elements, such as sidewalks, curbs, and roadways. In our design, these corridor design tools were repurposed to create a curvilinear landform shape. This closure strategy was implemented on a tailings dam that consists of a main embankment and two wingwalls positioned at offset angles from the main embankment. To start, an alignment was positioned at the crest of the new landform to control the slope radii at the existing dam corners and to control the primary direction of surface water flow. A design profile was created to minimize variations in elevation and prevent flow convergences on the landform slope. A convex-concave slope profile was defined in Civil 3D, and a custom subassembly was created from the landform. The landform design surface was then created from the corridor utilizing subassembly codes and corridor feature lines. Through the creative application of Civil 3D design tools, we can create an innovative design surface for long-term mine closure.

Keywords: *landform, slope, curvilinear, embankment, crest, grading, corridor, subassembly, assembly, surface, Autodesk Civil 3D*

1 Designing for erosional stability of a mine waste facility closure

The objective of this paper is to address a specific aspect of physical stability of closure design: the practical design of closure landforms to resist erosion due to surface water runoff. This paper omits the theory of surface water flow and erosion, as well as the mathematical prediction of where and how erosion occurs, since this is covered in detail by others (for example, McKenna and Dawson 1997; Hancock et al. 2003; Schor and Gray 2007; Hancock et al. 2020). While various resources exist for how to model and predict erosion, there appears to be limited instruction for a working designer to convert landform concepts onto paper. There are certainly many different and creative methods currently being employed in the industry; this case history presents one example of the techniques used for a landform design for the BHP Copper Inc.-owned Solitude Tailings Facility located in Arizona, USA, using commonly available civil design tools (Figure 1).

Figure 1 BHP Copper Inc.'s Solitude Tailings Facility was constructed using a starter berm and upstream raises, was operated from 1928-1959, and contains ~116 million tonnes of copper porphyry tailings

1.1 Traditional reclamation design using structural layouts

With some limited exceptions, traditional reclamation design for mine waste facilities have relied on a structural design approach where surface water runoff is controlled by a network of straight slopes, set bench intervals, and engineered drainage channels to break up long slope lengths and control surface water (Figure 2). The result is what Schor and Gray (2007) described as a man-made environment with few redeeming aesthetic visual qualities. In addition to visual impact, structural reclamations can be tricky to design and have a mixed history of success and failure. Structural layouts have a tendency to "blow-out" when channels overtop or downdrains fail (Figure 3). We believe the prevalence of these anti-landscapes to be founded in practical demands on the designer that grading plans be cost effective, efficient to design, and simple to construct. Furthermore, the modern implementation of structural closure designs is perpetuated by a tailwind of linear-oriented tools used in civil engineering, such as AutoCAD. It should be noted here that some legacy sites are space constricted and may require the use of structural design components; therefore, the design engineer should be prepared to evaluate both options. Grading tools specifically are rooted in architectural toolsets that are simply linear based: straight lines are the easiest to use. However, tools are improving every day, and more curvilinear possibilities are becoming available. For the long-term stability of waste covers, the geomorphic approach has gained increasing attention since the mid 2000s, arising as an alternative to the more traditional structural approach (Hawley and Cunning 2017). Today, a design for a mine facility reclamation must not only meet engineering criteria (such as geotechnical and environmental requirements) but also cultural and social ideals that also consider the visual impact and appearance of the reclamation design.

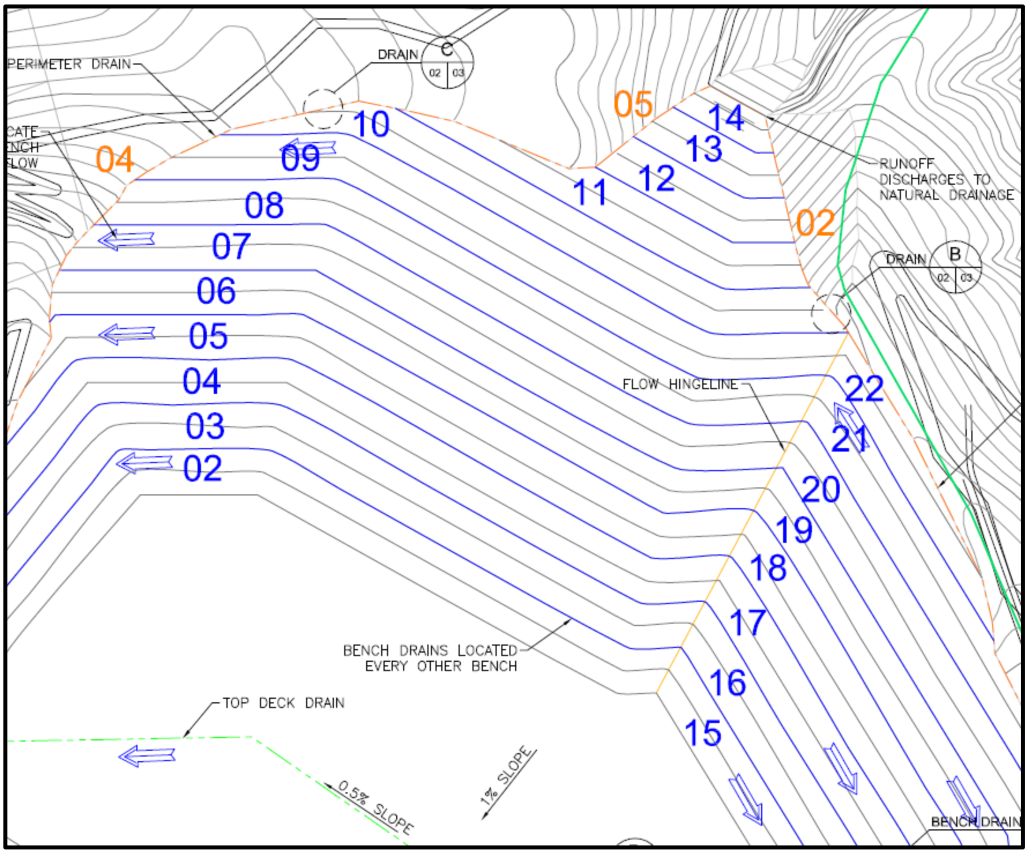

Figure 2 Example of a structural conceptual closure design for a long slope (>400 m) using a series of benches and lateral drains to control surface water runoff

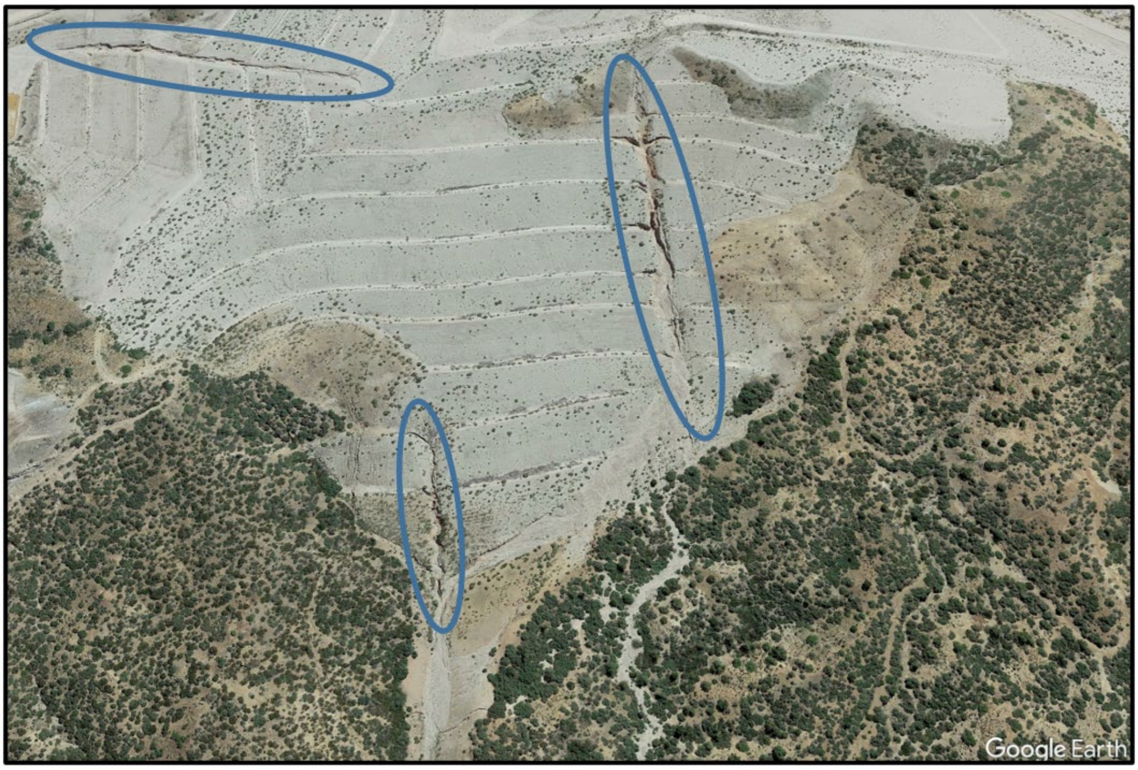

Figure 3 Example of an unsuccessful implementation of a structural tailings closure design (Google Earth, 2023); note the failed down drains undergoing severe gullying and cover damage

1.2 Definition of a landform

The design of slopes that are intended to mimic a natural landscape's appearance is known as landform design, sometimes referred to as geomorphic designs. The term landform refers specifically to the use of natural landform shapes which more closely mimic the surrounding landscape (in contrast to structural designs which lack the organic forms that blend with an existing landscape). Landform grading essentially attempts to respect the underlying, basic landforms by preserving or replicating them and their associated vegetative patterns and recreate or mimic important, stable natural hillsides with their rich variety of different slope elements and forms (Schor and Gray 2007). Landform design slopes must still adhere to the governing engineering criteria in terms of geotechnical and environmental safety as well as provide a new balance between slope appearance and construction complexity.

Different interpretations of a landform exist depending on the geography and geology of a specific site. Accordingly, what geomorphic means may vary, and the complexity of a landform shape may range from complex geofluvial networks to more-simple curvilinear slopes. Regardless, the approach for final landform design and planning should be the result of observation of the local climate, native hillside slope and soil characteristics, borrow material characteristics (especially when relating natural analogues to a design), the performance of locally relevant historical reclamation practices and, when possible, should be supported by numerical models with the ability to simulate the evolution of landforms subject to runoff and erosion over long periods of time. The analysis of local hillslopes is an applicable practice in cases when the designed landform will utilize a geotechnically similar soil material for construction. For some sites, a landform design offers not only visual improvements, but when constructed with appropriate construction materials, the designs may be more naturally resistant to surface erosion and therefore require less maintenance than a closure design with benches or cross-slope containment channels. The ideal outcome is equal or better in terms of closure safety, improved social acceptance, and a reduction in maintenance requirements that allows site owners to move more-rapidly toward a passive care (Canadian Dam Association (CDA) 2014) closure scenario.

1.3 Catena slope profile

In this paper, we will focus on a project utilizing landform design for the reclamation of the Solitude Tailings Facility, a closed historical tailings dam. The tailings dam footprint covers approximately 2 square kilometres (km^2) and sits behind an embankment that is approximately 1,830 m across and has a maximum height of 75 m. For the safe reclamation of this dam, a stability buttress is required. The buttress will be set at a 4H:1V slope extending from the toe to approximately mid-height of the existing embankment. Both the stability buttress and the landform design will utilize soil that has been sourced from local hillslopes. The new construction of the buttress and the eroding condition of the existing embankment required a landform that would serve as a protective cover from erosion for both the upper half of the existing dam embankment and the new stability buttress.

To select the shape of the slope to be used for the designed landform, the project team examined the native hillslopes that surrounded the project site to develop a natural analogue landform. Use of natural analogues as a strategy provides recognition that designers cannot fully understand the intricacies and interactions of various landform elements, e.g. substrate, reclamation material, flora and fauna, climate. Replication of natural analogues is an attempt to mimic their form and function on the reclaimed landscape (McKenna, et al. 2011). This approach was deemed appropriate since the surrounding hillsides are formed of unconsolidated Gila Conglomerate and will serve as the borrow source for both the buttress and landform fill. In addition to evaluating different landform profiles, the team considered construction complexity, overall cost, and a wide variety of other selection criteria (see Peroor et al. 2019 for more detail). The results of this analysis led the team to identify a catena profile shape that combines a convex curve near the crest of the slope and a concave curve near the toe of the slope as the ideal landform profile for this specific site. The convex-concave catena profile is also documented elsewhere in literature as being an efficient landform shape (Schor and Gray 2007; Priyashantha et al. 2009; Hancock et al. 2020). A concave slope formation anticipates the ultimate equilibrium of the slope and therefore establishes a mature landform from the start (Schor and Gray 2007). The selected catena profile can be seen on Figure 4. The cross-section includes the existing tailings embankment, the stability buttress, and the landform profile shown overtop. The steepest slope on the selected profile is 3H:1V and occurs in the upper portion of the slope. As the slope length of the profile increases, the slope of the landform begins to shallow; the slope at the bottom of the selected profile is 5H:1V. This gradual grade change makes the slope more naturally resistant to erosion even as the length of the slope increases.

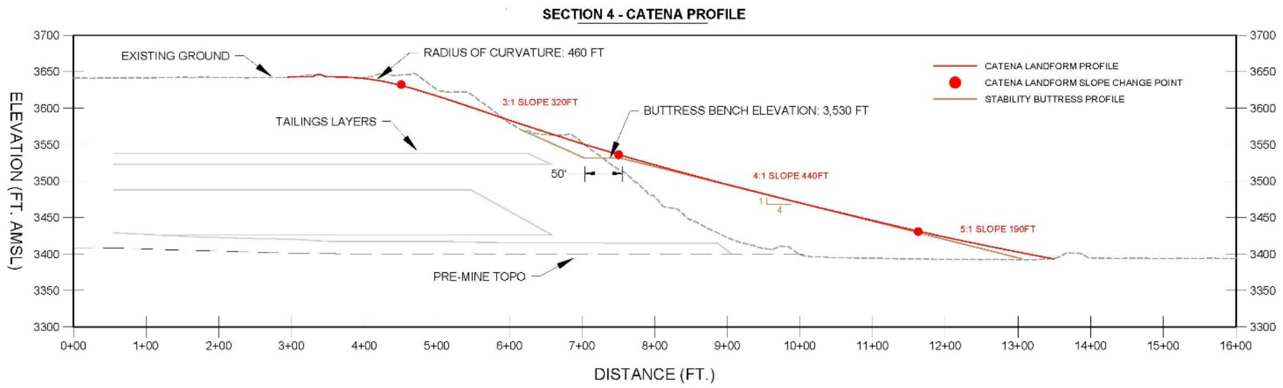

Figure 4 Catena slope profile laying directly overtop the existing tailings embankment and the designed stability buttress; the landform slope serves as a protective layer for the buttress, which must remain undisturbed

It is worth noting here that when the catena profile is applied to a design in 3D, it is critical to assess where and how planform curvature is expressed: divergent slopes tend to be erosion resistant, while convergent slopes tend to promote erosion.

2 Design methods for reclamation

2.1 Standard grading methods and surface creation

Civil 3D was the primary design program used in our tailings reclamation project. In this section, we will review the program's civil design capabilities and how we can apply those capabilities to landform design. Civil 3D boasts a variety of tools and functions utilized for grading and surface creation within its 3D-based design environment. In Civil 3D, to perform a grading function refers to the projection of a 3D object at a specified grade, slope angle, or percentage for a specified distance. The grading functions within Civil 3D are the basis for all surface creation and 3D design. Once a grading function has been performed, the initial 3D object and the newly created grading object can be used to define a 3D surface. Civil 3D has multiple tools that can be used to perform grading functions, such as feature lines, grading groups, and corridors. These tools perform similar functions but vary in application and capability. Unlike corridors, feature lines can only be graded at a single, specified slope angle for a specified distance. Thus, in the context of landform design, corridors can be considered a much more applicable tool.

2.1.1 Corridors

Corridors are a powerful grading tool in Civil 3D with a wide variety of civil design applications. Corridors are similar to feature lines but are capable of more-advanced grading functions, such as the grading of multiple slope segments in series. As an example, corridors are typically used for grading and creating the design surfaces used for constructing roads and intersections. A single corridor can create the grading areas and slopes necessary for designing a paved road with curbs, sidewalks, and cut-to-fill slopes on either end of the sidewalks. An example of a standard corridor cross-section can be seen on Figure 5.

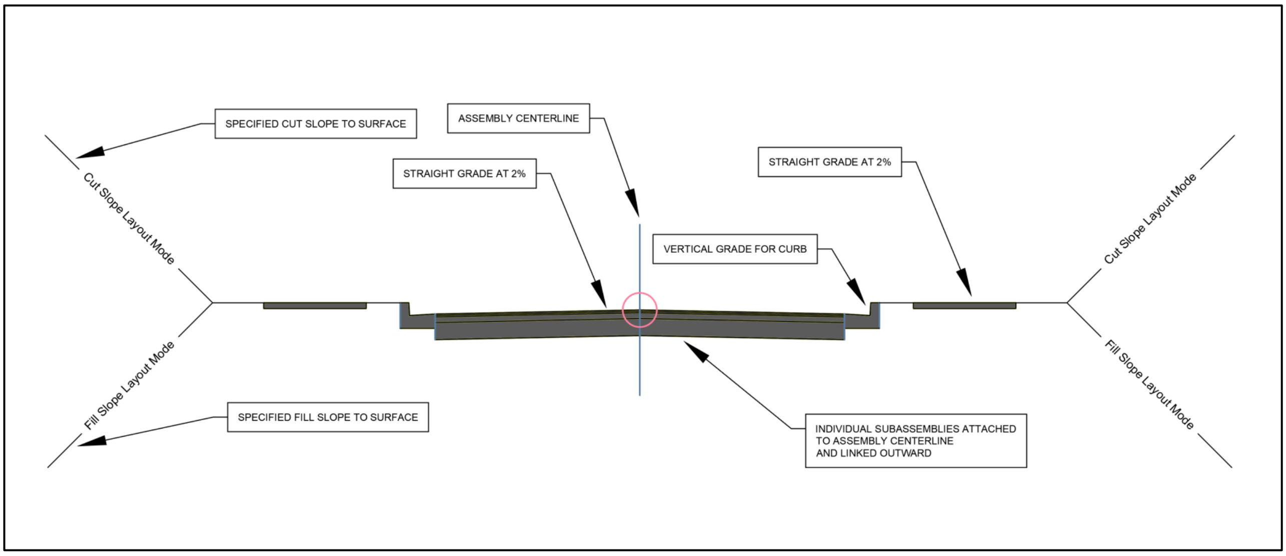

Figure 5 Standard Civil 3D corridor cross-section as applied to a roadway; this cross-section creates the grading slopes for a two-lane road, curbs, sidewalks, and cut to fill daylight grades

Corridors share a similarity with feature lines in that a lateral baseline must be established as the grading source. A baseline is established through the creation of an alignment, and the vertical data is established through the creation of a design profile. The design profile used here is comparable to the 3D vertices used in a feature line. The basis of the grading functions within a corridor is an item known as an assembly. An assembly is attached to the corridor baseline and serves as the starting point for the creation of a cross-section within the corridor. Corridor cross-sections can be built and customized by the user to satisfy multiple grading requirements.

Corridor cross-sections are built and attached to the assembly using individual entities known as subassemblies. Note that as subassemblies are individual components of a cross-section; each subassembly may perform only a single, specific grading action at a single, specified slope angle and distance. Subassemblies can be attached to the end of other subassemblies as the cross-section is built outward away from the assembly and corridor centreline. Civil 3D contains many template subassembly formations that can be used to quickly perform several grading scenarios at once; an example of these subassemblies is seen on Figure 5.

2.2 Using corridors for landform grading

As described above, the capability of corridors to create a grading slope containing multiple segments with varying slope angles makes it the most appropriate tool in Civil 3D for grading in landform design. Civil 3D is packed with pre-built subassembly components for items ranging from paved road lanes to medians, curbs, ditches, and even retaining walls. The key aspect to these pre-built subassemblies is that they are a combination of straight graded slopes placed one after another to form the required shape. A curve cannot be created as a subassembly. Instead, a curve can be created by compiling multiple short subassemblies together creating a linear approximation of a curved slope.

The catena profile selected by the project team and seen on Figure 6 connects multiple curves together of varying radii as the profile moves from convex to concave. As the slope length of the catena profile grows, the slope angles continually become shallower. Because of the complexity of the selected catena profile shape, the spline tool was used to create the profile within Civil 3D. The spline tool is useful in this case, as it helps to maintain proper tangency between the curves of the profile even as the profile was modified and edited throughout the design process. Once the final landform profile had been selected, the profile spline was turned into a two-dimensional (2D) polyline using the polyline creation command PEDIT. At this step is when Civil 3D will perform the linear approximation of our profile curves. When turning a spline into a polyline, Civil 3D will ask for a precision factor ranging from 0 to 99, with 99 being the most accurate linear approximation of the spline. For our purposes, a precision factor of 99 was used during this step.

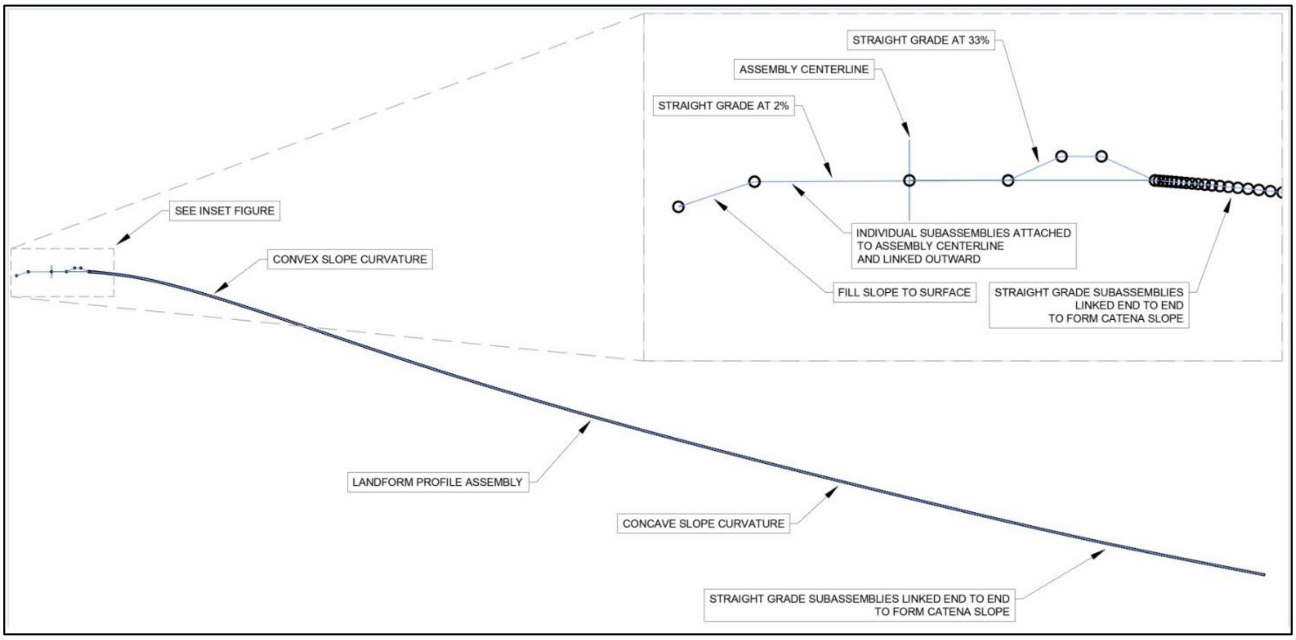

Figure 6 Landform profile assembly created using a spline, polyline, and subassembly creation tool

Along with the array of pre-built subassemblies, Civil 3D offers the user the freedom to create subassemblies that fit their needs by allowing for subassemblies to be built from user created polylines. The Create Subassembly from Polyline tool was used to turn our landform profile from a polyline into a single link subassembly. The newly created landform subassembly could then be added to our main corridor assembly. To complete the assembly cross-section of our landform profile, standard Civil 3D subassembly components were used to add specific design details to the profile, such as a crest berm, access road, and a 3H:1V daylight slope on the upstream side of our profile. These details can be seen in the upper left portion of the overall landform assembly, which can be found on Figure 6. The creation of our landform profile subassembly is the key step in this workflow, as it allows for the implementation of a curved slope into a design corridor, which will allow for the grading and 3D surface creation of that curved slope. Figure 6 shows the final design assembly, including the landform subassembly and other subassembly components that were created using the steps details above.

3 Final landform design

3.1 Crest alignment

With the landform profile shape selected and the landform assembly created, the first step in creating a 3D design from these 2D profiles was to establish an alignment and a design profile that would serve as the crest of the future landform. The primary design purpose for the establishment of the landform crest was to minimize the fill required to construct the landform over the stability buttress while ensuring that the design slope of the landform does not infringe upon the extents of the buttress. The second goal for the crest alignment and the profile design was to minimize areas of flow concentration on the face of the slope. The Solitude Tailings Facility embankment is 1,828.8 m across and consists of three main areas: a main embankment, a northern wingwall, and a southern wingwall. The crest alignment was designed to reduce the severity of the bends between these three areas of the embankment, with the goal of limiting erosion on the new landform. The design profile of the crest further reduces flow concentration by minimizing variations in crest elevation along the alignment. The landform crest alignment and existing topography can be seen on Figure 7.

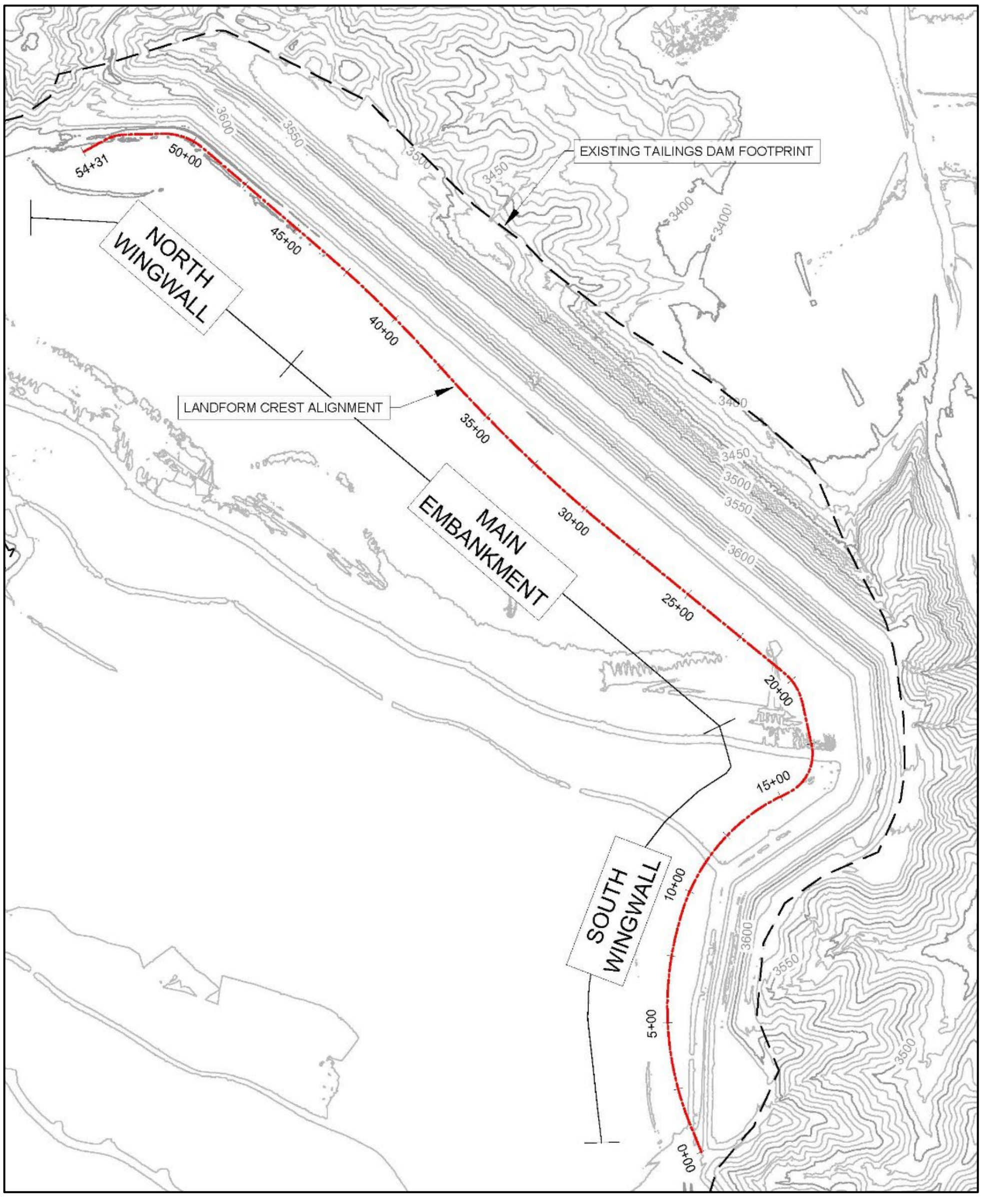

Figure 7 Landform crest alignment with respect to the crest of the existing tailings dam embankment

3.2 Corridor construction

With the crest baseline established and the slope assembly defined, a corridor was then built to perform the 3D grading of our landform shape. For this project, the landform profile subassembly was designed and created so that the profile would be long enough to accommodate the largest slope length required at any point along alignment of the 3D landform design. This means that our landform shape remains the same size at all portions of the alignment. This benefits our design, as it ensures that all curves used to create the landform profile remain uniform, and each of the varying slope segments of the landform retain the same slope length. This also simplifies the design by eliminating the need to scale the length of the profile up or down to match the varying distance from the crest of the existing embankment to the natural ground at the toe. The final landform corridor can be seen on Figure 8.

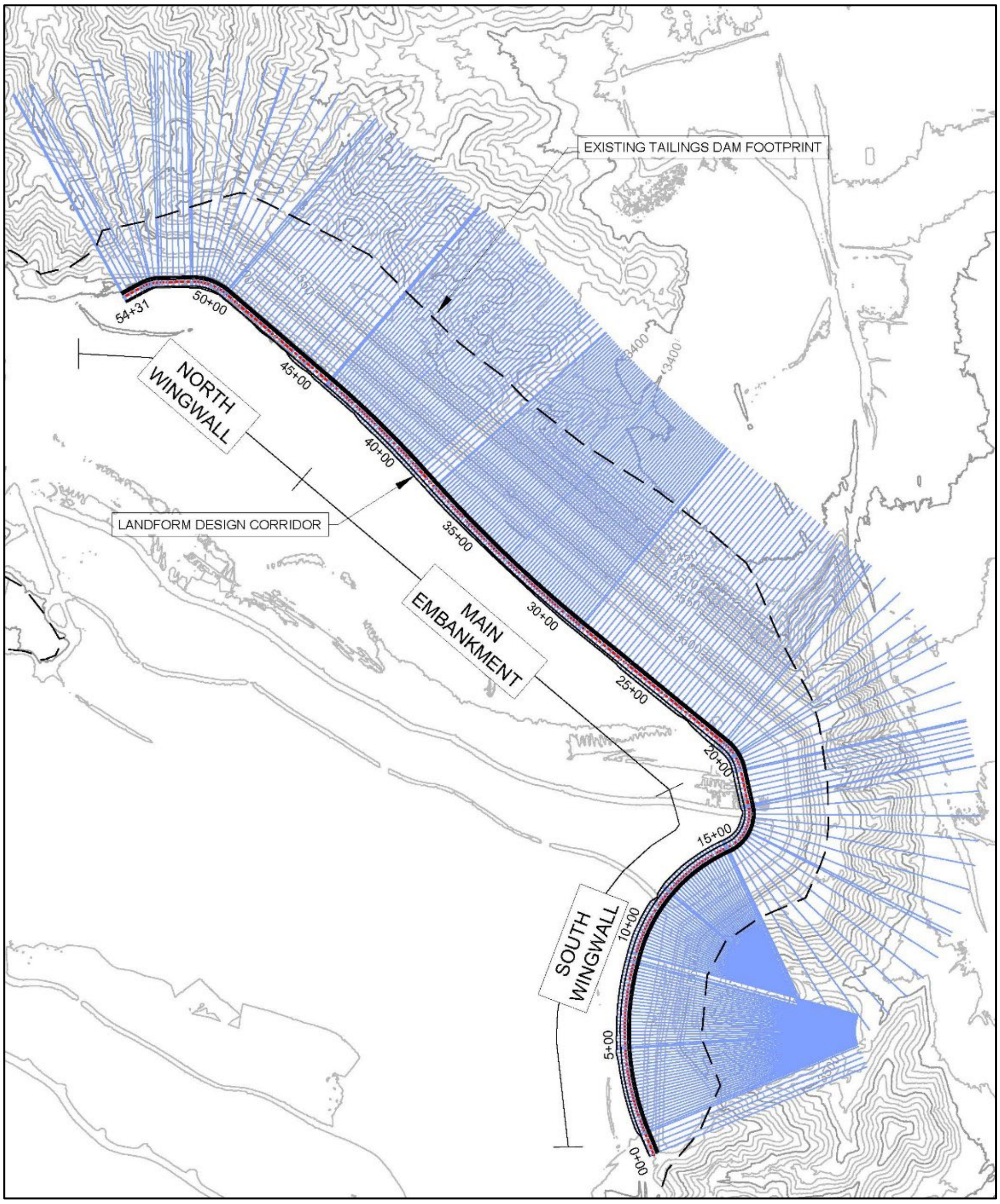

Figure 8 **Landform corridor with the contours of the existing embankment and natural ground seen underneath**

3.3 Surface creation

To create a surface from a corridor that uses a custom subassembly, a subassembly code must be manually assigned to that custom subassembly. An important step from Section 2.2 of this paper is the creation of the custom subassembly as a singular link, which must be specified within the Create Subassembly from Polyline tool. Because our subassembly was created as a single link, the single subassembly code will be applied to the length of the landform profile. If our subassembly were created from a polyline as a multiple link subassembly, the subassembly code would need to be applied to each of the short line segments that make up the curves of our profile.

The corridor surface is created by adding the subassembly links to the surface definition using the same code applied to the landform profile subassembly. In addition to this, feature lines from the other subassemblies were added to our corridor surface definition to properly define the access road and crest berm in the surface. With the completion of this step, our landform slope now existed as a 3D surface. In many cases, the final step of this workflow would be to simply add a boundary to the corridor surface and finalize the design; however, in this project, the complexity of the landform alignment required additional detailed grading in Civil 3D.

In specific locations, complex grading was required to ensure that our design surface daylighted properly with the existing ground and maintained positive drainage throughout the design. To perform these small adjustments, the feature lines and approximately 0.3-m contours were extracted from the corridor surface and used to create what would eventually become the final landform design surface. Creating a new surface defined by the data extracted from the corridor and the corridor surface allows for further definitions to be added that are not corridor related. In this case, feature lines were used to grade in small features and adjust slopes where necessary and were added to the final definition of the landform design surface. The final landform design surface contours can be seen on Figure 9, with the existing ground contours in the background. On Figure 10, two 3D renderings can be seen: the first is of the existing tailings dam, and the second is the tailings dam with our proposed landform design constructed over the existing embankment.

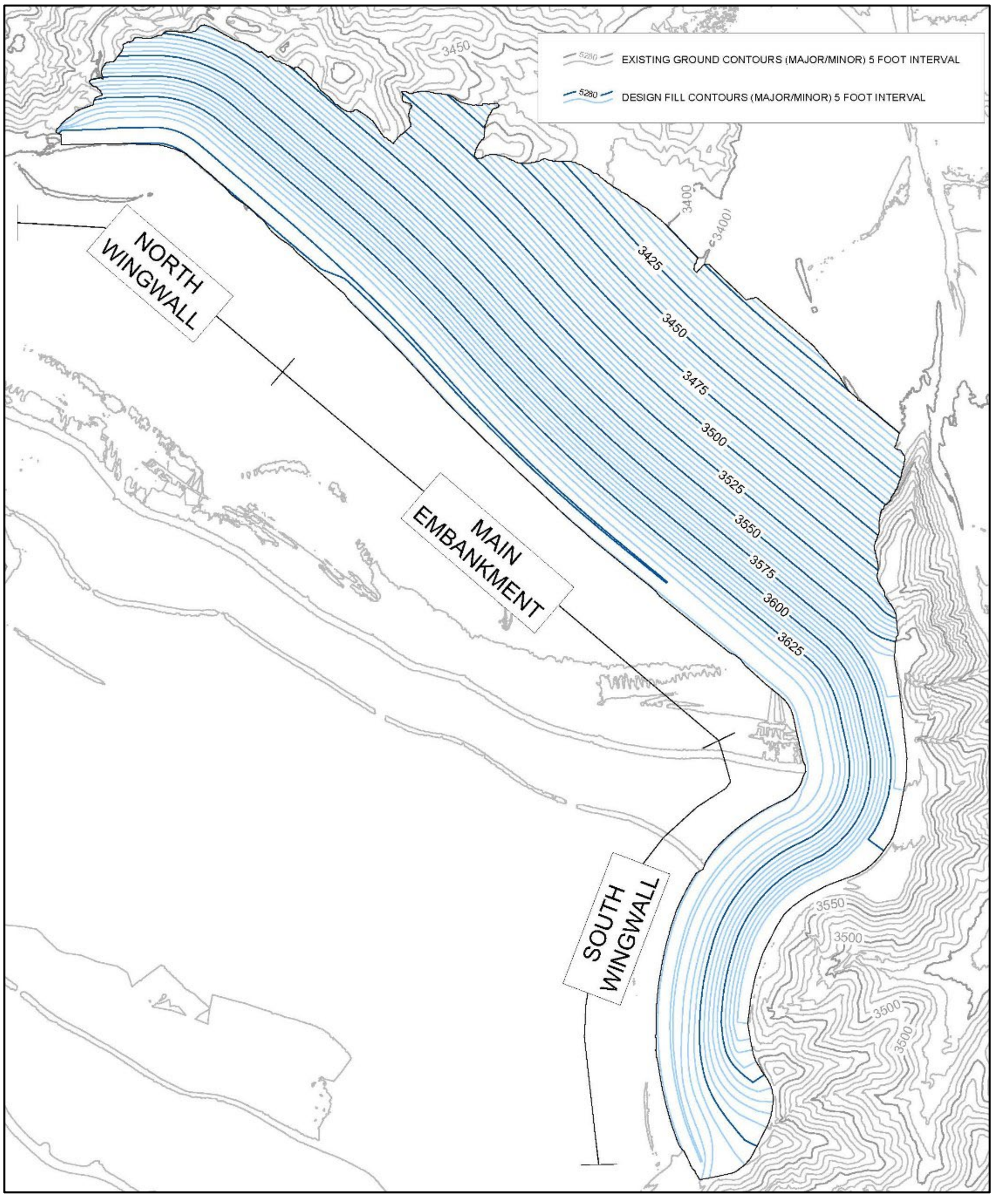

Figure 9 **Final landform surface contours with the contours of the existing embankment and natural ground seen underneath; note that perimeter surface water controls are included in the design but omitted from this figure**

(a)

(b)

Figure 10 3D renderings of (a) existing conditions and (b) designed conditions at our project site

4 Conclusion

The concept of landform design is a relatively new one, and in many cases the design tools at our disposal may limit our ability to implement these new designs. Traditional closure and reclamation methods are easy to design and easy to construct, as there are plenty of design programs capable of creating straight grade designs quickly and easily. The goals of landform design are aimed at creating designs that will improve on existing reclamation methods by creating low maintenance slopes that will perform better over longer periods of time. As designers of these landforms our biggest challenge is finding the balance between what our tools, both in the office and in the field, allow us to reasonably create while also pushing the boundary of what a standard reclamation project should look like.

The workflow detailed in this paper is one example of implementing recent landform design principles using the tools currently available to us. Improvements to this workflow will continue to be made as landform design becomes a more standard practice. These improvements could come in the form of new design programs made specifically for creating curved slopes or as new tools or methods within Civil 3D. For example, the ability to terminate a custom subassembly from polyline at the daylight with a specified surface, regardless of where the daylight falls within the subassembly, would eliminate the need for the manual creation of a daylight boundary. Additionally, the ability to grade slopes with a specific radius of curvature from a feature line would eliminate the need to create curved slopes in a corridor and export the curved slope data from the corridor for continued feature line grading.

As the design costs of these projects are reduced through faster methods and better tools, better landform designs will be created by more designers, and these designs will be more economically feasible for more site owners. Improvement of these design methods is a key for the advancement of landform design as an industry standard.

References

Canadian Dam Association (CDA) 2014 (2019 ed.), Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams.

Google Earth 7.6.3 2023 (Image date May 3, 2019), Map showing covered waste rock dump – undisclosed location. Google Earth, Accessed May 2, 2023.

Hancock, GR, Loch, R, Willgoose, GR 2003, The design of post-mining landscapes using geomorphic guidelines. Earth Surf. Process. Landf. 28, 1097–1110.

Hancock, GR, Martin Duque, JF, Willgoose, GR, 2020, Mining Rehabilitation – Using geomorphology to engineer ecologically sustainable landscapes for highly disturbed lands. Ecological Engineering 155.

Hawley, M, Cunning, J (Eds.) 2017, Guidelines for Mine Waste Dump and Stockpile Design. CRC Press.

McKenna, G, Dawson, RF 1997, Closure planning practice and landscape performance at 57 Canadian and US mines.

McKenna, G, Scordo, E, Shuttleworth, D, Straker, J, Purdy, B, Buchko, J 2011, Aesthetics for mine closure, in AB Fourie, M Tibbett & A Beersing (eds), Mine Closure 2011: Proceedings of the Sixth International Conference on Mine Closure, Australian Centre for Geomechanics, Perth, pp. 603-612, https://doi.org/10.36487/ACG_rep/1152_63_McKenna.

Peroor, R, Howard, EJ, Braun, T, Chesal, T, Chataut, S 2019, Integration of field erosion measurements with erosion models and 3D civil design tools for development of erosion resistant cover systems, in AB Fourie & M Tibbett (eds), Mine Closure 2019:

Proceedings of the 13th International Conference on Mine Closure, Australian Centre for Geomechanics, Perth, pp. 1561-1574, https://doi.org/10.36487/ACG_rep/1915_122_Peroor.

Priyashantha, S, Ayers, B, O'Kane, M, Fawcett, M 2009, Assessment of Concave and Linear Hillslopes for Post-Mining Landscapes. ICARD (8), June 23-26, Skelleftea, Sweden.

Schor, HJ, Gray, DH 2007, Landforming: An Environmental Approach to Hillside Development, Mine Reclamation and Watershed Restoration. Wiley.