Concave batter slopes on constructed landforms

For minesites, the concept of using concave slopes to create more stable outer batters on waste dumps and tailings dams is considered innovative.

But in nature, concave slopes have been forming for millions of years. Geographers have long recognised a slope-area relationship that basically indicates that as catchment area increases, gradient decreases (Gilbert 1909; Strahler 1964; Flint 1974). The classic hillslope profile is a convex upper section and a concave lower section, unless the upper section of the slope is controlled by a resistant cap, in which case the concave profile commences at the top of the slope.

Minesite application

For minesite landforms, Landloch has recommended and designed concave slope profiles for a number of years. There are two main benefits from this profile:

(a) it avoids the major problems associated with more engineered slopes, which generally require maintenance **in perpetuity** if berms and rock drains are to remain effective. Such slopes are typically heavily gullied due to overtopping and failure of the berms and drains (see below, and Landloch's article on gullying). Effectively, such slopes are "brittle", becoming completely dysfunctional once their capacity to retain or convey flow is overcome in some extreme event.

(b) the concave profile typically reduces erosion by a factor of 2-5, depending on slope height and material properties.

Concept validation

Conceptually, concave slopes "work" by having steepest gradients at the top of the slope where the amount of runoff is least, and reducing gradient as slope length and the quantity of runoff increase.

Experimental information demonstrating the benefits of concave slope profiles is surprisingly limited. The clearest information comes from Young and Mutchler (1969), who compared linear, concave, and convex slopes all of the same length and gradient, for a range of crops. Their data show a 2-3 fold decrease in erosion for a concave slope (Table below). More recently, a laboratory study by Hancock *et al.* (in press) found that sediment loss from concave slopes was approximately half that from linear slopes of similar gradient and length.

Crop	**Average soil losses (t/ha) from plots with slope shapes of:**		
	Concave	**Linear**	**Convex**
Corn	6.9	16.8	18.1
Oats	2.5	6.5	7.2
Fallow	4.6	15.1	15.7
Average	4.8	12.8	13.7

Hadley and Toy (1977) also found erosion on concave slopes to be half that from linear slopes, though their data are confounded by the slopes being at different positions in the landscape, so that the concave slopes were receiving greater runoff, and may not have been at the same average gradient as the linear slopes.

Erosion modeling – for at least 2 different models – also shows concave slopes to reduce sediment yield from a slope by a factor of 2-5 times. This largely confirms (as has considerable other work) that the slope length and slope gradient algorithms in the models are performing accurately. (It also confirms that the models can be used to design concave slopes.)

Slope design

For each landform, the slope design adopted should be site specific – a function of climate, dump height, and material properties. The design is developed using erosion models to achieve a profile that minimises sediment loss from the slope and ensures that erosion rates at any point on the slope are kept to acceptable limits. Where possible, rilling is eliminated. Accurate input data on material infiltration capacity, erodibility, and on climate are essential.

It would be extremely unwise to adopt or apply a profile that had been developed for a different site, material or climate.

Landloch has had considerable experience with the design and construction of concave slopes, with accurate construction being just as important as the proper design.

Examples

A number of concave slopes have now been constructed. Observations both of those slopes and of natural concave slopes confirm that the concave profile achieves considerable stability. Examples of some of the slopes that have been constructed using Landloch designs are shown below.

Concave slope – tailings dam outer batter

Gentle concave slope on a waste dump – newly formed slope

Tailings dam outer batter – berm near top and concave slope below it.

Waste dump – WA goldfields

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