rocscience

RocTopple

Toppling Analysis and Support Design of Rock Slopes

Theory Manual

Safety Factor Calculations – Block-Flexure Toppling

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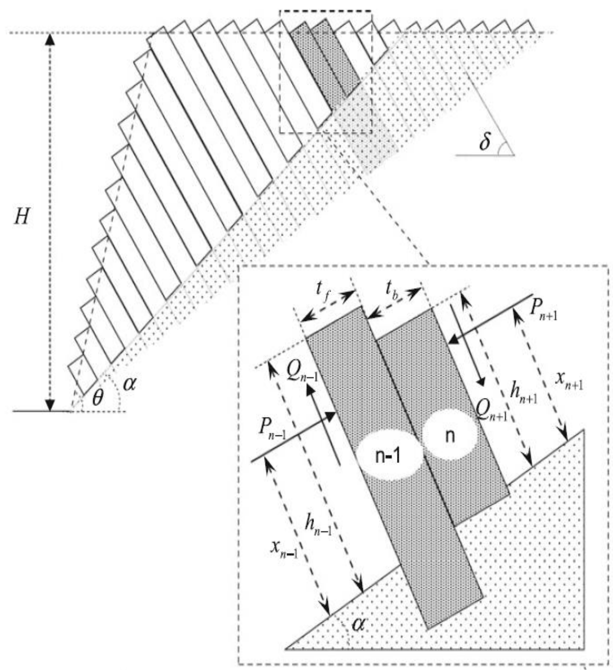
Block-Flexure Toppling Calculations

1. Introduction

This paper documents the calculations used in *RocTopple* to determine the safety factor using the **Block-Flexure Toppling** model. Proposed by Amini, Majdi and Veshadi in the literature “Stability Analysis of Rock Slopes Against Block-Flexure Toppling Failure”, the model calculates the FS of a slope with the potential to fail under both block and flexural toppling. The hypothetical model assumes that the slope of interest is composed of blocks that fall into one of the following 2 categories:

1. Block only subjected to only **Block Failure** (denoted as “Type 1 Block”)
2. Block only subjected to **Both Block and Flexural Failure** (denoted as “Type 2 Block”)

Note that no two blocks of the same category can exist adjacent to each other. In other words, blocks of different types are organized along the slope in alternating fashion.



2. Type 1 Block Analysis

The analysis of Type 1 Block is similar to that of the Goodman and Bray Model. For more information, please refer to the ***RocTopple* Theory Manual–Factor of Safety Calculations–Block Toppling**.

In summary, the critical $P_{n-1} = \max(P_{n-1,t},\ P_{n-1,s})$

The critical P_{n-1} for Type 2 Block is: $P_{n-1} = \max\,(P_{n-1,f}, P_{n-1,sh})$

3. Type 2 Block Analysis

The critical P_{n-1} for Type 2 Block is: $P_{n-1} = \max\,(P_{n-1,f}, P_{n-1,sh})$

3.1. Flexural Bending Force $P_{n-1,f}$

Let the pivot be at the center-base of the block (as opposed to left corner of the base), the governing moment equilibrium equation cam be expressed as follows:

$$P_{n-1} * L_n + \; Q_{n-1} * \frac{bedding\ width}{2} = P_n * M_n - \; Q_n * \; \frac{bedding\ width}{2} + \; driving\ weight * \frac{Y_n}{2} - \; M$$

Where M is the bending moment given by:

$$M = \frac{2I}{bedding\ width}\left(\frac{\sigma_t}{FS} + \frac{R_n}{beddingwidth}\right)$$

$$R_n = \; resisting\ weight + Q_n - \; Q_{n-1} + \; \sum(external\ forces\ in\ y)$$

So finally, we have

$$\begin{aligned} P_{n-1} * L_n + \; f(P_{n-1}) * \frac{bedding\ width}{2} \\ &= P_n * M_n - \; Q_n * \; \frac{bedding\ width}{2} + \; driving\ weight * \frac{Y_n}{2} \\ &- [\frac{2I}{bedding\ width}\Bigg(\frac{\sigma_t}{FS} \\ &+ \frac{resisting\ weight + Q_n - \; Q_{n-1} + \; \sum(external\ forces\ in\ y)}{beddingwidth}\Bigg)] \end{aligned}$$

where P_{n-1} is the only unknown we wish to solve for, and f is the shear function. Brent's method was used to solve for P_{n-1}.

Occasionally, the contribution of bedding shear to the normal force will give rise to abnormalities in $P_{n-1,f}$ calculation. To resolve this issue, the above calculation is repeated once more, with the exception that:

$$R_n = \; resisting\ weight + \; \sum(external\ forces\ in\ y)$$

and the final $P_{n-1,f}$ is taken to be the minimum of the two $P_{n-1,f}$.

3.2. Shear Force $P_{n-1,sh}$

The calculation of $P_{n-1,sh}$ is very similar to that of $P_{n-1,s}$. The only difference is that the force is no longer assumed to act on the base of the original block, but on the new fractured surface of the rock. For simplicity, it is also assumed that the fractured surface is positioned at the location of the base of the block. (or on the linear plane where the block lies).

4. Geometry Limitations of the Block-Flexure Model

In the Goodman and Bray Model, the slope is constructed by series of stepwise increment. The size of each step is determined by the difference is between the bedding dip angle and the overall base inclination level.

In the Block-Flexure Model, the slope is linear. As a result, bedding dip angle and the overall base inclination level have a fixed relationship in that:

$$overall\ base\ inclination = 90 - dip$$

A linear slope guarantees that there are no individual blocks to be considered.