LANDSLIDES IN VALLES MARINERIS, MARS: AN ANALYSIS OF FAILURE TYPES TO ASCERTAIN ROCK MASS PROPERTIES, PREDISPOSING AND TRIGGERING FACTORS.

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Introduction: Several gravitational failures which resulted in a series of large landslides up to several hundred cubic kilometers in volume are present in Valles Marineris (VM) in the equatorial area of Mars. The failures resulted in a series of long-runout landslides and the formation of sub-circular alcoves. In this work we address questions on the forces and strength at play in the stability of the walls of VM by analysing the strength of the materials of the chasma walls and the possible causes of landslides.

We test the following work hypotheses: i) a curvilinear failure surface is more suitable to explain slope instabilities and to estimate rock mass properties; ii) martian rock masses are not so weak as previously determined but resemble their earth equivalent; iii) cross section areas of failed slopes can be used to calibrate values for rock mass properties; iv) meteoritic impact-induced seismicity or seismic triggering are compatible with landslides and rock mass properties.

Methods: Using finite element calculations and the limit analysis upper bound method, we explore the range of cohesion and friction angle values associated to realistic failure geometries, and compare predictions with the classical Culmann's wedge model [1]. Finite elements analysis and log-spiral limit analysis are used to validate both failure geometry and the critical values for rock mass strength.

Our analysis is based on synthetic, simplified slope profiles (different heigh and slope angle) and also on the real shape of the walls of VM taken from the MOLA topographic data. Validation of the calibrated cohesion and friction angle values is performed by comparing the computed unstable cross sectional areas with the observed pre- and post-failure profiles and estimated failure surface geometry. This offers a link between rock mass properties, slope geometry and area or volume of the observed failure.

Results: A set of solutions in dimensionless form derived from limit analysis having assumed rotational mechanisms with a log-spiral failure surfaces has been derived (Fig. 1).

The set provides values of cohesion, friction angle and landslide areas for any assigned slope inclination. Pseudo-static seismic analyses generated another set of dimensionless charts for various values of horizontal acceleration expressed in terms of critical seismic coefficient K_h ($g_{mars}K_h$ is the maximum horizontal seismic acceleration where $g_{mars} = 3.7$ m s^{-2}).

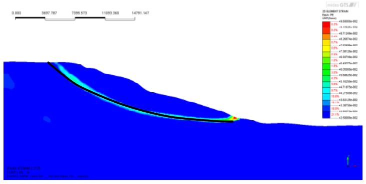

Fig. 1.Example of maximum shear strain field computed by FEM analyses for a real slope profile of VM taken from MOLA topography data. The black line is the prediction from the limit analysis.

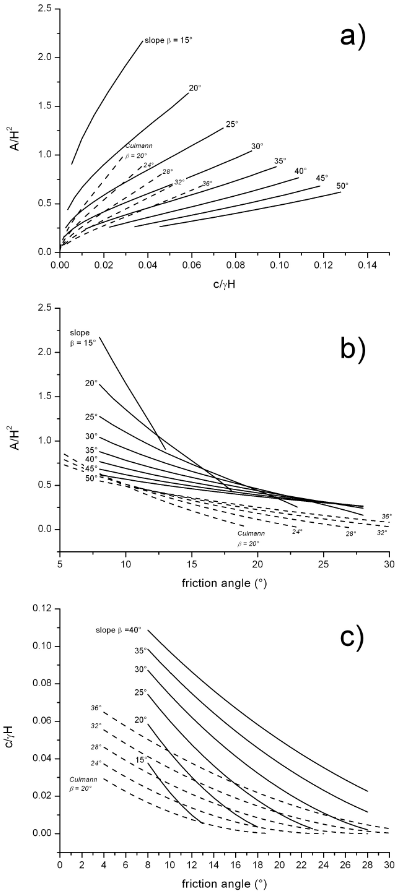

Figure 2 - Solutions in dimensionless form for different slope angles as from limit analysis (continuous lines) for log-spiral rotational mechanisms and Culmann planar (dashed lines) solution.

From our analyses, it emerges that Culmann's method allows only crude estimate of strength parameters for the rock walls of VM (see Figure2a,b, c). Moreover, if rotational landslide mechanisms with a log-spiral failure line are considered, the observed failure surfaces and landslide volumes of VM walls are in good agreement. Then, our pseudo-static analyses show that low seismicity events (Figure 3) induced by meteoroids with size compatible with the craters diameter (see Figure 4), would create seismic horizontal average accelerations of the order k_h=0.2-0.3 and, with few exceptions, maximum values k_h=0.5. Thus, in principle meteoroid impact could be a cause for the observed landslides, as also suggested in ref. [5]. However, abundant pieces of evidence suggest that no landslide occurred at sites located along the VM slopes in proximity of impact craters.

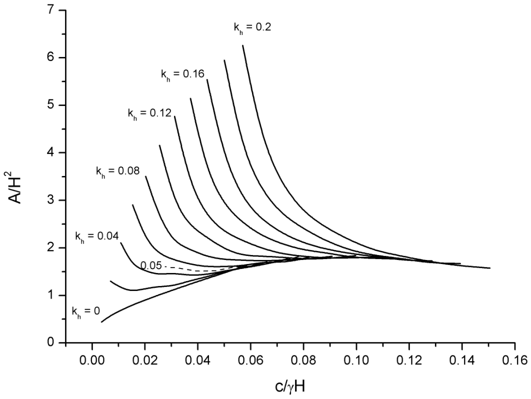

Figure 3 - Dimensionless plot for Limit Analysis method applied considering pseudo-static (K_h) conditions

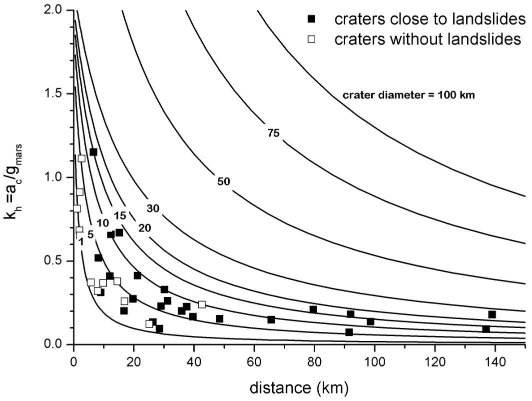

Figure 4 - Curves of horizontal acceleration coefficient (K_h) calculated at different distance from impact craters of different size; energy input calculated from ref. [4] and seismic attenuation from ref. [6].

Conclusions: We present our results by using the same figure settings (Figure 5) adopted by [2] and [3] to resume critical rock mass properties and critical slope heigths.

We show that by assuming a formally correct slope stability analysis method and by fitting correctly the most probable failure geometry, the set of property values are in good agreement with their terrestrial equivalent. However, Fig. 5 shows that a typical seismic load k_h=0.2 does extend the region of instability, but still appears insufficient to explain all the landslides in VM as due to impact loads, especially if intact basaltic rock or volcanic tuff is considered. Probably the presence of layers of softer sediments and weathered rock due to intense cratering prior to the formation of VM should be invoked together with seismic loads to explain the landslides in VM.

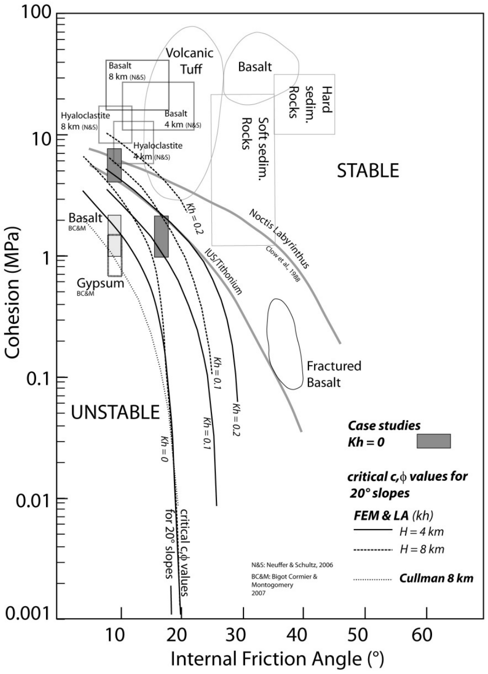

Figure 5 - Curves for rock mass strength properties (c and ϕ) as obtained from limit analysis and finite element simulations compared with results from previous studies and for rock masses on Earth. Data from literature [1], [2] and [3] are also shown.

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