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Back-analysis of a large landslide in a heterogeneous rock mass

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On April 6, 2013 a large landslide occurred on the mountainside about 2 km above Castel dell'Alpi, a small community located on the Savena River valley (Province of Bologna, Northern Apennines, Italy). Three houses collapsed, two were seriously damaged, and the existing roads and infrastructures were destroyed. The landslide was a massive rotational slide about 900 m long, 600 m wide and covering an area of 0.3 km2. The estimated volume was about 3 million cubic meters. According to eyewitnesses, diffuse ground deformations appeared in the morning of April 6 along the road that runs at the toe of the slope, and became more and more prominent during the afternoon. The landslide suddenly accelerated during the night and moved downslope 50 to 100 m in a few hours. Fortunately, residents were alerted by the sound of cracking wood and left their houses in time, thus resulted in no fatalities or injuries. The landslide created a large, bowl-shaped scar with a steep scarp about 70 m height and 800 m long. The head of the landslide moved almost vertically downward and tilted backwards, while ground bulging and compressive structures occurred at the toe. These kinematic features indicate a strong rotational component of the slide, although the high degree of internal deformation suggests a non-perfectly circular slip surface.

It is well known that rotational slides tend to occur in deep homogeneous material such as thick clay soils, weak rocks, or artificial fills. In this case, however, the failure involved a strongly heterogeneous flysch, apparently characterized by good mechanical resistance. The rock belongs to the Monghidoro Formation (Cretaceous sup.-Paleocene) and consists of thinly interbedded sandstone, marl, and shale. The rock mass outcropping on the main scarp is only slight to moderately weathered, with nearly-horizontal bedding planes. Therefore, failure conditions were probably reached within the "fresh" material and, despite its heterogeneity, the flysch behaved as an homogeneous medium at the slope scale. Such a behavior is typical of this rock. A number of old rotational slides can be found in the area, and they all show the morphological features (such as a steep arcuate scarp with exposed bedrock and sub-circular landslide deposit) that characterize rotational failures in homogeneous materials.

The landslide of April 2013 thus provides the opportunity to investigate in depth the mechanical behavior of this complex formation. The analysis mainly focused on the evaluation of the mobilized shear strength at failure. The slope geometry before the failure was reconstructed by combining the pre-failure 5 m DEM, the post-failure 1 m DEM (LIDAR) and the kinematic interpretation of the geomorphological features. Mobilised shear strength parameters were compute by limit-equilibrium and finite-difference back-analyses, considering a wide variation of groundwater head levels, initial stress state, and slip surface depth. The results clearly indicate that the flysch is characterized by low mass strength and small effective cohesion (in the order of few tens of kPa). The mobilized cohesion is much lower than that predicted by the geomechanical classification of heterogeneous rock masses, and casts doubts on the reliability of such estimates for the prediction of large slope instability.