A simplified analysis of the reactivation potential of earthflows

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Some earthflows have a history of multiple reactivations, which are elapsed by periods of rest lasting from a few years to several decades. Numerous earthflows show such pattern of episodic reactivations in the South Eastern Pyrenees. They commonly developed on highly fissured shales, tectonised during the Alpine Orogeny.

This contribution focus on the assessment of the reactivation potential of earthflows, in which reactivation is not caused by sub-continuous or seasonal (static) loading in the source zone, and for which monitoring data are lacking. The approach that is analysed here uses the safety factor (SF) and assumes that: a) simple earthflows are mainly reactivated by a raise of the groundwater level; and b) the lower is the safety factor, the higher is the probability of reactivation.

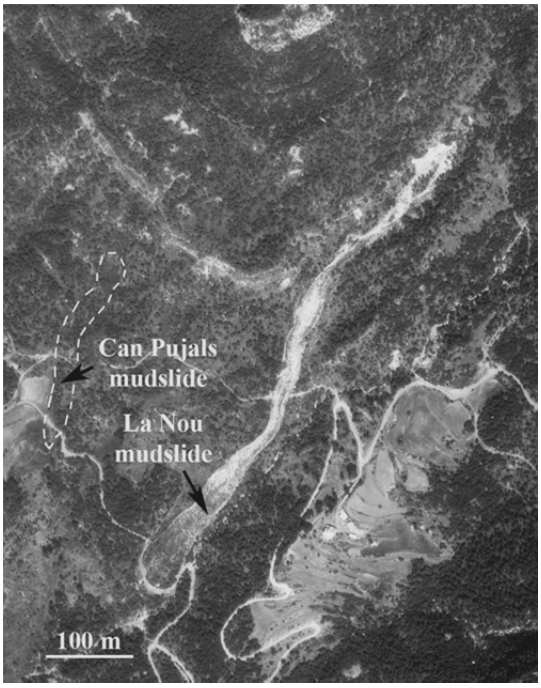

Figure 1. Aerial view of the La Nou and Can Pujals earthflows.

Three earthflows in South Eastern Pyrenees (La Nou, Can Pujals and Malanyeu) were selected within a radius of 2 km (Figure 1). The earthflows are mid-sized and very elongated, from 280 to 900 m long, and have an average width from 25 to 30 m. They developed in 10 to 15º slopes on tectonised silty clay shales of the Garumnian facies (LL = 35-42%, PI= 15-22%). Ring shear tests of samples taken at lateral scarps gave residual friction angles (ϕ_r) of 11º (parent shale) and from 13 to 17º (earthflow material). Rainy periods reactivated the earthflows several times during the last 50 years. Most of the reactivations occurred by sliding of part or whole the pre-existing landslide body, with no overloading of the head of the earthflow body. Other reactivations probably occurred by (episodic) retrogression of the main scarp and the consequent overloading of the pre-existing earthflow body by a new tongue, as it was documented for the last major reactivation of La Nou.

Reactivation by simple sliding of the earthflow body was analysed by a conventional 2D limit equilibrium method (LEM), considering nil cohesion and a ϕ_r from 11 to 15º. The stability of the slope above the main scarp was also calculated for La Nou. The same parameters were used for this latter case, taking into account that the parent shales probably have strength close to the residual even for first-time failures. No boreholes were drilled in the earthflows. Planar and shallow sliding surfaces (from 3 to 7 m deep) were estimated from transversal cross-sections. Two positions for the groundwater table were considered; one below the sliding surface ("dry conditions" or "low position") and other at the ground surface ("high" position).

According to the calculated FS-values (Table 1), La Nou earthflow body would not be stable even in dry conditions. The slope above the main scarp this earthflow would be stable only if ϕ_r is about 15º and if the groundwater table is very low. This latter result was also found for Malanyeu and Can

Pujals earthflows. All these SF-values are regarded as not realistic, because none of the earthflows reactivated since 1986-87.

Table 1. Safety factors obtained by a conventional LEM (no lateral strength) and considering the lateral strength (only the values corresponding to K_0= 0.5 are shown). Values for apparent cohesion due to the lateral strength are also shown (for K_0 = 0.5 and a mean slice width of 25 m, for Malanyeu, and 30 m, for La Nou and Can Pujals).

Earthflow	Groundwater table position	Safety factor (no lateral strenght)		Apparent cohesion (kPa)		Safety factor (lat. strength for K_0= 0.5)	
		ϕ_r= 11º	ϕ_r= 15º	ϕ_r =11º	ϕ_r =15º	ϕ_r= 11º	ϕ_r= 15º
La Nou: earthflow body	Low	0.65	0.90	0.99	1.37	0.79	1.03
	High	0.38	0.52	0.59	0.81	0.51	0.65
La Nou: above main scarp	Low	0.86	1.19	7.85	10.82	1.27	1.6
	High	0.48	0.65	4.74	6.53	0.86	1.04
Can Pujals	Low	0.90	1.24	2.25	3.10	1.02	1.4
	High	0.46	0.63	1.32	1.82	0.52	0.72
Malanyeu	Low	1.08	1.49	2.69	3.7	1.20	1.69
	High	0.55	0.79	1.59	2.19	0.62	0.85

The effect of the lateral strength on stability is neglected in a conventional 2D LEM analysis, although it can be significant for elongated earthflows. Consequently, a second analysis was carried out, including the effect of the lateral strength in a 2D analysis by a simple procedure. The lateral friction force, due to the earth pressure acting on the earthflow sides, was calculated and converted to stress dividing it by the basal area of each slice. Finally, it was considered as an apparent cohesion operating on the sliding surface. A range of K_0-values from 0.4 to 0.6 was used, considering results obtained from soft-oedometer tests.

The values obtained for the lateral strength as an apparent cohesion are not very high (from 0.5 to 13.0 kPa), but played a significant role on the stability of the earthflows. For La Nou earthflow, a ϕ_r of 15º and dry conditions, the SF increased more than 14% and up to 25% for a water table at the ground surface. For Malanyeu and Can Pujals earthflows the increase of the SF is less important, but still significant (between 11 and 14%). Only after taking into account the lateral strength, the SF calculated is higher than unity in dry conditions for most of the earthflows when a ϕ_r of 11º is used, that was the value obtained in the tests for the parent shales. Can Pujals is near equilibrium in dry conditions for a ϕ_r of 11º. However, this earthflow remained stable for the last three decades. A metastable condition was obtained for the most favourable situation of La Nou (SF= 1.03). Such low value of the safety factor should correspond to an almost active earthflow; nevertheless it remained practically inactive since 1987. The above cases suggest that the true value of ϕ_r can be ≥15º. Otherwise, an additional strength should be operating in the earthflows. This situation occurs probably in La Nou earthflow, which shows several changes of movement direction along the track.

The earthflows reactivated showing a return period from 5 (La Nou) to 14 years (Malanyeu). The comparison of the SF with the frequency of past reactivations showed that the lower the SF of the earthflow, the higher their return period of reactivation, as it was expected. Anyhow, a quantitative analysis of these data should be carried out with caution due to the increase of stability after each reactivation. This issue is currently under study for the three earthflows. Last, the approach studied here should be checked, obviously, by a further analysis considering real (borehole) data on the groundwater table and on the sliding surface (or basal shear zone) properties.