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Natural Hazards and Earth System Sciences Discussions

# *Interactive comment on* "Real-time monitoring and FEMLIP simulation of a rainfall-induced rockslide" *by* Zhaohua Li et al.

**Zhaohua Li et al.**

lizheng6224166@126.com

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The article deals with the problem of landslides (rockslide) based on both monitoring and numerical approaches. The article is composed of two parts. The first part is dedicated to the description of the physical problem, the engineering geological properties and the monitoring results. After a successful prediction for an excavation-induced rockslide in 2011, the monitoring system is proven to be suitable to the rainfall-induced rockslide. The second part of the article deals with numerical analysis (using an advanced numerical method, FEMLIP) of the stability problem. The stability is analyzed using the so called second-order work criterion, and a safety factor from numerical calculation is compared with the monitoring data. This paper is convincing and valuable in light of very interesting monitoring system and a deep comparison between in situ



measurements and the advanced computational results. I would recommend publication once after the manuscript has been modified according to the comments provided below.

Specific comments and questions:

- Fig. 5b should be explained. Why the CR-forces are different?

Thanks for your kindly reminder. The CR-forces in Fig. 5b were obtained from the CRLD cables with different specifications. The CR-force is determined by several factors, such as the geometry of the pipe and cone, the frictional coefficient on the pipe-cone interface, the material property of the components and so on. With the elastic assumption, the CR-force can be estimated by the expression as shown in Fig.1 (He et al. 2014).

where P is the CR-force, f is the frictional coefficient on the pipe-cone interface, I_s and I_c are the geometrical and elastic parameters, respectively.

He MC, Gong WL, Wang J, Qi P, Tao ZG, Du S, Peng YY (2014) Development of a novel energy-absorbing bolt with extraordinarily large elongation and constant resistance. INT J ROCK MECH MIN 67(67): 29-42

- p.7, l.1: The author said that ". . .have proposed several successful predictions for rockslides occurred in this zone". All these monitoring data have to be considered as "Big Data", or they can be managed in a usual way without considering an "ad hoc" software to detect some anomalous measurements? In the future, probably some specific Big Data treatments will be necessary.

The monitoring system provides the real-time monitoring data, and sends early warnings according to the increase of the anchorage force. Although we have already quite a few monitoring data, it cannot be considered as a "big data" treatment, which requires much more data to propose reliable predictions.

- How anchors are placed in the rock: inclination, depth, etc. What are the criteria that determine these parameters?

The anchors are placed in the rock generally with an inclination of 25o and a depth of 50-80m. The depth of the CRLD cable depends on the orientation of potential sliding band, such as the fault. The inclination is 25o because it is easy to install the sleeve pipe and the cone.

- I did not understand how the triggering point of the warning system is determined. It is very difficult to discriminate the onset of a slow/gradual sliding and a sudden/quick sliding prior to global failure. This point deserves more discussions.

You are perfectly correct. Our warning triggers are determined, based on a large number of applications in rock slopes. From the stable stage (the anchorage force is constant), if the anchorage force increases 400kN, the yellow warning will be sent, and then, once it increases 300 kN, the orange and red warning will be sent, orderly. Certainly, this is a qualitative prediction, and the in-situ observation is also needed.

- The authors claim that the measuring system is suitable for rockslides due to different triggering factors (excavation, rainfall, etc.). Is it suitable for other types of material? For example, the soil slopes.

Thanks for your question. Indeed, this measuring system was developed initially for rock slopes in open-pit mines, especially in which sliding might occur along certain weak zone (fault, joint, etc). It has been applied in 15 regions in China, with more than 200 monitoring points, and empirical warning criterion has also been obtained according to statistical method. In addition, recently, it has also been used in a soil slope located at Dandong, China.

- p.14, l.7 Give some explanations about the numerical infiltration process modeling.

Thanks for your question. The FEMLIP method used in this study can solve the full hydro-mechanical coupling, according to the previous contributions (Li et al. 2016, 2018). The formulations in the global calculation are written as shown in Fig.2. The



detail of the formations can be referred to the papers (Li et al. 2016, 2018). With the water flux q = 24 mm/h considered in the simulation, the velocity and water pressure fields could be calculated in the grid points and interpolated into material points according to the shape function, at each time step. With the strain and the water pressure in the material points, the stress and the degree of saturation were refreshed according to the constitutive model, presented in the manuscript.

Li, Z.H., Dufour, F., and Darve, F.: Hydro-elasto-plastic modelling with a solid/fluid transition, Computers and Geotechnics, 75, 69-79, 2016. Li, Z.H., Dufour, F., and Darve, F.: Modelling rainfall-induced mudflows using FEMLIP and a unified hydro-elasto-plastic model with solid-fluid transition, European Journal of Environmental and Civil Engineering, 22(4), 491-521, 2018.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-40/nhess-2018-40-AC1-supplement.pdf

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$$P = 2\pi f I_s I_c$$

**Fig. 1.** Estimation of the CR-force with elastic assumption



$$\boldsymbol{A}\dot{\boldsymbol{U}}^{t+\Delta t} + \frac{\boldsymbol{L}}{\Delta t}\boldsymbol{U}_w^{t+\Delta t} = \boldsymbol{F}^{t+\Delta t}$$

$$\boldsymbol{L}'\dot{\boldsymbol{U}}^{t+\Delta t} + \left(\frac{\boldsymbol{S}}{\Delta t} + \boldsymbol{R}\right)\boldsymbol{U}_w^{t+\Delta t} = \boldsymbol{Q}_{ext}^{t+\Delta t} + \frac{\boldsymbol{S}}{\Delta t}\boldsymbol{U}_w^{t}$$

with $\boldsymbol{A} = \int_V (\boldsymbol{B}^T\boldsymbol{D}^{ve}\boldsymbol{B})dV$, $\boldsymbol{L} = -\int_V (\boldsymbol{B}^T\boldsymbol{W}\boldsymbol{N}_w)dV$, $\boldsymbol{M} = \sum\int_V (\boldsymbol{B}^T\chi^t\boldsymbol{m}\boldsymbol{N}_w)dV$, $\boldsymbol{F}^{t+\Delta t} = \sum\left(\int_V (\boldsymbol{N}^T\boldsymbol{b}^{t+\Delta t} - \boldsymbol{B}^T\boldsymbol{\sigma}'^t)dV + \int_s (\boldsymbol{N}^T\boldsymbol{t}^{t+\Delta t})dS\right)$, $\boldsymbol{L}' = \sum\int_V (\boldsymbol{N}^T\boldsymbol{T}\boldsymbol{B})dV$, $\boldsymbol{S} = -\sum\int_V (\boldsymbol{N}_w^T H\boldsymbol{N}_w)dV$, $\boldsymbol{R} = \sum\int_V (\boldsymbol{B}_w^T\frac{\boldsymbol{k}}{\rho_w g}\boldsymbol{B}_w)dV$, $\boldsymbol{Q}_{ext}^{t+\Delta t} = -\sum\left(\int_{Sw}(\boldsymbol{N}_w^T q^{t+\Delta t})dSw - \sum\int_V (\boldsymbol{B}_w^T\frac{\boldsymbol{k}}{\rho_w g}\boldsymbol{b}_w)dV\right)$.

**Fig. 2.** Global formulation of hydro-mechanical coupling within the FEMLIP framework