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Discussions

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

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Anonymous Referee #2 Received and published: 11 December 2018

Dear Editor and Authors, This paper addresses the issue of monitoring of rocky slope instability and failure analysis using the FEMLIP method, and the normalized global second order work as failure index. The paper is innovative in terms of methods and tools and provides useful results for the efficiency of the monitoring and the numerical analysis of rock slides, as tools for the prediction and simulation of failure and the early warning. The methods used and the results are clearly explained. Figures are sufficient, although the quality can be improved (please check comments on the pdf file for Figure 2b). Thanks so much for your pertinent comments. The 2 figures you

pointed out had been substituted, and the resolution had been improved.

I would suggest a thorough review of the English style, as some parts need to be rephrased in order to be correct and clear.

You are reasonable. A thorough review will be performed.

In terms of methodology and concepts I would like to raise the issue of rock bridges and their failure. The Authors claim that failure occurs along the strongly weathered two-mica quartz schist, which is simulated as continuous in the numerical model. However i in rockslides the occurrence of failure through the breakage of intact rock bridges is quite common. This has not been taken into account in the numerical analysis. How do the Authors deal with this, in this work?

Thanks very much for your question, and you are reasonable. The stability of the engineering rock mass is generally determined by the rock blocks and the geological discontinuities. The instability of rock slopes usually proceeds with the breakage of intact rock bridges, and then the global sliding. A consideration of the discontinuous phenomenon into the FEMLIP method is interesting, and this is effectively an ongoing work. We are trying to implementing level-set functions to describe it, but now the FEMLIP method cannot yet solve this issue. In conclusion, this issue will be presented as a shortcoming and a perspective of this study. According to the geological data, the failure occurs principally along the two-mica quartz schist, which is highly fragmented presenting as blocks and debris and filled with mud. Hence, we considered it as granular material, and simulated it as continuous medium. In addition, based on the mechanical parameters of the rock bridges and the fissures, their weighted average values can be used as the mechanical parameters of the weak zone [1, 2]. In this work, the involved mechanical parameters are reduced in line with the empirical strength reduction method.

Please find more comments on the .pdf file. Kind regards

The comments on the PDF file are responded as follows:

P.1 L.14, correct “was” as “were”

Thanks so much, and it has been modified in the manuscript.

P.1 L.16, I think this sentence “and the normalized global second order work was implanted to assess the structure instability as a safety factor” should be rephrases

You are reasonable, and this sentence is rephrased as “and two forms of the normalized global second order work were calculated to analyze the stability of the rock slope”. Is it OK?

P.2 L.16, It would be interesting to know more about the monitoring system that was used.

You are right, more details about the monitoring system will be added in the manuscript.

P.4 L.3, resolution needs to be improved.

Thanks for your kindly reminder, and it has been replaced by one with a higher resolution.

P.4 L.10, It would be better to use a legend. Also the resolution of figure 2b needs to be improved.

Thanks for your kindly reminder. A legend has been added and the resolution improved.

P.6 L.19, How is the depth of the anchored end into the rock, determined? How is it guaranteed that it is anchored on a fixed end?

The CRLD cables are generally installed in the rock mass with an inclination of 25o and the depth depends on that of the potential sliding band, such as the weak zone. As the monitoring system is used principally for rock slopes, the weak zone is determined by boreholes. The fixed end should be anchored into the stable rock, under the weak

zone. About the installation of the CRLD cables in rock mass, more details can be found in the paper [3].

P.7 L.14, In how much time was this increase observed? What was the monitoring time interval before?

Thanks very much for your careful review! Regarding the monitoring results, it is not written clearly, and a detailed explanation has been made in the manuscript. The increase was observed from the initial installation of the monitoring system to the current time. The monitoring frequency is once per hour before the long term warning, and twice per hour after it. After the medium and short term warnings, the monitoring frequency should be doubled.

P.7 L.17, Please be clear about what is the cumulative force increase, the rate of the increase (including the observed time span). Which criteria were used for the warning, the cumulative force or the rate, or both?

Thanks so much for your careful review. Regarding the monitoring results, it is not written clearly, and a detailed explanation has been made in the manuscript. The cumulative force increase is the difference between the anchorage force at current time and that at the time the monitoring system is firstly installed. Regarding the criteria, the criteria are summarized based on a large number of practical applications in rock slopes, and are not strictly quantitative. In fact, the gradual and quick slidings in rock slopes are still very difficult to distinguish. In this study, the cumulative force is considered as the major index. In case that the range of the cumulative increase of [300, 400] is satisfied, the long term warning can be sent; in case that the range of [500, 700] is satisfied, the medium term warning can be considered; if a sudden decrease of 10 kN is monitored under a high force level, the short term warning can be sent. These are the latest criteria summarized and applied. It should be noted that the warning criteria are not strictly quantitative and based on numerous empirical results. They are applied only in the Nanfen open-pit mine. Besides the cumulative force increase, the current force level, the increase rate (sudden increase or dive) and the observation in the field are also necessary to be considered by the field staff.

P.7 L.17, What does the long term and the medium term warning refer to?

In case that the range of the cumulative increase of [300, 400] is satisfied, the long term warning can be sent. After that, the monitoring staff in the field is requested to enhance the monitoring intensity, and the monitoring frequency is augmented to be twice per hour. In case that the range of [500, 700] is satisfied, the medium term warning can be considered. After that, the large equipments are suggested to be evacuated and the mining activities should be temporarily ceased. The monitoring frequency is 4 times per hour. In case that a significant dive is observed under a high force level, the short term warning can be sent. All staff in the field must be evacuated and the mining activities must be ceased. The monitoring frequency is 8 times per hour.

P.7 L.25, Is the mining activity affecting the stability by induced vibrations? Please explain more.

The mining activity usually plays an important role to affect the stability, especially the blasting mining. However, the blasting areas were located on the bottom of the mining camp, and there was a distance of about 500m in between (as shown in Fig. 1). The influence of the vibration on the studied slope was very small. The mining excavation was once partially restarted on October 28, and the anchorage force remained constant. However, it quickly increased during the intensive rainfall on October 30, and the rockslide occurred just one day later. The rainfall was thus considered as the major cause.

P.8 L.12, Is the increase of the force starting from 2011-10-02 and on related to rainfall or other causes? please comment. Doesn't the anchorage fail after the rockslide? Why does it keep measuring force?

Thanks for your careful review. The rockslide in 2011 had been discussed in the paper

[3]. The excavation on the toe of the slope, from October 2 to 6, 2011, was considered as the major cause. The blasting areas were located on the bottom of the mining camp, and there was a distance of about 500m in between. The influence of the vibration on the studied slope was very small. The excavation at bench 430 was performed 15 days after the last blasting, and on rockslide occurred during the blasting and before the excavation. In addition, there was not rainfall from October 1 to October 5 as shown in Fig. 7c. The rainfall on September 29, 2011 was slight and no influence on the anchorage force was observed; the rainfall on October 6, 2011 was moderate and lasted only 3 hours, it could be a factor of the instability to some extent, but was not the major cause. After the rockslide, the CRLD cable didn't completely fail, due to its tolerance of large deformation. As shown in Fig. 5a, a relative sliding between the cone and the pipe makes the tolerance possible. As long as the pipe is well anchored in the rock mass, and the rockslide is not too drastic to exceed the tolerance, the CRLD cable can keep working.

P.9 L.1, Not very clear what is meant here. I understand that this is the case that the anchorage works and stabilizes the rock mass but what is the point of this phrase?

Thanks so much for your attentive review and kindly reminder, these sentences are not very clear. In some cases, the sliding force is significantly changing during the instability process, but the displacement on the surface of the slope is not yet clearly observed (for example, the potential sliding surface is deep). In these cases, the monitoring system based on the anchorage force of the CRLD cable may be a more suitable tool. "Measurement on the slope cannot work", for example, the GPS surface displacement monitoring point destroyed by rockfall in Fig. 6. This sentences have been rephrased in the manuscript.

P.21 L.21, The authors do not comment at all the role of rock bridges that progressively fail, before leading to the rockslide. This is neither taken into consideration by the numerical model, although very common in rock slides.

Thanks very much for your question, and you are reasonable. The stability of the engineering rock mass is generally determined by the rock blocks and the geological discontinuities. The instability of rock slopes usually proceeds with the breakage of intact rock bridges, and then the global sliding. A consideration of the discontinuous phenomenon into the FEMLIP method is interesting, and this is effectively an ongoing work. We are trying to implementing level-set functions to describe it, but now the FEMLIP method cannot yet solve this issue. In conclusion, this issue will be presented as a shortcoming and a perspective of this study. According to the geological data, the failure occurs principally along the two-mica quartz schist, which is highly fragmented presenting as blocks and debris and filled with mud. Hence, we considered it as granular material, and simulated it as continuous medium. In addition, based on the mechanical parameters of the rock bridges and the fissures, their weighted average values can be used as the mechanical parameters of the weak zone [1, 2]. In this work, the involved mechanical parameters are reduced in line with the empirical strength reduction method.

[1] STIMPSON B. Failure of slope containing discontinuous planar joints. Proceedings of the 19th U.S. Symposium on Rock Mechanics: Stateline Nevada PublicationïijŇ1978, 296–300. [2] Xia CC, Xu CB. Study of Fracturing algorithm of intermittent joint by DDA and experimental validation. Chinese Journal of Rock Mechanics and Engineering, 2010, 29(10): 2027-2033. [3] Li, Z.H., Jiang, Y.J., Tao, Z.G., He, M.C.: Monitoring prediction of a rockslide in an open-pit mine and numerical analysis using a material instability criterion, Bulletin of Engineering Geology and Environment, published online, 2018b.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-40/nhess-2018-40-AC3-supplement.pdf

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