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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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Anonymous Referee #1 Received and published: 19 Mars 2018

Comments from Referee 1: The article deals with the problem of landslides (rock-slide) 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,

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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? Author's response: 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 [1]. 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.

Comments from Referee 1: - 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. Author's response: 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.

Comments from Referee 1: - How anchors are placed in the rock: inclination, depth, etc. What are the criteria that determine these parameters? Author's response: 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.

Comments from Referee 1: - 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. Author's response: 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.

Comments from Referee 1: - 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. Author's response: 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.

Comments from Referee 1: - p.14, l.7 Give some explanations about the numerical infiltration process modeling. Author's response: Thanks for your question. The FEMLIP method used in this study can solve the full hydro-mechanical coupling, according to the previous contributions [2, 3]. The formulations in the global calculation are written as shown in Fig.2. The detail of the formations can be referred to the papers [2, 3]. 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

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according to the constitutive model, presented in the manuscript.

Anonymous Referee #2 Received and published: 11 December 2018

Comments from Referee 2: 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). Author's response: Thanks so much for your pertinent comments. The 2 figures you pointed out had been substituted, and the resolution had been improved. Author's changes in manuscript:

Comments from Referee 2: I would suggest a thorough review of the English style, as some parts need to be rephrased in order to be correct and clear. Author's response and author's changes in manuscript: You are reasonable. A thorough review will be performed.

Comments from Referee 2: 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? Author's response and author's changes in manuscript: 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 [4, 5]. In this work, the involved mechanical parameters are reduced in line with the empirical strength reduction method. Author's changes in manuscript: In addition, the instability of rock slopes usually proceeds with the breakage of intact rock bridges. The description of this discontinuous phenomenon using the FEMLIP method is worth being considered. By implementing the level-set functions, widely used in X-FEM, the FEMLIP method can be extended to solve the issues of discontinuous media.

Please find more comments on the .pdf file. Kind regards The comments on the PDF file are responded as follows:

Comments from Referee 2: P.1 L.14, correct "was" as "were" Author's response and author's changes in manuscript: Thanks so much, and it has been modified in the manuscript.

Comments from Referee 2: 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 Author's response and author's changes in manuscript: 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?

Comments from Referee 2: P.2 L.16, It would be interesting to know more about the monitoring system that was used. Author's response and author's changes in manuscript: You are right, more details about the monitoring system will be added in the manuscript.

Comments from Referee 2: P.4 L.3, resolution needs to be improved. Author's response and author's changes in manuscript: Thanks for your kindly reminder, and it has been replaced by one with a higher resolution.

Comments from Referee 2: P.4 L.10, It would be better to use a legend. Also the resolution of figure 2b needs to be improved. Author's response and author's changes in manuscript: Thanks for your kindly reminder. A legend has been added and the resolution improved.

Comments from Referee 2: 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? Author's response: 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 [6].

Comments from Referee 2: P.7 L.14, In how much time was this increase observed? What was the monitoring time interval before? Author's response: 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. Author's changes in manuscript: From September 7, 2015, the anchorage force monitored at point 478-3 showed a series of slow increases and three sudden increases, which accumulated a force increase from 270kN to 600kN until September 1, 2016, as remarked by the points A, B and C in Fig. 7a. Before September 1, 2016, the cumulative value had not strictly reached the warning threshold proposed by He (2009), and no obvious fissures were observed according to in-situ surveys; therefore, no warning was sent. As a result of constant mining activity, the cumulative increase of anchorage force reached 330 kN and the fourth sudden increase appeared after September 1, 2016, as remarked by the point D in Fig. 7a. Although no fissures were observed, the first long-term warning was sent due to the sudden increase by the field staff, and the monitoring frequency was increased to twice per hour. When the anchorage force returned to constant on October 1, 2016, the cumulative force increase exceeded 220 kN and a few surface fissures appeared, the medium term warning was sent. The mining activities were ceased and the monitoring frequency was doubled to 4 times per hour. In the following days, the curve remained constant and no obvious fissures continued to develop; therefore, mining excavations restarted along the bench at 442 m elevation on October 28, 2016. On October 30, the anchorage force suddenly increased again at 04:53, and reached a peak value of 855 kN at 17:07, during a period of rainfall. A subsequent dive of the anchorage force was observed. The short term warning was sent at 08:56 on October 31, and all staff was urgently evacuated. At 23:52 on October 31, the rockslide occurred, prompting a large volume of rock to slide downhill and pile up on the bench at 442 m elevation.

Comments from Referee 2: 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? Author's response: 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.

Comments from Referee 2: P.7 L.17, What does the long term and the medium term warning refer to? Author's response: 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.

Comments from Referee 2: P.7 L.25, Is the mining activity affecting the stability by induced vibrations? Please explain more. Author's response: 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.

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Comments from Referee 2: 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? Author's response: Thanks for your careful review. The rockslide in 2011 had been discussed in the paper [6]. 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.

Comments from Referee 2: 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? Author's response: 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 rock-fall in Fig. 6. This sentences have been rephrased in the manuscript. Author's changes in manuscript: In some cases, the sliding force is significantly changing during the instability process, but the displacement on the surface of the slope cannot yet be 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.

Comments from Referee 2: 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. Author's response: 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 [4, 5]. In this work, the involved mechanical parameters are reduced in line with the empirical strength reduction method. Author's changes in manuscript: In addition, the instability of rock slopes usually proceeds with the breakage of intact rock bridges. The description of this discontinuous phenomenon using the FEMLIP method is worth being considered. By implementing the level-set functions, widely used in X-FEM, the FEMLIP method can be extended to solve the issues of discontinuous media.

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Short comments: Received and published: 2 May 2018

Short comments from Mubashir Aziz: The monitoring method is interesting, and the comparison between the monitoring data and the numerical result, the global second order work, is a good attempt. I just wonder how the CRLD cable is installed in the borehole, how it is anchored? Author's response: Thanks for your kindly comments. Regarding the installation of the CRLD, the borehole is drilled through the geological discontinuity as shown in the figure as follows. The sleeve pipe is anchored in the borehole by the grouting material generally with a thickness of 14.5 mm, and one end of the stands is fixed on the slope surface.

Short comments from Mubashir Aziz: In addition, the space is missed in P.20, L.11 and L.20 (However, the mining activity. . ., . . .prove that the October 31, 2016 rockslide. . .). Author's response: Thanks for your kindly comments, the errors will be corrected in the manuscript.

Short comments from Mubashir Aziz: Finally, the authors claim that the global second order work could be used as a safety factor. It's a little abrupt. It is better to compare it with a current one, for example, the safety factor used in the FLAC3D software. Author's response: Thanks for your kindly comments. Regarding the safety factor, the second order work can describe the stability of the structure in the Lyapunov sense, and not only a limit equilibrium state. It is thus more general and more physical. In addition, the safety factor used in the FLAC3D software cannot solve the large strain problems, but it is not an obstacle for the second order work. Thanks for your valuable suggestion, more detailed discussion about the safety factor will be given in the manuscript.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-40/nhess-2018-40-AC4-supplement.pdf

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2018-40, 2018.