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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Use of a remotely piloted aircraft system for hazard assessment in a rocky mining area (Lucca, Italy)" *by* Riccardo Salvini et al.

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We prepared a point by point response to review 1, please refer to the attached revised manuscript to see the applied changes.

RC -This paper presents an interesting case study of the application of RPAS for rock slope characterization in a mine/quarry for hazard assessment. It highlights the advantages of using recently developed technologies (RPAS and SfM) in a mine/quarry. In my opinion, the main contribution is related to the persistence of critical joints and the role of intact rock bridges in rock slope stability. This is a difficult topic, and lots of literature exists already. New characterization techniques, such as photogrammetry,

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Discussion paper

bring new perspective and may allow better understanding of the role of rock bridges. Therefore, I think that this manuscript is a topical case study, and the discussion (Section 5) is interesting. However, before being published, I think the manuscript needs to be further completed. I would suggest including a more comprehensive literature review on the topic of discontinuity persistence and rock bridges in the introduction (including the current paragraph Line 14-19 on Page 8). I would suggest reviewing recent case studies on rock bridges such as the one by Frayssines and Hantz (2006), Sturzenegger and Stead (2012), Tuckey and Stead (2016), and Matasci et al (2014). In particular, the results presented in Line 15-18 on Page 9 could be compared to rock bridge percentage estimate by the above authors.

AC -As suggested, a more comprehensive literature review on discontinuity persistence and rock bridges has been included in the introduction (including paragraph line 9-19 on page 8 and line 5-11 on page 9). The following text has been added: “Nevertheless, there are controlling factors that can have a great influence on the stability condition of a block or slope that cannot be fully determined, such as discontinuity persistence. The presence of intact rock bridges, that represent intervals of intact rock between adjacent discontinuities (ISRM, 1978), can significantly increase the stability of a rock slope, since the cohesion of the intact rock is generally of at least two orders of magnitude greater than the shear strength of a discontinuity (Park, 2005). In general, joint persistence (K) is defined as the fraction area that is actually discontinuous (Einstein et al., 1983), and can be calculated with the following Eq. (1):

K= lim(A_D$\rightarrow\infty$)((∑ _ia_Di)/A_D)(1)

where D is a region of the plane with area A_D and a_Di is the area of the joint in D. The limit of the application of this method is that the discontinuity area is practically impossible to measure deterministically in the field, for this reason persistence is commonly measured as trace length on rock outcrops. Jennings (1970) proposed the following Eq. (2) for persistence calculation starting from trace length values on rock exposure:

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K = $(\sum JL)/(\sum JL + \sum RBR)(2)$

where JL is the total length of the joints segment and RBR is the total length of rock bridges. Mathematically, it is possible to consider the presence of rock bridges in terms of effective cohesion along the shear surface (Eberhardt et al., 2004) by using the following Eq. (3):

c_i=c A_g/A (3)

where c is the intact rock cohesion, A_g the total area of intact rock bridges along the shear surface, and A is the total area of the shear surface. Importantly, as recently reported by Tuckey and Stead (2016), in spite of the importance of intact rock bridges in slope stability, there are still no standard accepted methods for estimating the extent of rock bridges and incorporating rock bridges into slope stability analysis." In addition, the indicated case studies have been added in the discussion section, for purposing of comparison: "Similar values of rock bridges percentage have also been found in different case studies, where back-analysis revealed low values of estimated rock bridge content at the moment of failure, in the order if 0 to 5 % (Frayssines and Hantz, 2006; Grøneng et al., 2009; Sturzenegger and Stead, 2012; Matasci et al., 2014; Tuckey and Stead, 2016). Therefore, a small amount of rock bridge may be sufficient for guaranteeing stability of a rock slope."

RC -Finally, the specific comments listed below should be addressed. SPECIFIC COMMENTS: Page 1, Title: Is there a specific reason why the authors use "remotely piloted aircraft system" instead of UAV, which is more commonly used in the literature?

AC -The choice of using "remotely piloted aircraft system" instead of UAV is done trying to be as closer as possible to the title of Special Issue.

RC -The abstract is well written. I would suggest adding a sentence on the rock bridge analysis, which is an important aspect of this manuscript.

AC -We agree with the suggestion. The following sentence has been modified as it

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follows: “A preliminary stability analysis, with focus on investigating the contribution of potential rock bridges, was then performed in order to demonstrate the potential use of RPAS information in engineering geological contexts for geo-hazard identification, awareness and reduction”

RC -From Page 1, Line 33 to Page 2 Line 5: these sentences seem a bit vague. In what ways does alteration of geological structures by exploitation, or morphological features influence slope stability? In my opinion, the main parameter controlling slope stability is the relationship between the slope morphology and geological structures, as rightly explained in the third sentence.

AC -The correction has been applied and the new sentences have been modified as it follows: " According to Zajc et al. (2014), for example, hazardous situations may occur when unfavourable sedimentological characteristics and geological discontinuities (e.g. joints, faults) of rock masses are made even more critical by extraction of the resource or ore material. In addition, Zheng et al. (2015) highlight the crucial role played by morphological features, such as sharp cuts and steep slopes, for potential triggering of rockfalls in mining areas. As widely demonstrated in the literature, the understanding of geometric relationships between geological discontinuities and slope morphology is essential to evaluate the potential occurrence of rock failures, since orientation of joint sets may influence both size and failure mechanisms of rock blocks prone to collapse (e.g. Stead and Wolter, 2015).".

RC -Page 3, Lines 10-13: is it really necessary to add these sentences and to mention this accident? Safety is definitely very important for mining operation, but is this really relevant for the scientific contribution of this paper?

AC -The suggestion has been applied and the sentences eliminated.

RC -Section 3.1: Could “zenithal”, “parallel” and “frontal” be defined?

AC -The correction has been applied and the new sentences have been modified as it

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follows: " In order to assess and localize the slope stability hazard in the rocky mining area, two RPAS surveys were carried out with direction of photo acquisition in zenithal modality (perpendicular to the open pit floor) and in frontal modality (perpendicular to the rock faces).".

RC -Section 3.1: What is the exact meaning of Ground Sample Distance: is it the ground pixel size? Or the distance between points in the generated point clouds?

AC -The sentence has been modified as it follows: "An average estimated distance between pixel centers measured on the ground (i.e. ground sample distance - GSD) of 2.4 cm was calculated.".

RC -Section 3.2: I don't think it is necessary to explain in detail every steps of the processing work using Agisoft. It may be better to explain the key steps and refer to Agisoft manual for more information. Details about the parameters and options selected in Agisoft could be listed in a table if necessary. In addition, I would consider including Section 4.1 here instead of in the Result section of the manuscript.

AC -Considering that the title of the Special Issue is "The use of remotely piloted aircraft systems in monitoring applications and management of natural hazards" we have considered this part very important in order to explain as better as possible the main steps of image processing and the utilized methods. In addition, we prefer to explain the utilized methods (ex. topographic survey with GPS and Total Station, GPS post-processing, GCP correction to orthometric heights) more than just listing the parameters in a table. We consider Section 4.1 a description of the obtained results and not a method. For this reason we prefer to leave it as it is.

RC -Section 3.3, Lines 16-17 and Lines 25-26 do not seem necessary.

AC -We don't completely agree with these suggestions and we would prefer to leave them as they are, since they introduce the next sentences and steps of the analysis.

RC -Page 7, Line 10: a table showing the parameters used to obtain the RMRb and

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GSI would be useful here. I assume the geometric parameters come from the RPAS, but what is the source of the non-geometric parameters?

AC -The non-geometric parameters were manually collected in accessible areas; we added a sentence in the text to explain this. Moreover, we added a table (table 4) where RMR parameters are shown. We didn't add a table for the GSI parameters since it is a "qualitative" index. We don't think it is useful to add an image with the GSI chart in this paper, anyhow we included in the text a comparison with the Hoek et al. (2013) equation. To summarize, the text was has been changed as follows: "The final stereonet allowed identification of four discontinuity sets, whose properties listed in table 3 were obtained from traditional engineering geological survey carried out in accessible areas of the mine.." "..Based on the discontinuity characteristics derived from RPAS and traditional engineering geological surveys, the basic RMR (RMRb) and GSI index were calculated. The RMRb was found to be 67 (table 4), while the GSI was estimated to be between 60 and 65 using the modified chart proposed by Hoek et al. (2013). In addition, application of Hoek et al. (2013) equation for GSI quantification (GSI=1.5 JCond89 + RQD/2) confirmed the results of the qualitative chart interpretation with a value of 65."

Please refer to the attached revised manuscript to see Table 4.

RC -Page 6, Line 30: is the reproduction error resulting only from manual placement of GCPs or also to other parameters of the alignment process?

AC -As described in Paragraph 3.2. the reprojection error does not result only from manual placement of GCPs but also from other parameters of the alignment process and from the characteristics of data acquisition. For these reasons the sentence has been modified as it follows: "The image alignment process, described in paragraph 3.2, resulted in a reprojection error of 0.41 pixel for the zenithal survey and 0.48 pixel for the frontal survey.".

RC -Section 4.2: would it be possible to add a paragraph to discuss the results of the

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kinematic analysis? How do they compare with field-/SfM-based observations? What are the main failure mechanisms?

AC -We added the following sentence: “Three different possible kinematic modes were identified, with K2b and K4 systems having the most influence on potential instability. The majority of the potential failures identified relate to planar sliding or wedge sliding, in agreement with field and SfM-based observations.”

RC -Page 7, Line 25: do the orientation of the faults and discontinuity basal plane correspond to specific discontinuity sets defined previously? I think the sentences Line 14-19 on Page 10 should appear here.

AC -We agree with the suggestion. Therefore, the following sentence was included where indicated: “The basal plane appears not to correspond with any of the identified discontinuity sets, but is probably connected to planes of weakness of the marble in correspondence with a particular orientation of minerals crystallographic axes. The lateral and rear faults, however, may be associated with the K3a and K3b systems respectively. The rear fault may also be associated with the East-West fault system that characterizes the geology of this area of the Apuan Alps complex (Fig. 2).”

RC -Section 4.3: it is not clear how Block A parameters shown in Table 5 were input in Swedge. What is the slope orientation? How were the geometric parameters of Table 5 used to generate the wedge shown in Figure 10? Can the “length” and “height” of the block in Table 5 be defined, or illustrated on Figure 9? How was Total Cohesion in Table 6 calculated?

AC -In Swedge the block can be created using few input data (Slope Dip/Dip Direction and Height; rear discontinuity Dip and Dip Direction; lateral and basal plane Dip/Dip Directions). We think that including explanation on how to insert data into Swedge is not necessary in this case. Moreover, the geometric characteristic of the block can be derived from bar scale of figure 9 and vertical and horizontal axes on figure 10. Nevertheless we added a sentence specifying the slope direction used in the analysis: “The

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geometry of Block A was deterministically re-created in Swedge using the geometrical information obtained from the point cloud provided in table 6, with a slope direction of 30 degrees.". Concerning the cohesion values on table 6, they were calculated according to equation (3) c_i=cA_g/A. The equation allows calculation of effective cohesion due to rock bridges. For example, if we consider 1 m2 discontinuity plane with the 2 % of rock bridges, the effective cohesion of that plane will be equal to 16 MPa (intact rock cohesion) times 0,02/1 that is 0.32 MPa (effective cohesion considering 2% of rock bridge). This is the value to be used in Swedge. However, in our case study the basal plane is 510 m2, therefore the total effective cohesion is 0.32 times 510, that is 163.3 MN. The driving force on table 6 instead, is mainly due to the effect of the block weight on the basal plane. In our opinion all these information are already present in the text, nevertheless we are willing to discuss eventual modification if needed.

RC -TECHNICAL CORRECTIONS: For clarity, I suggest subdividing the introduction into more paragraphs. I would start a new paragraph from (1) "Generally, ..." (Page 2, Line 5); (2) "However, ..." (Page 2, Line 13); (3) "Digital images..." (Page 2, Line 22); (4) "However, ..." (Page 2, Line 30), and I suggest deleting the word "however" here.

AC -The suggestions have been applied

RC -I suggest starting a new paragraph on Page 10, Line 10 at "In this work"

AC -The suggestion has been applied

RC -All references to figures in the text should be in brackets (Fig. X)

AC -The correction has been applied

RC -Sections 3 and 4 need to be reviewed for clarity and the English checked.

AC -The text has been checked by a native English speaker and corrected where needed. Please, refer to the attached revised manuscript to see the applied changes.

RC -Page 2, Line 3: I suggest using either "geological discontinuities" (Page 2, Line 3)

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or “geological structures” (Page 1, Line 4), but being consistent

AC -The suggestion has been applied

RC -Page 2, Line 6: I suggest adding a period and start a new sentence from “Measurement”

AC -The suggestion has been applied

RC -Page 2, Line 10: “DP” should be “TDP” for Terrestrial Digital Photogrammetry

AC -The correction has been applied

RC -Page 2, Line 12: “rocky outcrops” should be “rock outcrops”. Similarly, on Page 7 “rocky slope” and “rocky blocks” should be “rock slope” and “rock block”.

AC -The corrections have been applied

RC -Page 2, Line 13: I suggest rephrasing this sentence, something like “A limitation of ground-based remote sensing is related to the survey of complex topography from suboptimal camera or scanner positions, resulting in occlusion zones..."

AC -The correction has been applied

RC -Page 2, line 16: I suggest deleting this sentence. It seems a bit redundant, and not really true, since the next sentences list several examples of the application of RPAS in open-pit mining.

AC -The correction has been applied and the new sentence has been modified as it follows: "There are several photogrammetric studies using RPAS for the geomorphic feature characterization or mapping of the surface extent in open-pit mines (Lamb, 2000; Chen et al., 2015; Shahbazi et al., 2015; Tong et al., 2015; Esposito et al., 2017). Few of them concern the use of RPAS for discontinuity characterization of rock slopes affected by mining activity.....".

RC -Page 2, Line 20: delete “an”

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AC -The correction has been applied

RC -Page 2, Line 26: a word is missing “...multicopters results ARE particularly suitable...”

AC -The correction has been applied and the new sentence has been modified as it follows: "In order to analyze rock outcrops, the use of RPAS multicopters results particularly suitable because it allows different geometric configurations for the image acquisition (i.e. zenithal, frontal, oblique).".

RC -Page 2, Line 28: delete “both”

AC -The correction has been applied

RC -Page 2, Line 34: should read “ allow only a rough estimation of airborne camera external orientation”

AC -The correction has been applied

RC -Page 3, Line 1: I think the word “accurate” is not appropriate here, because SfM provide accurate models whether they are geo-referenced or not. I suggest rephrasing, something like “in order to geo-reference (or register) 3D models, ...”

AC -The correction has been applied and the new sentence has been modified as it follows: "In order to obtain accurate and georeferenced the 3D models, the use of ground control points (GCPs) surveyed with geodetic GNSS receivers and total station (TS) is generally employed (Francioni et al. 2015).".

RC -Page 3, Line 3: should be “dependent not only ON” (not “from”); same comment at the end of the line

AC -The correction has been applied

RC -Page 3, Line 3: I suggest rephrasing and use “a preliminary rock fall hazard assessment, requested...”

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AC -The correction has been applied

RC -Page 3, Line 24: I suggest rephrasing “The bottom of the pit is located at 1,180 meters above sea level (masl) and the top of the excavated rock face is at 1,300 masl.

AC -The correction has been applied and the new sentence has been modified as it follows: "The bottom of the pit is located at 1,180 meters above sea level (m.a.s.l.) and the top of the excavated rock face is at 1,300 m.a.s.l..".

RC -Page 3, Line 29: “compressive tectonic phase WHICH originated...”

AC -The correction has been applied

RC -Page 3, Line 32: “fragile” should read “brittle”?

AC -The correction has been applied

RC -Page 4, Line 1: “motion” should read “displacement” or “offset”?

AC -The correction has been applied and the word "displacement" has been used instead of "motion".

RC -Page 4, Line 3-5: please rephrase with something like “AS involves the oldest LITHOLOGIES of the ..., INCLUDING pre-Alpine...”

AC -The correction has been applied

RC -Page 5, Line 5: would “baseline” be a better terminology for the “two points necessary for the roto-translation of the measured GCPs”?

AC -The correction has not been applied since the terminology "baseline" is correct, especially for GPS measurements, but, in our opinion, less explicative than our long sentence to explain the concept of roto-translation.

RC -Page 7, Line 20: where are the results of block shape and size? Do you mean to say that the results of the kinematic analysis highlight potential for discontinuity-controlled failure mechanism and “therefore the high resolution images and the dense

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point cloud were analyzed in order to locate possible block source areas"?

AC -We wanted to say that since the traditional kinematic analyses don't allow localization of blocks source areas, the high resolution images were used to localize them. We don't think it is necessary to include the properties of each block, since the paper focus on the 2 bigger and most dangerous blocks. Nevertheless, the sentence wasn't clear, and it has been rewritten it in this way: "The results highlight the potential for blocks to form that may be subject to gravity induced instability but, as previously stated, traditional kinematic analyses do not identify the location of these unstable blocks. Therefore, further analysis of the high resolution images and the dense point cloud was performed in order to locate possible block source areas. More than 20 blocks were deterministically characterized in terms of size, shape and barycentric coordinates, varying from about a cubic meter to a few hundred cubic meters."

RC -Page 7, Line 23: do you mean to say :"In particular, the adopted approach identified two large blocks..."?

AC -The correction has been applied.

RC -Page 7, Line 29-30: I suggest moving this sentence to Line 25, after "high persistence".

AC -The correction has been applied.

RC -Page 8, Line 14: I suggest wording "impossible to measure deterministically"

AC -The correction has been applied.

RC -Page 8, Line 15: I suggest saying that for this reason, persistence is commonly measured as trace length on rock outcrop, and use a more appropriate reference than Einstein et al (1983)

AC -The sentence was rewritten in this way: "The limit of the application of this method is that the discontinuity area is practically impossible to measure deterministically in

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the field, for this reason persistence is commonly measured as trace length on rock outcrops. Jennings (1970) proposed the following Eq. (2) for persistence calculation starting from trace length values on rock exposure:"

RC -Page 10, Line 10: "slope stability analysis" instead of "slope instability analysis"

AC -The correction has been applied and "instability analysis" has been changed in "stability analysis" in the whole text.

RC -Page 10, Line 25: the reference should be "(Kemeny and Donovan, 2005)"

AC -The correction has been applied.

RC -Figures 3 and 5 captions: "top view" should read "plan view"

AC -The correction has been applied. Figure1 has been similarly modified.

RC -Figure 5 needs to be referenced in the text; the caption should explain that the blue rectangles correspond to the photographs locations; there is not scale nor indication of the north on the figure.

AC -Figure 5 was already referenced in the text (Pag. 5, Line 2). The caption has been modified and the sentence "blue rectangles correspond to the photographs locations, black lines to normals" has been added. A reference scale and the indication of the north have been added to the Figure 5a. Please, refer to the attached revised manuscript to see the modified figure.

RC -Figure 7: could you please clarify: the caption mention equal area, while the figure shows equal angle. In addition, Figure 7 uses Schmidt method while Figure 8 uses Wulff method.

AC -That was a mistake, the figure has been changed and "Equal angle" corrected. Please, refer to the attached revised manuscript to see the modified figure. Figure 7 uses Schmidt method since it represents a joint density analysis, while Figure 8 uses Wulff method since it refers to a slope kinematic stability analysis. They are both in

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theory correct.

RC -Figure 9: “insect photo” should read “inset photo”

AC -The correction has been applied

RC -Figure 13 captions should read “Details of a series of tight discontinuities...”

AC -The correction has been applied

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-194/nhess-2017-194-AC1-supplement.pdf

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