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Discussions

Interactive comment on "Effects of the impact angle on the coefficient of restitution based on a medium-scale laboratory test" *by* Yanhai Wang et al.

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The paper discusses the effect of the angle of impact with respect to the slope on the coefficient of restitution of rockfalls in the normal and tangential directions to the slope and the loss of kinetic energy during the impact. The discussion is based on a set of close to natural size rockfall experiments with limestones blocks dropped in free fall on a concrete slab inclined at various angles. The authors observe that the normal coefficient of restitution decreases and the kinetic energy dissipation increases as the impact angle increases, which seems in agreement with previous impact tests experiments with various material, impactor size (for smaller size than in this study)

and various impact speeds. The authors however state that one should not deduce that a high normal coefficient of restitution necessarily means a high kinetic energy coefficient of restitution because no correlation is observed between the to coefficients. Indeed, the kinetic energy coefficient of restitution increases has the normal coefficient of restitution Rn for small values of Rn (i.e., for large angles of impact) but decreases as Rn increases for small angles of impact, when Rn > 1. They interpret that the large Rn coefficients > 1 are caused by basal roughness that impeach the impactor to rebound with a small angle of rebound when there are basal obstacles.

The paper is globally well written and the figures are clear. The experimental setup and results are clearly presented and seem of good quality. However, I think the paper suffer from several problems and should be rewritten and improved. I detailed here my main remarks and more specific comments that refer to line numbers below.

General Comments

- Most of the results given in the paper, in particular the variation of the coefficients of restitution as a function of the impact angle, were already reported in previous studies. It is not clear what this paper brings new to the research on energy losses during impacts. Please state clearly in the introduction what are the main questions that are posed at the end of the previous studies and needed additional experiments and answer to these specific questions in the conclusions. It is not clear what people doing computer simulations of rockfalls should retain from this work and how they could use the presented results.

- I think that one important parameter that could allow us to better understand why kinetic energy losses are larger at high impact angles is the energy lost in rotational modes of the impactor. The more energy is dissipated in rotation after the impact, the less energy is restituted to the block as kinetic energy for rebound (cf Farin et al. (2015) Characterization of rockfalls from seismic signal: Insights from laboratory experiments, JGR:Earth Surface, Figure C1b). The authors could take advantage of the fact that their experimental setup has 8 cameras around the impact to measure precisely the rotation of the impactors before and after the impact and evaluate the rotational energy. This energy could be defined as 1/2* I * omega_r^2, where I is the moment of inertia of the block (that could be approximated to a full sphere) and omega_r is its rotation speed. A figure showing the kinetic coefficient of restitution, Re, as a function of the rotational energy after impact could be interesting to show to bring additional contribution with respect to the previous work on the subject. Also, it is important to precise in the paper that the 'energy coefficient of restitution' is the 'kinetic energy coefficient of restitution', which does not represent the whole energy lost by the block but only the kinetic energy Ek lost. If a lot of energy is transmitted in rotation energy Er maybe the total energy of the block Ek + Er does not decreases at large impact angles (?).

- The authors suspect at several times in the paper that the impact speed has an influence on the coefficients of restitution. Thus, they should produce a Figure showing the coefficients of restitutions (and the rebound angle) as a function of the impact speed (event if only 3 different impacts speeds are investigated here, they could also use the data from previous work). Such a figure could support their discussion.

- I find that the discussion section is a bit difficult to follow. Maybe it could be reworked with subsections, discussing for example 'Interpretation of normal coefficient of restitution larger than 1', 'Relation between kinetic energy losses and normal coefficient of restitution'. . .

Specific comments: Abstract : - l14: the impact angle 'with respect to the slope' page 2, L2: define the coefficient of restitution

Introduction: - l 26: 'the similitude requirements. . . cannot be easily matched': I do not understand this sentence. Please rewrite.

- page 2 L32: define the energy coefficient of restitution. 'The kinetic coefficient of restitution' is more appropriate.

- page 2 l.34: Please do not give the same results as that given in the abstract. Please raise the general questions that require you to conduct additional experiments and that you answer in this paper, and answer these specific questions in the conclusion section. Sections 1.2 and section 2 should be merged with 1.Introduction and this whole section should lead to the problematic of the paper: what new contribution are you bringing to this research subject? To what questions are you answering?

- Page 3, L.15: n_cor and t_cor are never used in the following of the paper thus they should not be introduced.

- Page 3, L.20: it could be also interesting to present the results for Rv as a function of the impact angle and the kinetic energy lost because lots of people are using this definition. Is it varying differently than Rn with the impact angle ?

- Page 4, l.2: ratio of kinetic energies

- Page 4, l.26: 'the impact angle can influence the rebound angle': be more precise. Does the rebound angle increase or decrease when impact angle increases ?

- Page 4, l.29: 'the kinematic coefficient of restitution Rv was more appropriate than the normal COR for use in correlations with the impact angles'. The relation between Rv and the impact angle should be also represented in this paper to check whether this statement is also true with the present experiments.

- Page 5, l.3-4: These are poor sentences to sum up the previous results and motivate your work. Please clearly state at the end of the introduction what is missing from the previous work and requires you to do additional experiments.

- Page 5, l.14: what is the 'rebound hardness value' ? Does not it have units ? I think it could be more useful to give the Poisson's ratios and Young's modulii of the materials composing the impactors and the slabs. For example, people may want to use your data to compute impact forces (for example using Hertz's impact model) and compare the impact forces to the coefficients of restitution and impact angles and such computations require the Poisson's ratios and Young's modulii.

- Page 7, L.12: define the acronym COR beforehand

- Page 8, L.9: the sentence 'The values of Rn . . .' is unnecessary, one can read the values on the figure.

- Page 9, equations (4-1), (4-2) and other equations in the paper: only two significant digits are sufficient because the standard deviation on the data is at least 0.01. For example, equation (4-1) should rather be: Rn = 4.41 aˆ(-0.6), Rˆ2 = 0.81

- Fig 6: The coefficient of restitution does not seem to depend on diameter, except 2 data points of higher value for D=10cm at low impact angle. In fact, the theory says that the coefficient of restitution should not depend on impactor size for impacts on a thick block (when the thickness of the impacted slab is large compared to the size of the impactor) and that the COR decreases as the impactor size increases when the impact is on a substrate whose thickness is small compared to the impactor size (cf Farin et al. (2015) Characterization of rockfalls from seismic signal: Insights from laboratory experiments, JGR:Earth Surface). The slab you are using could be considered as thin compared to the impactor size but because the slabs seem to be a bit buried in ground, they may be considered as thick substrates, thus the coefficient of restitution does not depend on the impactor size. A comment on this could be interesting to explain the fact that the measured COR is independent of the impactor size in your experiments.

- All Figures in general: Please use a larger and sans-serif font to improve figures readability.

- Figures 6, 7 and 8: I would use the same kind of scaling law (power law) for the 3 coefficients of restitution to compare them. A 2nd order polynomial law for figure 8 makes no sense because (1) you could fit everything why it and (2) you change your mind after that and use a linear law in figure 5c because it compares better with the previous results.

- Please merge some of the figures together (e.g Fig. 2,3,4; Fig. 6,7,8; Fig. 12,13. . .)

- Page 9, L.14: the sentence 'The values of Rt . . .' is unnecessary, one can read the values on the figure.

- Page 10, L.5: the sentence 'The values of Re . . .' is unnecessary, one can read the values on the figure.

- Page 10, L.16: Have you measured the depth of erosion created by the impacts? Maybe the largest impactor have caused more erosion of the slabs and thus lose more energy in deformation of the slab than the smallest impactors. A figure showing the energy lost as a function of the depth of erosion due to the impact could be interesting if you can do it.

- Page 12, L.3: 'The data points are stably located above the 45° line until the impact angle reaches 36°' may be a clearer sentence.

- The '45° line' is misleading because the compared variables are angles. The 'equality line' or 'y = x line' are other possibilities.

- Page 12, l.5: 'the kinetic energy loss constituted 50-75% of the total kinetic energy' This is false: total energy also includes the rotation energy.

- Page 12, l.6: 'the energy loss level can not be assessed by comparing the rebound and impact angle': not clear

- Page 12, l.18: Maybe you should directly compare your results with that of previous studies before drawing conclusions because your conclusions seem to change a bit after the comparison with the other studies (for example you say later than Rt does not depend on the impact angle and you change the scaling law for Re), thus sections 4.1, 4.2 and 5 are redundant and confusing.

- Page 12, L.23 to Page 13 L.2: This should be in the introduction.

- Page 13, L.9: what is the 'ideal state'? If you observe rebound angles larger than 1.2

times the impact angle, there is a chance that we can also observe this in nature. You should not exclude data points just because they do not compare well to the previous work. On contrary, you should keep these points and interpret why you observe such a situation in your experiments and why it is not observed in the previous work.

- Table 2 and Fig. 11: please replace 'Wang 2018' by 'this study' to avoid confusion.

- Page 15, L.3: 'The minimum Rn occurred… erosion and particle breakage'. This explanation that stronger kinetic energy dissipation due to erosion may explain the lower Rn value for Cagnoli's experiment does not work because (1) you also observe erosion by the impacts and the Rn in your experiments are larger and (2) you state later that the normal coefficient of restitution does not correlate with kinetic energy loss…

- Page 15, L.9-12: the exact scaling law that describe best the data is not very important given the large scattering in the data. What matters more is if you can explain the general trend. Also, if you give a scaling law for you data, you should also try to fit the data of the previous work with the same kind of scaling law. If the scaling law works for your data and not with the other work, its usefulness is very limited…

- Page 15, L.15: The variation of the kinetic energy COR with impact angle may be better understood if you also show the rotation energy (more energy dissipated in rotation means less energy restituted in kinetic energy for the rebound). You should not remove data points just because they do not compare well with previous work. Explain the difference otherwise the same conclusions could have been drawn by just comparing the previous work together and this present work contribution is limited.

- Page 10, l.16: 'The impact velocity is an important… resulting coefficients of restitution': please show a figure of the CORs as a function of the impact speed (even including the previous work data) to support your conclusion.

- Discussion section. Different things are discussed here, please add subsections to make the discussion clearer.

- Page 16, L. 24: I do not understand what you mean by 'with a parallel motion'

- Page 16, L. 27: 'Therefore,Âă…' I do not understand the logical link with the previous sentence. If rotation speed has an important effect on rebound angle and coefficient of restitution, you should show it on Figures.

- Page 17: I understand that basal roughness can lead to higher angles of rebound, but in this case, the impactors on intact slabs should have in average lower angles of rebound than impactors on eroded slabs. Can you draw a figure or give the average rebound angles on intact vs eroded slabs to support your discussion ? If you measured the depth of erosion on the slabs, maybe the rebound angle could be correlated to with erosion depth (?).

- Page 20, l. 5: This conclusion does not bring anything new to the research. I believe you could draw much more results from you experimental data.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-108/nhess-2018-108-RC2-supplement.pdf

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2018-108, 2018.

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Fig. 1.