Review of: Effect of structural setting of source volume on rock avalanche mobility and deposit architecture

Overview:

The paper describes a series of physical models where different configurations of rectangular blocks in a sand matrix were released down a steeply inclined plane to test the difference in runout resulting from different block configurations and different inclinations of the plane for one block configuration. The different block configurations are hypothesized to be analogous to different rock mass structures and discontinuity patterns within the source zones of natural rock avalanches.

General comments:

The paper does a good job of showing how this work builds on previous physical modelling studies that examined the effect of large particles. However, there are some general comments that should be addressed or expanded upon.

1. In the title and through out the paper, the authors refer to “deposit architecture”. I would replace architecture with “morphology”, “structure”, or something similar, as “architecture” implies human design.

2. The authors refer to “rock masses disaggregated by discontinuous sets” throughout the manuscript. I recommend the authors use more standard and descriptive terminology for the description of rock masses, particularly when describing actual events, and the description/classification system should be referenced. For example, many of the references used by the authors use the GSI system to describe the in-place source rock masses (Hoek and Brown, 1997). I associate disaggregation with the process where the rock mass goes from its intact state in the source pre-failure, to the final, fragmented deposit, not a as a characteristic of the source area. Throughout “discontinuous sets” should be replaced by “discontinuity sets”.

3. The experimental procedure has a variety of initial block configurations that have been systematically tested. However, as I understand it, only one run was completed with each block configuration, so the repeatability of the experiments cannot be quantitatively assessed. The variation between many of the experiments is rather small, so it is hard to assess whether these differences in runout and deposit area are the result of the changes in block configuration, or the result of natural variability within the experiments. I think this should be addressed in the discussion when interpreting the results.

4. I do not agree with referring the cause of the rotation resulting in the zig zag pattern of the large blocks in the deposits as a “bending moment”, as that is generally used to refer to a moment that would cause a deflection within the block, as opposed to something that would cause a rotation of the entire block.

5. The limitations of the experiments should be more clearly stated throughout the manuscript. One factor of note is the “excess mobility” of rock avalanches, with travel angles less than what is expected on the basis of friction (following the definition of Hsü, 1975). The experimental results presented in this study all have a travel angle of approximately 30 degrees, which is within the range that would be expected for a sandy material. At some point within the paper it should also be stated there is significant

scientific debate regarding the physical processes that result in the enhanced mobility of rock avalanches. Given the limited mobility of the laboratory flows, it is likely the experiments are not capturing the mechanisms leading to the mobility of natural events. There was a review paper published recently that addresses some of the potential effects of discontinuities on rock avalanches (Lan et al., 2022) which could help to provide context.

Specific comments:

Line 10: I'm not sure what is meant by "direct threads", I would recommend "methods" or some similar wording.

Line 11: The phrase "geologic setting" is used here and throughout the paper, which is very broad, it could refer to the lithology, tectonics, etc. As the authors seem to be discussing the structural geology in particular, I would make that clear throughout.

Line 11: When I think of the "structures of the disaggregated rock mass", I interpret that as the deposit structure, however; I think the authors are referring to the in-place rock mass structure.

Line 19 – 20: This sentence is unclear, I think the authors are saying a zigzag structure is created in the blocks resulting from the lateral spreading of the deposits causing the blocks to rotate.

Line 26: You could say that rock avalanches are a "ubiquitous geological phenomenon in mountainous regions", but there are many places on the earth's surface in general where they are not found.

Lines 32 – 33: What was unique about the block orientation and distribution in the referenced studies?

Line 39: Remove the phrase "In addition", as no other methods of examining rock avalanches have been introduced, missing "the" between "of" and "fundamental".

Lines 40 – 44: References should be provided to support the statements made in these sentences.

Line 43: Be more specific as the initial structures within the rock mass, as all rock masses have some sort of structure.

Lines 61 – 63: Following general comment 5, the previous work referenced has looked at the effect of the movement of the material, particularly areas of extension and compression within the sliding mass as it comes to rest, and that effects the orientation of the blocks within the deposit. With the limited runout of the lab cases there is still significant uncertainty surrounding the effect of the source zone geologic structures, and if that affects the deposit morphology after a long runout event, or if at longer runouts the effects of source geologic structures is of less importance than the movement processes for the final deposit.

Line 70: It is unclear what the authors mean by "differences in geological environments", or how the geology relates to a systematic field investigation of the source structures and deposit characteristics.

Lines 70 – 71: Please elaborate on the motion processes, what are the specific challenges with obtaining this information?

Line 75: Replace "parallelly" with "parallel".

Lines 84 – 85: State what the interpretations from these experiments were.

Lines 85 – 86: Delete the words “Nonetheless” and “about”, state the main findings regarding the deposit morphologies and sedimentary characteristics.

Line 94: Missing the word “the” before “resulting”.

Line 120: Recommend changing “bird view” to “overhead view”, as some readers may not be familiar with the phrase “birds-eye view”.

Lines 127 – 128: I find this sentence difficult to follow, I recommend rephrasing as: “A layer of quartz sand was attached to the surface of the cuboid blocks using epoxy glue to produce a rough surface.”

Line 130: Replace “uneven coefficient” with “uniformity coefficient”, I would recommend including a reference for the C_c and C_u for readers who may not be familiar with particle size distribution metrics.

Lines 131 – 132: What is the significance of the proportion of particles in the 0.075 mm to 0.42 mm range? The upper bound of 0.42 mm does not correspond to a particle size class in the MIT system shown in Figure 4. On line 132 it states the average particle size is 0.18 mm, while on line 130, it states 0.2 mm, this only needs to be stated once, and a consistent number of significant figures should be used.

Lines 132 – 133: As written it is not clear if the interface values between the plexiglass and the sand were from lab testing or assumed values. The information included in lines 158 – 162 as well as Figure 7 should be a paragraph within the Materials section.

Line 136: The ratio of glue to sand was already stated in line 126.

Line 151: The volume of the sand was stated already on line 111.

Line 153: Rephrase “the sand of 150 g” as “150 g of sand”.

Table 1: The center of gravity height and matrix density could be pulled out of the table as they have the same values for all experiments.

Figure 9: I think it would be helpful to show where the slope break is on the displacement plots, that is an important control on the pattern of acceleration and deceleration and will help readers to interpret the results shown.

Lines 192 – 193: As you say below, the time to the peak velocity just the time to reach the bottom of the steep incline, which implies this finding is related to the experimental apparatus, not the effect of the slope angle per se. If the steep slope were longer, it would be expected that the material would continue to accelerate, and the steeper slopes would attain higher velocities until a terminal velocity was reached.

Lines 219 – 220: It should be noted the difference in the results for the different configurations is quite small, a rough comparison of the plots indicates a relative difference from the LV50 case well under 20% in most cases. With the relatively small difference between the cases, how robust are the trends discussed further in the paper?

Line 230: Replace “data” with “digital”.

Line 231: Replace “under the impact of” with “resulting from”.

Line 234: I'm confused by the statement that "no apparent protrusion of the blocks was visible", to me it seems that raised areas are visible in the deposits for the EP, LP, and R configurations, albeit less pronounced than is seen for the LV tests.

Line 235: Is "separation of the blocks and granular matrix" referring to blocks that runout further than the main deposit, such as the LV-40 and LV-50 results? Please make this clearer, and ideally highlight the behaviour you are referring to in the figure.

Figure 11: The x and axis on the one panel of 11b is quite small, I recommend more clearly labelling the x and y directions for these figures to make the following discussion easier to follow. In the legend I would also recommend replacing "arrangement of zigzag-like" with "zigzag-like structures" for consistency with how it is referred to in the main text.

Line 242: Replace "present" with "presents".

Line 244: It seems strange to refer to "contact by matrices" as a contact type, since the matrix is between the blocks and preventing them being in direct contact. I would suggest referring to what are currently called contact types more generally "deposit characteristics", and coming up with different terminology to describe the blocks having a consistent orientation, but separated by matrix material.

Line 246: What is meant by the R-50 deposit exhibiting "no symmetry", to me the large blocks are approximately evenly distributed throughout the deposit Is the sentence "Direct contact and contact by matrixes were just two kinds of contact ways" meant to say the those were the only two contact types observed in the R-50 test? As written, it is not clear.

Line 247: The sentence "The blocks in the deposit showed a good sequence" is unclear, please be more descriptive about what the sequence of the blocks was, and how it differs from any other tests. Replace "up" with "upper".

Lines 248 – 251: Was the colour pattern for the blocks the same for each experiment, or is this information only applicable to the LV experiments? It would be helpful to refer back to the schematic in Figure 6.

Line 252: By "farther distribution of the blocks", do you mean the blocks are more spread out? Please clarify this point.

Lines 253 – 254: The EP cases have very similar deposits to the NB cases, is the general statement that the blocks control mobility supported for all cases?

Line 259: Replace "counted" with "measured".

Lines 262 – 263: It seems to me that the scatter in the EP case is quite random, with no dominant direction.

Line 267: Are the orientations to 40 and 120 degrees significant? Visually the pattern looks very consistent for all of the LV results.

Line 277: I would add "is thought to be" before "decreased", as this is an inference and not something directly measured in the experiments.

Line 278: Is the "high level of the center of gravity" referring to the deposit thickness? Please clarify.

Lines 279 – 280: With the variation in deposit thickness being on the order of millimeters between the various tests with a fall height of 0.7 m, is the variation in the final potential energy significant?

Line 281: Replace “present” with “aligned”.

Lines 286 – 287: Make it clear that statements related to collisions and frictional losses are inferences.

Lines 296 & 297: Replace “interlock” with “interlocked”.

Lines 300 – 302: Is this referring to the present study, or that of Manzella and Labiouse?

Lines 307 – 311: Following general comment 2, please be more descriptive and provide details on the specific rock mass structures and orientation of discontinuity sets for both cases discussed.

Lines 314 – 315: The influence of topography has been shown to have a strong influence on the runout distance of rock avalanches using analysis of much larger datasets of different cases (Nicoletti and Sorisso-Valvo, 1991; Strom et al., 2019; Mitchell et al. 2020; Liu et al., 2021). The effect of volume on runout is also very well established, going back to Heim (1932). The volumes of the two cases mentioned are radically different, with the Ganlou event having a volume of 5.2×10^4 m^3, while the Sierre rock avalanche has an estimated volume of 1.6×10^9 m^3, according to the studies referenced by the authors. Using these two events as test cases for the effect of discontinuity orientation is a poor comparison, because the mobility difference expected based on the difference in volume is so great. Any comparison to infer the effect of the rock mass structure on observed runout would have to control for the effects of volume and topography.

Lines 319 & 321: Do you mean “beneath the blocks” as opposed to “somewhere between the deposits”? It is not clear as written.

Line 322 – 324: Please clarify this sentence and check the grammar.

Lines 326 – 327: By “initial discontinuous structures”, do you mean the blocks remain separated by matrix material at deposition, or that the arrangement of the blocks in the source area is preserved in the deposit? Please clarify.

Line 329: Delete “a” between “to” and “less”.

Line 337: It is not clear what is meant by the blocks “immersing into the area”, please be more specific.

Lines 346 – 348: Following general comment 4., remove “bending”. Replace the period between “clockwise” and “the” with “and”.

Lines 385 – 387: I think this is all referring to the matrix promoting rolling contacts between the blocks, but this should be stated more directly, for example, the statement “the contact of the blocks flexible, and hence, easily have rotation and variation in position” is not clear.

Figure 14: Provide a more descriptive caption that refers to all four panels.

Lines 411 to 413: Is this sentence referring to the current study, or describing characteristics of natural rock avalanches?

Line 416: Replace “actual” with “realistic”.

Line 429: Specify the relationship with slope angle was only tested for the LV configuration.

Lines 435 – 436: Contradicts line 364 which stated that the block structure went from disorderly to orderly. Given there was only one test of the random configuration, how much confidence is there that a different random arrangement of blocks would not lead to a different result?

References:

Heim, A. (1932). Landslides and human lives (Bergstürz und Menschenleben), Translated by: Skermer, N. Bi-Tech Publishers, Vancouver.

Hoek, E., & Brown, E. T. (1997). Practical estimates of rock mass strength. *International Journal of Rock Mechanics and Mining Sciences (Oxford, England : 1997), 34*(8), 1165-1186, https://doi.org/10.1016/S1365-1609(97)80069-X

Hsü, K.J. (1975). Catastrophic debris streams (sturzstroms) generated by rockfalls. Geological Society of America Bulletin 86: 129-140.

Lan, H., Zhang, Y., Macciotta, R. *et al.* The role of discontinuities in the susceptibility, development, and runout of rock avalanches: a review. *Landslides* **19**, 1391–1404 (2022). https://doi.org/10.1007/s10346-022-01868-w

Lui, H., Zhoa, X., & Xiao, D. (2021). Effects of local topography on the mobility of rock avalanches; a statistical analysis based on 36 cases from south-western China. *Engineering Geology, 294*, 106351. https://doi.org/10.1016/j.enggeo.2021.106351

Mitchell, A., McDougall, S., Nolde, N., Brideau, M.-A., Whittall, J. and Aaron, J. (2020a). Rock avalanche runout prediction using stochastic analysis of a regional dataset. Landslides 17: 777-792. doi.org/10.1007/s10346-019-01331-3

Nicoletti, P.G., Sorriso-Valvo, M. (1991). Geomorphic controls of the shape and mobility of rock avalanches. Geological Society of America Bulletin 103: 1365-1373.