Quantifying lahar damage using numerical modelling

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Response to Reviewer #2:

The authors identify that both hydrostatic and hydrodynamic forces contribute to the bending moment (and eventually the collapse) of the walls of a building. The former is related to the flow depth whereas the latter is related to its momentum. For describing the momentum transported by the lahar, the authors introduce the concept of "dynamic pressure", defined by the authors as ρv^2 (see line 294), and describe the components of the force as "directional components of dynamic pressure" (see eg: line 305). Although, I agree with the adopted philosophy, I suggest to slightly modify the used nomenclature. In fact, the "dynamic pressure", is usually defined as ½ ρv^2 and it is a scalar. It is used in the context of the Bernoulli theorem for describing the variations of the fluid pressure along a streamline. I propose that, the author adopt the concept of flux of momentum, which is a tensor defined as (see eg: Landau and Lifshitz, 1959):

$$\Pi = P\mathbf{n} + \rho\mathbf{v}(\mathbf{v} \cdot \mathbf{n})$$

where is the density of the fluid, **n** is the unitary vector normal to a surface, and **v** is the flow velocity. Considering a surface normal to the flow (parallel to *n*), the component of the flux of momentum perpendicular the surface becomes P + ρv^2, whereas when the velocity of the fluid is parallel to the surface, the only component of the flux of momentum perpendicular to the surface is *P*. The flux of momentum is related to the force exerted by a wall to deviate or stop the flow.

We would like to thank the reviewer for their suggestion and further suggested corrections. We incorrectly (in the manuscript, not in calculations), referred to dynamic pressure as ρv^2 when we actually used ½ ρv^2. As you have mentioned, the dynamic pressure is a scalar quantity and therefore using terminology as 'directional components of dynamic pressure' could be misleading. However, we disagree with the suggestion to adopt momentum flux instead.

Dynamic pressure is used extensively in literature examining the forces applied to buildings by fluids (see e.g. Roos (2003), Zeng et al. (2015), Zuccaro et al. (2008) and Jenkins et al. (2015)) and the theoretical basis for using dynamic pressure is sound, based on Bernoulli's theorem: when a fluid interacts with a fixed solid surface, the velocity normal to the surface is zero and the total pressure (i.e. force per unit area) is given as the *stagnation pressure* (see e.g. Landau and Lifshitz, 1959 pp. 11-21)

$$P_{max} = P_{static} + 0.5\rho v^2$$

Where *v* is the velocity normal to the wall.

This was not explained in enough detail in the original manuscript, and discussion of 'directional components of pressure' is misleading. To solve this, we intend to (1) add discussion to the section on lahar simulations explaining how dynamic pressure is calculated and (2) modify the flow behaviour section to explain the difference between using the velocity magnitude (scalar, not normal to walls) and normal velocity to determine forces exerted on the walls.

Minor corrections

In equation (1), *b* is referred as the thickness of the bricks used in the wall (see line 145). Later, at line 147, *b* is referred as the wall thickness. This is different for walls with a thickness greater that the width of a single brick. Do you consider only walls made of a single layer of bricks?

Here, we assume that brick and wall thickness are equal (i.e. only single layer walls), as observed in the field investigation – this has been clarified in the manuscript and *b* now consistently refers to wall thickness throughout the manuscript.

Line 149: In this context, I suggest to specify that the "normal forces" are vertical forces.

Thank you for the suggestion, this has been changed and helps in reducing confusion between terms.

Line 170: Symbol $a \rightarrow a_v$

Changed.

Line 190: "The critical height". Do you mean "The critical depth"?

Correct. Height vs. depth inconsistencies have been fixed throughout the manuscript, depth is used throughout.

Line 223: Usually the coefficient μ (eq.7) is defined "viscosity" only when the exponent *m* is equal to 1.

Commonly, the symbol *k* would be used, however that clashes with other symbols used in the building strength sections. We have changed the symbol to k_μ to reduce the confusion.

Line 252: "equation 3". Perhaps you mean eq. (7) or (8)?

Lines 256 and 262: "equation 4"? Perhaps eq.(7)? Please check.

References to equations are corrected.

Line 305: The "directional components of the dynamic pressure ...". Pressure, and dynamic pressure are scalars (see above).

See previous response.

Lines 315-323: Please check if the concepts of "normal stress" is more appropriate than "normal pressure component".

This part has been changed slightly in response to the "flux of momentum" suggestion. Normal stresses would differ by building and material properties, whereas the normal pressure (now flux of momentum) does not. In this context, it is more appropriate to use flux of momentum.

Line 437: contribution number "XXX", please provide the number if necessary.

Number provided.

Jenkins, S., Phillips, J., Price, R., Feloy, K., Baxter, P., Hadmoko, D., and de Bélizal, E.: Developing building-damage scales for lahars: application to Merapi volcano, Indonesia, Bulletin of Volcanology, 77, 1-17, 10.1007/s00445-015-0961-8, 2015.

Roos, W.: Damage to buildings, Delft Cluster, 2003.

Zeng, C., Cui, P., Su, Z., Lei, Y., and Chen, R.: Failure modes of reinforced concrete columns of buildings under debris flow impact, Landslides, 12, 561-571, 10.1007/s10346-014-0490-0, 2015.

Zuccaro, G., Cacace, F., Spence, R. J. S., and Baxter, P. J.: Impact of explosive eruption scenarios at Vesuvius, Journal of Volcanology and Geothermal Research, 178, 416-453, 10.1016/j.jvolgeores.2008.01.005, 2008.