Use of friction between suspension and surface to predict run-out distance using a physical model in small-scale

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ABSTRACT

Mudflow can be considered a geological hazard, mainly when occur near a city, because destroy all the infrastructure. After the rupture, the soil may suddenly change the behavior from solid-like to fluid-like. It may be caused by the increase of water content. Thus, comprehend the flow movement is important and one alternative is the use of a small-scale model, because it is possible to control the boundary conditions and isolate the variables to understand a specific parameter. So, this paper presents a simplified calculation to estimate the run-out distance using a small-scale model. By using a generic suspension composed by CaCO$_3$, with different water content it is possible to evaluate the run-out behavior and morphology. In this is study, all the variables maintained constant (ramp inclination, volume of material, deposition surface) and only altered the water content. Therefore, the run-out was influenced only by the water. The results indicated that using a classic mechanics and energy conservation is possible to estimate the run-out, by estimating the friction between the suspension and suspension. The predicted distance was the same as observed in the experiment.

1 INTRODUCTION

Mudflow is a concentrated suspension composed of soil and water and it is considered a serious geological hazard, because it may reach long distances and high velocities, becoming a very rapid flow-like movement. Mudflows are one of the most significant types of mass movements due to sudden occurrence and change of behavior, from solid-like to fluid-like (Iverson 2015). Right after the slope rupture, the soil may change from solid to plastic, as the mass gradually becomes deformed. When the water content increases (equal or higher than the liquid limit (LL)) the mass starts to move very quickly and the behavior changes completely, turning into a liquid-like mass (Lee and Widjaja 2013).

One alternative to comprehend the flow movement is using models in small scale. In this method, the boundary conditions are controlled, thus it is possible to isolate the analyzed variable, and, consequently, understand the influence in the flow dynamics.

So, this paper presents a simplified calculation to estimate the run-out distance using a small-scale model.

2 EXPERIMENTAL

2.1 Microfiller

This work was carried out using a CaCO$_3$ microfiller. The real density of dry material was determined by gas Helium pycnometer (Multi Pycnometer – Quantachrome), the granulometric distribution was measured by a laser granulometer with a detection range of 0.1 – 350 micra (Helos – Sympatec).

Figure 1: Particle size distribution of microfiller, density, and SSA
The material approaches to a particle size distribution of a silt and clay (<75 μm) (ASTM D2487). It presents a liquid limit (LL) of 46.4% and plastic limit (PL) of 28.1%. Thus, three suspensions with different water content were analyzed and Table 1 summarizes the main characteristics of each composition evaluated.

### Table 1: Suspension composition and powder characteristics: percentage in weight and volume of solid and liquid part, real density ($\rho_\text{esp}$).

<table>
<thead>
<tr>
<th>Suspension</th>
<th>wt% sol.</th>
<th>wt% liq.</th>
<th>vol% sol.</th>
<th>vol% liq.</th>
<th>$\rho_\text{esp}$ (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>50</td>
<td>50</td>
<td>27.47</td>
<td>72.53</td>
<td></td>
</tr>
<tr>
<td>55%</td>
<td>45</td>
<td>55</td>
<td>23.66</td>
<td>76.34</td>
<td>2.64</td>
</tr>
<tr>
<td>60%</td>
<td>40</td>
<td>60</td>
<td>20.16</td>
<td>79.84</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Runout evaluation

To evaluate the runout distance and morphology, a small-scale inclined ramp was used to study the behavior. Dimensions are the same as ‘L box’ used for self-compacting concrete characterization (EN 12350). The ramp (Figure 2) allows a adjust of inclinations (5°, 15°, 30° and 45°). In order to film the suspension runout, a semiprofessional camera (NIKON D7100) was used and setup with a rate of 60 frames/s and resolution of 720p.

![Figure 2](image)

Figure 2 (a) Inclined plane used to evaluate flow dynamics (b) Detail: $L = 60$ cm e $\alpha = 15°$.

Post-treatment of each suspension was analyzed using the Digital Image Correlation (DIC) technique and the procedure is presented in (Sakano et al. 2018). DIC allows the quantification of flow velocity.

3 RESULTS

By using the DIC technique it is possible to quantify the velocity and flow position in every instant. Figure 3 presentes the suspension runout for each water content. In this study, the surface had little interaction with the suspension (rigid base), the flow volume remained constant and the slope was maintained at 15° and only the water content was altered.

![Figure 3](image)

Figure 3: Velocity surface for different water concentrations (a) 50%, (b) 55% and (c) 60%. For the 50% concentration the velocity ranges from 0 to 0.35 m/s, 55% from 0 to 0.7 m/s and 60% from 0 to 0.85 m/s.

It is observed that as the amount of water increased, not only the velocity increased, but also the runout distance. The morphology of the deposited material is related to the composition, velocity, and friction of the
surface with the suspension (Kaitna, Dietrich, and Hsu 2014). By the captured images is notable that as the water content increase, and, consequently, the suspension velocity, the morphology changes completely. The morphology altered from circle to elliptical shape and this it may be related to the viscosity of the suspension.

From the velocity surface, it is possible to obtain the rate of deposition on the horizontal plane (Figure 4). The profile used is the central region according to the dashed white line indicated in Figure 3.

![Figure 4: (a) Speed profile (u) for suspensions with different contents at each instant of the horizontal plane (L). (b) Flow position (L) as function of time.](image)

There is a deceleration of the suspension from the initial \(v_0>0\) to a final velocity \(v_f=0\). This deceleration is caused by the friction between the suspension and the surface on which it is flowing. Thus, it is possible to make some assumptions and simplifications to calculate the maximum displacement of the suspension. Because it is a relatively simplified system: homogeneous suspension formed by fine particles and spread over a rigid smooth surface (without interaction between particle and surface), some hypotheses can be assumed:

1. There is no sedimentation of particles and the suspension behaves as a homogeneous material;
2. Only the friction force acts on the suspension after the exit of the ramp, being the resulting force of the system, so the kinetic energy of the system will be dissipated in the form of heat caused this force;
3. It will be considered only the flow front, considering it as a block;

So, it is possible to calculate the maximum distance that the suspension will travel in the horizontal plane. Firstly, it is necessary to define the coefficient of dynamic friction \(\mu_c\) between the surface and the suspension. Based on the experimental data and using Newton's Second Law, which says that the resulting force \(F_R\) acting on a body must be equal to the product of the mass of the body \((m)\) and its acceleration \((a)\). Since the only force acting is the friction force \((F_A)\) it is possible to calculate \(\mu_c\) dividing the body acceleration by gravitational acceleration \((g)\), according to Equation 1.

\[
F_R = F_A \rightarrow ma = mg\mu_c \; \therefore \; \mu_c = \frac{a}{g} \tag{1}
\]

However, it is still necessary to know the value of the system acceleration to calculate the coefficient of dynamic friction. Through the equations of the classical mechanics of uniformly varied motion, in especial the Torricelli equation, it is possible to calculate the system deceleration. Parameters for calculation and results are summarized in Table 2.

<table>
<thead>
<tr>
<th>Water content (%)</th>
<th>(v_0) (m/s)</th>
<th>(\Delta S) (m)</th>
<th>(a) (m/s²)</th>
<th>(a_{mean}) (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0,31</td>
<td>0,29</td>
<td>0,170</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>0,62</td>
<td>1,04</td>
<td>0,186</td>
<td>0,177</td>
</tr>
<tr>
<td>60</td>
<td>0,76</td>
<td>1,64</td>
<td>0,175</td>
<td></td>
</tr>
</tbody>
</table>

Thus, by substituting the mean deceleration value in Equation 1 it is possible to calculate the coefficient of friction. As was pointed out by one of the hypotheses, all kinetic energy \((E_c)\) will be dissipated in the form of work performed by friction force \((W_A)\), and thus it will be possible to calculate the maximum distance \((L_{max})\)
traveled by the suspension, according to Equation 2. And Figure 5 compares the runout distance of the experiment (\(L_{\text{meas}}\)) and the calculated (\(L_{\text{calc}}\)).

\[
E_c = W_A \rightarrow \frac{m v_0^2}{2} = m g \mu_c L_{\text{calc}} \Rightarrow L_{\text{calc}} = \frac{v_0^2}{2 g \mu_c}
\]  

(2)

![Figure 5: Comparison between runout distance measured and calculated.](image)

It is verified that the runout distance prediction using the principle of conservation of energy and classical mechanics is valid. But it is worth mentioning that, it is only valid because of the hypotheses and because it is a simplified system. In a real condition, the result would be divergent, because there is the presence of thick particles immersed in the suspension formed by the fine particles, causing to the greater interaction between them and, also, exchanges of material between the base and the suspension.

4 CONCLUSIONS

By the ramp tests, it was verified that the water content has great influence on the flow and spreading of the suspension. As the water content was increased, higher flow velocities and, consequently, longer deposition distances were observed. The water content also affected the deposition morphology. For low water content, the morphology was close to a circumference and as water is added into the system, the shape approaches to an ellipsoid. With the quantification of velocities and positioning over time, it was possible to model the flow in a simplified way using classical mechanics. Thus, it was possible to estimate the friction between the suspension and the surface and calculate, from conservation of energy, the runout distance using. The predicted distance was the same as observed in the experiment.

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REFERENCES


