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IMPACT LOAD OF A GRANULAR FLOW AGAINST AN OBSTACLE BASED ON DISCRETE ELEMENT METHOD

Adel Albaba¹, Stéphane Lambert², François Nicot³, Bruno Chareyre⁴

This paper presents a numerical study for evaluating the impact force of dry granular flow against a rigid wall. The granular material was modeled using poly-dispersed clumps where each clump consisted of two overlapping spherical particles accounting for the shape effects of gravel particles. The particles were flowing in an inclined flume where different inclination angles were tested and interaction forces with the wall were recorded at different heights. Compared with the experimental results, the model showed good agreement regarding the peak impact force, the time of the peak force and the final (residual) force at the end of the tests.

Keywords: DEM, granular flow, rigid wall, impact force, numerical modeling

INTRODUCTION

Granular flow exerts large forces within a short period of time leading to major infrastructural damage and loss of lives. Such a force generally varies with slope angle, thickness of the flowing material and velocity at the moment of the impact. Granular flow hazard is classically mitigated by protection structures similar in principle to rockfall barriers. These structures are either retaining walls [1] or flexible structures made of nets [2]. For rigid walls [3], hydraulic models are used for force estimation of the impact which are mainly separated into hydro-static and hydro-dynamic models. Hydro-static models are generally simple and only require the height of the granular flow. The maximum impact pressure (N/m^2) is generally calculated as $P_{\max} = k \rho g h$, where k is an empirical factor (ranging from 2-7), ρ granular flow density (kg/m^3), g gravitational acceleration (m/s^2) and h granular flow height (m). On the other hand, the hydro-dynamic model is evaluated as $P_{\max} = a \rho v^2$ where a is an empirical factor which depends on the type of the flow (e.g. laminar or turbulent, muddy or stony etc.) and v is the granular flow velocity (m/s). The factor a is sometimes considered as flow cross section where; if so, the units have to be adapted. For flexible structures design [4], the dynamic wave acts on the lower part of the net with a force per meter run on the rope calculated as $F_{\text{dyn}} = \rho v^2 h$.

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Discrete Element Method (DEM) is widely used for modeling granular media. It is particularly efficient for static and dynamic simulation of granular assemblies where medium can be described at a microscopic scale. It has been in use in the last decade for simulating granular flow mainly in experimental flumes. However, little attention has been given to coarse-grained flow of angular particles which is the main case for natural dry granular flow.

In this paper we present a DEM-based model using visco-elastic contact law to simulate dry granular flows. The experimental data of Jiang & Towhata [5] have been used for model calibration and validation purpose. The experiment gives detailed measurements of impacts of dry granular flow (made of angular gravel particles) against a segmented rigid wall (Fig. 1) using different flume inclination angles and sample volumes. In order to take the shape effect of gravel particles into account, clumped particles were preferred over spherical ones. Clumped particles provided lower rotational energy leading to better representation of the angular gravel. Results in this paper are presented for a granular sample having 44 cm in length, 15 cm in height before being released in the 40° inclination angle flume.

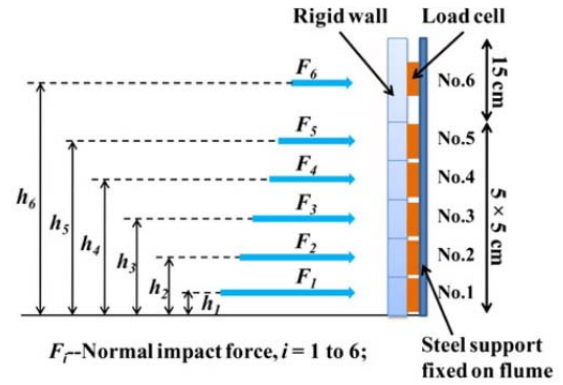


Fig. 1 Position and heights of different segments of the rigid wall [5]

IMPACT FORCE ON EACH PART OF THE WALL

By quantitative comparison with experimental results, good agreement has been observed in terms of the peak force on each part of the wall, the time of the peak and the residual force at the end of the test (Fig. 2). Comparing impact forces, we have observed a non-linear distribution along the different parts of the wall. In particular, the force at the toe of the wall is sometimes smaller than the one on the segment above. According to [5], this might be due to an arching effect forming an arch-like protective layer on segment 1 of the wall resulting in a non-linear distribution of forces with depth. Such a mechanism is also thought to affect the residual force values. For the model, to some extent, arching was observed to be present in the model, especially for residual forces of F1-F2 and F3-F4 which might be due to the force chain distributions and particles shape arrangement behind the wall. Force chains are strongly depending on the particles position and orientation with respect to the wall.

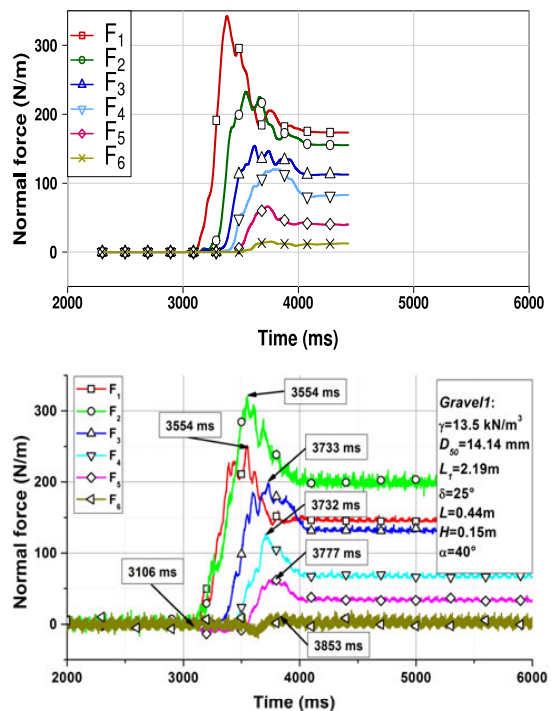


Fig. 2 Time history of normal force variation: model (top) and experiment [5] (bottom)

TOTAL IMPACT FORCE AND BENDING MOMENT

By considering the normal force on each part of the wall (F_i) and the distance between the centroid of the wall's parts and bottom of the retaining wall (h_i), the total normal force (F) and

bending moment (M) can be calculated as $\sum_{i=0}^6 F_i$ and $\sum_{i=0}^6 F_i h_i$ respectively. The model fairly agrees with the experiment in terms of the peak value, peak time and residual value (Fig. 3). It gives a peak impact force value of 735 N/meter width of the wall which is much closer to the experiment. By comparison, the simple models presented in the introduction gives lower values: the peak force ranges between 175.0 and 613.0 N/m for hydro-static model (for k ranging from 2 to 7) and the hydro-dynamic model gives a peak force of 595.0 N/m.

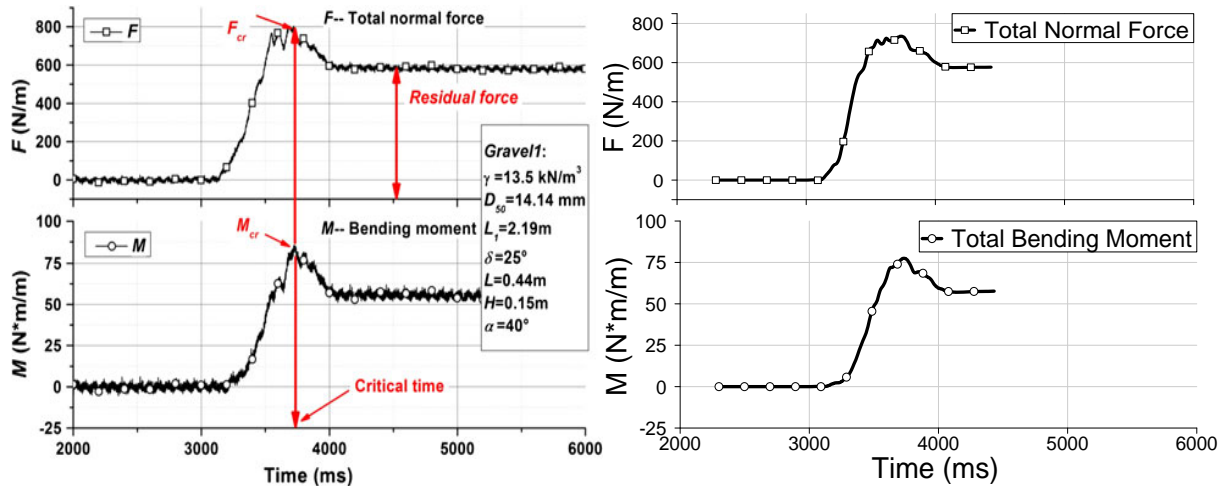


Fig. 3 Time history of total normal force and bending moment: model (right) and experiment [5] (left)

CONCLUSIONS

We have numerically studied the impact behavior of dry granular flow made of clumped particles (resembling gravel particles) against a segmented rigid wall. The model has been validated for impact force measurements against a rigid wall. This model can thus be used to study impact against other types of structures, and in particular flexible structures such as net fences.

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