Load displacement in grape harvesters: Discrete Element Analysis.

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Abstrat

Dynamic weighing of the hopper in grape harvesters is affected by a number of factors. One of them is the displacement of the load inside the hopper as a consequence of the terrain topography. In this work, the weight obtained by a load cell in a grape harvester has been analysed and quantified using the discrete element method (DEM). Different models have been developed considering different scenarios for the terrain.

Key words: load cell, discrete element method, grape harvester, dynamic weight.

1. Introduction

Assessing crop yield requires the development of accurate weighing systems. In an extensive study of Baguena et al. (2011) a dynamic weighing system was developed for a grape harvester, consisting of two load cell mounted respectively underneath of the two hoppers of the machine. In such study, a review of the state of the art for crop yield monitoring is provided, together with the assessment of experimental errors under extensive field validation. These errors are a consequence of the displacement of the load inside the hopper, as the grape harvester moves along vineyards of irregular topography profile.

Recently the discrete element method (DEM) has demonstrated to provide an adequate ability to simulate the real behaviour of real granular materials (González-Montellano et al., 2011, 2012).

In this work, the discrete element method has been used to simulate the displacement of the load in the interior of a grape harvester in relation to its inclination. Different DEM models have been developed and for each model, the grape harvester has been inclined forward and backward several times to consider the conditions found in the terrain. Different variables have been analysed to extract conclusions about the measuring errors observed.

2. Materials y Methods

2.1. DEM models

DEM models developed in this research work simulate the behaviour of the material stored in the grape harvester. The geometry of the grape harvester and the location of the load cell are shown in Fig. 1a. The load cell aims to estimate the mass of the material stored inside the hopper. Additionally, on the rear of the grape harvester there is a hydraulic cylinder that allows the inclination of the hopper during the discharge process.

The material simulated inside the hopper consists of spherical particles made of hydrogel instead of grapes because their mechanical properties are very similar. But the most important reason was that the hydrogel is a material non-perishable that does not depend on the harvest season. This makes it easier to perform laboratory tests that are used to validate the DEM models of the present work.

EDEM Academic 2.3 (2010) has been used to carry out the simulations presented in this paper. The Hertz-Mindlin (Tsuji et al., 1992) contact model was selected. To ensure the representativeness of the model, the mechanical properties of the particles of hydrogel were determined experimentally in a dedicated test. Table 1 summarizes the values considered, indicating in each case the procedure used for determination. The hydrogel spheres have been simulated as spherical particles according to a normal size distribution with a mean diameter of d=8.85 mm and a standard deviation of σ = 1.30 mm.

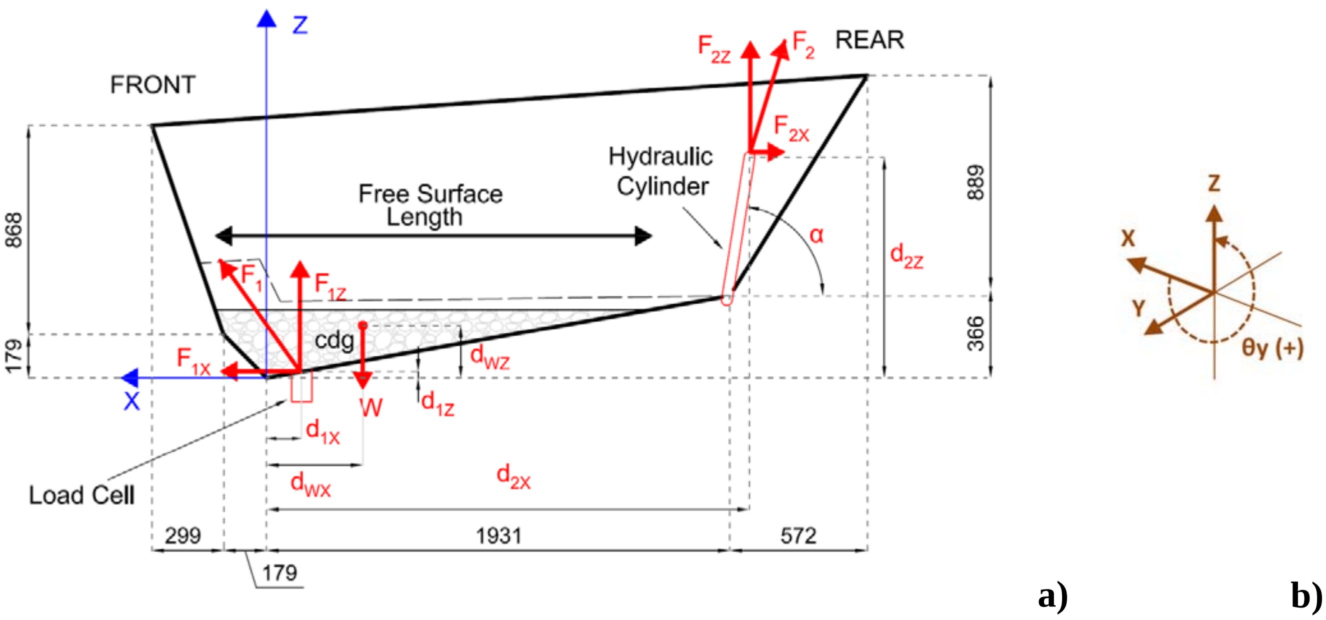

FIGURE 1. (a) Geometry of the hopper in horizontal position (θy = 0º); (b) X-Y-Z system.

TABLE 1. Microscopic values of the properties used in the DEM models

PROPERTY		VALUE	DETERMINATION METHODOGOY
Material properties			
Density (kg/m3)	ρ_p	1035	Pycnometer Test (ASTM D854-10 (2010))
Stiffness (Pa)	E_p	106	Paralel Plate Compression Test (ASAE S368.4 (2006))
Poisson's ratio	ν_p	0.24	Estimated
Interaction properties			
Particle-Wall Restitution coeff.	e_w	0.8	Drop Test (Gonzalez-Montellano et al, 2012)
Particle-Particle Restitution coeff.	e_p	0.7	Estimated
Particle-Wall Friction coeff.	μ_w	0.05	Estimated
Particle-Particle Friction coeff.	μ_p	0.05	Estimated

2.2.- Simulation process and model definition.

The simulation process followed in every model carried out in this work consisted of two stages: static and dynamic. The filling process, where the hopper stays static without any movement, starts with the generation of the particles inside the hopper and finishes once these particles lay in a static way on the bottom of the hopper. The particles are generated from a small rectangular surface located on the rear of the hopper with a generation rate of 40 kg/s, until a total mass of W=75 kg is achieved. The dynamic process starts just immediately after the end of the filling process. In this process the hopper is moved forward and backward around the Y axis (according to the X-Y-Z system of Fig. 1b). In this work three different rotation series (S1, S2 and S3) have been considered; the instantaneous inclination angle (θ_y) is shown in Fig. 2. Each of the rotation series considered –S1, S2 and S3– corresponds to a different DEM model –M1, M2 and M3– respectively. This will allow studying the influence of the displacement of the load with regard to the load cell signal, under varying work conditions. Series S1 and S2 present a low inclination rate (ω_y= 2º/s), including periods where the hopper is flat in the first case. For series S3, the inclination rate is higher (ω_y= 4º/s) than before without periods of no inclination. The use of several values of ω_y allows simulating the grape harvester movement along the field (way and return along vineyard lines). When the inclination rate is zero that will mean that the area has a constant slope.

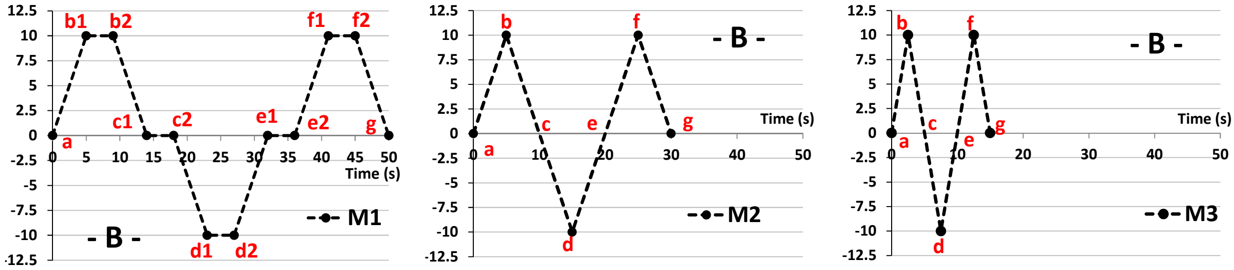

FIGURE 2. S1 (a), S2 (b) and S3 (c) series in M1, M2 y M3 models.

2.3.- Variables used in the analysis of the numerical results. Experimental validation.

Aiming at the analysis of the displacement of the load in the grape harvester under different working conditions and how this fact influences the weight value recorded by the load cell, the following variables have been defined:

- Evolution of the free surface length (FSL) of the material. The value of FSL (Fig. 1a) is defined as the length of the hopper, in the direction of the X-axis, filled by the material in a specific instant of time. This variable is related to the extension of the mass of particles in the hopper and its value have been obtained by means of the analysis of orthogonal images (from the negative Z-axis, Fig. 1) taken along the whole series of inclinations (Baguena et al., 2011).
- Evolution of the position of the centre of gravity (CoG) at each instant of time of the rotation series.
- Evolution of the vertical load detected by the load cell. The vertical load that would be detected in the load cell can be estimated from the numerical results by means of a mass balance calculation. The weight of the stored mass (W) would be considered applied in the CoG of the system. This weight must be compensated by two forces F1 and F2, developed respectively at the load cell is and in the hydraulic jack. Both forces could be decomposed following X and Z directions (Fig. 1a) By means of a balance of forces and moments, it is possible to determine the values of the F_{1x}, F_{1z}, F_{2x} and F_{2z} components, being the value of F_{1z} the one that will give an estimation of the vertical load detected by the load cell.

The models developed in this work were experimentally validated aiming at verifying the capacity of prediction of the reality. For that, an experiment for the situation described in the model M2 was carried out, checking that the FSL values obtained in the model and in the reality were similar.

3.- RESULTS AND DISCUSSION.

Figures 3, 4 and 5 show the results gathered for every DEM model carried out in this work. They provide the following information for each instant of the rotation series: Evolution of the

FLS value (Graph A); Evolution of the position of CoG of the stored mass in the Hopper (Graph B); Evolution of the value of the vertical load detected by the load cell (F_{1x}) (Graph C).

3.1.- Model M1

The evolution of the value of FLS (Fig. 3A) is a result of the displacement during the series of inclination. When the hopper is inclined forward ($d\theta_Y/dt > 0$) a concentration of particles is produced nearby the load cell, reducing the value of FLS. In the opposite situation, the load is distributed along the hopper, increasing the FLS value. However, these increments or decrements of FLS are not always of the same magnitude for the same angle of inclination due to the inertia of the particles that play an important role in the redistribution of the load. When the hopper, after a long static period, starts the inclination towards a new side (periods b2-c1, d2-e1, f2-g), the modification of the FLS is very small. The particles in this case almost have inertia or even have an opposite inertia to the new inclination. However, when the hopper starts again the inclination towards the same side after a static period (periods c2-d1, e2-f1) or even in some static periods (periods d1-d2 y e1-e2) the particles present a higher inertia, increasing the FLS rapidly.

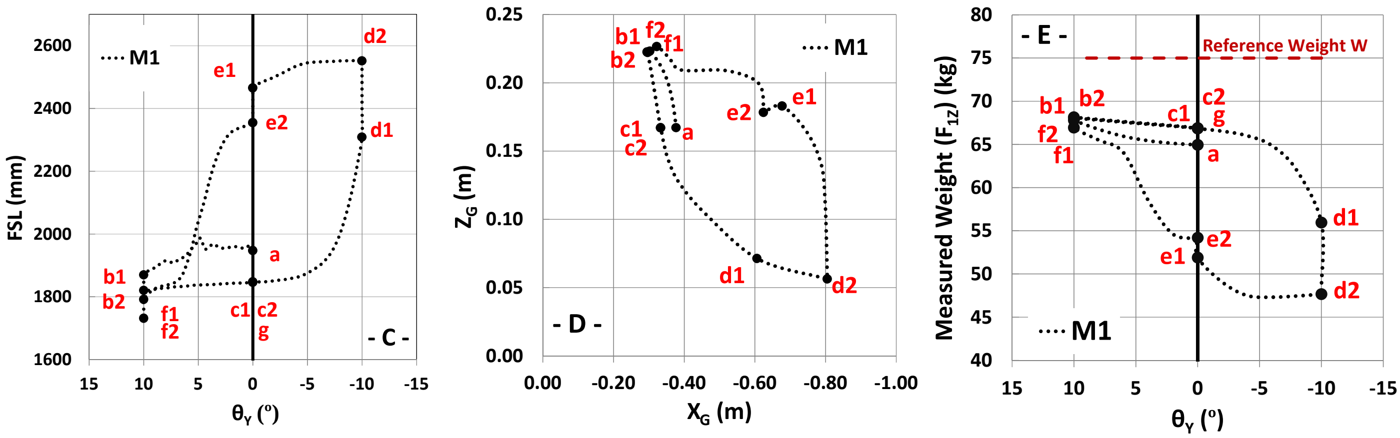

FIGURA 3. Results obtained for M1 model

The evolution of the CoG of the mass of particles in the hopper (Fig. 3B) is linked to the displacement of the particles, that is, to the evolution of the value of the FLS. The variation of the CoG is produced in the Z direction as well as in the X direction, and also is analogue to the increments or decrements of FLS. Therefore, increments of the LSL (periods b2-c1, c2-d1 y d1-d2) cause a decrement of the Z_G coordinate and an increment of the absolute value of the X_G coordinate, having the opposite situation in the opposite case (periods d2-e1, e1-e2 and e2-f1).

The vertical load detected by the load cell can be approached from the value of the F_{1z} component (Fig. 1a). The value of this component, for a particular position of the hopper and for a weight W given, is very dependent of the value of X_G. The F_{1z} value will tend to get closer to the value of W when the absolute value of X_G will tend to zero, being more distant in the opposite case. In this last case, part of the weight W is taken by the hydraulic cylinder to reach the equilibrium, reducing consequently the value of F_{1z} and generating a measuring error in the measurement of the load cell signal.

Figure 4C shows that F_{1z} is always lower than the expected value (W), for any position of the series of inclinations, since the absolute value of X_G is always higher than zero, which causes the hydraulic cylinder to take part of the weight W. In the most favourable case the load detected by the load cell is of 0.9W. This situation is reached when the hopper is totally inclined forward (points b1-b2 and f1-f2) and the material is concentrated nearby the load cell. In the most unfavourable case, the value detected by the load cell is of 0.6W, which corresponds to the stored material in the hopper being totally spread along the hopper (points d1-d2).

3.2.- M2 Model

In the M2 model, the modification of FLS (Fig. 5A) is similar to that described for model M1. However in this case, since no static periods are included between inclination periods, it always exist an opposite inertia at the beginning of a new inclination period. This causes the maximum values of FLS to be lower than for M1, which is translated into a lower expansion of the particles on the hopper.

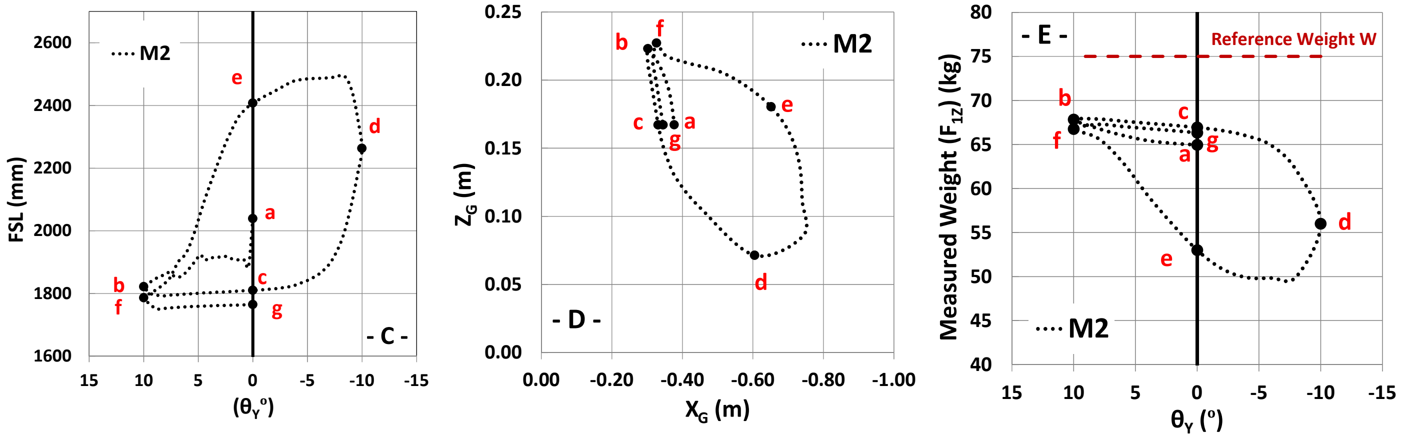

FIGURE 4. Results obtained for M2 model

The modification of the position of the CdG (Fig. 5B), as for M1, follows an evolution according to that observed for FLS. However, in this case, the lower extension of the particle distribution observed in the hopper in M2 model causes the absolute value of X_G to stay under that observed for M. As before, the evolution of recorded weight is dependent of the evolution of CoG, and thus F_{1z} varies between 0.9 W and 0.67 W, a narrower range than for M1 model.

3.3.- M3 Model

The evolution of FLS in the case of M3 model is very similar to that observed for M2. However, the higher inclination rate for M3 makes the inertia reached at the end of a complete inclination series to be higher than that for M2 model. This fact causes the inertia that opposites the start of a new inclination to be more important, as shown by a higher reduction of the FLS in comparison to models M1 and M2.

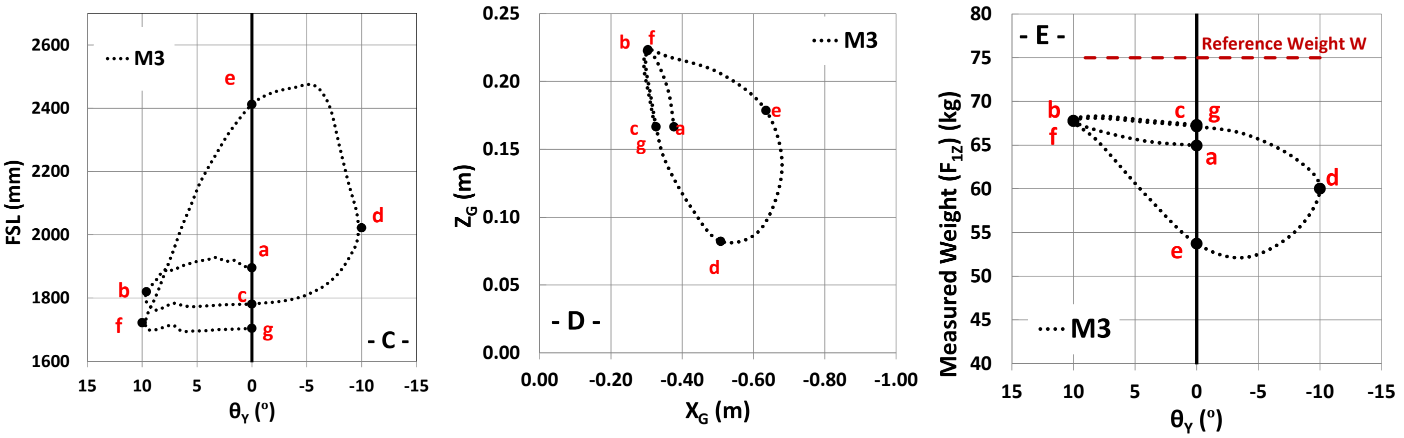

FIGURE 5. Obtained results in M3 model

The evidence of change for CoG found for M3 model accordingly generates a narrower variation of the load detected by the load cell (F_{1z}). In this case the load detected oscillates within a lower rank, between 0.9W until 0.7W.

4.- CONCLUSIONS.

- The weight detected by the load cell is very dependent of the distribution of the load within the hopper, underestimating the real value stored in the hopper in any case.
- Such weight distribution is not only dependent on the inclination angle as a consequence of the terrain topography, but also on the history of inclinations (inclination rate, presence of static periods…) since the side effects of the inertia of the particles is not negligible.
- Due to the large number of variables that influence the measuring accuracy of the load cell, it is not feasible a systematic instantaneous correction. The most effective solution would imply a simultaneous measurement of the force developed in the load cell and in the hydraulic cylinder. This solution is being studied for the near future.

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