Modeling the behavior of dry sand with DEM for improved impact prediction

S.Sridhar, SushilKumar Vishwakarma

Whirlpool Corporation.

1 Abstract

Pumpkin ball impact test is similar to simple pendulum impact test. It represents a rough handling test conducted on user interface parts to check its robusteness in case of abuse loading. The objective of this work is to create a standard simulation model that would capture the behavior of sand particles inside a rubber ball and scope is limited to create and validate a finite element model used to replicate a pumpkin ball impact test. Pumpkin ball is a rubber ball filled with dry sand up to 3/4th of its volume. The major challenge in this activity was simulating the real behavior of dry sand inside the rubber ball during the impact. Dry sand granules interact with each other as well as with the inner surface of ball during the course of impact. To capture this behaviour of dry sand granules discrete element method (DEM) was used.
In the current study, the experimental test was conducted on concrete wall and measured acceleration was used for the validation of developed finite element model. The simulation results had shown a close agreement with the experimental results. The validated model is useful to verify the various design concepts early in the product development process..

Keywords: DEM, Console, User interface, Pumpkin ball, accelerometer, dry sand, finite element methods.

2 Introduction

Pumpkin ball is a rubber ball filled with dry sand used to conduct impact test on user interface parts. This impact test represents a rough handling test conducted on console (user interface) of home appliances for safety related concerns. As of now these tests are carried out after the availability of prototype parts much later in the development process, limiting the possibility of design improvements. The main objective was to create a standard FE model that would capture the dynamic behaviour of sand particles inside the rubber ball during impact and use the same to perform virtual impact tests on user interface parts at early stage of product development. The major challenge was to simulate the real world behavior of dry sand inside the rubber ball during impact.
Sand assemblies are made up of grainnules in contact and surrounding voids, which change their arrangements depending on environmental factors and initial density. Macro-mechanical and fabric behaviour is inherently discontinuous, heterogeneous and non linear making their overall behaviour complex [1]. Type of sand considered for simulation is coarse of dimension 1 -2 mm.
Discrete element method (DEM) is widely used for modeling granular materials [1]. Discrete elements are modeled as rigid spherical particles. A dynamic behaviour of the discrete system is solved numerically using a force-displacement Lagrangian approach and tracks the positions, velocities, and accelerations of each particle individually. It uses an explicit finite difference algorithm assuming that velocities and accelerations are constant in all time step. To calculate forces acting in particle-particle or particle-wall contact, a particle interaction model is assumed wherein the forces are typically subdivided into normal and tangential components. The total force acting on each particle is summed. A penalty-based contact is used to capture the particle-particle and particle-surface interaction of dry and wet particles. Non spherical particles introduce the additional moments, which is addressed by rolling friction parameter [2].
To validate the FE model, experimental tests were conducted. The lab test set up consist of a rubber ball filled with dry sand. Ball was hung from ceiling using steel rope, pulled back and released to impact the concrete wall. The test setup is shown in Fig 2. During the impact, normal and side acceleration of ball was measured and used to correlate the simulation model. This FE model would replicate the pumpkin ball used in test, which can later be used to simulate the product level impact test on different concepts and optimize the design before physical prototyping.

3 Experimental test set up

A rubber ball was filled 3/4th of its volume with dry sand. The ball was hung from the hinge point by steel pendulum chain, pulled back and released to impact on concrete wall. While testing two accelerometers were attached to ball with glue and tapes as shown in Fig 1. to obtain acceleration data with reference to wall during impact. One accelerometer was attached in the impact direction and other to the right adjacent side of the ball. Pumpkin impact test is repeated for ten times to get average acceleration data during impact. Peak acceleration value from normal and side accelerometers were noted on each occassion.


(a)

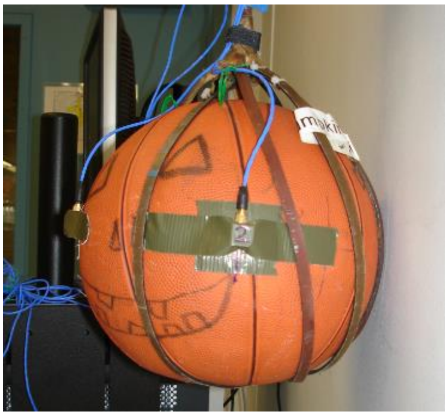

(b)

Fig.1: (a) Back or Normal accelerometer. (b) Side accelerometer.

Specification of accelerometer used is listed below.
- LMS Scadas III data acquisition Hardware.
- LMS Test.Lab data acquisition and analysis software.
- PCB triaxial accelerometer model (qty. 2)

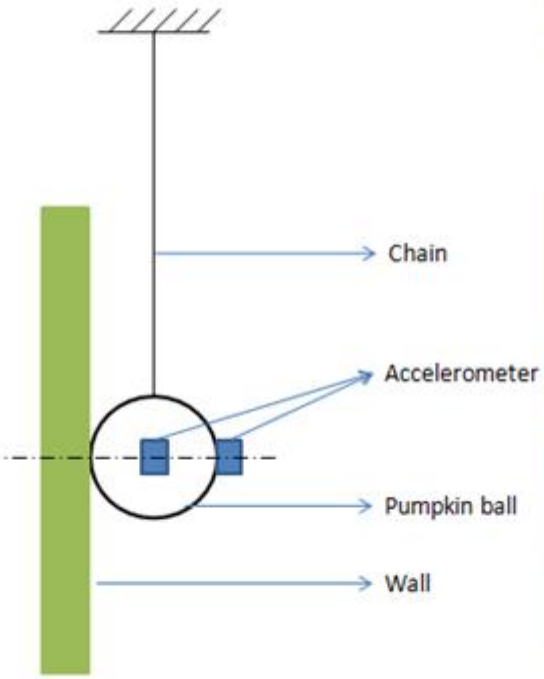
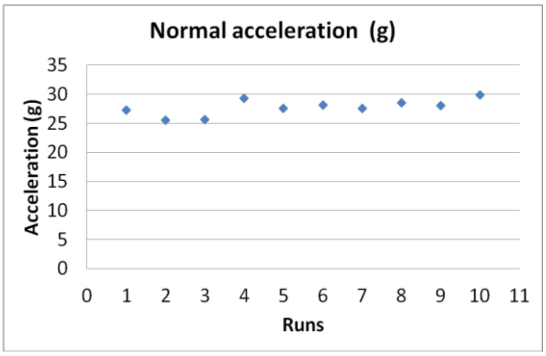
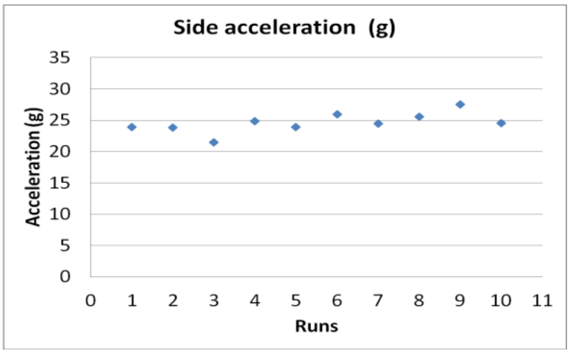


Fig.2: Solid wall concrete set up



(a)



(b)

Fig.3: (a)Normal acceleration data ball. (b) Side acceleration data on ball.

Above plots in Fig 3. shows the normal and side acceleration values measured on ball.

4 Simulation model set up

Important aspects of overall behavior are considered while developing the simulation model. Model consists of 2D shell elements and discrete element spheres. 2D Shell elements are used to model rubber ball and concrete wall; dry sand particles are modeled with discrete element spheres. Entire model consists of 73,745 elements including sphere and shell elements.

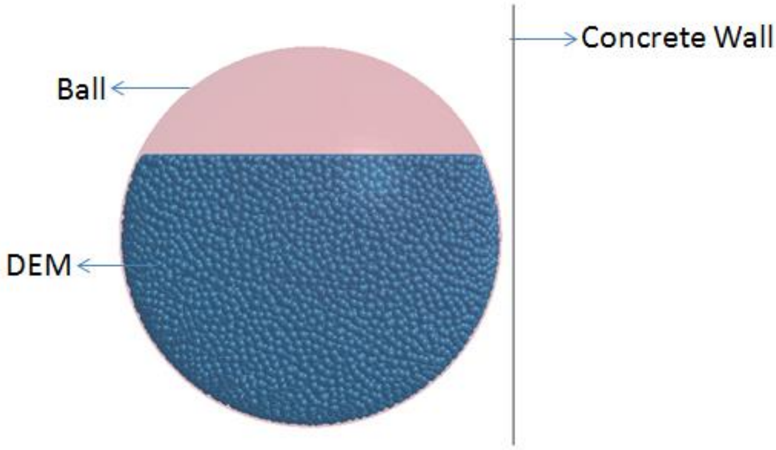


Fig.4: Finite element model

Shell elements used to model rubber ball and concrete wall, dry sand particles are modeled by DEM technique[1]. The definition of particles was done using the card *ELEMENT _DISCRETE_SPHERE_VOLUME.

*MAT_PIECEWISE_LINEAR_PLASTICITY (TYPE 24) material model is used for rubber ball and *MAT_ELASTIC (TYPE 001) material model for discrete elements. Concrete wall is modeled using *MAT_RIGID (TYPE 20) material model of LS DYNA. Material parameters for sand particles, concrete wall and rubber ball are referenced from literature's and publications.

*CONTROL _DISCRETE_ELEMENT card was defined for self interaction of discrete element spheres and particle-surface interaction is handled by *DEFINE_DE_TO_SURFACE_COUPLING contact definition[3][4][5]. Herein the spherical particles are assigned as slave side of contact using part set and the master side is outer shell elements. The translation and rotational degrees of freedom for rigid wall is constrained.

5 Simulation result and validation

With above described finite element details the impact test has been simulated in LS-DYNA solver.

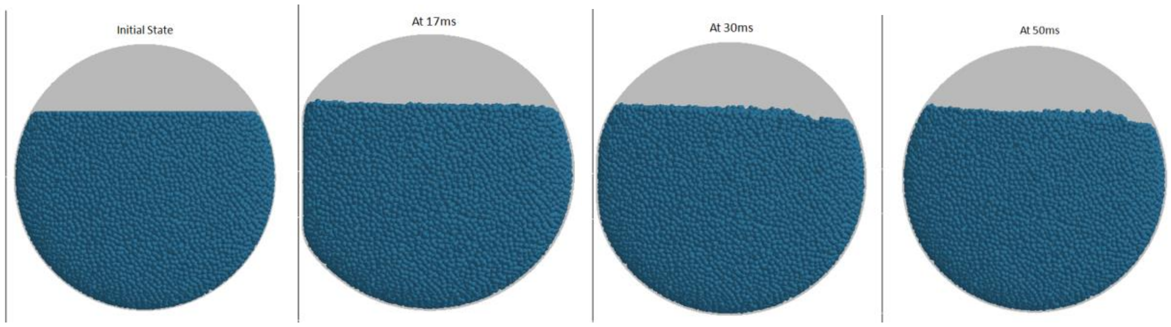
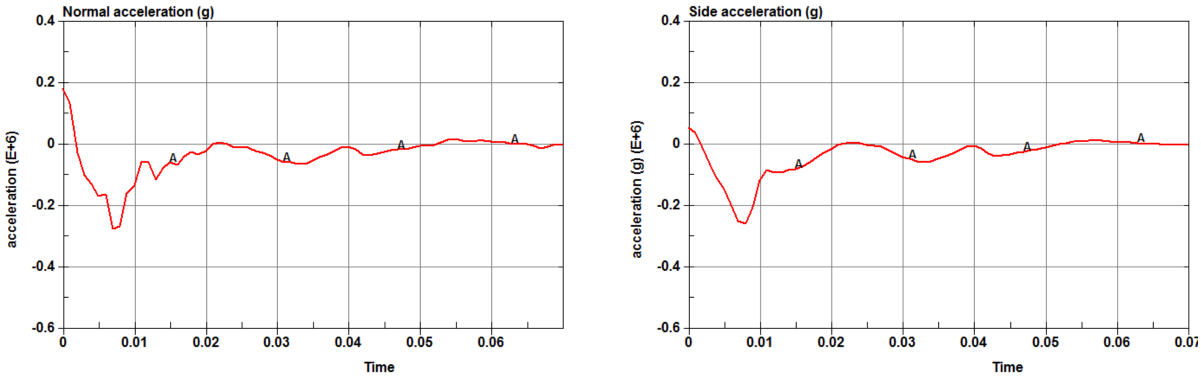


Fig.5: Sand particle behavior during impact

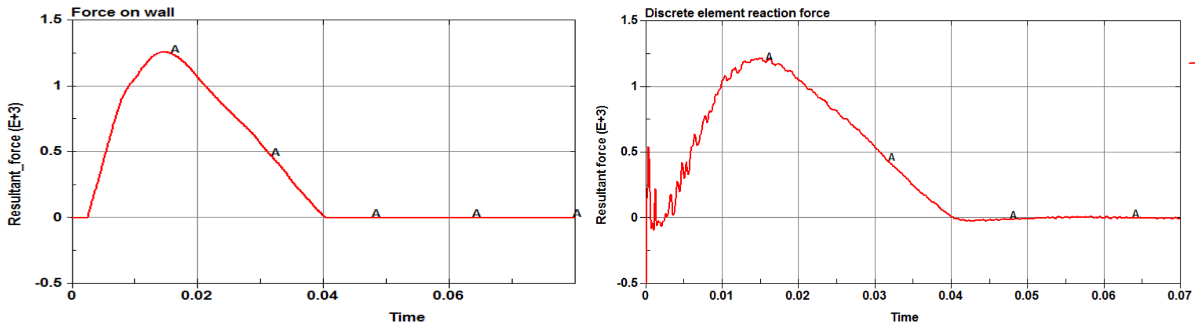
The important parameters identified and tracked in simulation to validate the model are accelerations on the ball surface. From simulation results, self contact between the particles, contact between the particle and surface and contact force on the wall are monitored.



(a) (b)

Fig.6: (a)Normal acceleration on ball. (b) Side acceleration on ball.

The impact is observed to be highly damped owing to the characteristics of the sand particles. Looking at the impact in the time domain, they are about 0.04 seconds long, and die out almost immediately. Fig 6 shows the



(a) (b)

Fig.7: (a) Force on wall. (b) DE reaction force.

The above Fig 7. plots the force on concrete wall, at 0.015 milliseconds the force value reaches maximum and falls as ball starts to re-bounce. The discrete element reaction force is the major contributor of forces imparted on the wall.
Acceleration measured in physical test data was used to enhance the behavior and validate the simulation model. Below figure shows the simulation as well as test result data. The simulation results are in close agreement with the experimental test values.

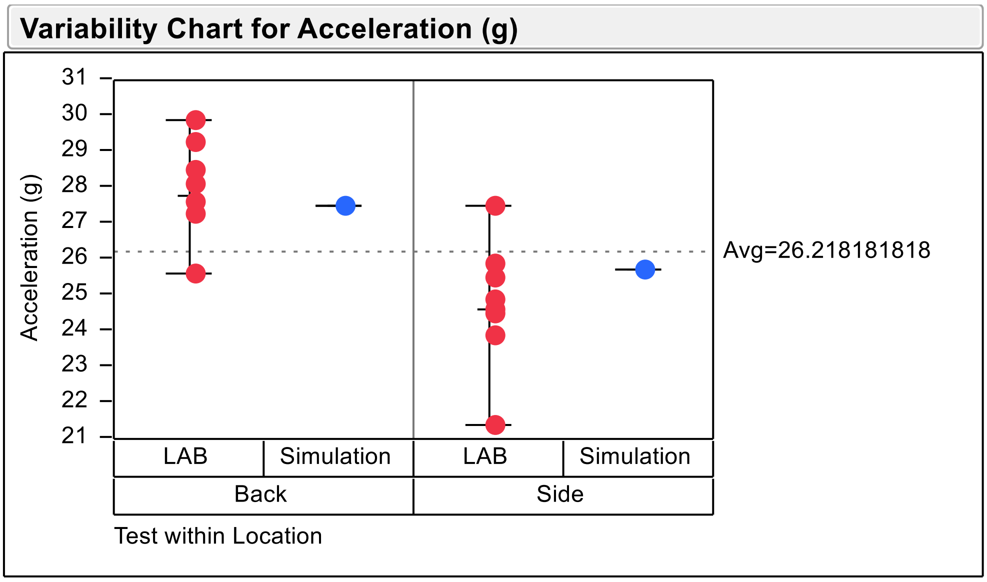


Fig.8: Simulation result against experimental lab test.

6 CONCLUSION

The results from LS DYNA simulation shows good correlation with experimental lab test data. The simulation model created can be further used to verify and optimize design early in the concept stage, instead of depending on physical prototype testing later. Current simulation model can further be improved by better representation of initial shape and material properties of rubber ball.

7 REFERENCES

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