LOAD INTENSITY CALCULATIONS ON TIPPER BODY USING DEM FEM COUPLING

D. FORSSTRÖM¹,³, P. JONSÉN²,

¹ Department of Engineering Science and Mathematics
Luleå tekniska universitet
971 87 Luleå Sweden
e-mail: Dan.forsstrom@ltu.se, http://www.ltu.se/staff/d/danfor-1.86660

² Department of Engineering Science and Mathematics
Luleå tekniska universitet
971 87 Luleå Sweden
e-mail: Par.Jonsen@ltu.se, http://www.ltu.se/staff/p/parj-1.12049

³ SSAB, 613 31 Oxelösund, Sweden, Dan.forsstrom@ssab.com

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Abstract.
Constructions and machines like conveyers, chutes and dumper truck bodies are examples of structures that can be exposed to abrasive wear during handling of granular materials. Abrasive wear has far reaching economic consequences which involve not only the costs of replacement, but also the costs involved in machine downtime and lost production. In order to effectively predict abrasive wear in large scale applications, models for solid structure, material flow and wear behaviour have to be coupled together. In this work the discrete element method is used to represent the granular material and finite element method is used to model the structure of the tipper body. The methods are coupled together with a contact model to mimic real unloading. Physical interaction between the granular material and the tipper body is studied in three different cases. A validation of the load intensity pattern and the wear pattern of a real tipper body is done. The comparison shows a close agreement between the position and size of areas with highest load intensity and highest wear. This combination of numerical methods gives new possibilities to understand the wear process and is a step towards more physically correct models for large scale predictions between tipper bodies and granular material. The ability to use improved numerical tools can give future opportunities to optimise material selections and geometry with the intention to increase functionality and life of wear applications.
1 INTRODUCTION

Constructions and machines like conveyers, chutes and dumper truck bodies are examples of structures that can be exposed to abrasive wear during handling of granular materials. Abrasive wear has far reaching economic consequences which involve not only the costs of replacement, but also the costs involved in machine downtime and lost production. Investigations of fundamental mechanism of abrasive wear on steel grades in contact with granular material have been presented by e.g. Moore [1, 2]. Models that describe the sliding abrasive wear from rock and granular materials have earlier been developed e.g. Atkinson [3]. These models can predict the relative wear of different steel grades. Large scale simulations with a combination of numerical models of truck bodies have been done before [4]. In that case the smoothed particle hydrodynamic method (SPH) and the finite element method (FEM) were combined to study unloading of dumper truck bodies. In this paper the focus is on tipper trucks, this mainly due to the fact that these types of structures are commonly used and faces major changes in the design to suite the new demands on the market.

In the numerical simulations, FEM is used to represent the tipper body structure and the discrete element method (DEM) represents the granular material. An important issue is to mimic the granular flow and its loading to the tipper structure and the treatment of sliding and impact along the interfaces are essential for the response of the model. Coupling FEM with DEM elements is done using a penalty based “nodes to surface” contact algorithm. This type of contact is a so-called one-way contact. In this kind of contact the DEM-elements are defined as the slave side and the FEM defined as the master side.

Three different load cases with different fractions of the granular material are modelled and used to load the structure. The simulations of unloading is carried out using the commercial program LS-Dyna, from this simulation a pressure map and relative velocities between the structure and granular material is obtained. At each spatial point and time step, pressure and velocity is integrated to obtain the load intensity. The different load intensity maps are then correlated with field measurement maps of tipper body working in similar conditions. These simulations are also used to study the deflection caused by the load on the structure. This knowledge is then used in designing new tippers with lighter and more optimised design both in structural and wear life.

The main objective with this work is to investigate the ability of couple DEM-FEM models to find the load intensity in realistic large scale simulations. This includes having correct material flow and contact conditions in order to do find the load intensity on the structure. In the end, have the ability to use numerical tools to optimise material selections and geometry with the intension to improve functionality and life of wear applications.
2 TIPPER BODYS

Tipper trucks are used for transporting material on roads. There are different types of bodyworks used and in this specific case the tipper body is of the free hanging U shaped type. This means that the design is in high strength steel with a modern design without any unnecessary beams and stiffeners. The free hanging design uses the steel structure abilities to deflect and absorb the load. In this specific case the tipper is used to transport blasted rocks on a road working site. The tipper model used in this case is showed in Figure 1.

3 EXPERIMENTAL MEASUREMENTS

In this work, wear on a tipper body of the U shape type using a specific design and material from SSAB is studied. Thickness measurements wear done on a similar design used for the simulations this was done using ultrasonic thickness gauge. Measurements on the tipper wear preformed after 15 months of service, which equals 3424 tilts of material, and each load weights about 30 tons. One working cycle consists of a loading procedure followed by transportation and ending with an unloading sequence. For this type of working cycles the unloading is the main cause for the wear. This specific tipper have been transporting large fraction crushed rock, small fraction crushed rock and soil. The remaining thickness of the plates was systematically measured in a more or less rectangular mesh manner. The results of the thickness measurements were analyzed and wear maps constructed, see Figure 2.
Figure 2: shows the measuring pattern in the tipper, and wear map.

The analysis shows that maximum wear is located in the bottom close to the outlet of the tipper which seems logical since this area is affected by the highest force. The result also shows an increase of wear along the sliding direction which is correct since the area at the bottom of the tipper is affected by more sliding of abrasives. A peak at 160 cm from the rear door is also discovered. This can probably be explained by the beams located on the outside of the tippers. Measurements of the beams, presented in the picture of the side of the tipper, show a distance of 150 cm from the rear door. This design is probably causing the bottom plate to bend slightly beyond 150 cm, but not below 150 cm, hence creating a small bump leading to an increase in wear rate.

3 MODELING

In the finite element (FE) model, the tipper body structure is represented with a shell element mesh. To virtually reproduce a realistic load to the tipper body, discrete element (DE) is used. A penalty based “nodes to surface” contact algorithm is used to couple the methods. All simulations are done in the commercial multi-physics program LS-Dyna [5].

3.1 Discrete element method

DEM has been developed and used over the past 30 years for modeling many applications, starting with simple geometries in two dimensions and small scale (100-1000s of particles). In DEM, calculations alternate between the application of Newton’s second law and a force-displacement law at the contacts. Newton’s second law is used to determine the motions of
each particle arising from body and contact forces acting upon it, while the force-displacement law is used to update the contact forces arising from the relative motion of each contact. For particle-wall contacts, the force-displacement law is only required since the wall motion is specified by the user. For a more detailed description see Cundall (1971) [6] and Cundall and Strack (1979) [7]. More recently DEM has been able to be used for industrial applications in complex processes such as tumbling mills [8].

In LS-DYNA, DEM is realized using rigid spherical particles, while interactions with other rigid or deformable structures are accomplished using penalty-based contact algorithms. In these simulations the DEM formulation is used to simulate the granular material in this case stone material. As measured above the unloading is divided into 3 different load cases with different diameters on the DEM elements with the diameter of A: 50 B: 200 and C: 300 mm, see Figure 3.

![Figure 3: Three different load cases with granular material, from left 50mm, 200mm and 300mm.](image)

The characteristics of the granular material are taken from the LS-DYNA pre-defined models for dry sand [9]. Rigid material model is used for the DEM elements, with density and Poisson’s ratio taken from a material model for sand.

### 3.2 Finite element method

For structural analysis, FEM is the most developed and used numerical method. FEM is a numerical solution method based on continuum mechanics modeling, a constitutive relation for the actual material is described and the governing equations are solved (Zienkiewicz and Taylor, 2000)[10]. Varieties of different constitutive models for a large number of materials are implemented in modern finite element (FE) code. A material model approximates a real physical behavior. Many factors affect the accuracy of a mechanical response computation, for example: the smoothness and stability of the response, the inadequacies and uncertainties of the constitutive equation, the boundary and initial conditions, the uncertainties in the load. The computability of nonlinear problems in solid mechanics is investigated in e.g. Belytschko and Mish (2001)[11].

For the tipper body shell elements in two different thicknesses are used to build the structure such a model are showed below in Figure 4. The bottom floor has the thickness of 10 mm and the sides are in 8 mm. The material model used is an Elastic-plastic material model for HARDOX 450.
3.3 Elastic-plastic structure model

The material model used in the finite element structure is a common material card in LS-Dyna with an arbitrary stress versus strain curve and arbitrary strain rate dependency can be defined, in this case given by SSAB.

4 LOAD INTENSITY

One approach to estimate load intensity (I) from contact between different interfaces is to calculate the integral of pressure and velocity. From the DEM simulations the contact pressure and velocities are taken from the point-net of tracer nodes for every time step. Data is imported into Matlab and for every spatial point is a numerically calculate load intensity value obtained using the equation:

\[ I = \int P \nu \, dt \] (1)

Where \( P \) is the contact pressure (Mpa), \( \nu \) is the velocity (m/s). A load intensity distribution can then be obtained for the current granular unloading of the tipper body.
5 RESULTS AND DISCUSSION

For the studied application the material flow is driven by gravity. During this motion particle-particle and particle-structure interactions occurs in the material system. The contact between particles and structure of the tipper body results in a load to the structure of the tipper body. The contact pressure and velocities are saved for every time step for each point in the net in the tipper body floor when unloading of a load. This is used to make a colour map that represents the distribution of load intensity in the tipper bottom. The influence of particle size on the load intensity is studied with three different load cases, Case A has a particle diameter of 50 mm, Case B has particle diameter of 200 mm in diameter and Case C a particle diameter of 300 mm. A comparison of the load intensity distribution for simulated tipper body load cases is shown in Figure 5. Increased load intensity is located in the back end of the tipper body. The beam located in the back end of the tipper body makes the structure stiffer and therefore leads to increase in load intensity just before the beam in the flow direction. As shown in the comparison of load intensity between the different load-cases, a smaller and finer granular material give a more localised and detailed pattern, in load case B the intensity is more intense but spread out. In the load case C the intensity map is more stochastic and there are not so easy to see a pattern, this is showed in Figure 5.

![Figure 5](image_url): Load intensity plots for the different load cases. From the left granular material of 50mm, 200mm and 300mm.
Validation of the numerical model is done by comparing the load intensity pattern to the experimentally obtained wear map. A comparison for the 50 mm case is shown in Figure 6. An interesting observation, the wear map in Figure 6 corresponds with load intensity distribution of case A and B in the way that the highest wear are in the area of the highest load intensity and lowest wear are in the area of the lowest load intensity. The enhanced wear before the first stiffener that is measured can be spotted in the simulations and the increased wear at the back end is captured, this is showed in Figures 5 and 6.

**Figure 6:** Load intensity plot of the tipper loaded with granular material with the diameter of 50mm.

**Figure 7:** Shows the displacement of the tipper body under the influence of granular load.
When looking on the deflection on the structure in the different load scenarios an even
distributed deflection of 17mm in the middle of the structure is localised, see Figure 7. This is
what to expect in real life. The deflection is one of the reasons for the increased load intensity
before the stiffener, this because of the change of material flow direction leading to higher
contact pressure. In this area the material flow also has quite high speed, this two together
leads to high load intensity. The deflection of the structure is important to include as it will
affect the granular flow and by that the load intensity.

An interesting development would be to calculate absolute wear on a large scale application.
This will demand coupling of load intensity to the wear process. Models for large scale
simulations and a coupling to the wear process between structure and granular material is
interesting. Such models would open up opportunities to optimise the structure to minimise
abrasive wear in e.g. tipper bodies.

6 CONCLUSION

A numerical method using DEM-FEM combination is used to simulate the working condition
of a tipper truck body. A strategy to calculate the load intensity in large scale simulations is
presented. The load intensity maps given by the calculations are in agreement with the wear
pattern measured in the experiment results. In load case A, the load intensity is concentrated
and shows increased load intensity were the flow direction changes. In load case B and C the
high load intensity zones are more distributed due to less contact points and higher contact
mass. In conclusion the size of the granular material is of greater importance. When using
larger particle size there are less contact points contributing to the load intensity but the
contact points has greater contact pressure leading to higher load intensity.

The main difference with using SPH-FEM and DEM-FEM model combination is that the
computational time is much lower for the DEM-FEM combination. The DEM-FEM
combination is also a step forward when it comes to precision due to the fact that the contact
pressure at the contact interface between DEM and FEM structure is used. For the SPH-FEM
the pressure inside the granular material (SPH) is used.

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