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Using Software Program to Study Wearing Phenomenon on the Dumper Vehicle Body and comparing it with Reality

ABBAS MOHAMMED ISMAEL
Kirkuk University / College of Engineering - Mechanical Dept.

Abstract: Abrasive wear is largely involved in many industries processes, and can cause serious problems and economic loss. A number of theoretical models and numerical models have been established to study wear phenomena. However, simulation and prediction of wear at large scale are seldom presented. Sliding abrasive wear of steel plates from interaction with granular material is here studied with numerical simulations. Abrasive wear of unloading of two different dumper body geometries are studied with the smoothed particle hydrodynamics method coupled to the finite element method. These numerical tools are of interest as they can reproduce interaction between solid and granular material. Wear pattern on the dumper bodies obtained from numerical simulation shows a reasonably good correspondence to experimental measurements. An advanced analysis tool that takes into account both the actual material flows, coupled with wear calculation model would be a new tool to design and optimize handling equipment against wear.

Keywords: wear phenomena, granular material, numerical solution, Reality.

1. INTRODUCTION

Constructions and machines like conveyers, chutes and dumper vehicle 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. Mechanisms of erosion and abrasive impact-wear have also been investigated by many authors e.g. [4,5]. A natural next step is to couple these models for the relative wear with simulations of material flow and thus obtain a basis for further understanding of the real situations of abrasive wear found in industrial processes. In recent years numerical tools have been developed for large flow simulations for example Smoothed Particle Hydrodynamics (SPH) method invented independently by Lucy [6] and Owen, Villumsen[7], Discrete Element Method (DEM) invented by Cundall [8] and Particle Finite Element Method (PFEM) by Oliver et al. [9]. These numerical tools are of interest as they can reproduce granular flow and can be used to realistically load different structures.

For structural analysis, the Finite Element Method (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, see Zienkiewicz and Taylor [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 and the uncertainties in the load. The computability of nonlinear problems in solid mechanics is investigated in e.g. Belytschko and Mish [11].

In order to effectively analyse and simulate a structural wear process of dumper vehicle bodies, solid structures, material flows and wear calculation models have to be coupled. Such tool would open up entirely new possible areas of work. The ability to use numerical simulation to optimise material selection, geometry on designs is another advantage that would increase functionality and life of wear applications. The main objective with this work is to investigate the ability of couple SPH-FEM models to predict wear in realistic large scale simulation. This includes having correct material flow and contact conditions in order to predict wear. An important part is also to validate the computational models against experimental measurements of material flows and wear.

2. EXPERIMENTS

In this work, wear on a dumper vehicle body with commercial name Mercedes-Benz here referred as Case A and a concept Man dumper vehicle body here referred as Case B is studied. Thickness measurements were done on the two different designs, using ultrasonic thickness gauge. The measurements were done during service on a dumper vehicle after 3500 working hours. Both dumper vehicle bodies have been working on road sight, and suffered similar work conditions. 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. One loading consists of about 35 tons of material mainly blasted granite rock, but also mud and sand. 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. Wear maps from the two cases are shown in Figs. 1 and 2.

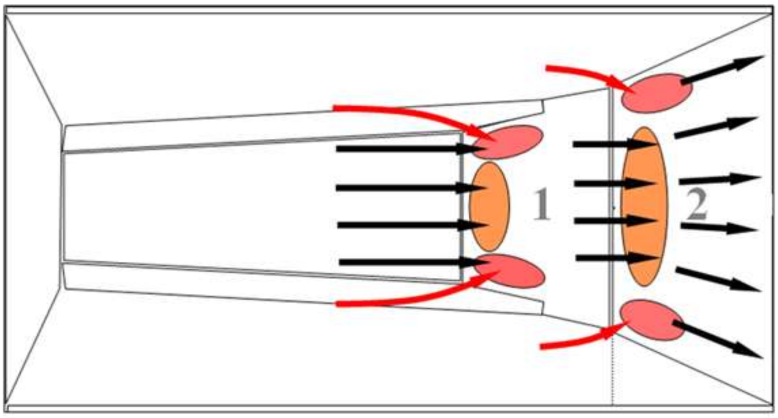

Fig. 1: Case 1: The areas that are subjected to higher wear are coloured. Yellow are areas that experience slightly higher wear, towards red, wear rate increases.

The analysis shows that the highest wear was located at entrance (from the sliding direction) of plate 1 and 2. This is mainly due to the change in angle of the material flow, casing a higher contact pressure. The measurements also showed that the wear rate was highest on the sides at both plate 1 and 2. At the rock box sides the material slides from the sides as the red arrows shows and will hit the side on plate 1 and 2. The impact angle is sharper and the material flow is higher. In Case B, the area exposed to wear is larger. Compared to Case B the magnitude of wear is lower, see Fig. 2. The area of wear is also more distributed compared to Case A.

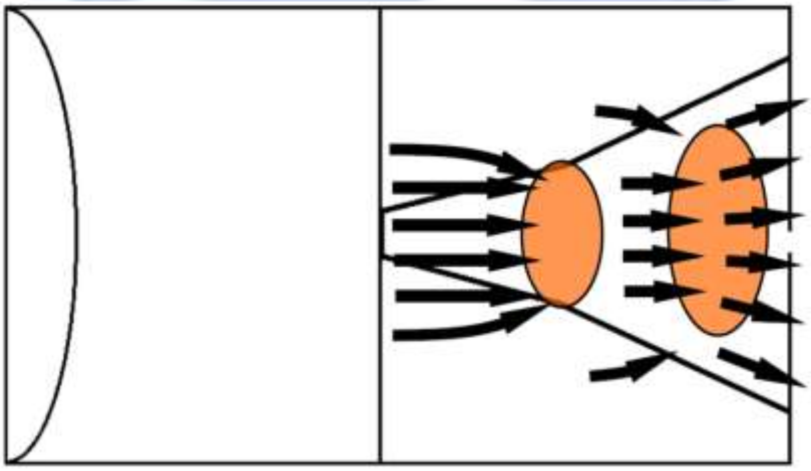

Fig.2: Case B: The areas subjected to wear in this design are more extended, and not of the same magnitude as in Case A.

3. MODELING

Numerical analysis has been performed on the two cases above to study how material flow will affect the wear. From CAD models have a FEM mesh been constructed consisting of shell elements, see Figs 3 and 4. To facilitate numerical calculation both cases have been modeled with rigid material.

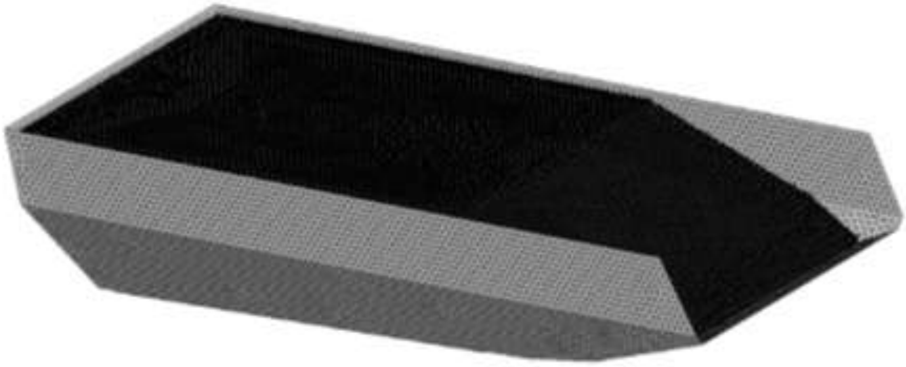

Fig.3: Case A, dumper vehicle body

Fig. 4: Case B, dumper vehicle body f

Both cases have a load of 12 m^3 gravel modeled with SPH elements. Unloading of dumper bodies are usually a gravity driven process where the dumper body is tilted and the material slides off. In the simulation, the platform remains in a fixed position while the gravity vector is rotated to simulate tipping. The maximum tilt angle is 70° and the unloading time is 10 seconds. The simulations have been done in the nonlinear FE program LS-Dyna [12].

3.1. Smoothed Particle Hydrodynamics

The smoothed particle hydrodynamics method is a mesh-free, point-based method for modeling fluid flows, and has been extended to solve problems with material strength. Today, the SPH is used in areas such as fluid mechanics (for example; free surface flow, incompressible flow, and compressible flow), solid mechanics (for example; high velocity impact and penetration problems) and high explosive detonation over and under water. The main advantage with SPH is the ability to virtually reproduce free surfaces, which is a known to be a difficult problem to solve with CFD using an Euler approach.

The ability of SPH-FEM models to numerically reproduce granular material flow and its interaction with solid material is demonstrated by Jonsén et al. [13]. The difference between particle and grid based methods as the finite element method, is that the problem domain is represented by a set of particles or points instead of a grid. Besides representing the problem domain, the points also act as the computational frame for the field approximation. Each point is given a mass and carries information about spatial coordinate, velocity, density and internal energy. Other quantities as stresses and strains are derived from constitutive relations.

3.2. Granular material model

To mimic the behavior of granular material during unloading the SPH method is used. Each particle has an initial radius of 50 mm and the model contains about 50 000 particles. In 3D, a sphere represents the SPH element with its radius controlled by the value of the smoothing length, h. A constitutive relation developed by Coon and Evans [14] Eq. (1) is used to govern the interaction between the particles.

$$f = \sigma_{vm} - \left[3(a_0 + a_1 p + a_2 p^2)\right]^{1/2} \qquad (1)$$

Where, p is the mean pressure, σ_{vm}, the von Mises flow stress and a_0, a_1 and a_2 are yield surface parameters. An elastic shear modulus and a bulk modulus are used and considered constant for the actual range of density and loading conditions. Material parameters used in the simulations are presented in Table 1. The bulk density of the particles is 2200 kg/m^3.

Table 1: Constitutive model parameters of the granular material

G [kPa]	K [MPa]	a_0 [Pa^2]	a_1 [kPa]	a_2
600	16.5	0	476	-0.1461

3.3 Wear model

When the SPH particles interact with each other or the rigid structure the variation of the stress state can be calculated. The local mean pressure and velocity of the material sliding over the rear of the vehicle bed, the so called chute, is saved during unloading. This is done in a number of distributed measurement points (tracer points) placed a particle radius above the plate of the chute. For the different cases the position of these points is indicated in Figs. 5 and 6 with the large white elements.

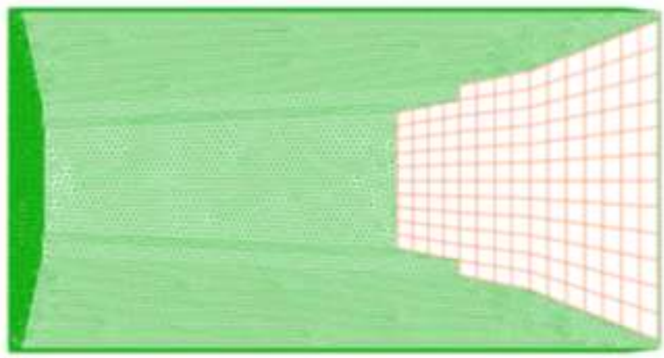

**Fig.5: For Case A, wear is studied in the area with large white elements.
The area contains tracer points that record the local pressure and particle velocity.**

One approach to estimate load intensity I from contact between different interfaces is to calculate the integral of mean pressure and velocity, v, see Eq. 2. This done for all measurement points in the numerical model:

$$I=\int pvdt \qquad (2)$$

The values of p and v are sampled by 0.01 s intervals. For Case A, an additional analysis was conducted where the results collected with 0.001 s intervals and a finer division of the chute was made (half the distance between the measurement points). In addition, for this case the pressure are filtered by an averaging over 50 values. The value of I will not give the amount of wear, but an idea of how the load intensity is distributed in the dumper body.

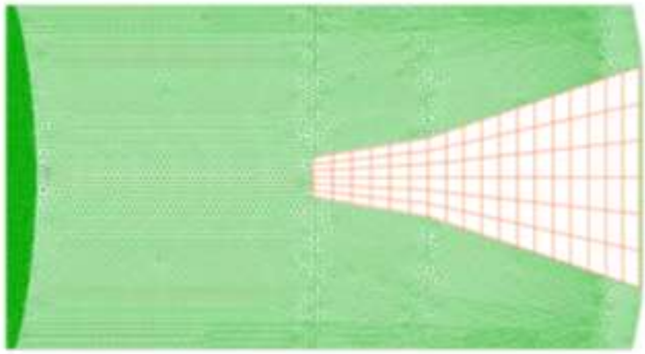

Fig. 6: For Case B, wear is studied in the area with large white elements. The area contains tracer points that record the local pressure and particle velocity.

4. RESULT 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 dumper vehicle body results in a load to the structure of the dumper body. A set of particles or points represents the problem domain for the granular material. Initially, each point is given mass and coordinate information. Throughout calculation, each point stores information about spatial coordinate, velocity, density and internal energy. The behavior of the granular material is controlled by a constitutive relation from which stresses and strains are derived. A snapshot of the pressure distribution obtained from material flow during unloading for Case A is shown in Fig. 7. Close to the plate in the area of interaction between the dumper vehicle body and the granular material, the highest pressure is found. Especially, high pressures are found where the material flow direction is changed.

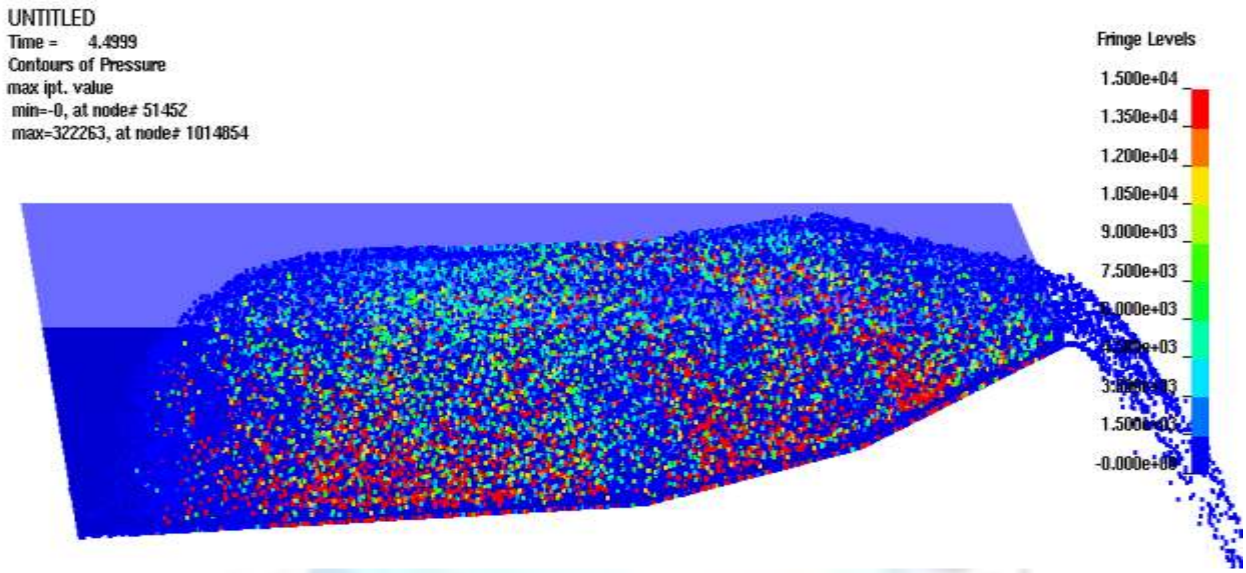

Fig.7: Material flow and pressure in the middle of dumper vehicle body for Case A. For the areas where the flow changes direction a change in pressure is shown.

At the tracer points, local pressures and velocities are saved for the unloading process. By numerical integration of Eq. 2, the load intensity can be calculated for each tracer point. Delaunay triangulation of the load intensity data at the positions of the tracer points is used to construct maps of the load intensity for both cases. For Case A, a load intensity map is presented in Fig. 8. By comparing the wear map obtained from experimental measurements on Case A and the numerically calculated load intensity map, it is show that the location of the highest wear and the highest load intensity agree.

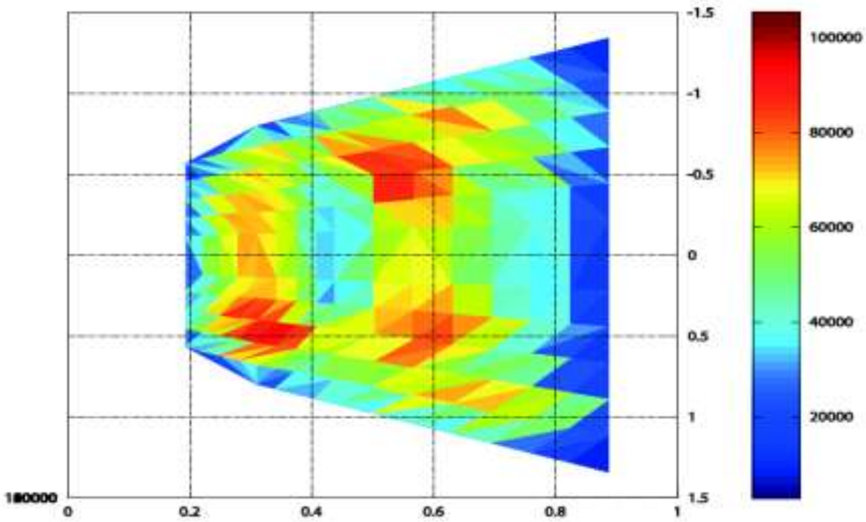

Fig. 8: Calculated load intensity for Case A. Red represents the highest load intensity and blue the lowest.

A snapshot of the pressure distribution obtained from material flow during unloading for Case B is shown in Fig. 9. As for Case A, the highest pressure is found close to the plate in the area of interaction between the dumper vehicle body and the granular material. In Case B geometry is smoother and no large change in the flow direction is found. This will also give an evenly distributed pressure.

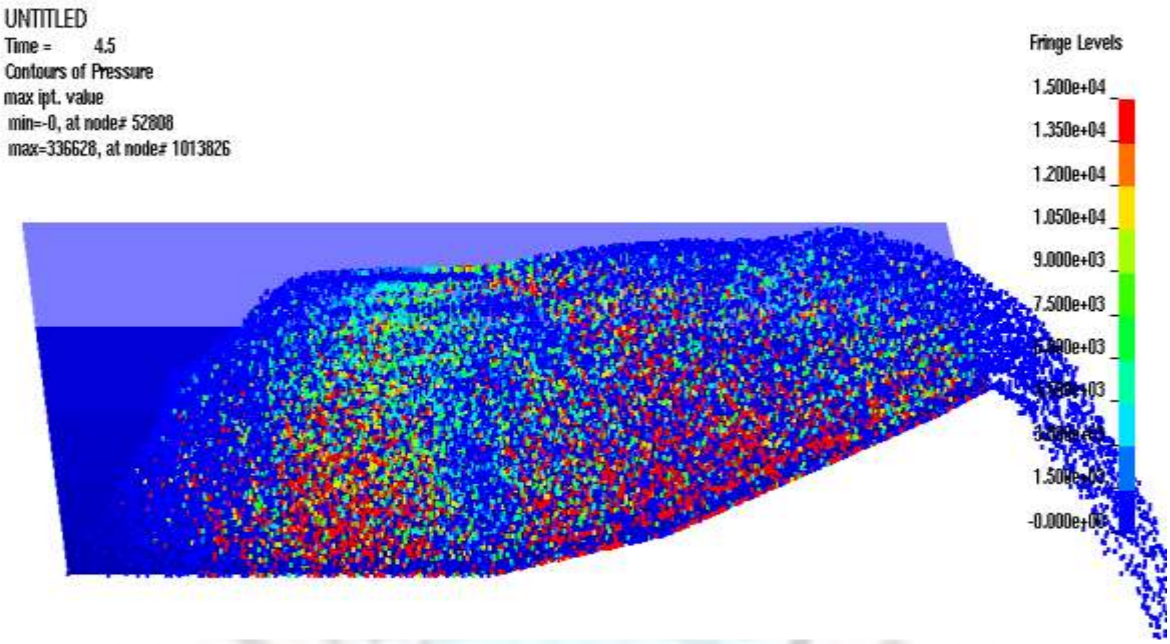

Fig. 9: Material flow and pressure in the middle of dumper vehicle body for Case B. For the areas where the flow changes direction a change in pressure is shown.

The load intensity map calculated by numerical integration of Eq. 2 and Delaunay triangulation also show more distributed load intensity, see Fig. 10. A design that even out the contact pressure over a larger area like Case B usually gives improved wear resistance. Comparing the numerically obtained results with the experimental results it is obvious that the wear pattern is distributed and no high local wear are shown.

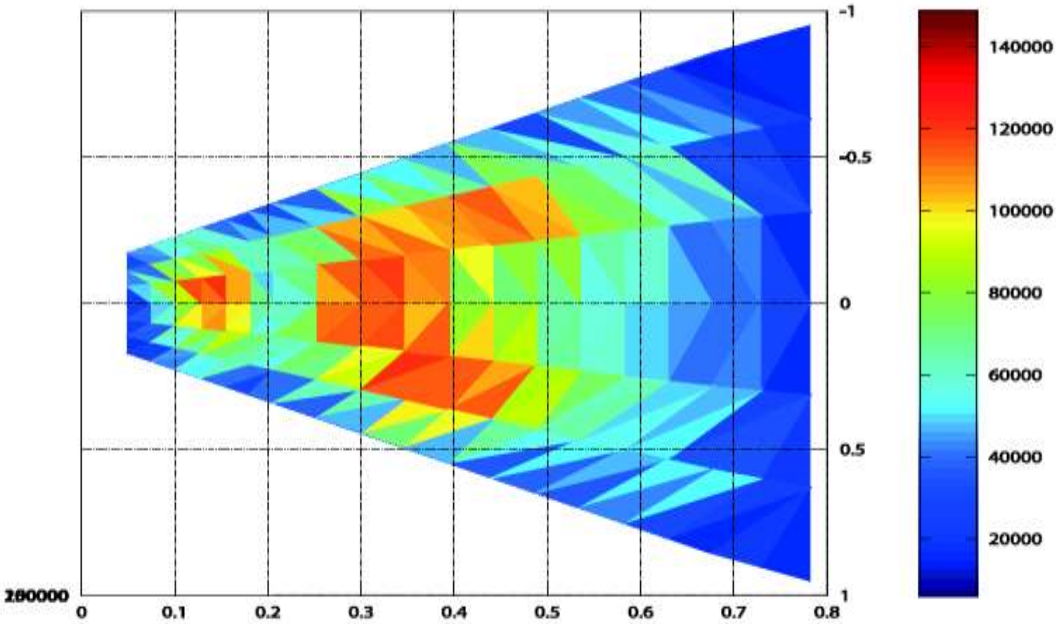

Fig.10: Calculated load intensity for Case B. Red represents the highest load intensity and blue the lowest.

From comparing the numerical result with field measurements shows that it is possible to numerically predict wear pattern in large scale simulations of abrasive wear. An additional numerical investigation on the resolution of the wear map was done on Case A. The result show that the high resolution gives a closer agreement to the experimental result, see Fig. 11. More local phenomenon can be observed with the high resolution.

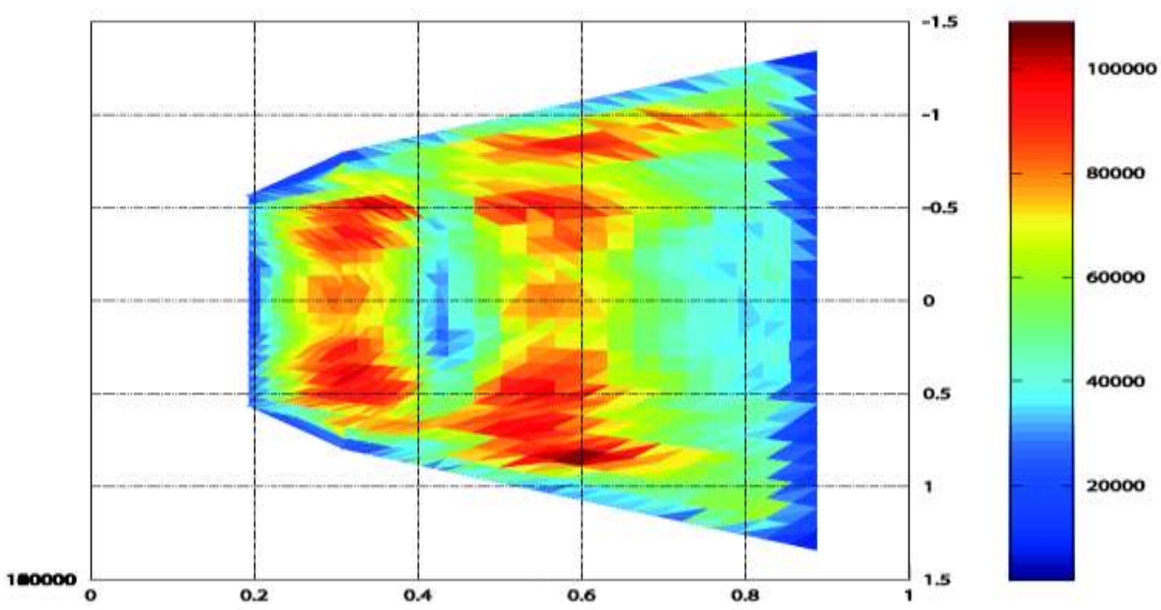

Fig.11: Calculated load intensity for Case A with high resolution. Red represents the highest load intensity and blue the lowest.

It is important to have in mind the complex nature of the abrasive wear process. To decrease the gap between model and reality, physically accurate models are necessary. This implies complex models that require high accuracy experimental measurements for the validation.

CONCLUSION

A numerical method using SPH-FEM combination is used to simulate the working condition of a dump vehicle body. The load intensity maps given by the calculations are in agreement with the wear pattern measured in the experimental results. Case A show more local wear, especially where the flow direction changes. For Case B the wear is more distributed due to a smoother design. In conclusion, the SPH-FEM model can be used to model solid material interacting with granular material. This result is highly promising for future calculation of abrasive wear. Also the unloading time for the unloading sequence match the measured times in the simulations. These results agree qualitatively, but to improve models furthermeasurements and modeling have to be done. Numerical tools that accurately can calculate wear from interaction with granular material would facilitate design and improve life of dumper bodies and other applications handling granular material.

REFERENCES

[1]. Moore M.A., 1974.The relationship between the abrasive wear resistance, hardness and microstructure of ferritic materials. Wear, 28: 59–68.
[2]. Moore M.A., 1981.Abrasive wear. In: Rigney D.A. (ed.), Fundamentals of Friction and Wear of Materials, ASME, Metals Park: 73–118.
[3]. Atkinson, T. and Cassapi, V.B. (1984) The prediction and reduction of abrasive wear in mine excavation machinery, inInternational Conference on Tribology in Mineral Extraction, War on Wear, Institute of Mechanical Engineering, Nottingham University, pp. 165–174.
[4]. S. Das, B.K. Prasad, A.K. Jha, O.P. Modi, A.H. Yegneswaran, "Three-body abrasion wear of 0.98% carbon steel," Wear, Vol. %1 av %2162-164, pp. 802-810, 1993.
[5]. S. Das, B.K. Prasad, A.K. Jha, O.P. Modi, A.H. Yegneswaran, "Three-body abrasion wear of 0.98% carbon steel," Wear, Vol. %1 av %2162-164, pp. 802-810, 1993.
[6]. Lucy, L.B., (1976).Astrophys.J. 205, 208.
[7]. Owen J. M., Villumsen J. V., Shapiro P. R. and Martel H. (1998), Adaptive smoothed particle hydrodynamics methodology ii, Astrophysical Journal Supplement Series, 116:155-209.
[8]. Cundall, P. A., and B. Damjanac.(2009) "A Comprehensive 3D Model for Rock Slopes Based on Micromechanics," in Slope Stability 2009 (Universidad de Los Andes, Santiago, Chile, November 2009).
[9]. Oliver J, Oller S, CanteJC (1996) A plasticity model for simulation of industrial powder compaction processes. Int. J. Solids and Structures 33:3161–3178.
[10]. O.C.ZienkiewiczandR.L.Taylor.TheFiniteElement Method, volume 2: Solid Mechanics. Butterworth–Heinemann, Oxford etc., 5th edition, 2000. ISBN 0-7506-5055-9.
[11]. Belytschko T, Liu WK and Moran B (2000) Nonlinear Finite Elements for Continua and Structures, Wiley, Chichester.

[12]. FE program LS - Dynahttps://www.dynamore.de/en.
[13]. P. Jonsén, B. I. Pålsson, K. Tano and A. Berggren, Prediction of mill structure behaviour in a tumbling mill. Miner.Eng. vol. 24, pp 236-244, 2011.
[14]. Coon, M. D., and R. J. Evans, "Incremental Constitutive Laws and Their Associated Failure Criteria with Application to Plain Concrete," Int. J. Solids Structures, Vol. 8 (1972), pp. 1169-1183.

AUTHOR

B.Sc. Mosul University / Mech. Eng. – Iraq – 1992
MsD. Gazi University (Ankara) / Turkey – 1998
Specialist: Heat Transfer
Lecturer in College of Engineering / Kirkuk University

ABBAS MOHAMMED ISMAIL