PhD RESEARCH: NUMERICAL MODELING OF COAL EXCAVATOR – ROCK FORMATION INTERACTIONS

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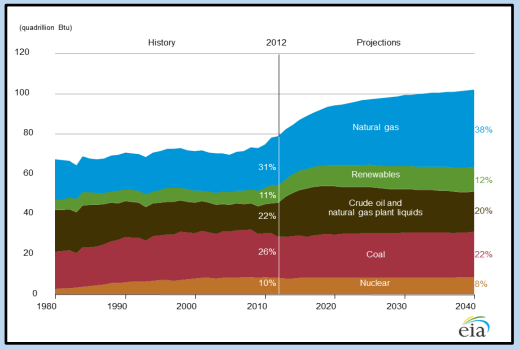
Abstract

- Coal contributes over 20% of the energy in the US and the rest of the world. This is not expected to change over the next 20 years.
- A recent focus of coal production research studies has been to develop new excavator bucket designs which outperform conventional buckets.
- A major bottleneck in the current bucket design approach is that every proposed design has to be physically built, tested and compared.
- A computer model, that sufficiently replicates real-life excavator-ground interactions, will lead to huge savings in time, efficiency, design & opportunity costs.
- The exact relationship between DEM parameters and actual rock properties is unknown. Hence, replicating the behavior of a **specific** setup is tough.
- Existing models adopted 'trial and error' property-matching techniques. However, these models overpredict excavation outcomes by 300% - 500%.
- This study introduces a material calibration and excavation simulation approach that reduce excavation prediction errors from 300% to 16.55%.
- The material calibration method combines DEM-based tri-axial rock testing with the XGBoost machine learning algorithm to achieve prediction accuracies of between 80.6% and 95.54%.

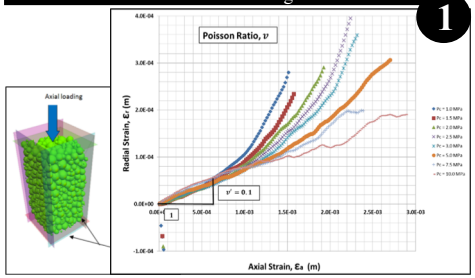


Forecast US Energy Production (EIA, 2014)

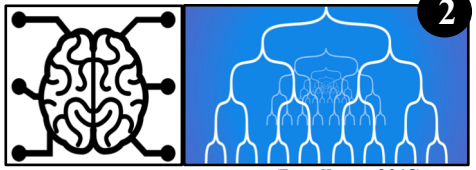
Methods

1. DEM simulations of laboratory rock test experiments are performed in PFC FishTank to generate data (1500 observations) for model training and testing.
2. A model is trained with the XGBoost ML algorithm (Chen, 2016) to predict DEM rock parameters based on corresponding laboratory rock properties.
3. The excavator bucket – rock interaction is simulated and the results are compared with field observations.

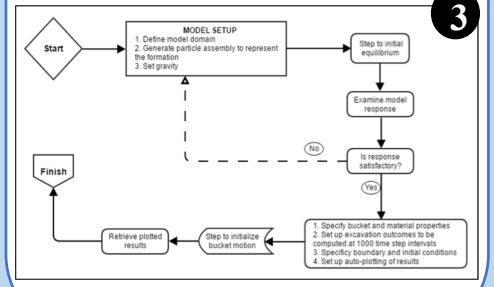
DEM simulation of triaxial rock testing in PFC FishTank



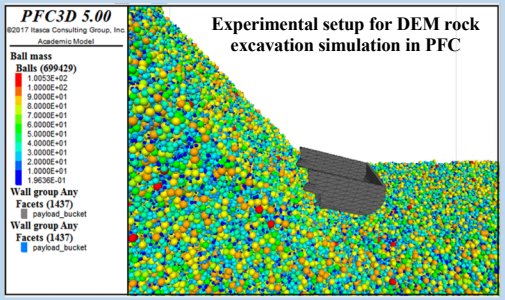
Predictive modeling of DEM properties with XGBoost ML algorithm



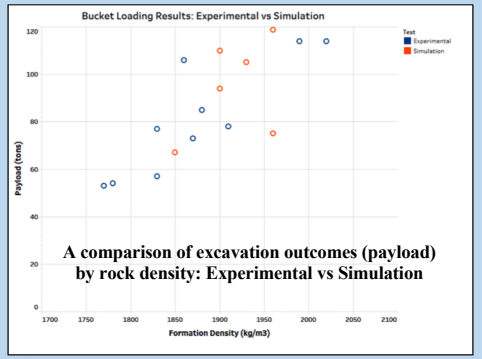
(Lundberg, 2018)



Flowchart for DEM simulation of rock excavation

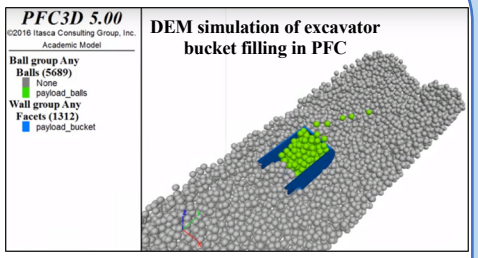


Experimental setup for DEM rock excavation simulation in PFC

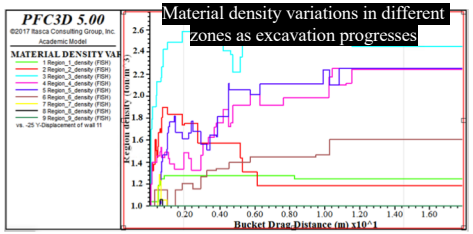


A comparison of excavation outcomes (payload) by rock density: Experimental vs Simulation

Results

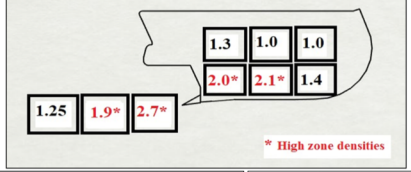


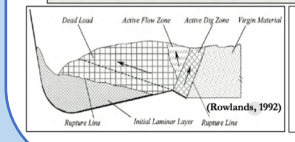
DEM simulation of excavator bucket filling in PFC



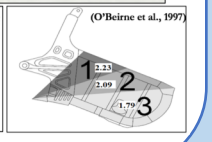
Material density variations in different zones as excavation progresses

A comparison of excavator bucket filling behavior: Simulation vs Field experiment





(Rowlands, 1992)



Conclusions

1. The relationships between DEM parameters and rock properties are more complex than can be explained by simple calibration models.
2. The proposed material calibration process is able to achieve prediction accuracies of 80.6% to 95.54%. The DEM excavation model reduces excavation prediction errors from 300% to 16.55%.
3. The optimum rock size distribution for excavation ranges from fines up to ~25% of the bucket width.
4. There is a material density distribution which develops inside and ahead of the excavator bucket during filling. This distribution decreases towards the rear of the bucket.
5. The most active material zones are typically within a distance equal to two-thirds of the bucket length.

Novelty / Impact

- This study introduces a new approach to DEM geomaterial calibration by combining extensive rock test simulation with the XGBoost ML algorithm.
- This DEM model complements coal studies by providing a cheap and time-efficient tool for comparing different bucket geometries for design improvements.
- This study is the first DEM attempt to investigate dragline bucket loading behavior in 3D & at full scale.

References

* All uncited images are from the PhD dissertation