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MODELING OF UNRELIEVED ROCK CUTTING TEST BY USING PFC^{3D}

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1. INTRODUCTION

Full-scale tunnel boring machines (TBMs), roadheaders are some of the machines extensively used in both mining and civil engineering applications in order to excavate the rock economically, safely and rapidly.

The selection of appropriate machine depends on the evaluation of the test results performed in the laboratories. These tests involves the strength, deformation and index tests. Also, rock cutting tests are carried out in Linear Cutting Sets.

In this study, unrelieved rock cutting test was modeled in order to assist to the selection of a mining machine.

During the numerical studies, a conical cutter were modeled. The cutting forces acting on the cutter (pick) were recorded and the failure mechanism were observed.

PFC^{3D} is one of the programs that has the capability of determining these forces

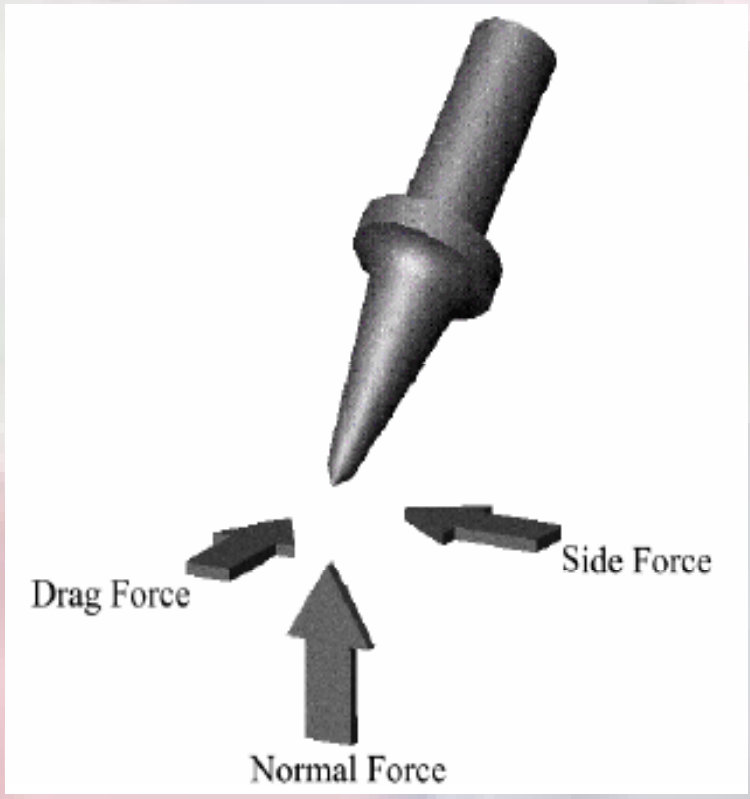
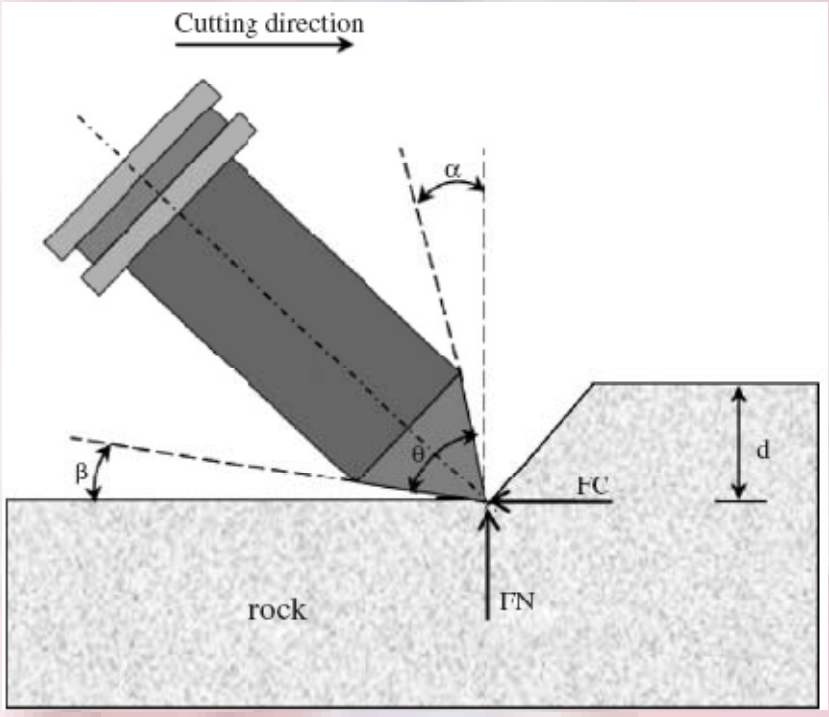


Figure 1. Various types of conical cutters and the forces acting on the cutters.

2. ROCK CUTTING



α = rake angle
θ = bit angle
β = clearange angle

FC=cutting force
FN=normal force
d=cutting depth

Figure 2. Rock cutting parameters

Rock cutting is an action which involves the movement of the tip. It is moved through a given depth into the material.

The cutter is moved until the force generated by the cutter exceeds the resistance of the material. The cracks propagate from up to down.

The cutting parameters govern the efficiency and play an important role in the course of cutting process.

3. LABORATORY STUDIES

In the scope of laboratory studies, unrelieved mode of rock cutting test was carried out on a fine-grained (0.15-0.25 mm) sandstone sample taken from Z. Hardcoal Basin in Turkey.

The test was performed at 3 mm of cutting depth by using a conical cutter. During the test; the attack angle of 57°, tip angle of 80° and the clearance angle of 17° were used.

The cutting forces (FC) and normal forces (FN) were recorded during the tests (Table 1).

Table 1. Results of unrelieved rock cutting test.

d (mm)	F_C (kN)	F_N (kN)	SE (kWh/m^3)
3	3.9	4.4	47.2

4. NUMERICAL MODELING

- A fine-grained particle assembly was generated and calibrated using the contact bonds.
- A conical cutter was modeled and it was placed on right top of the specimen depending on the cutting parameters.
- The cutter was moved horizontally with a constant velocity in order to excavate the artificial rock.
- In the course of simulation, normal and cutting forces acting on the cutter and the interaction between the cutter and the rock were investigated.

4.1 Calibration Procedure

The uniaxial compressive strength test was performed at the laboratory and the triaxial test was used for calibration procedure by setting the confining stress to a low value. Then, the triaxial test was carried out.

- The particles, whose diameter range from 0.30 to 0.50 mm, were compacted in the specimen-genesis procedure.
- The porosity was selected as 25%.

By varying the assigned micro-properties, a suitable stress-strain curve reflecting the elastic behavior of rock was obtained. Finally, the corresponding values of strength and deformability were matched with laboratory values (Table 2).

Table 2. Macro and micro properties of sandstone sample.

Laboratory determined macro properties	
Uniaxial compressive strength	113.6 MPA
Young modulus (E_{lab})	17 GPa
Micro-mechanical properties	
Particle radius	0.15-0.25
Young modulus (E_{sim})	17.0 GPa
Peak strength value	116.7 MPA
Normal stiff./Shear stiff. (k_n/k_s)	2.5
Normal contact bond strength (S_n)	69 MPa
Shear contact bond strength (S_s)	69 MPA
Particle friction coefficient	0.50

4.2 Modeling of Rock Cutting

Unrelieved mode of rock cutting test at 3 mm depth of cut was modeled in *PFC*^{3D} in order to investigate the cutter-rock interaction and monitor the cutting forces on the cutter.

Numerical studies were associated with the laboratory studies.

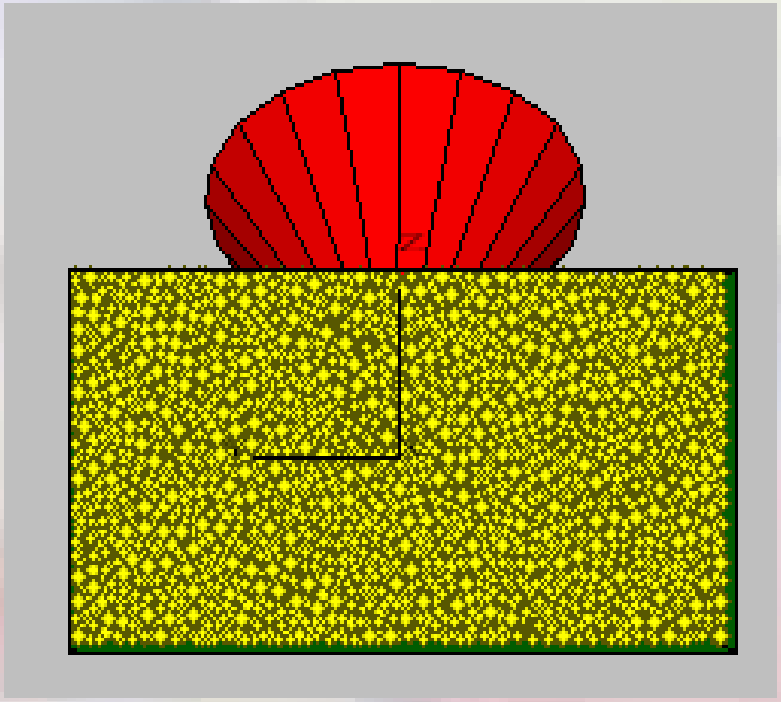
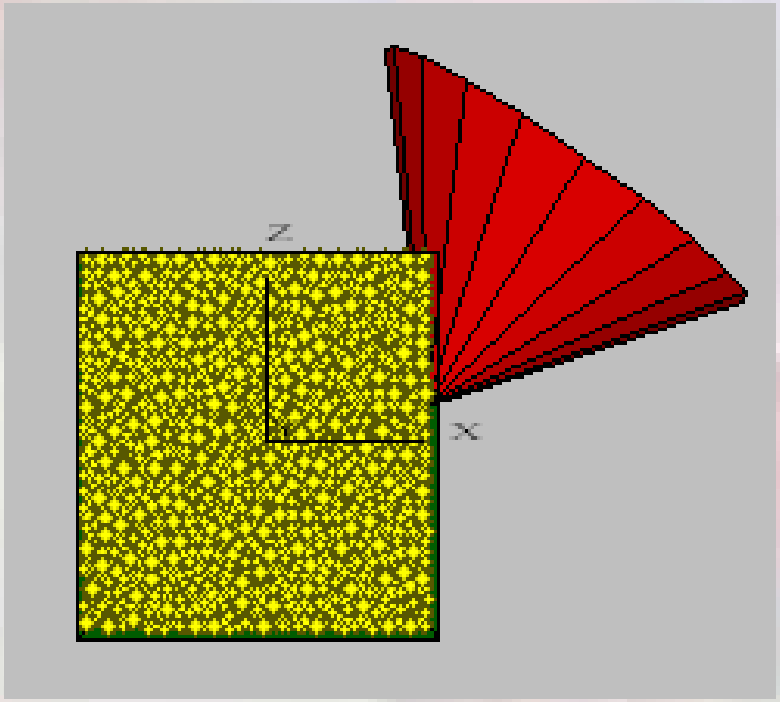


Figure 3. Front view of specimen and cutter.

• A rock having 7.5×7.5×15 mm dimensions was created.

• A conical cutter was placed on the right side of the specimen depending on cutting parameters which were selected as the same in lab. studies.

• The traveling distance of cutter was selected 4 mm since the width of the specimen was 7.5 mm for this model.



Cutting Parameters

Cutter angle: 80°
Attack angle : 57°
Clearance angle: 17°
Rake angle: -7°
Length of cutter : 5.5 mm

• At the beginning of the simulation, the top surface of the specimen was deleted.

• The conical cutter was then moved horizontally from the right wall through the left wall at a constant low velocity.

• During the cutting, the boundary particles in front of the cutter were updated every 100 cycles.

• An atmospheric (confining) pressure was applied to those particles in order to prevent them from flying away.

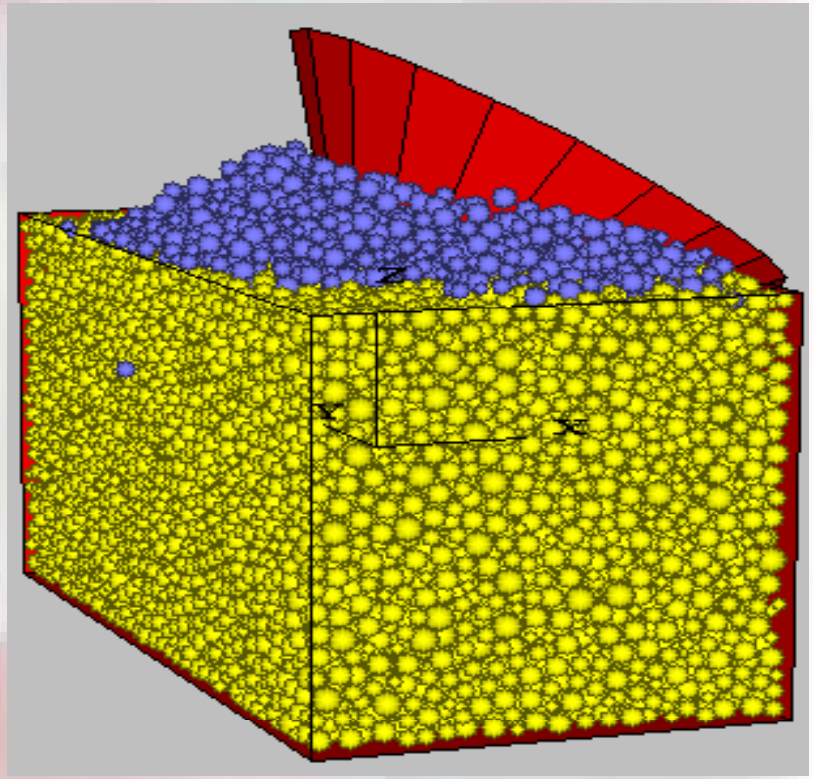


Figure 4. The material cut by the cutter.

5. RESULTS

1, 2, 3, 4, 5, and 6 MPa of atmospheric pressures were applied to the boundary particles.

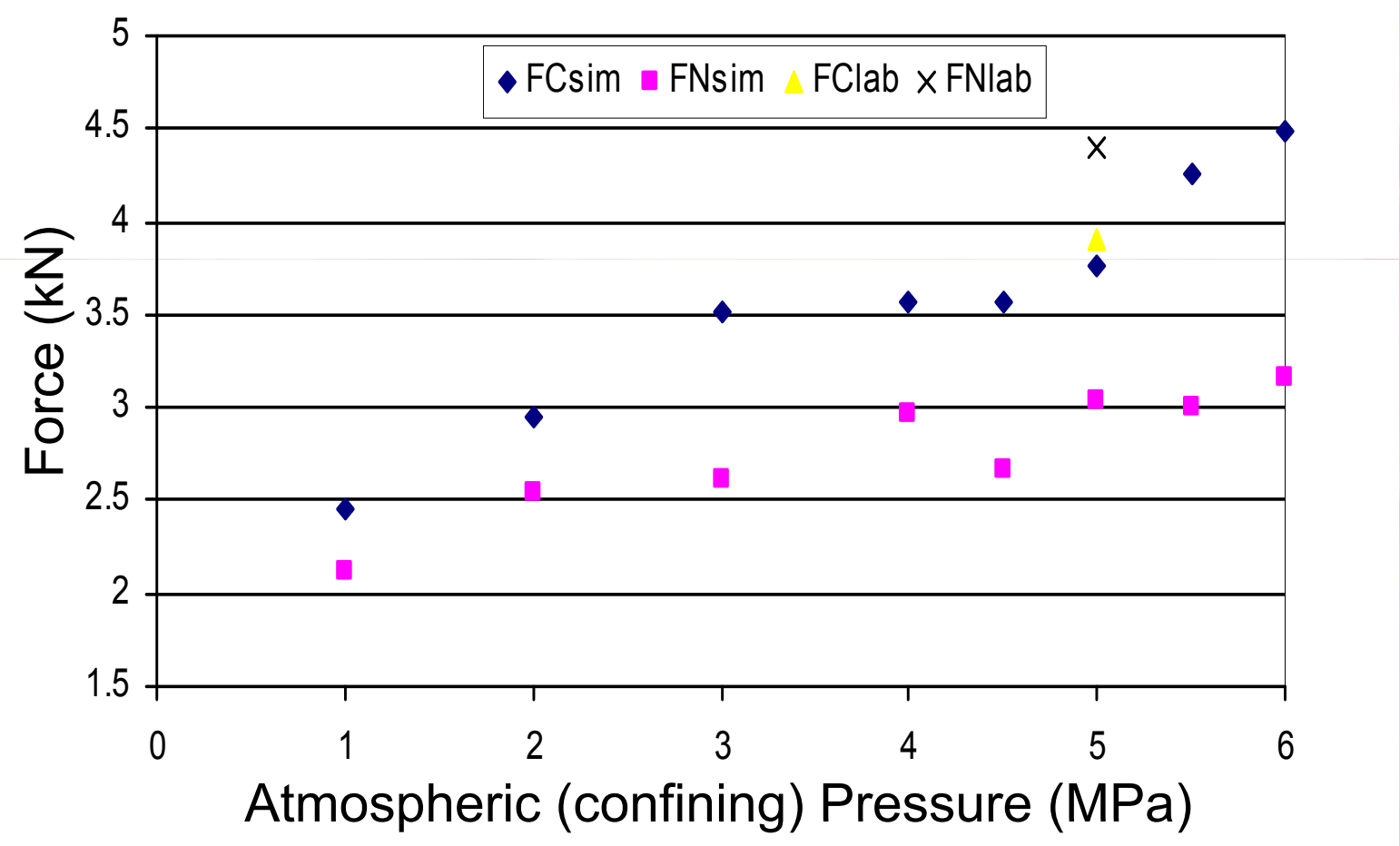


Figure 5. The variation of confining pressure with maximum normal (FN) and cutting forces (FC)

• The normal and cutting forces were monitored and the best agreement with the lab. studies were obtained at 5 MPa of atmospheric pressure.

•At this value, the normal force and cutting force were found 3.04 and 3.76, respectively.

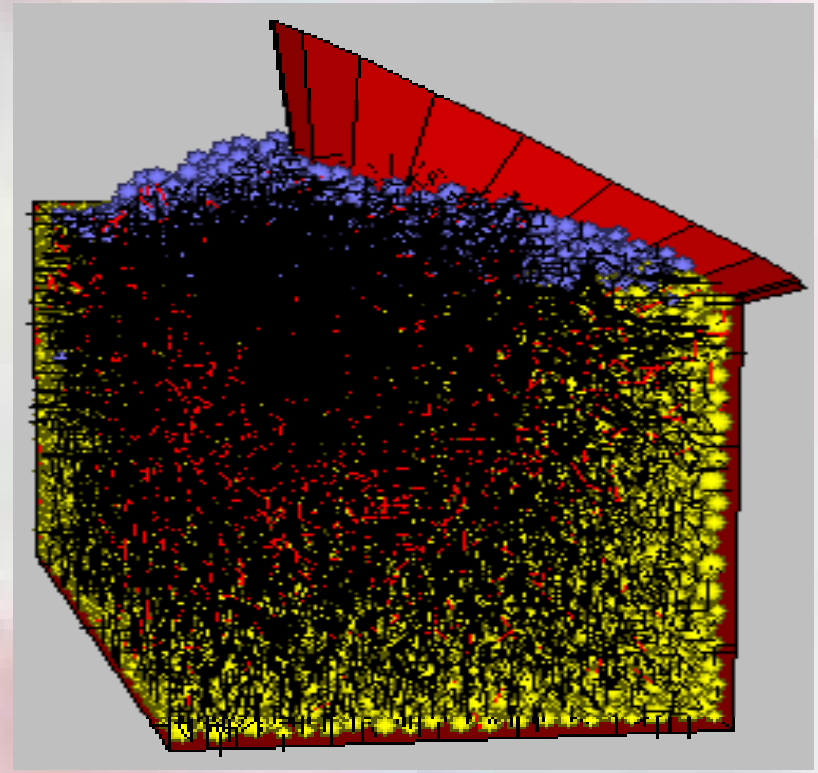


Figure 6. The contact forces around the cutter.

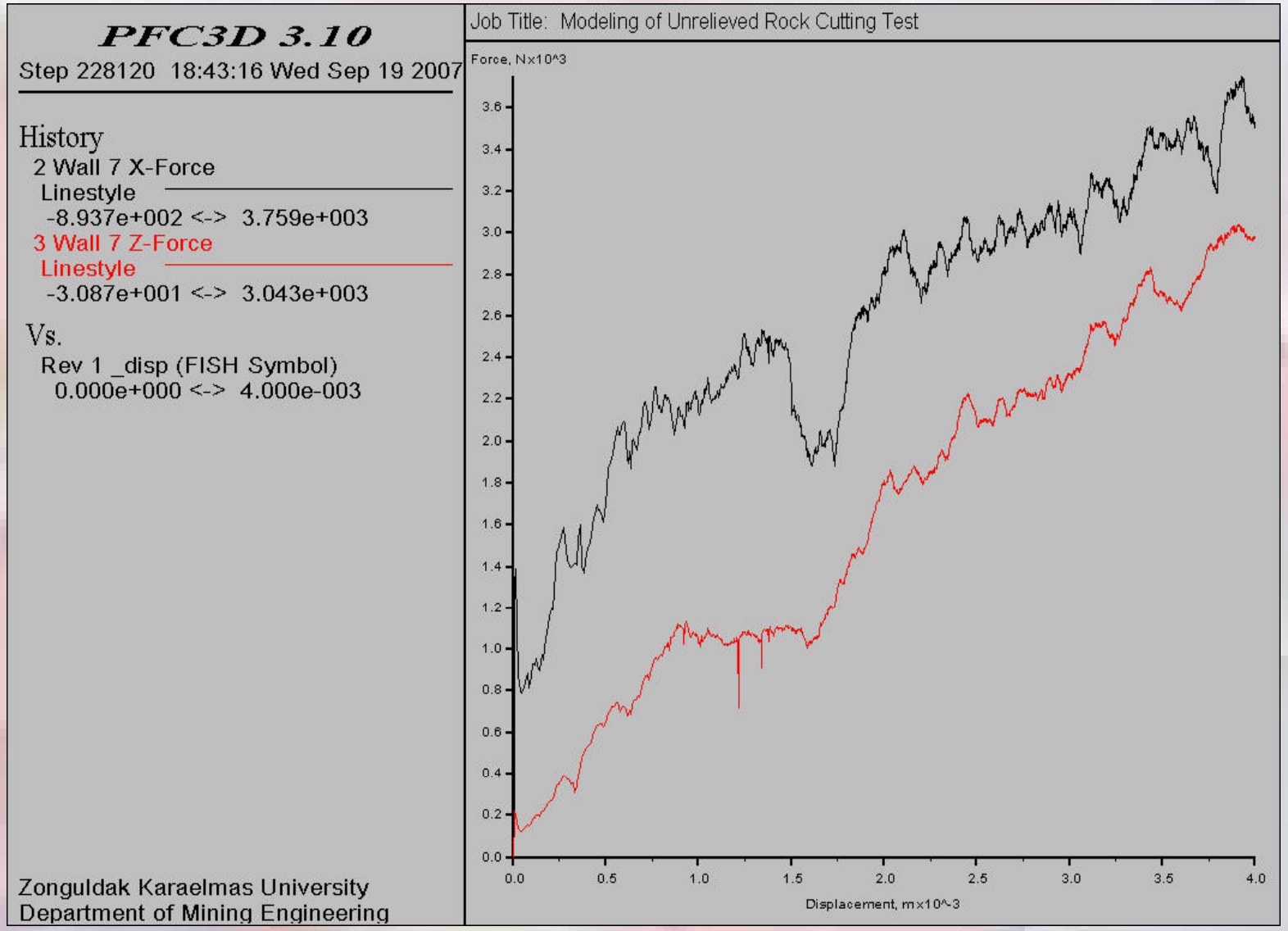


Figure 7. The relationship between cutting & normal forces versus displacement of cutter at 5 MPa of confining pressure.

6. DISCUSSIONS

Some of the problems encountered during the rock cutting simulation discussed as follows:

- The particle radius was chosen in small sizes due to low depth of cut. Thus, the specimen was created in small size owing to increasing number of particles. Therefore so far only depth of cut up to 3 mm was investigated in this study.

- Since the dimension of the specimen was small and the radius of cutter was large, the effect of longer cutting distances didn't be able to evaluate. Therefore, the specimens which are 4-5 times larger than the radius of conical cutter should be created for longer cutting distances.

7. CONCLUSIONS

A code for unrelieved rock cutting test that assists the performance prediction of mining machines was developed using *PFC*^{3D}.

During the modeling studies, the cutter-rock interaction, the variation of cutter forces with traveling distance, and the suitable confining pressure on the forces were investigated.

With respect to normal and cutting forces, the best agreement between laboratory and modeling studies was obtained at 5 MPa of confining pressure.

8. FUTURE WORKS

- Since this paper is ongoing Ph.D. study, the effect of each cutting parameter and atmospheric pressure will be studied more carefully.

- Specific energy values can be obtained by defining the excavated volume of particles and will be calculated later.

- Relieved cutting tests will be simulated by modeling two conical cutters that work simultaneously.

Thank You
for Your Attention…