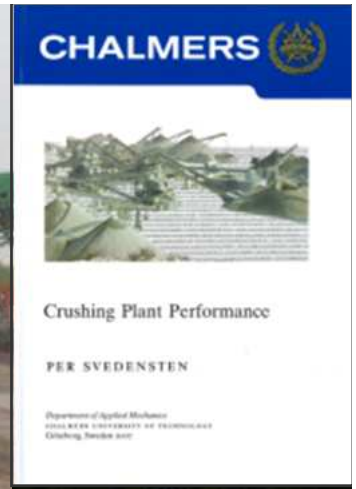
Principles of Mechanical Crushing

Per Svedensten

ORICA VOLVO SANDVIK

Per Svedensten

- Manager Crushing Chamber and Materials Development
  - Construction Crusher and Screens, R&D Quality
- Master of Science in Mechanics, specialized in mechatronics
- Ph.D 2007, Chalmers University
  - Partly funded by Sandvik
  - Modeling, simulation and optimization of crushing plants
  - Technical-Economic Optimization
- Sandvik employee since 2004
- Road biker
- Home improvement projects

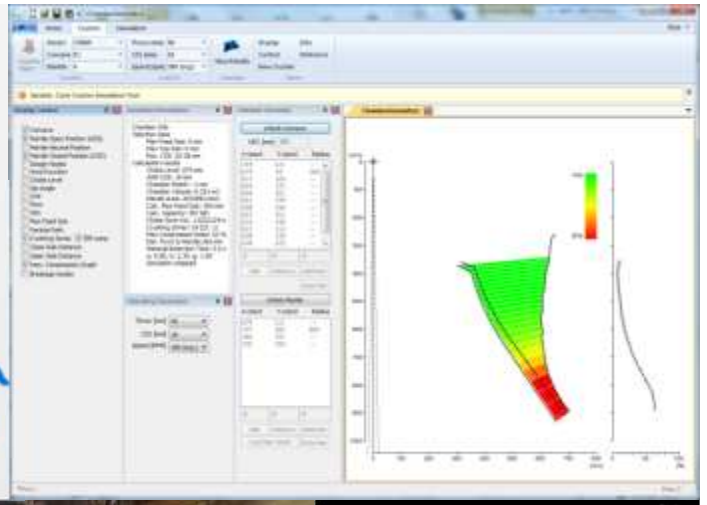


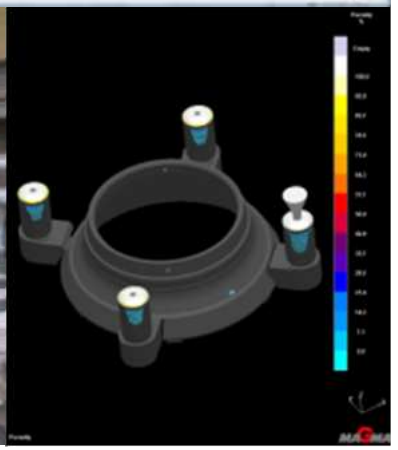
QUARRY ACADEMY

Crushing Chamber and Material Development

What we do

- Crushing Chambers
  - Design of the wear parts in the crusher
  - The part were the crushing is done
  - Determines crusher performance
- Material Technology
  - Wear parts, crushing chamber in manganese steel
  - Other parts, big casted parts

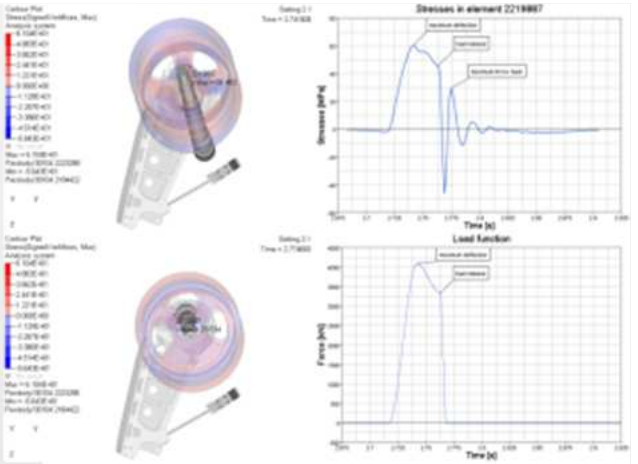


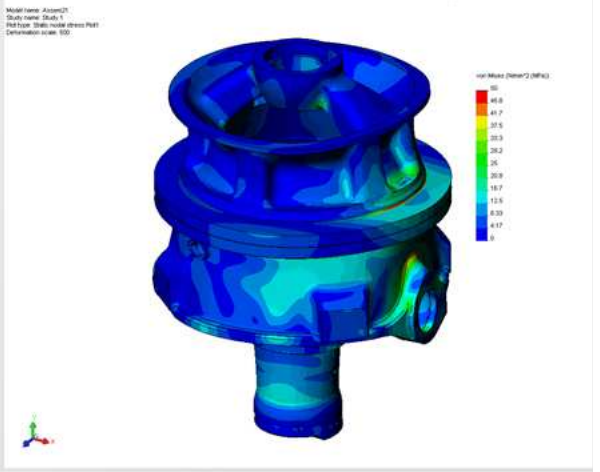


Crushing Chamber and Material Development

What we do

- Technical Calculations
  - FEA
  - Other analysis
- Hydraulics and Automation
  - Bearings and lubrication
  - Crushing Process Control System





Objective

Explain the interaction between

Rock Material

and

Crusher

QUARRY ACADEMY

Take home messages

The Take Home Messages will address:

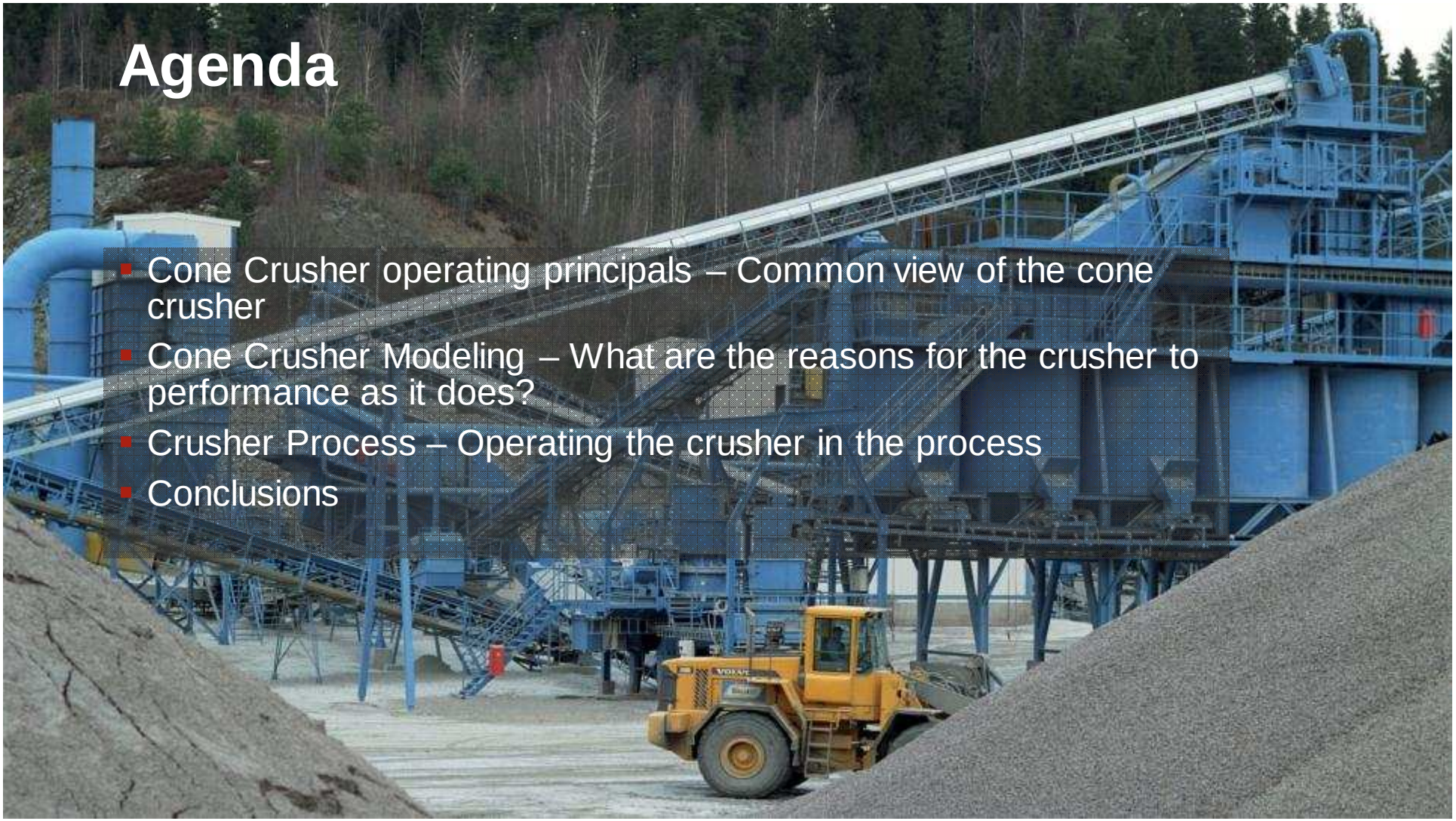
Trouble Shooting

Improve Yield

Improve Performance

QUARRY ACADEMY

Agenda

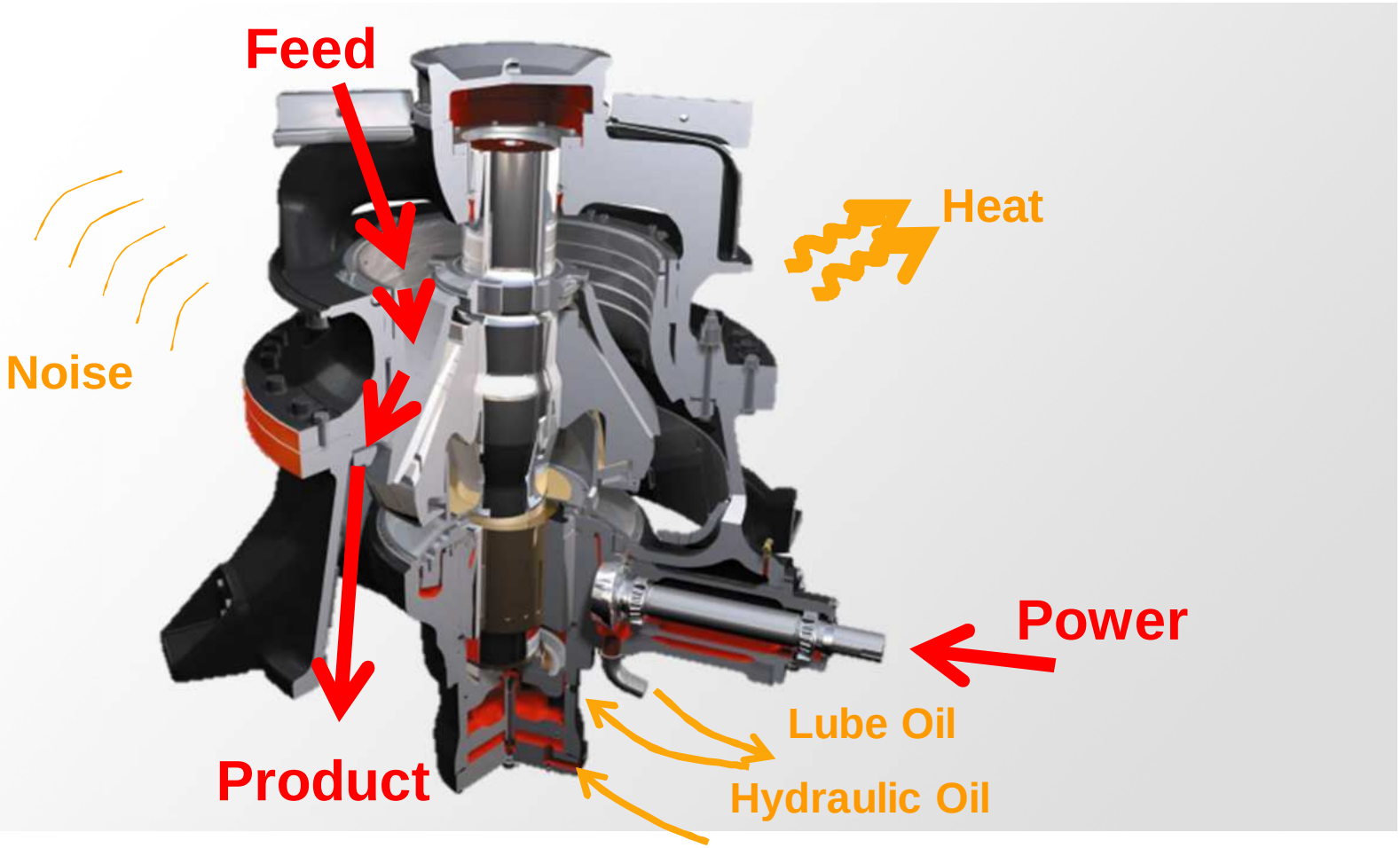


- Cone Crusher operating principals – Common view of the cone crusher
- Cone Crusher Modeling – What are the reasons for the crusher to performance as it does?
- Crusher Process – Operating the crusher in the process
- Conclusions

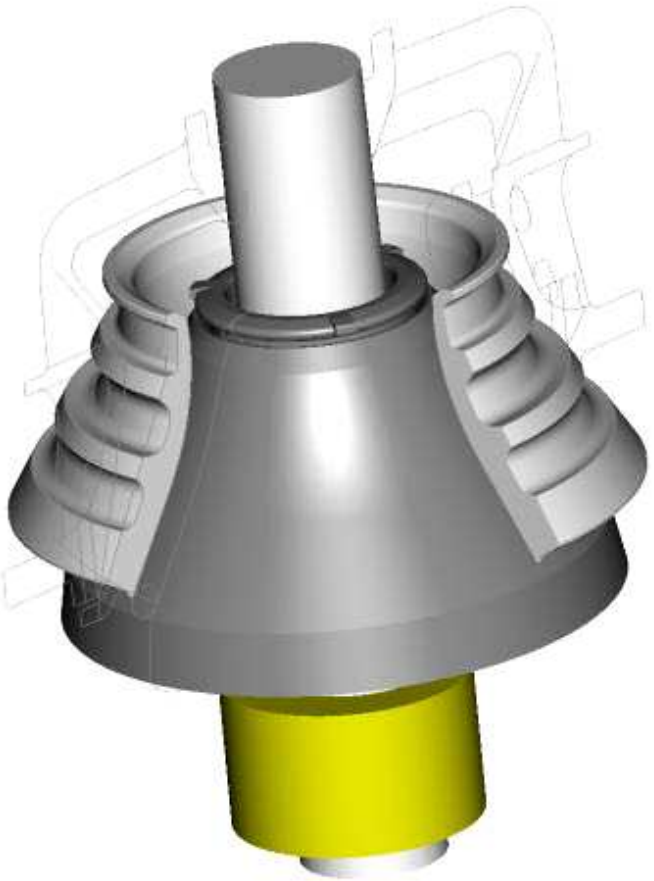
The Cone Crusher

- Why Cone Crusher?
- The cone crusher design concept is an effective and smart way of realizing compressive crushing
- Aggregate Production
- Mechanical Liberation of Valuable Minerals

QUARRY ACADEMY



QUARRY ACADEMY



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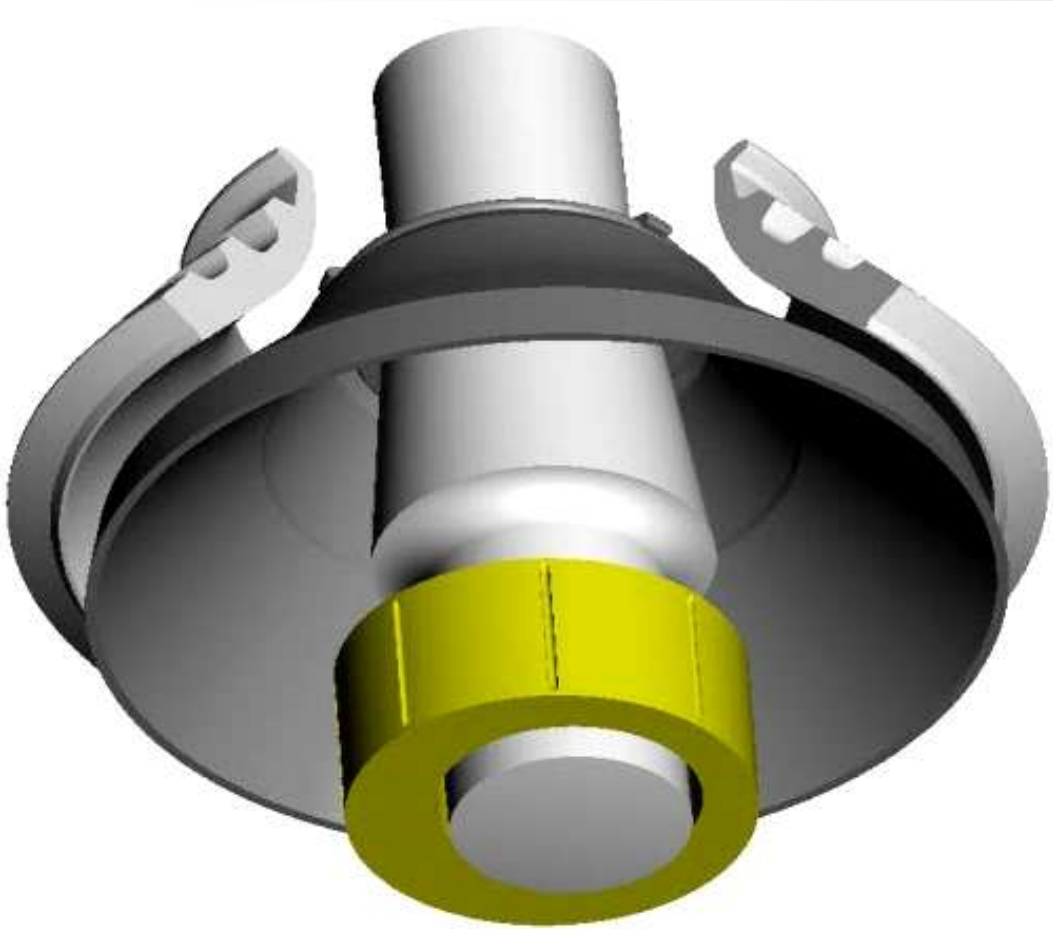

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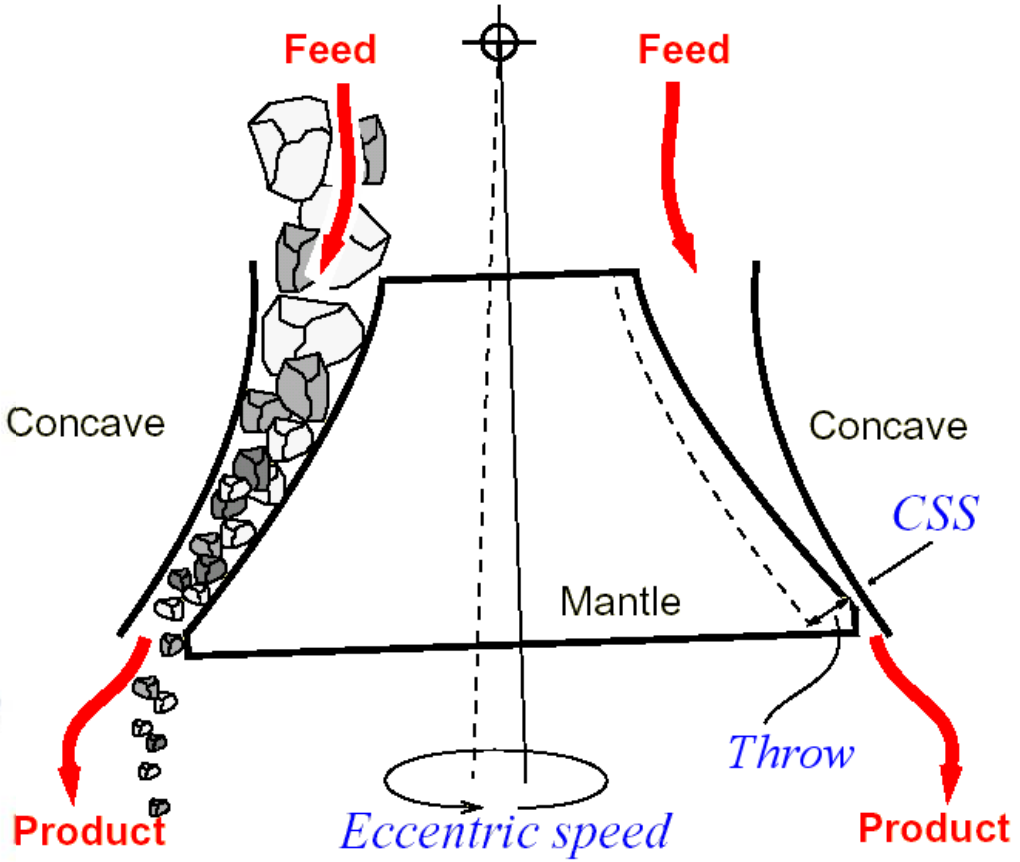
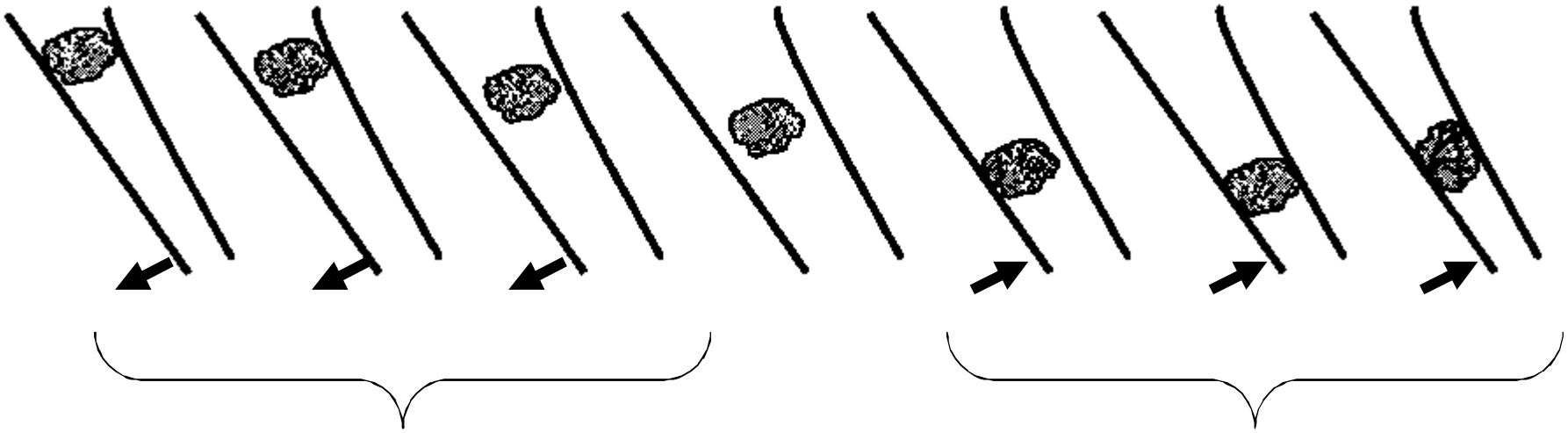


QUARRY ACADEMY

Operating Principals

Material Flow

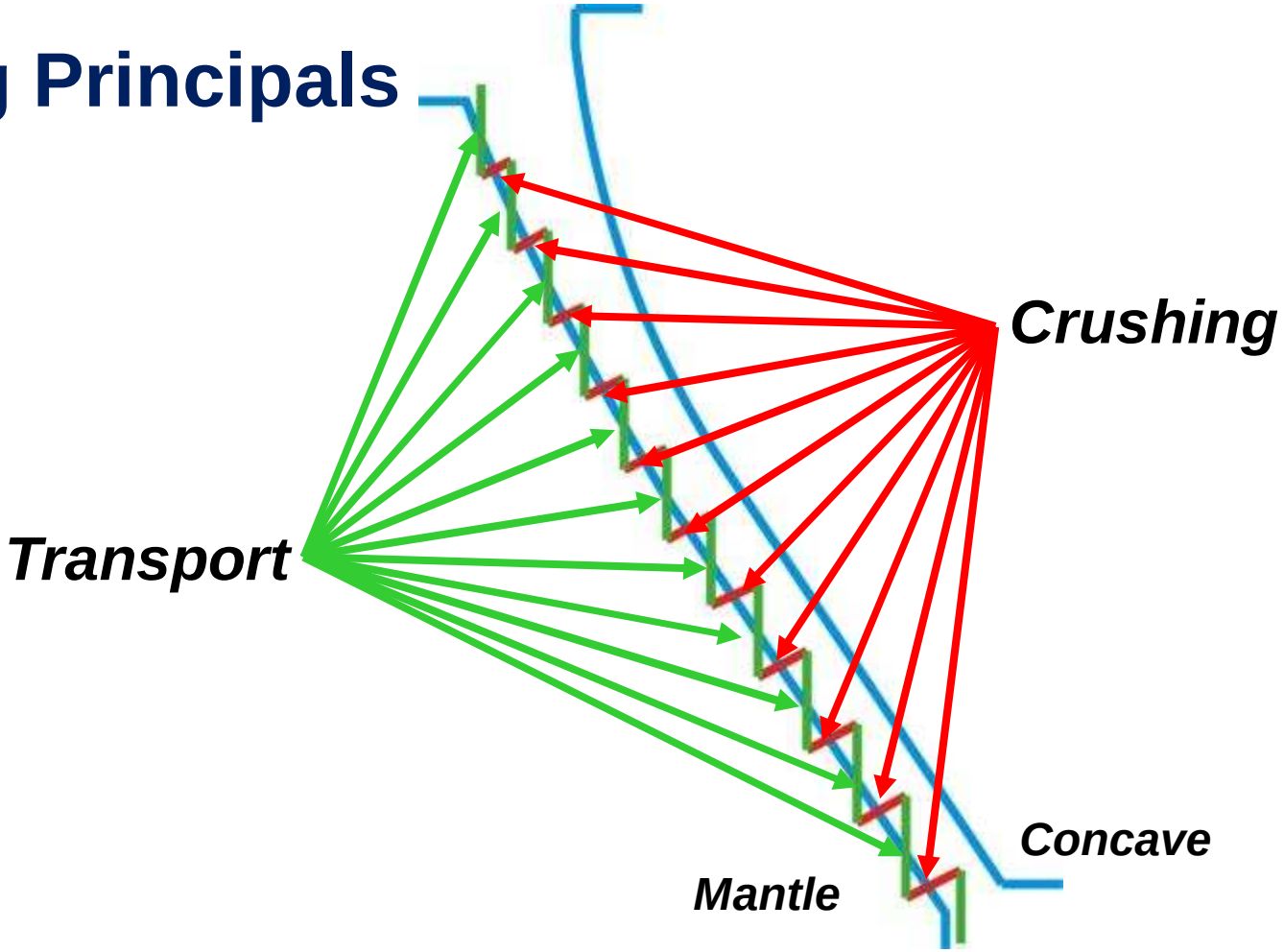


Opening Phase =
= Transport

Closing Phase =
= Crushing

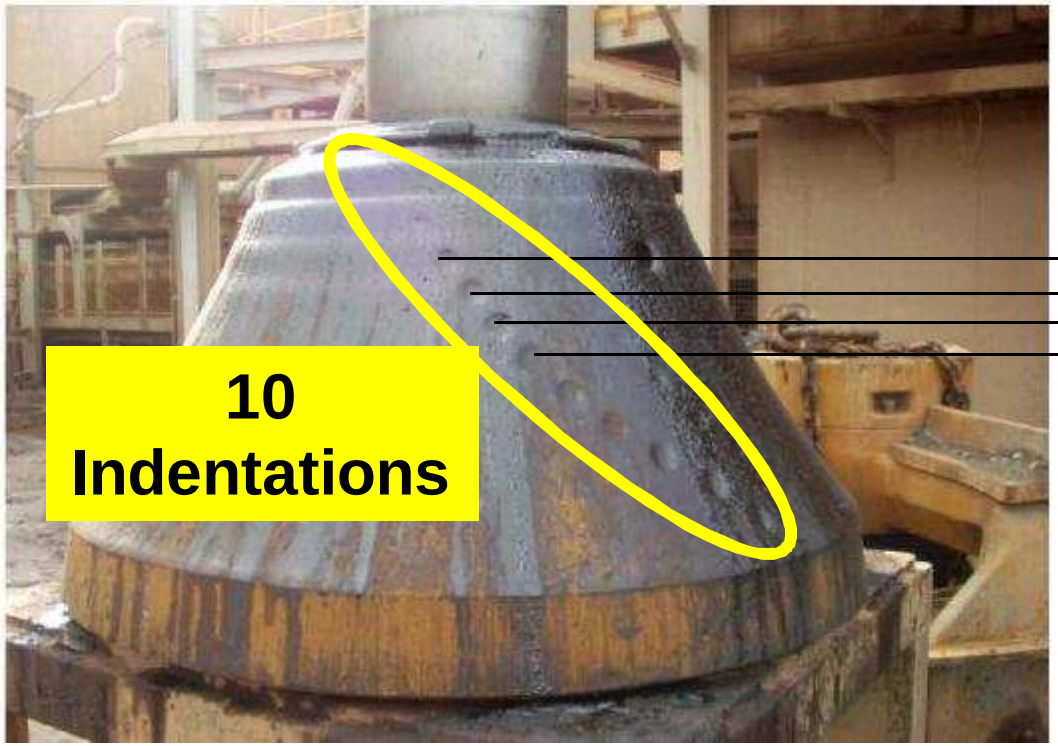
QUARRY ACADEMY

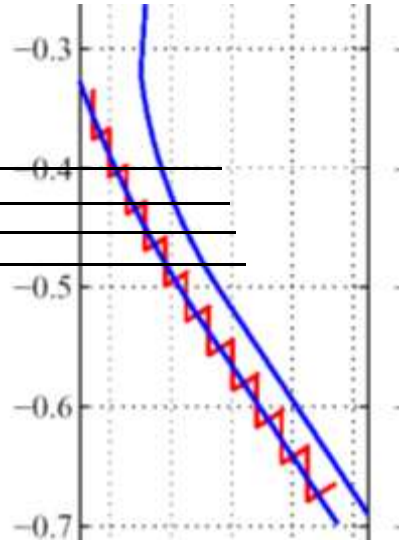
Operating Principals



QUARRY ACADEMY

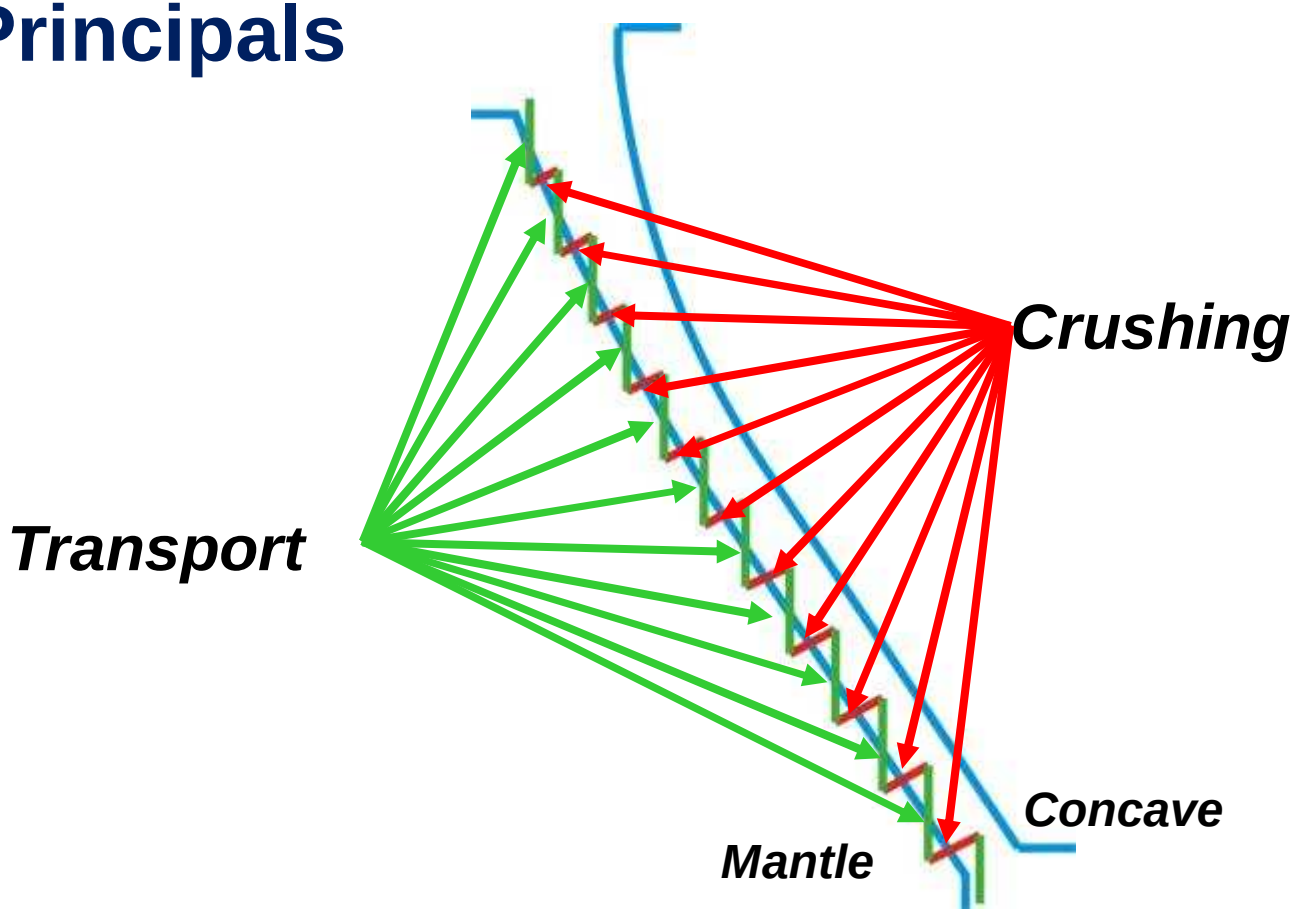
Operating Principals





QUARRY ACADEMY

Operating Principals



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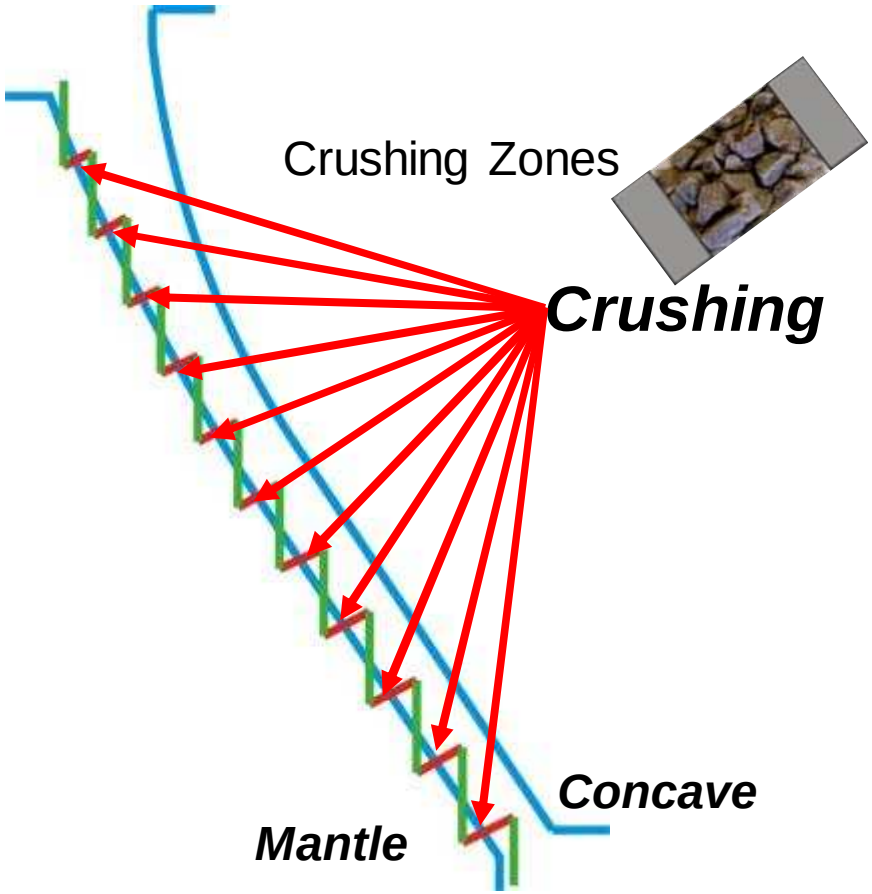
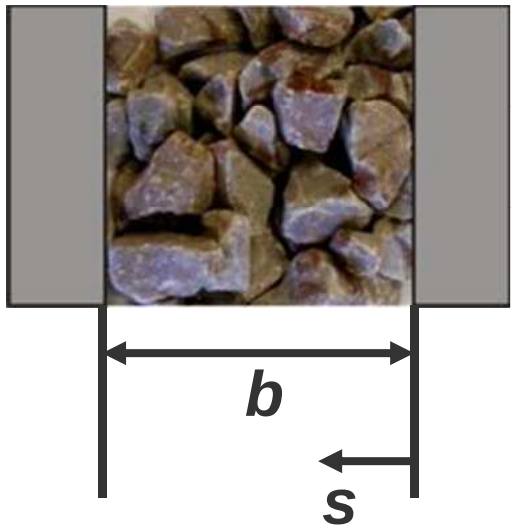


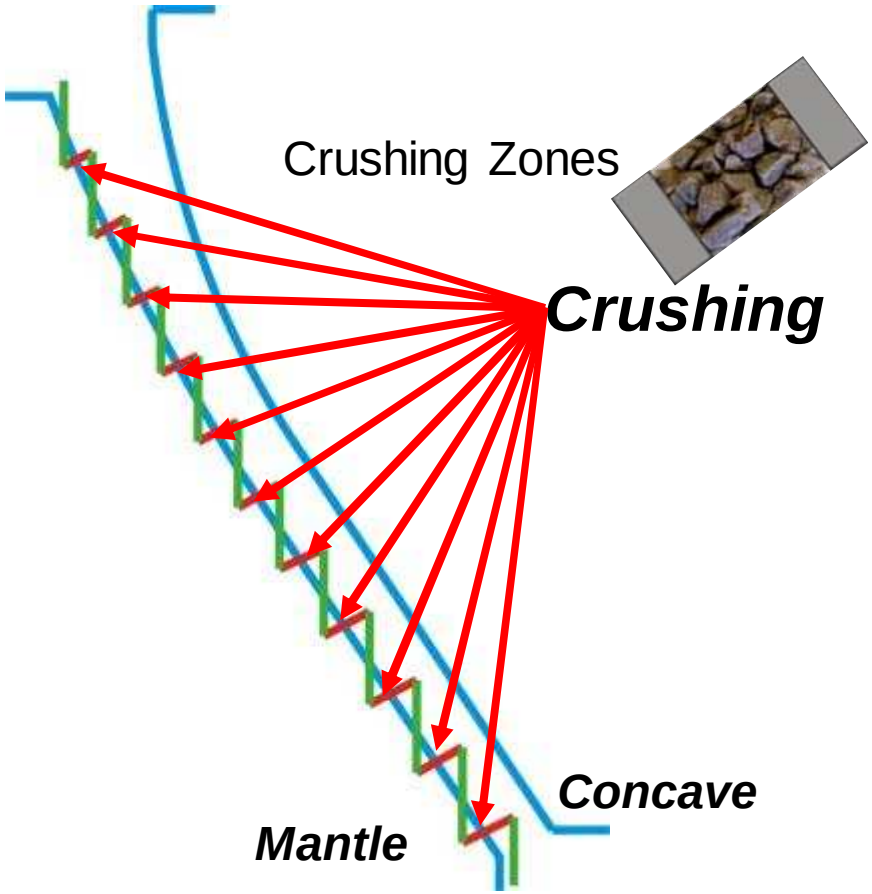


b: Bed Height

s: Compression

s/b: Compression Ratio

QUARRY ACADEMY



Single Particle Breakage SPB

Inter Particle Breakage IPB

QUARRY ACADEMY

Operating Principals

Breakage Modes

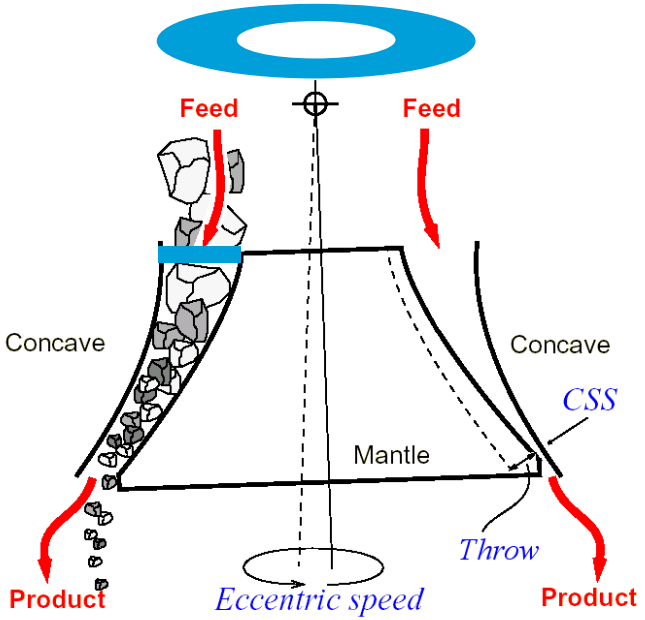
- In a cone crusher the stones are crushed with both SPB and IPB as the material moves down through the chamber.
- The relative amounts of IPB and SPB depends on factors like chamber design, crusher geometry, speed, css, eccentric throw, and others.

	SPB	IPB
		
Fines	Less	More
Shape	Flaky	Cubic
Force	Low	High

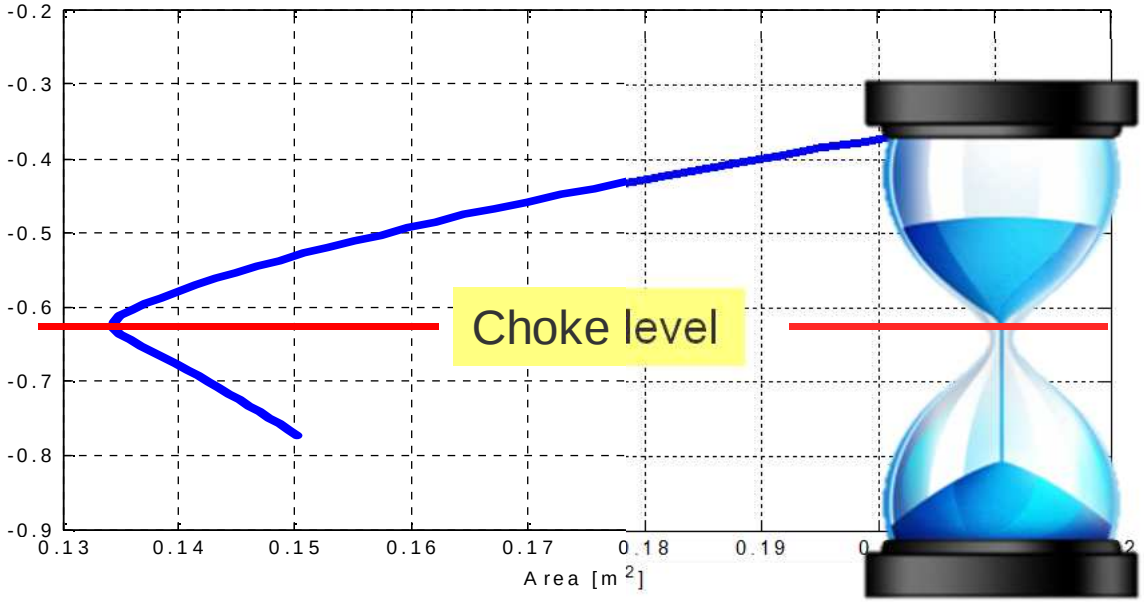
Operating Principals

Capacity

Cross section area



Area function

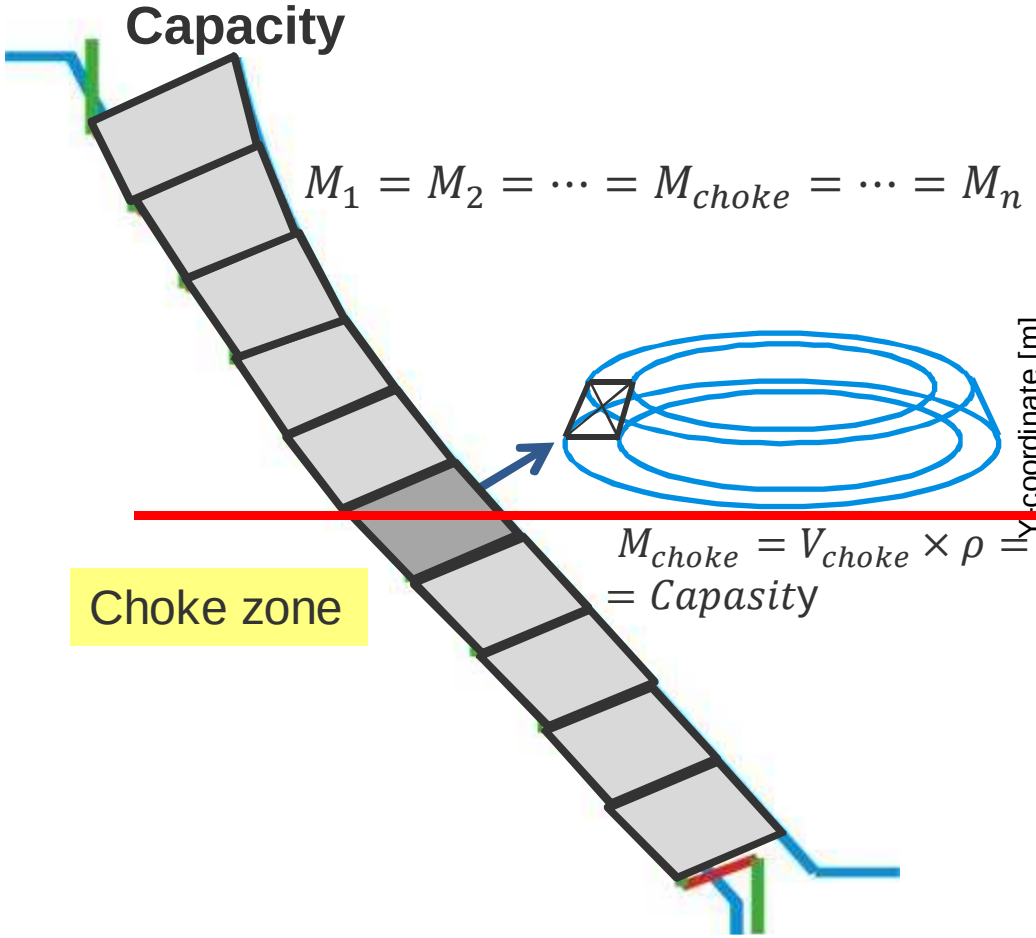


QUARRY ACADEMY

Operating Principals

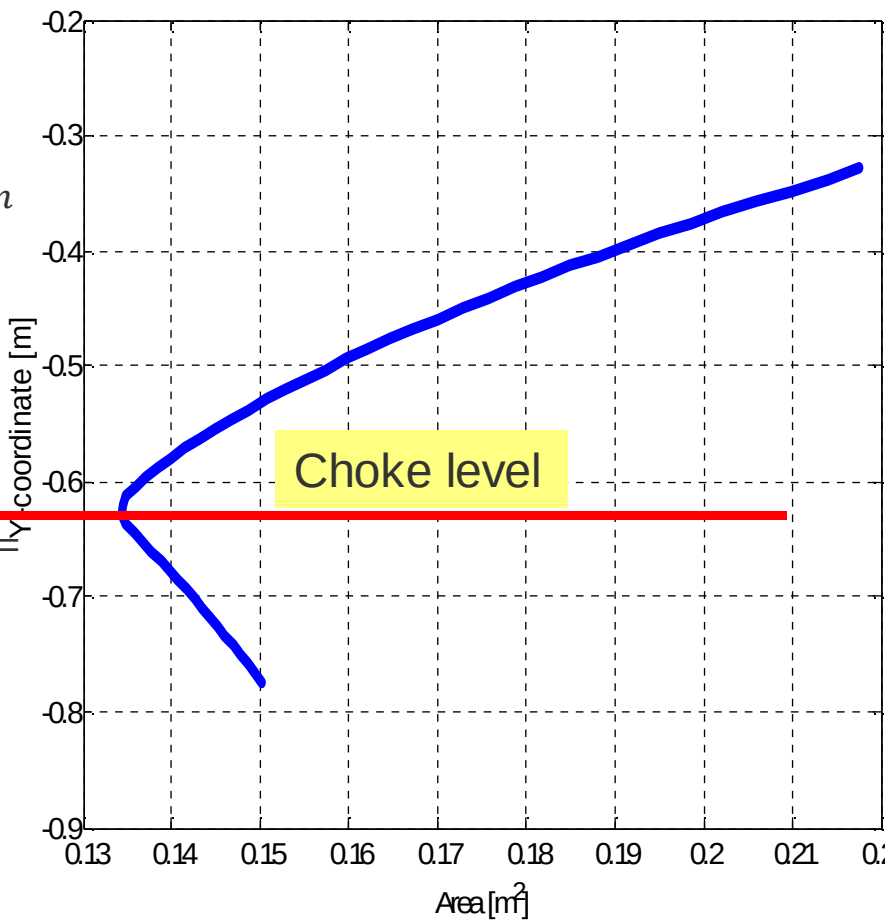
Capacity

$$M_1 = M_2 = \cdots = M_{choke} = \cdots = M_n$$

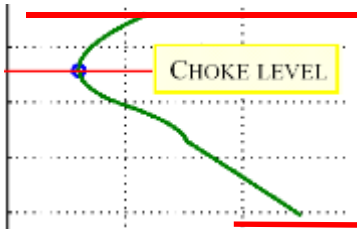


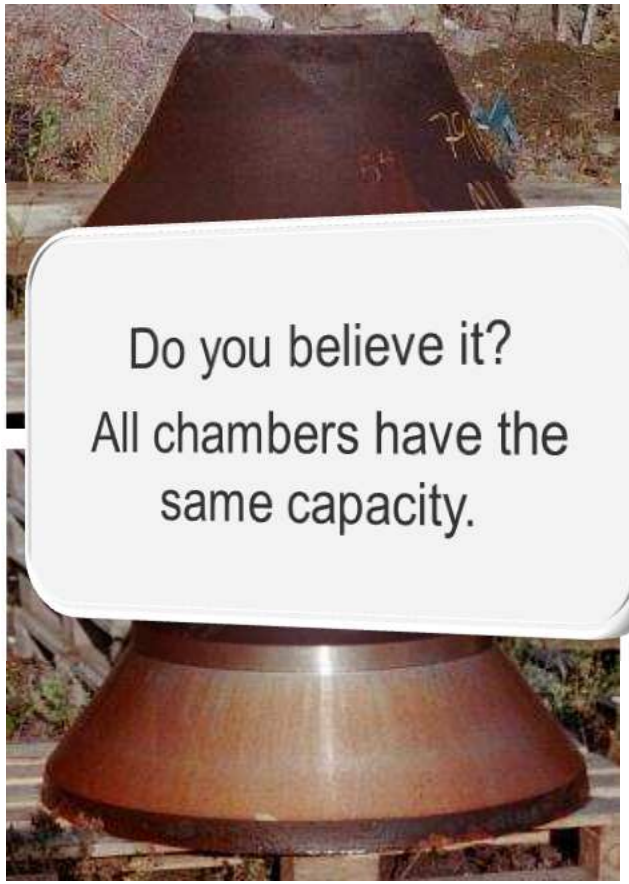
Choke zone

$$M_{choke} = V_{choke} \times \rho = Capasity$$



Choke level



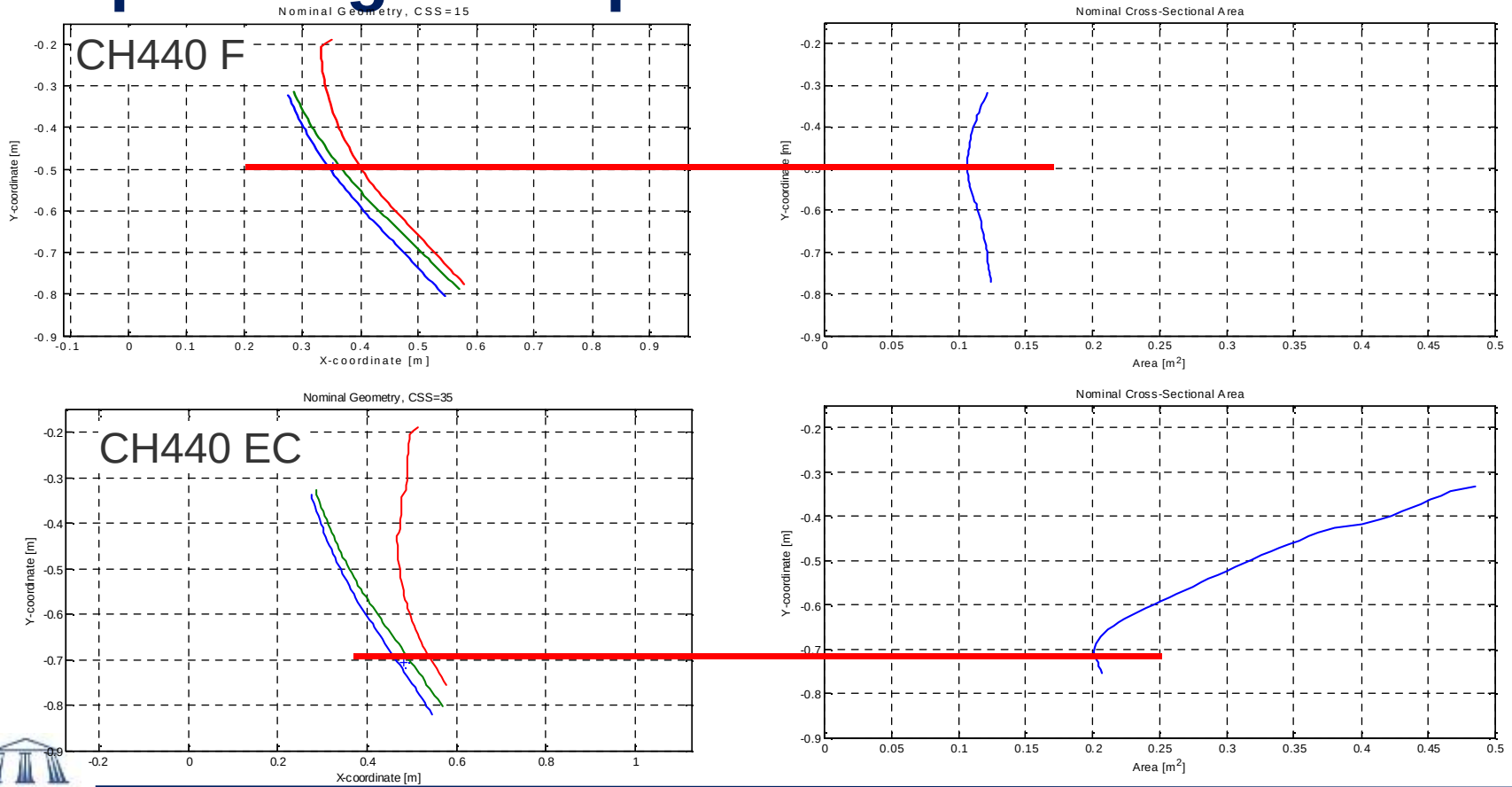


Do you believe it?

All chambers have the same capacity.

QUARRY ACADEMY

Operating Principals



QUARRY ACADEMY

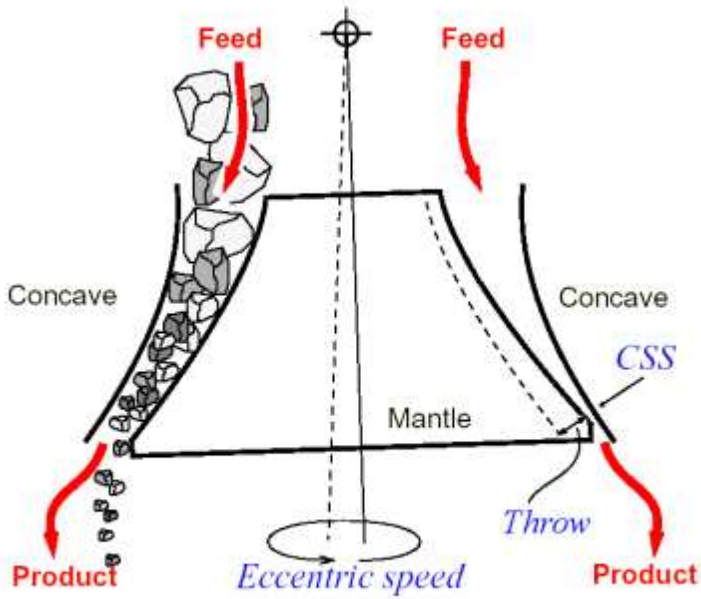
Crusher Modeling

Intro

Why speak about modeling?

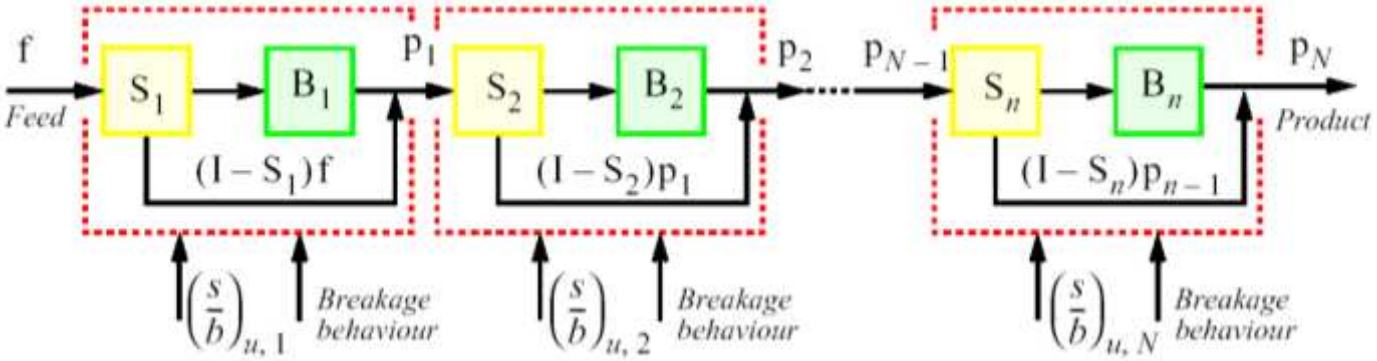
Modeling has two purposes:

- Predict the performance of a process – Simulation software
- Knowledge on the process operating principals – Common language and understanding



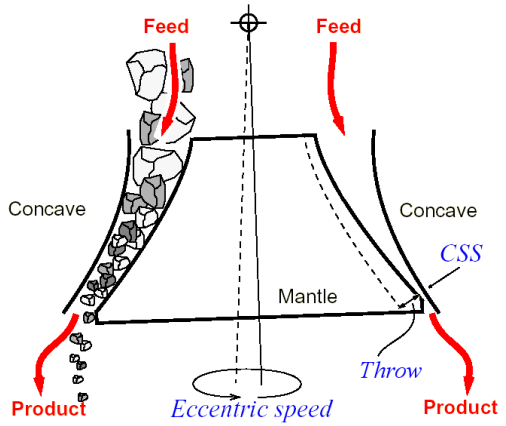
Crusher Modeling

The Theory



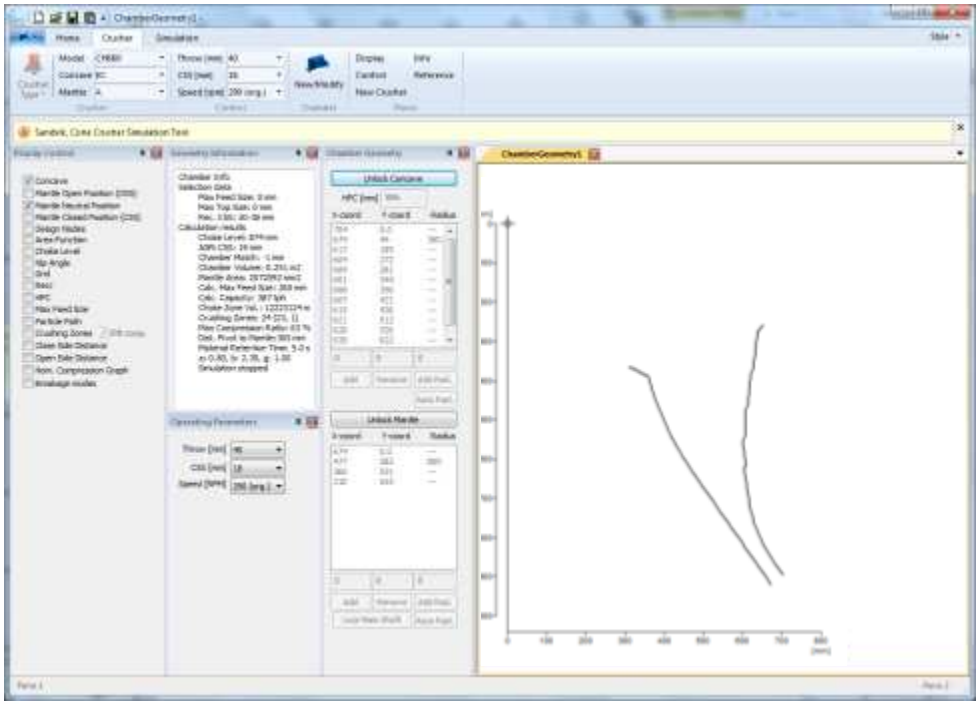
$$\mathbf{p}_i = \{[\mathbf{B}_i^{\text{inter}}\mathbf{S}_i + (\mathbf{I} - \mathbf{S}_i)]\mathbf{M}_i^{\text{inter}} + \mathbf{B}_i^{\text{single}}\mathbf{M}_i^{\text{single}}\}\mathbf{p}_{i-1}$$

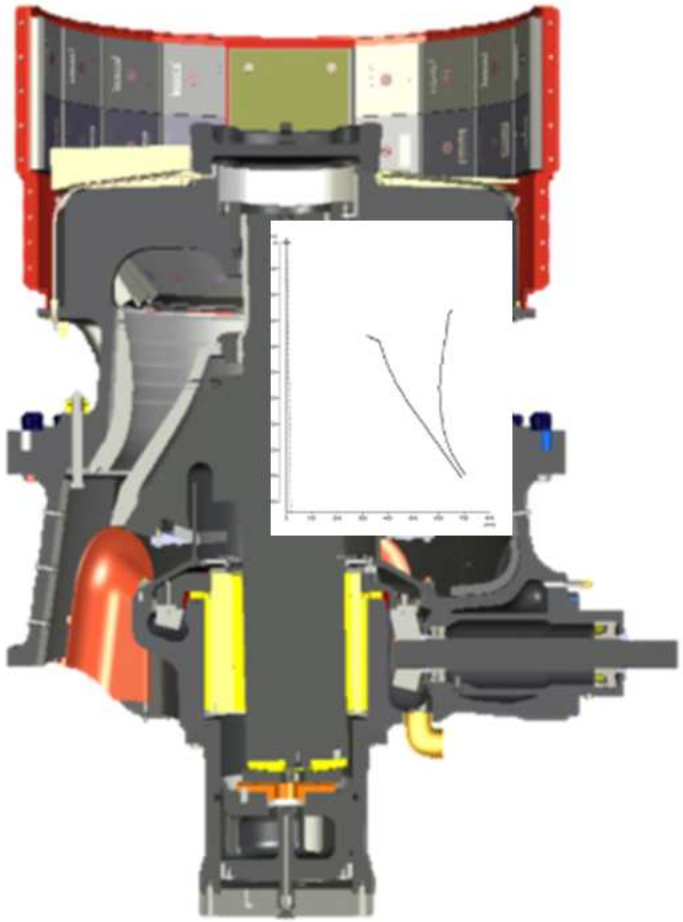
$$\left(\frac{s}{b}\right)_{u,i} = \text{Compression ratio}$$



QUARRY ACADEMY

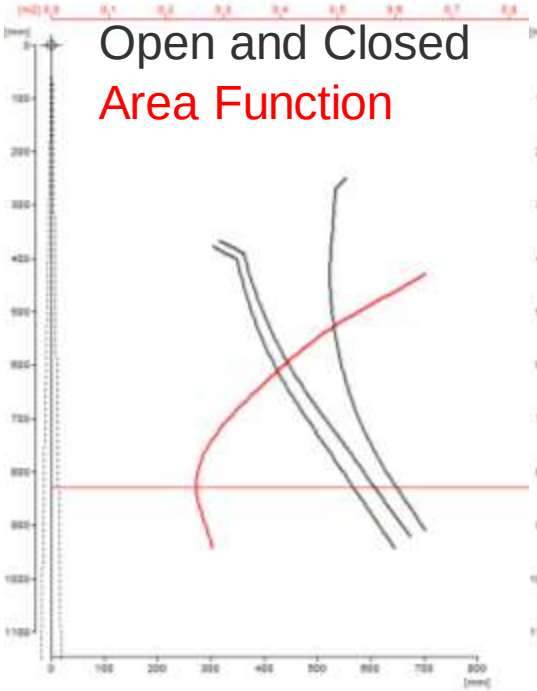
Crusher Modeling



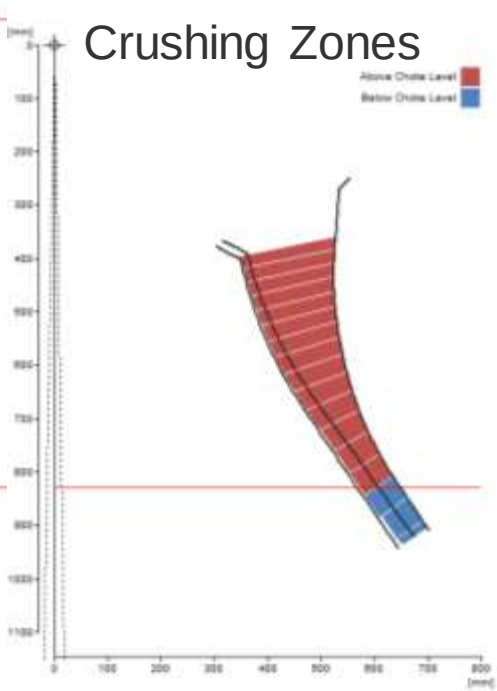


QUARRY ACADEMY

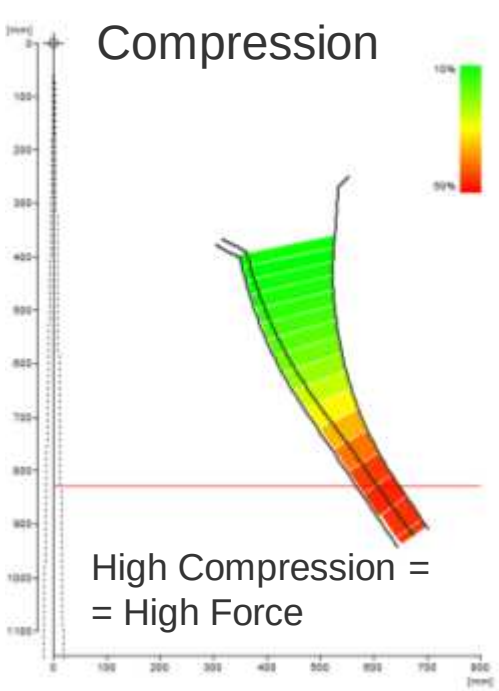
Crusher Modeling



Open and Closed
Area Function



Crushing Zones



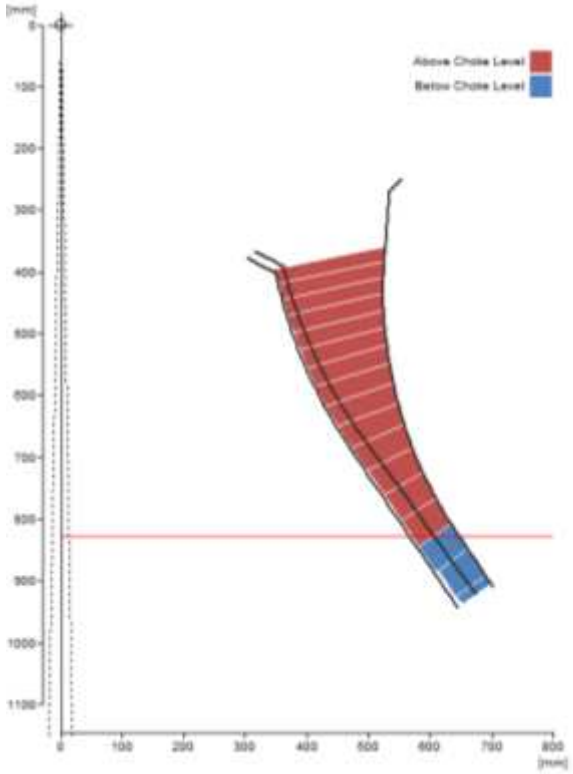
Compression

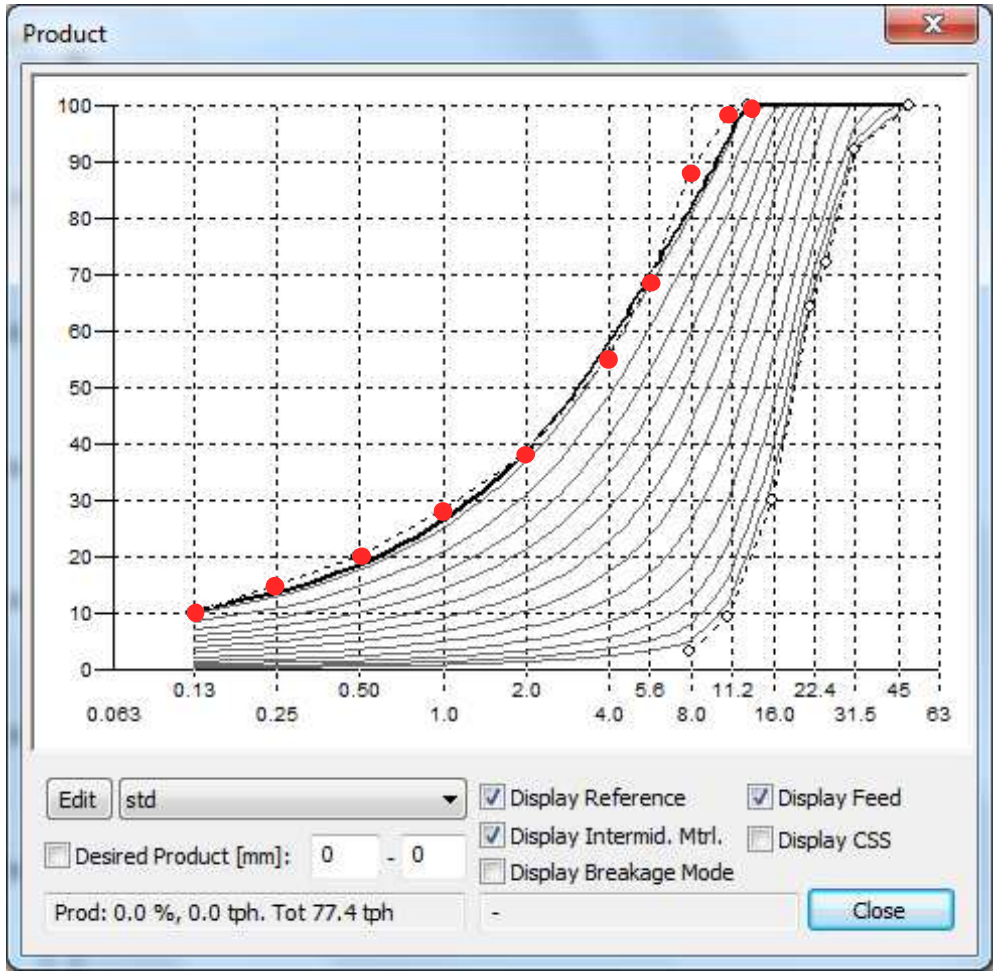
High Compression =
= High Force

QUARRY ACADEMY

Crusher Modeling

Simulation results

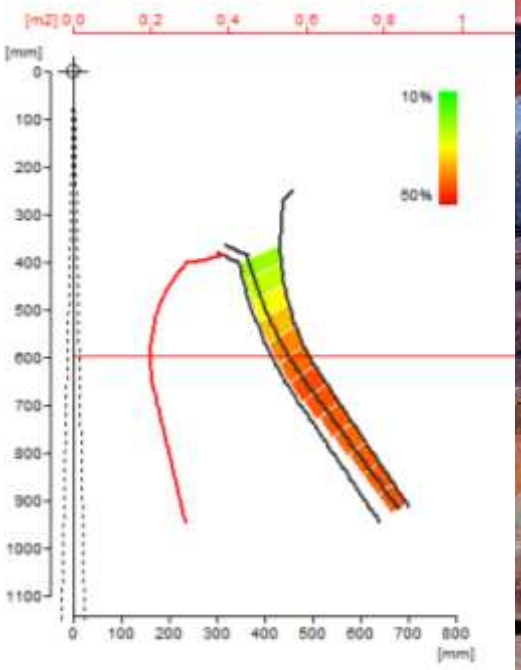


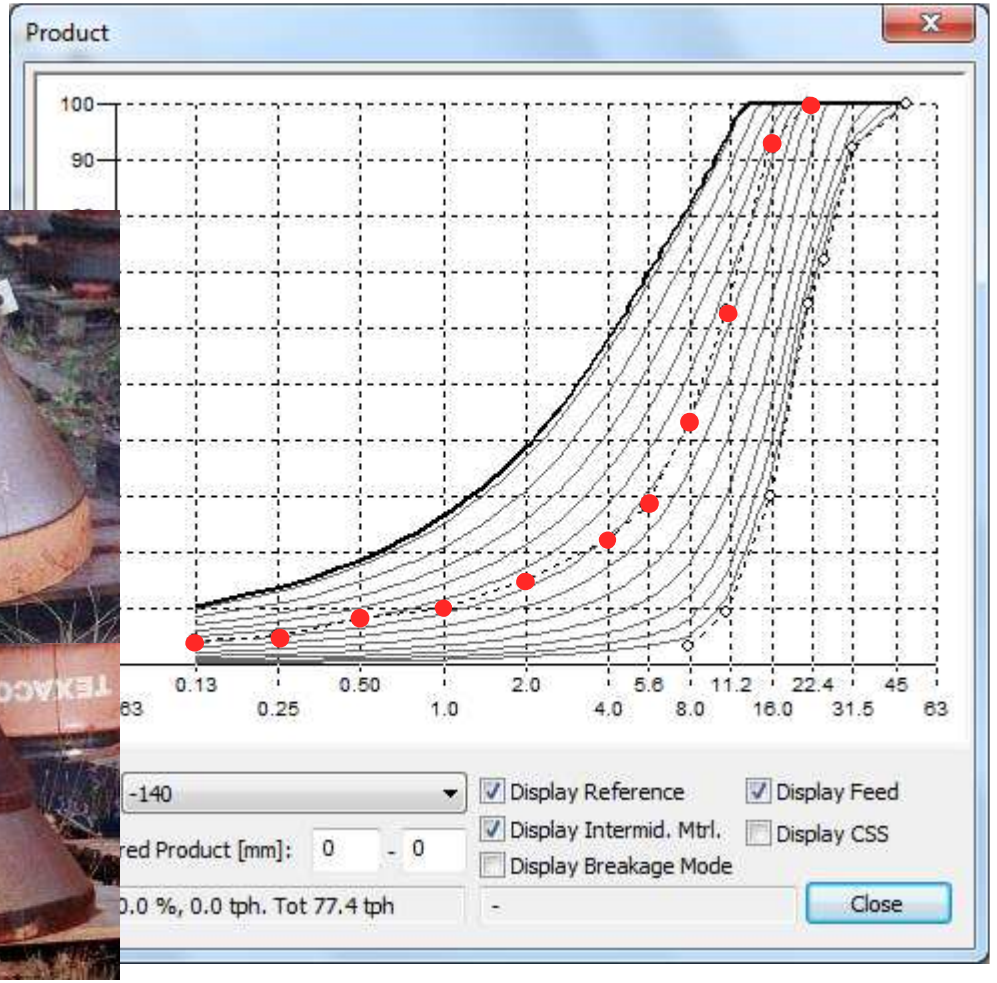


QUARRY ACADEMY

Crusher Modeling

Simulation results

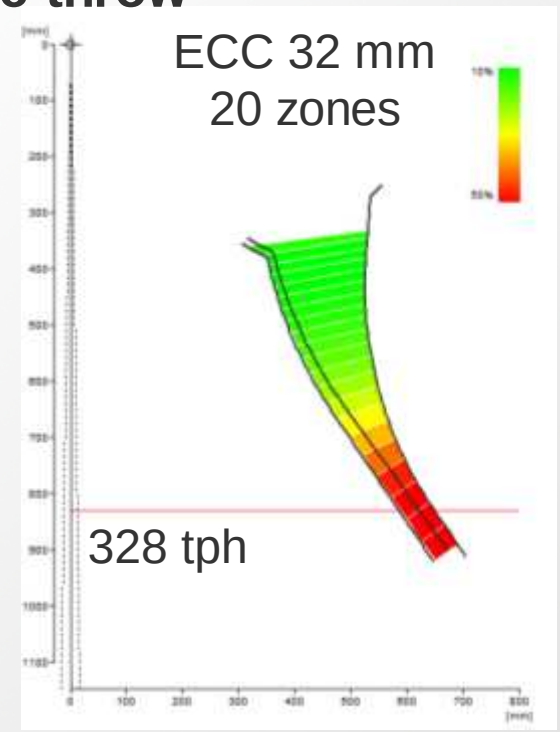


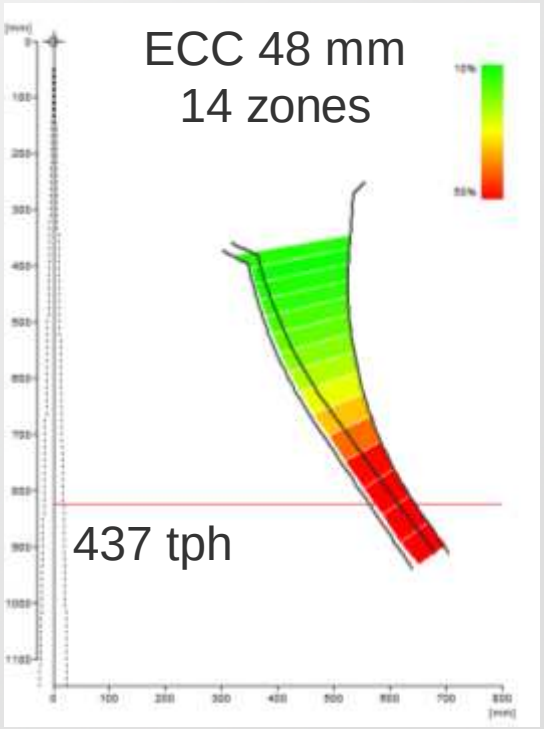


QUARRY ACADEMY

Crusher Modeling

The effect of eccentric throw

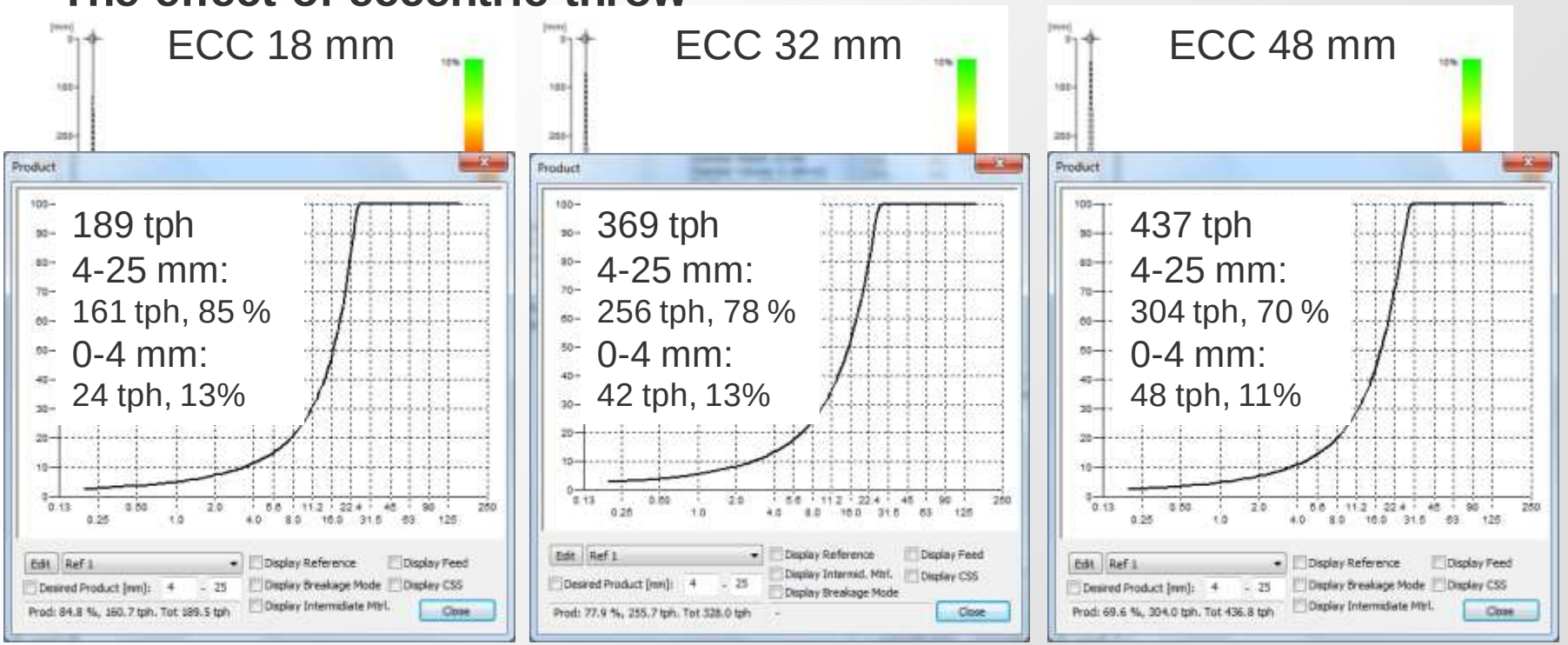




QUARRY ACADEMY

Crusher Modeling

The effect of eccentric throw



Crusher CSS not optimized!

QUARRY ACADEMY

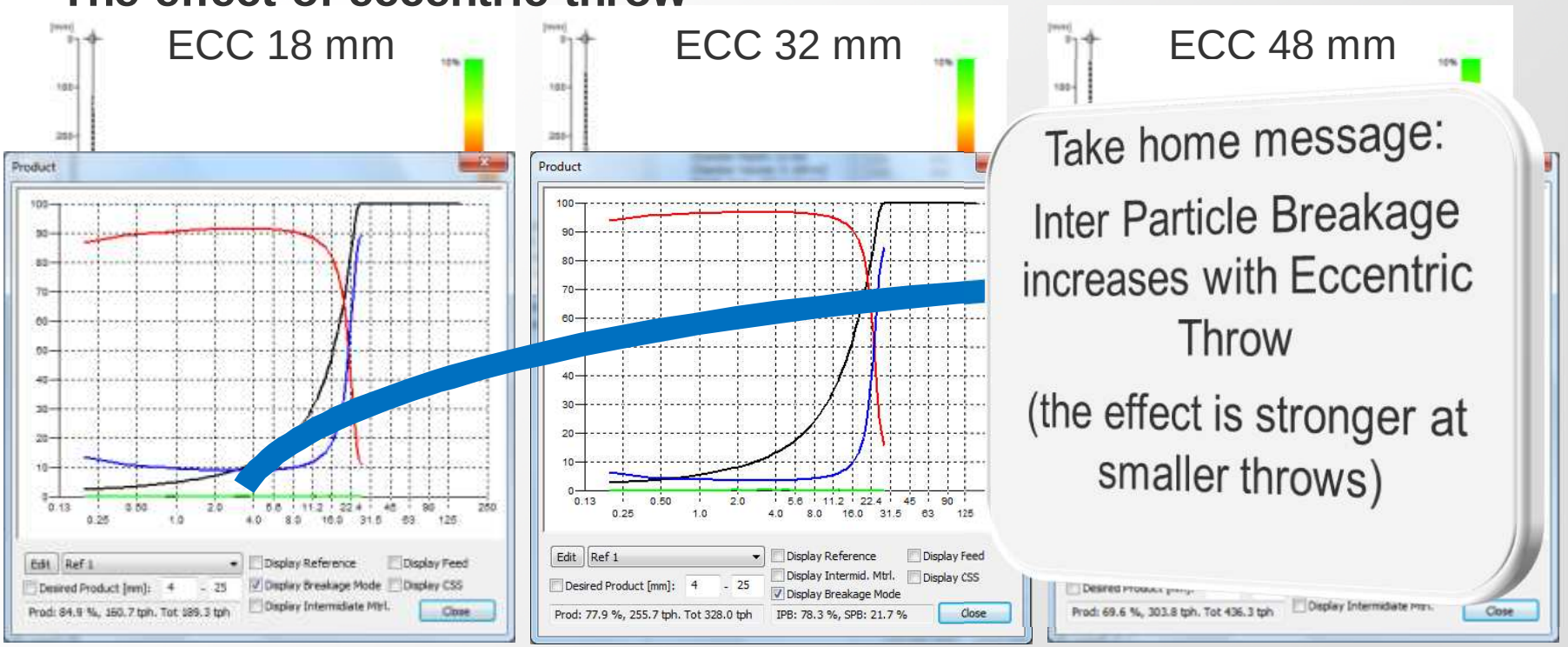
Crusher Modeling

The effect of eccentric throw

ECC 18 mm

ECC 32 mm

ECC 48 mm



Take home message:

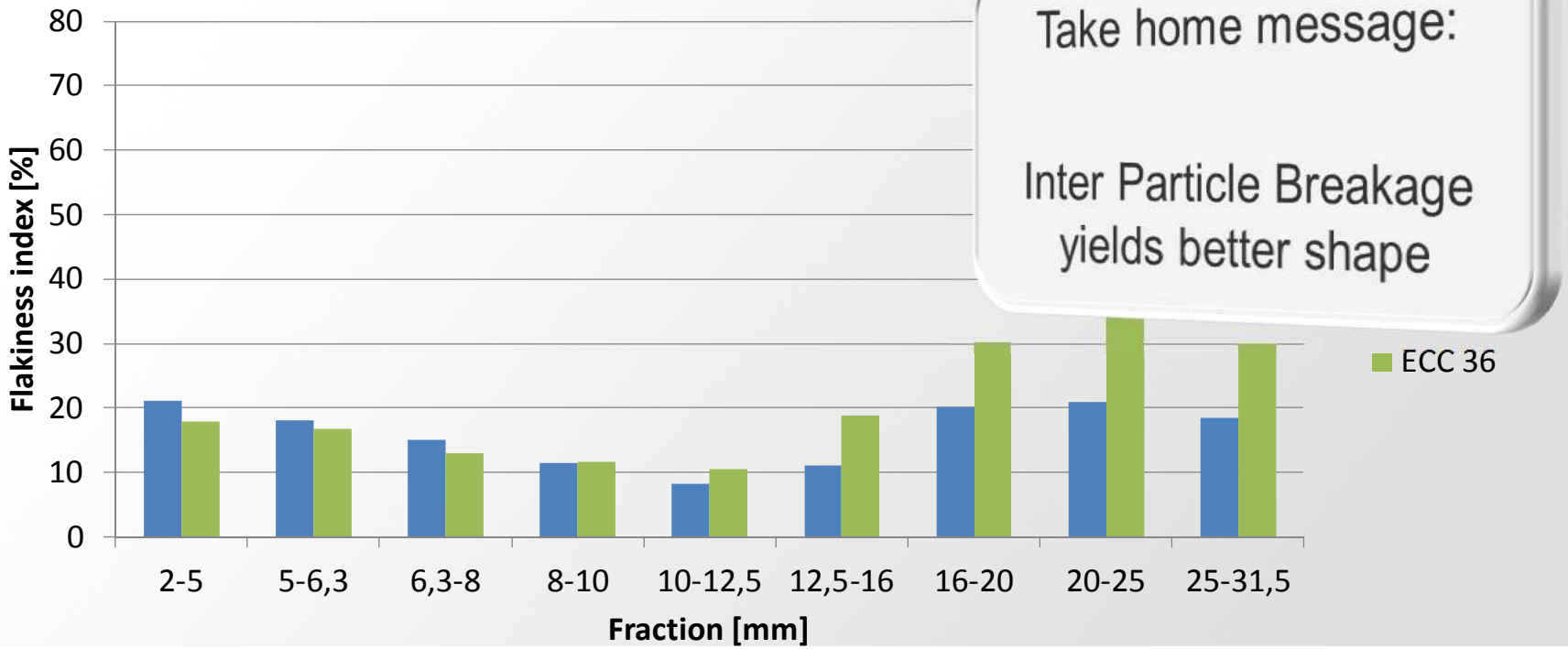
Inter Particle Breakage increases with Eccentric Throw

(the effect is stronger at smaller throws)

QUARRY ACADEMY

Crusher Modeling

Results from field test



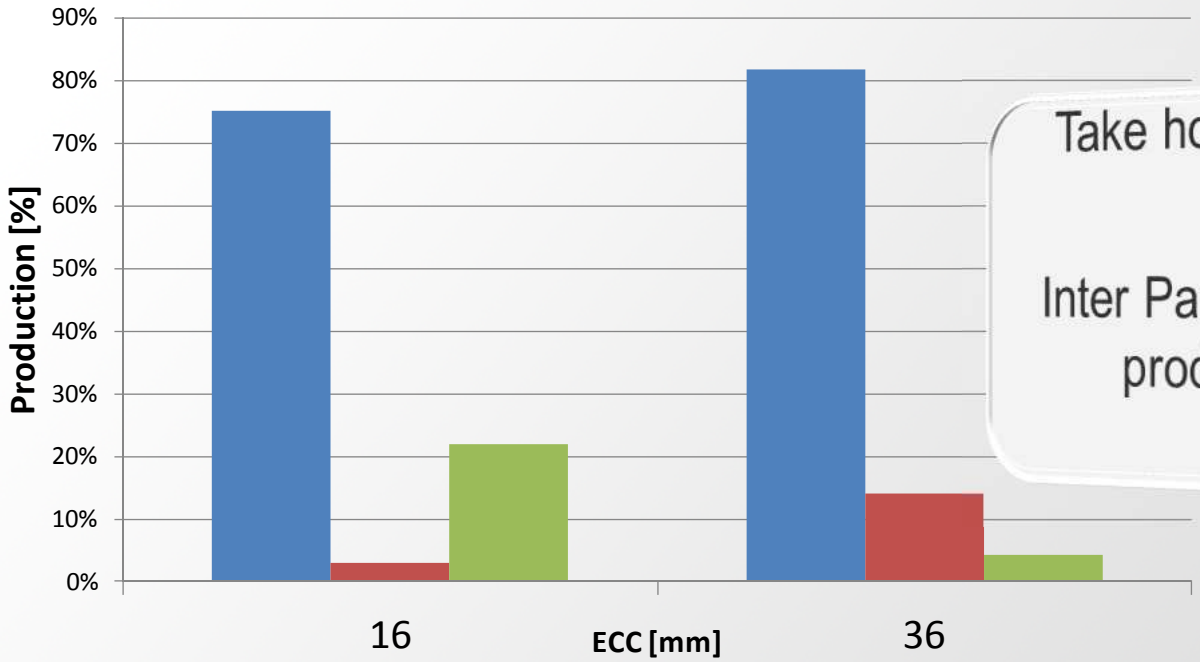
Take home message:

Inter Particle Breakage yields better shape

QUARRY ACADEMY

Crusher Modeling

Results from field test



Take home message:

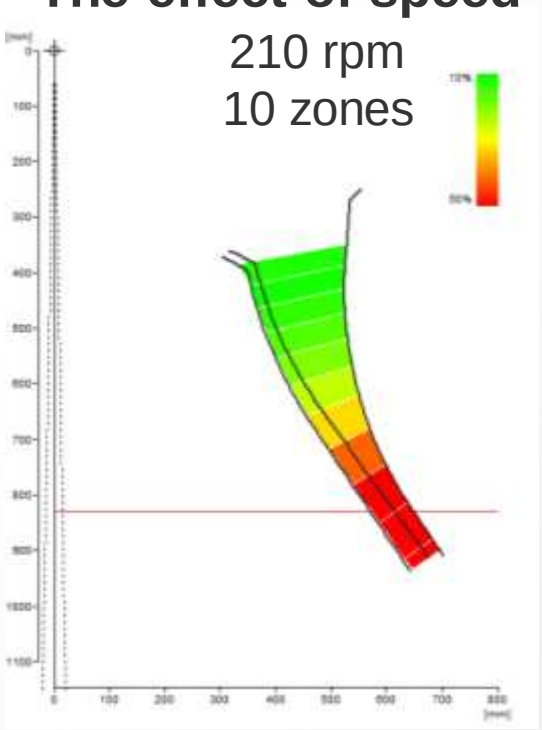
Inter Particle Breakage produces fines

QUARRY ACADEMY

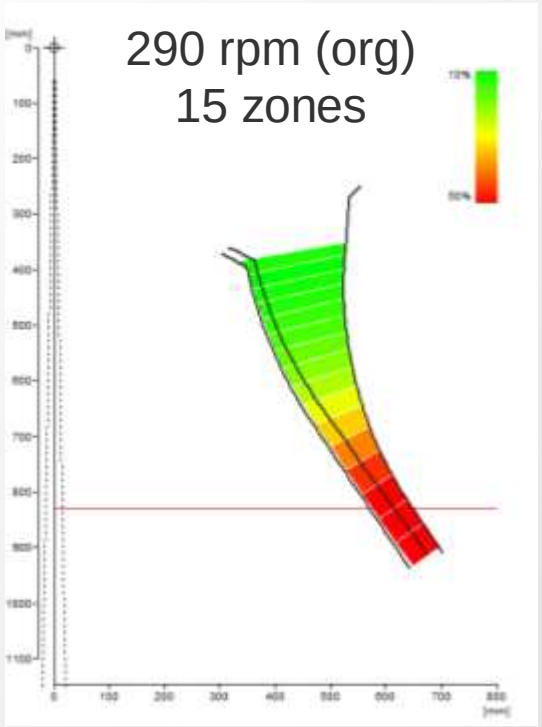
Crusher Modeling

The effect of speed

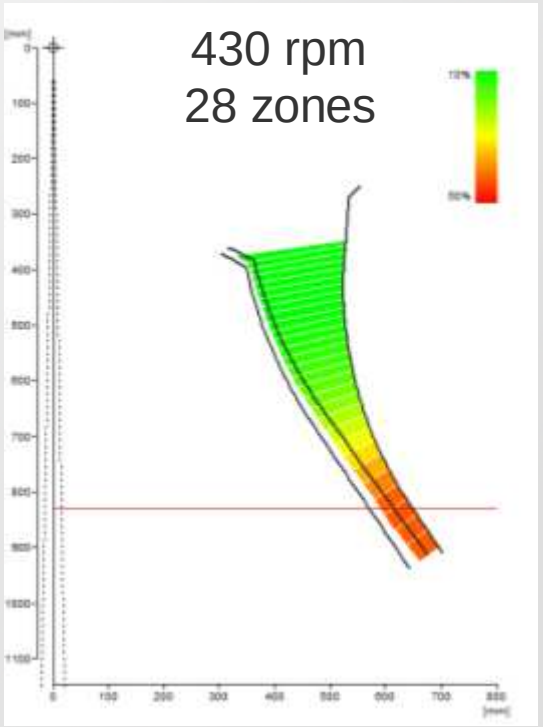
210 rpm
10 zones



290 rpm (org)
15 zones



430 rpm
28 zones

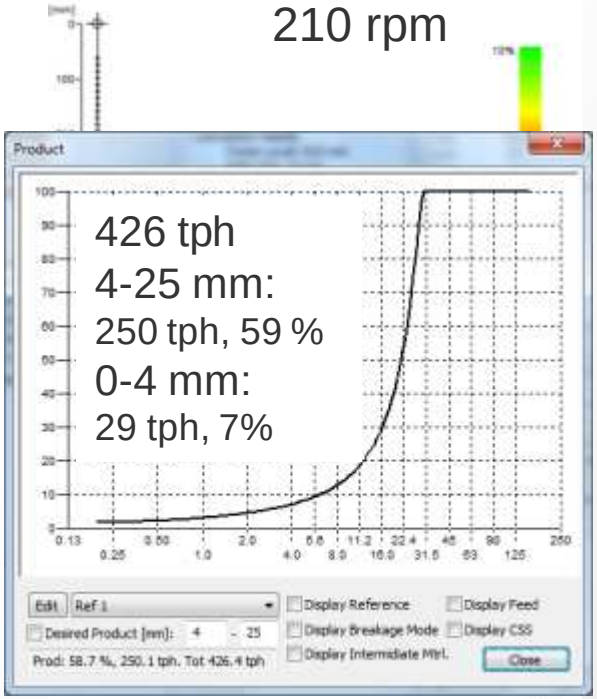


QUARRY ACADEMY

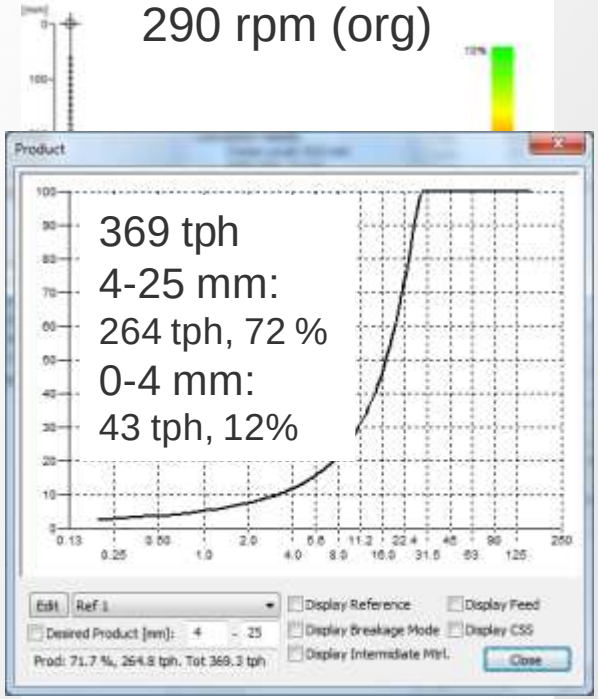
Crusher Modeling

The effect of speed, production of 4-25 mm

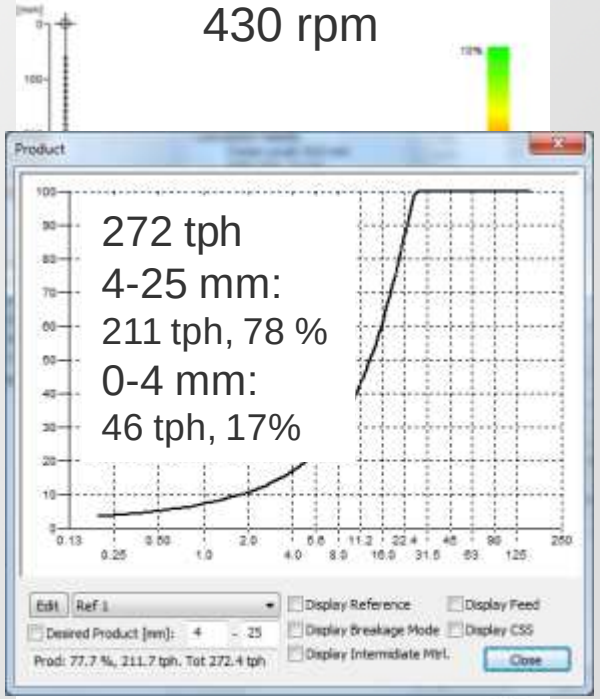
210 rpm



290 rpm (org)



430 rpm

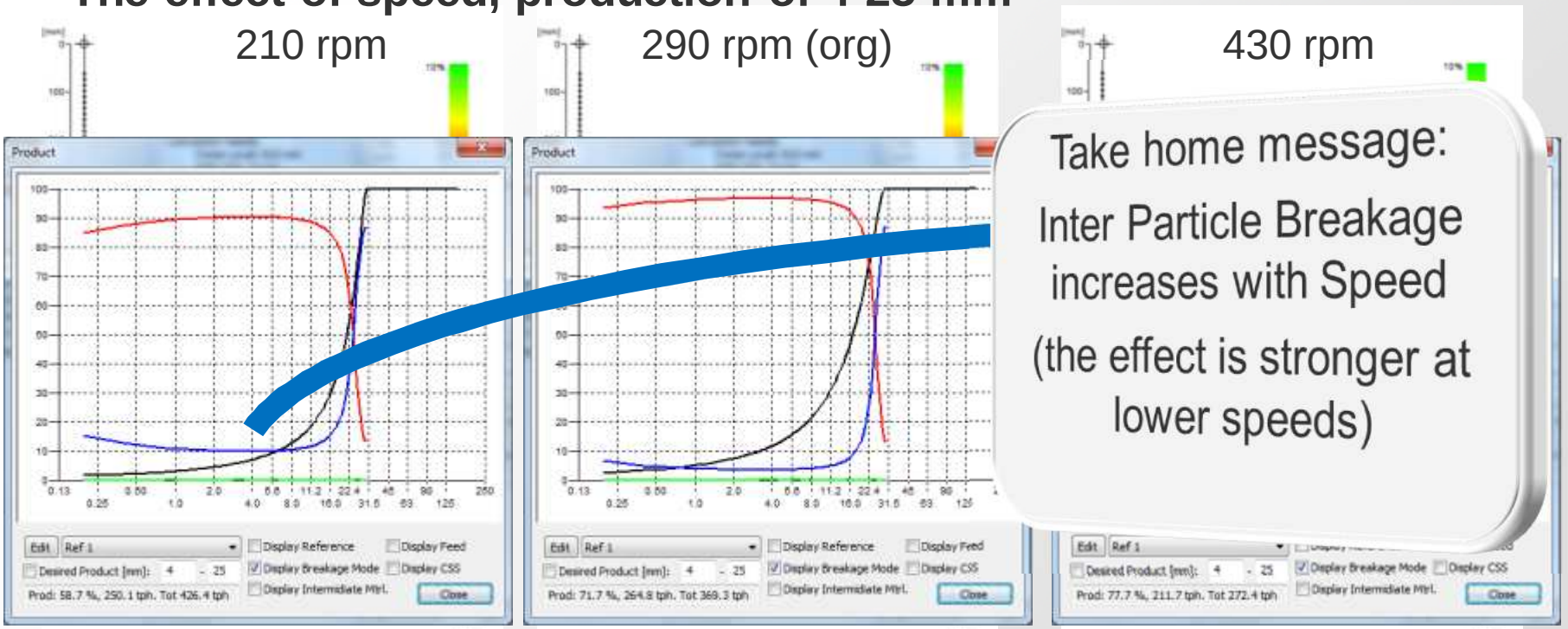


All on CSS 20 mm. CSS should be optimized for each setting

QUARRY ACADEMY

Crusher Modeling

The effect of speed, production of 4-25 mm

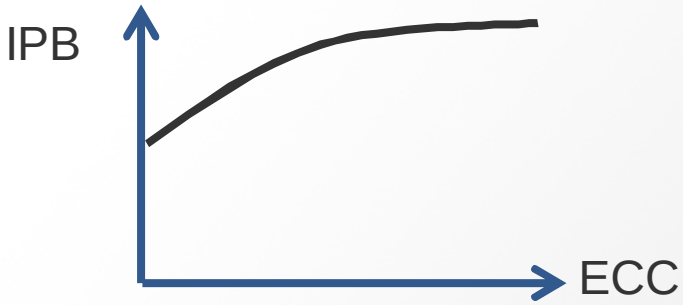


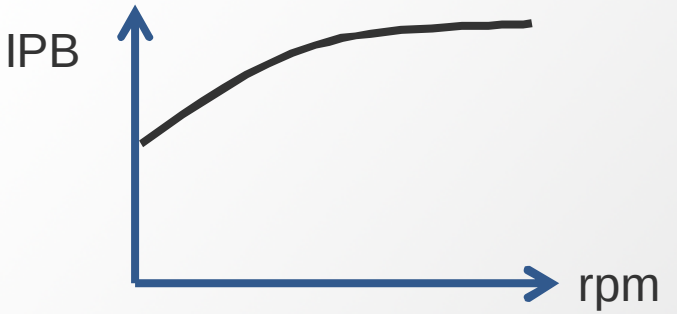
All on CSS 20 mm. CSS should be optimized for each setting

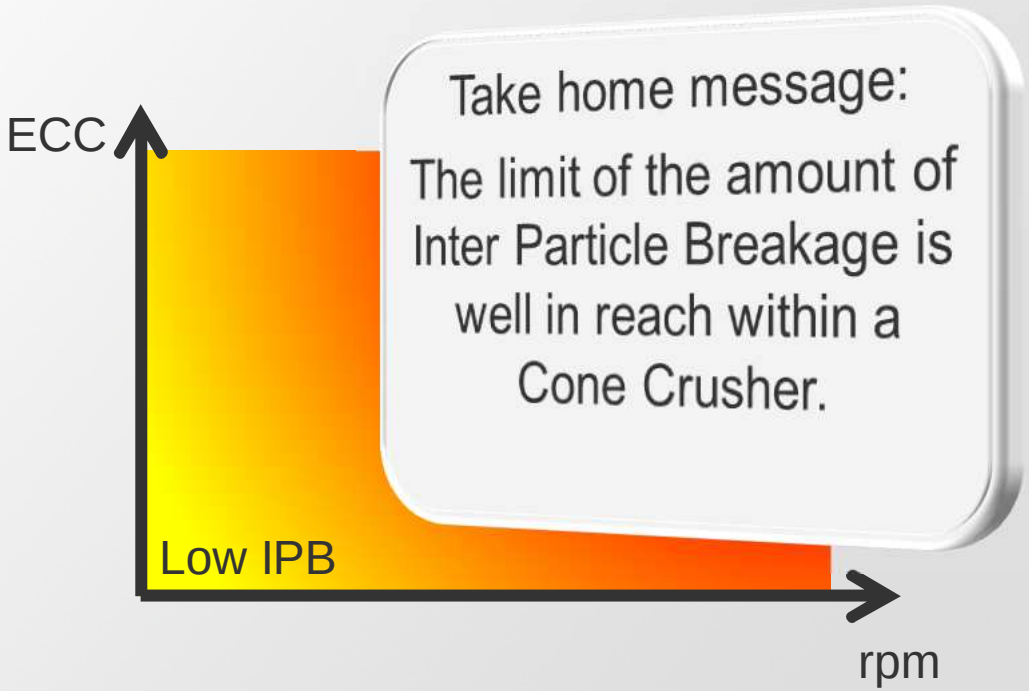
QUARRY ACADEMY

Crusher Modeling

Inter Particle Breakage







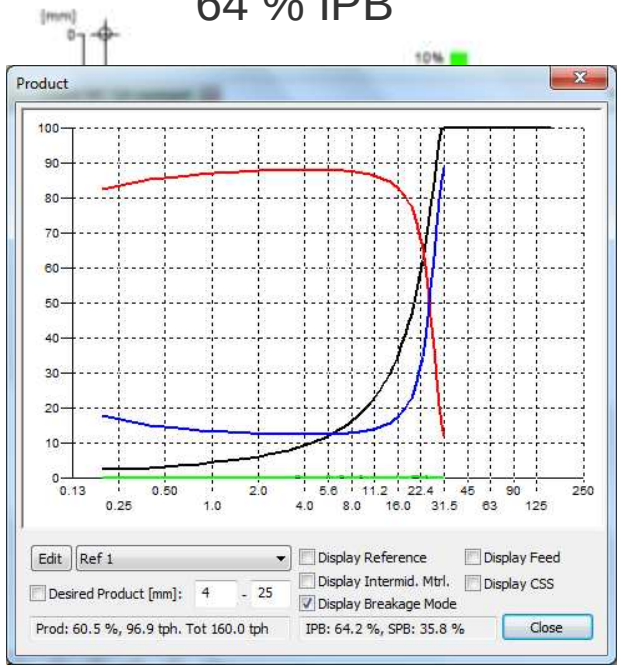
Crusher Modeling

Inter Particle Breakage, Worst and Best Case

Worst Case:

- Small Throw
- Low Speed
- Large CSS

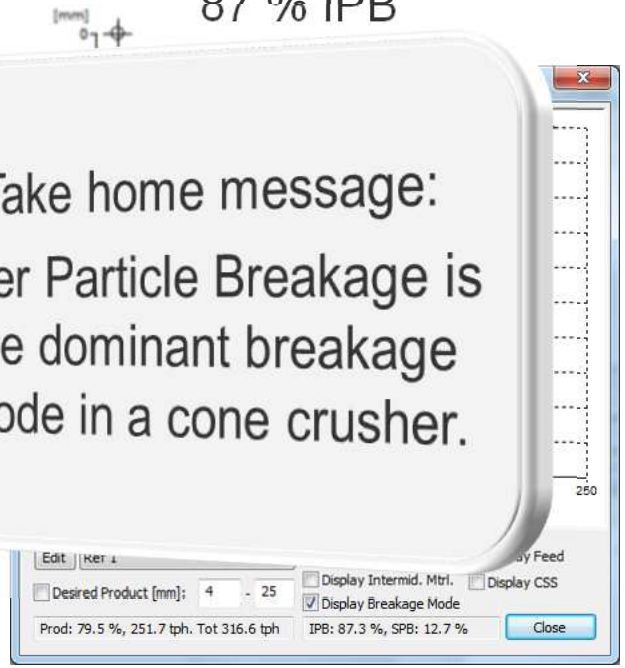
64 % IPB



Best Case:

- Large Throw
- High Speed
- Medium C

87 % IPB



Take home message:

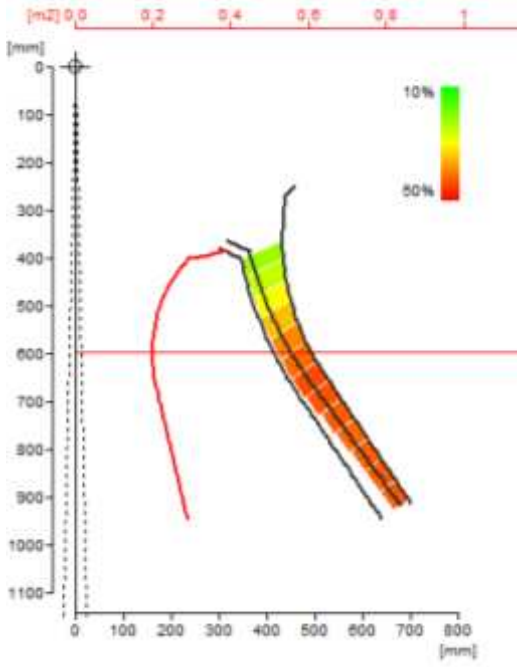
Inter Particle Breakage is the dominant breakage mode in a cone crusher.

QUARRY ACADEMY

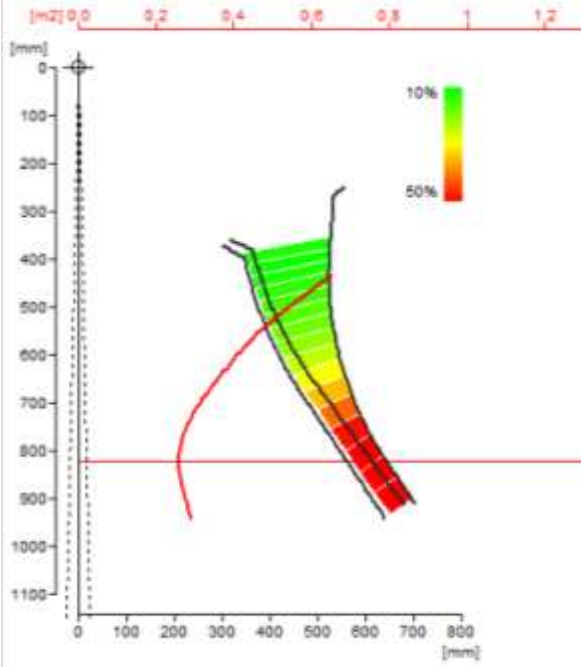
Crusher Modeling

The effect of chamber geometry

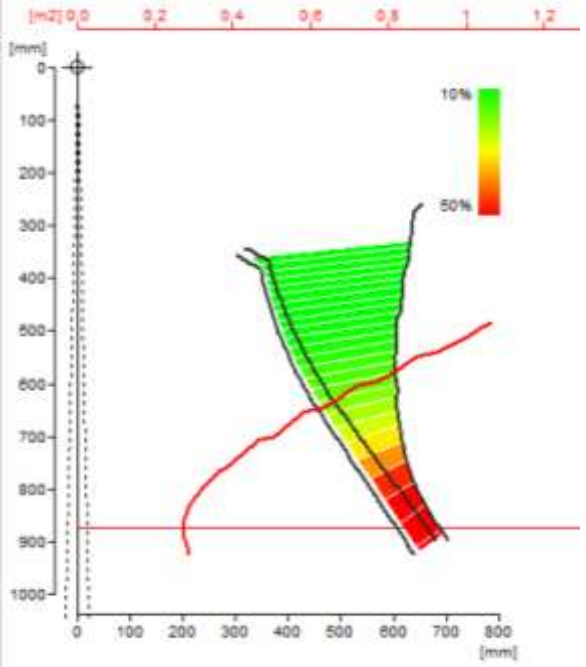
Fine



Medium Coarse



Extra Coarse

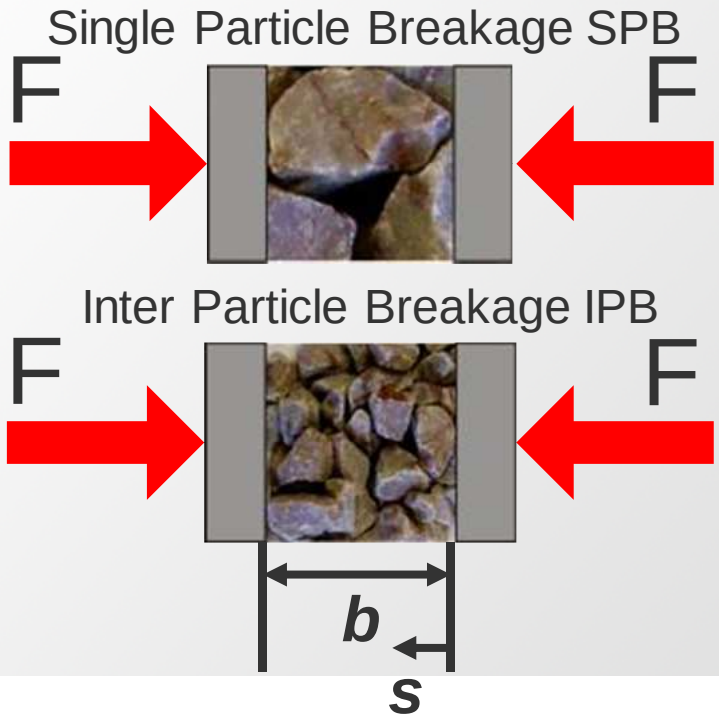


Wear, IPB, Forces, Reduction

QUARRY ACADEMY

Crusher Modeling

Crushing Force



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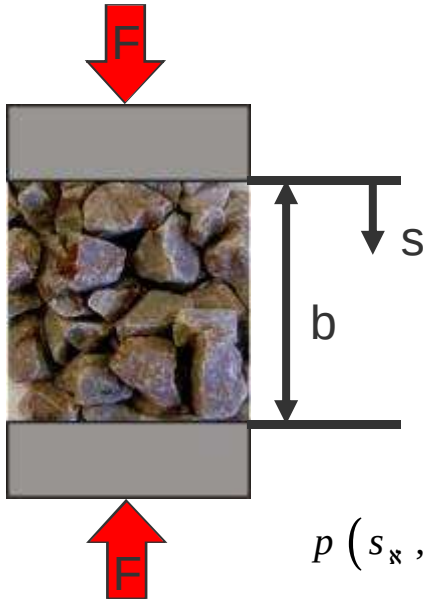
Crusher Modeling

Inter Particle Breakage Force



b: Bed height
s: compression
s/b: compression ratio

F: Force
F = f(s/b, σ)
σ: Fraction length

Packing!

Long

Take home message:

Inter Particle breakage

Longer fractions results in higher crushing pressure

$$p\left(s_N, \sigma_N\right) = a_1 s_N^2 \sigma_N^2 + a_2 s_N^2 \sigma_N + a_3 s_N^2 + a_4 s_N \sigma_N^2 + a_5 s_N \sigma_N + a_6 s_N$$

$$\sigma_N = size\ distribution\ width$$

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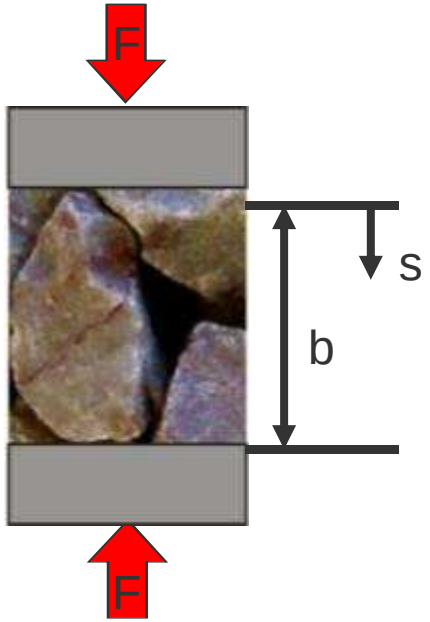
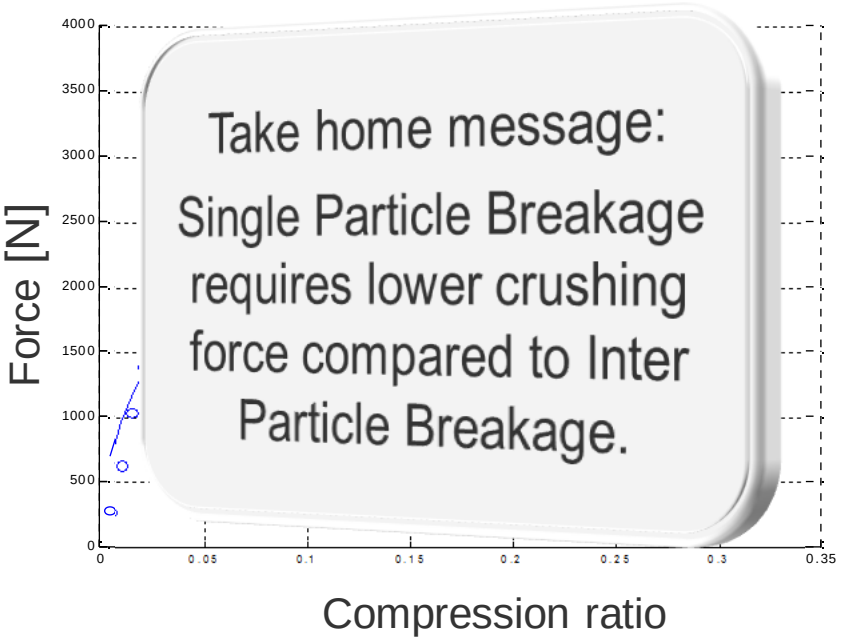
Crusher Modeling

Single Particle Breakage Force



b: Rock height
s: compression
s/b: compression ratio



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The Crushing Process

Why not always use a big throw?

Design capacity: 200 tph

Crusher Capacity: 300 tph

Choke fed Crusher operation(300 tph):

Material in surge bin runs out at even intervals

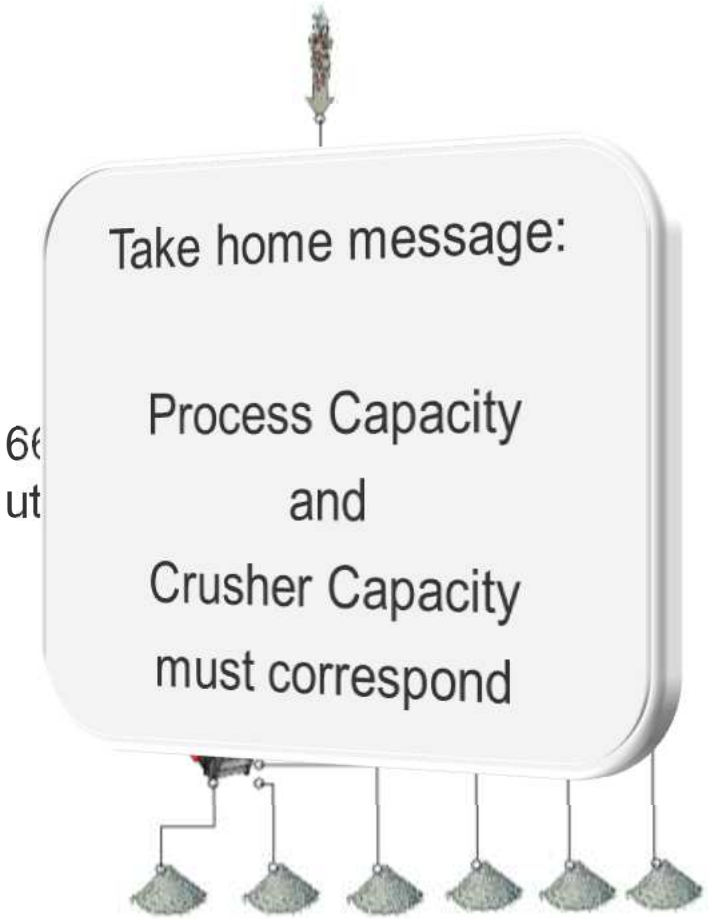
Consequence:

Crusher is operated choke fed 66% of total operating time feeding the screen with 300 tph

Screen overload

Solution: Adjust throw in order to reach 200 tph capacity

Improvement in fines production



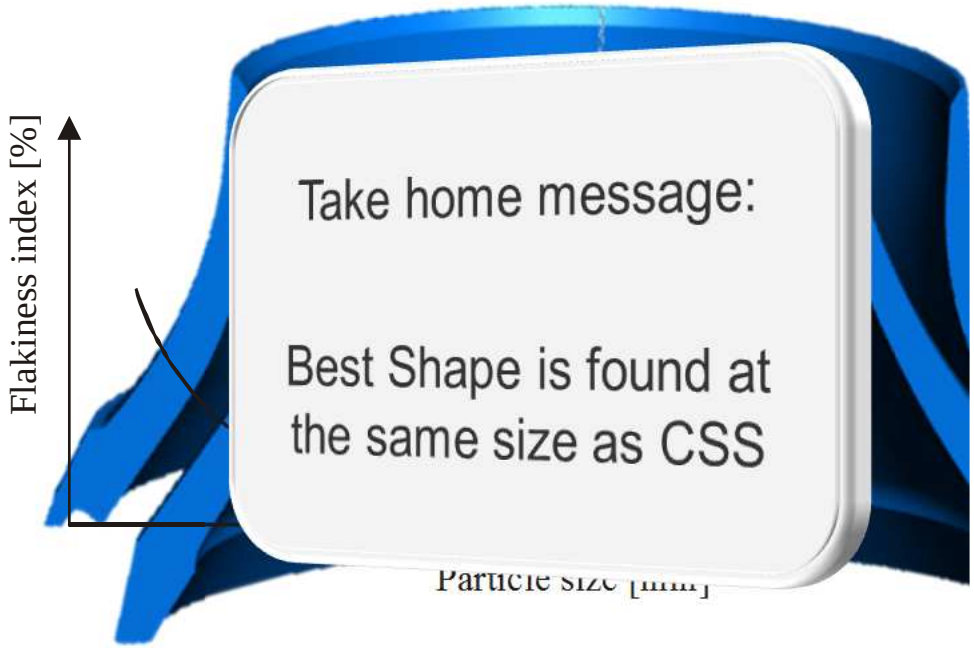
QUARRY ACADEMY

The Crushing Process

Optimizing Particle Shape

Relation between CSS and Shape

- The size were the best shape can be found is at CSS
- It is very difficult for cubical stones larger then CSS to pass the chamber
- Breakage of stones creates flaky particles. Smaller flaky stones will more easily find its way through the chamber



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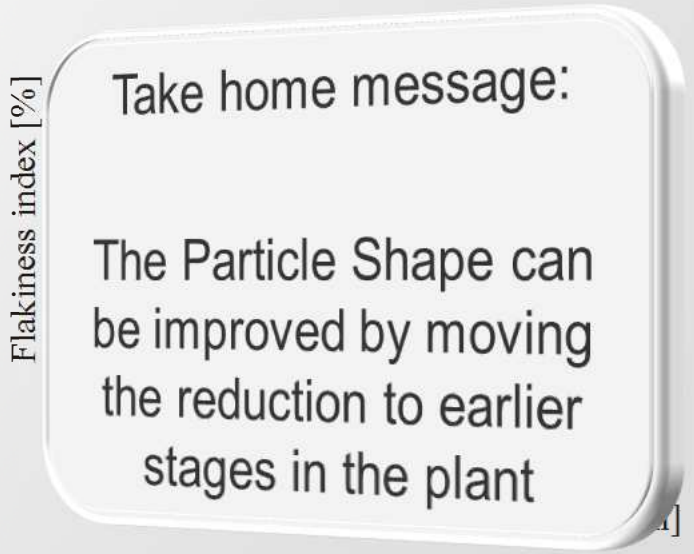
The Crushing Process

Optimizing Particle Shape

Relation between Feed size and Shape

- The greater reduction ratio the worse particle shape.
- Inter particle breakage improves shape. When crushing a bed of material weaker particles will break first. Flaky or elongated particles are weaker then round.
- Breaking round particles gives flaky material.



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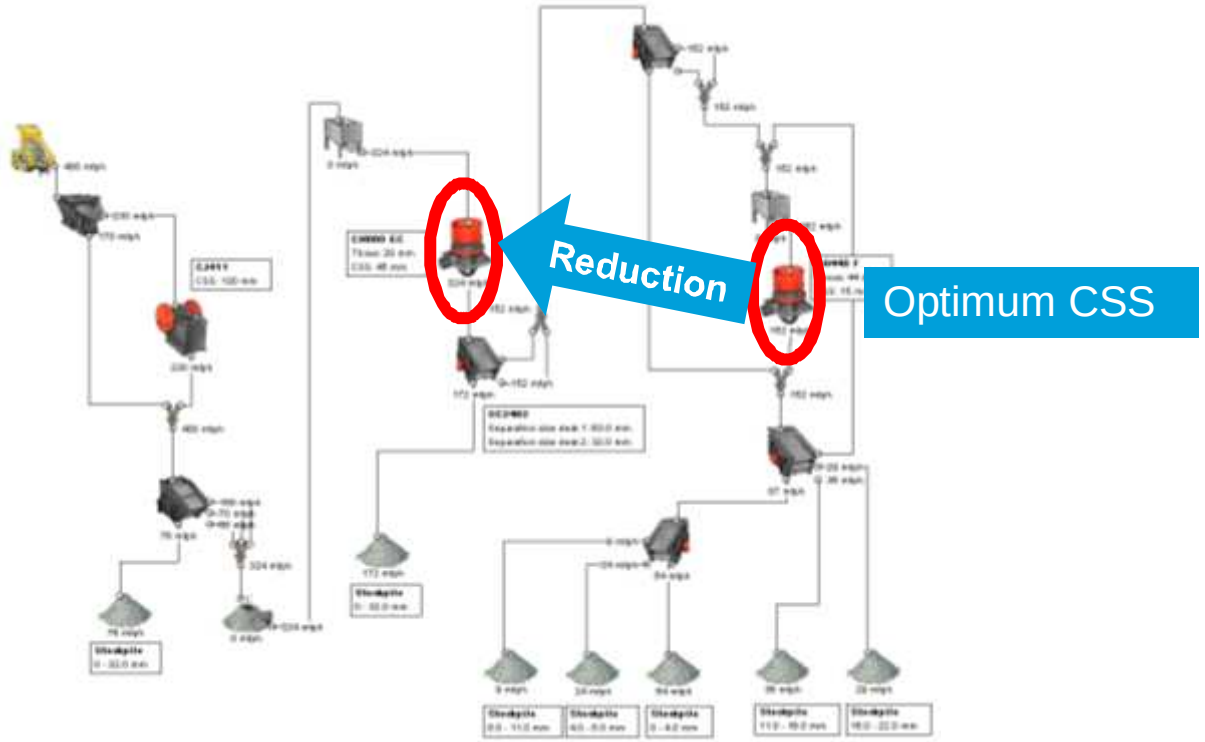
The Crushing Process

Optimizing Particle Shape



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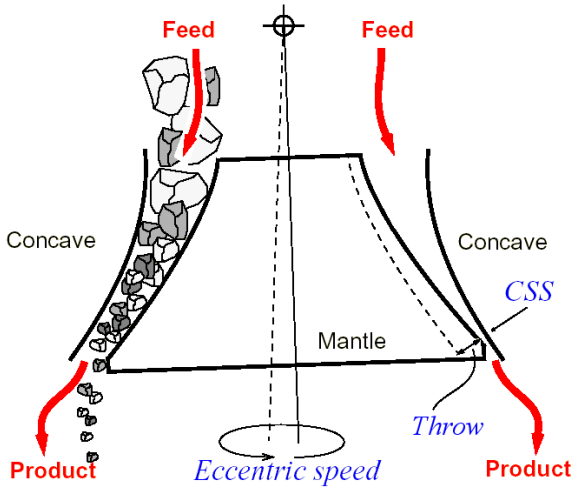

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Take home messages:

Capacity is determined by the choke area

Inter Particle Breakage:

Is the dominant breakage mode in a cone crusher

Increases with Eccentric Throw

Increases with Speed

Longer fractions results in higher crushing pressure

The limit of the amount of Inter Particle Breakage is well in reach within a Cone Crusher.

Take home messages:

Single Particle Breakage requires lower crushing force compared to Inter Particle Breakage.

Process Capacity and Crusher Capacity must correspond

Best Shape is found at the same size as CSS

The Particle Shape can be improved by moving the reduction to earlier stages in the plant

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