Crushing
- Principles of Mechanical Crushing

Per Svedensten

QUARRY ACADEMY

Improving Processes. Instilling Expertise.

DYNO
Dyno Nobel

SANDVIK

Per Svedensten

- Manager Crushing And Screening Process Expertise
- Sandvik employee since 2004
- Ph.D from Chalmers University of Technology Gothenburg, Sweden. 2007
  - ✓ Part 1: Partly sponsored by Sandvik
  - ✓ Part 2: Fully sponsored by Sandvik
  - ✓ Modeling, simulation, and optimization of crushing plants.
  - ✓ Technical-Economic optimizations
  - ✓ Start of PlantDesigner 10
- In Svedala since August 2007

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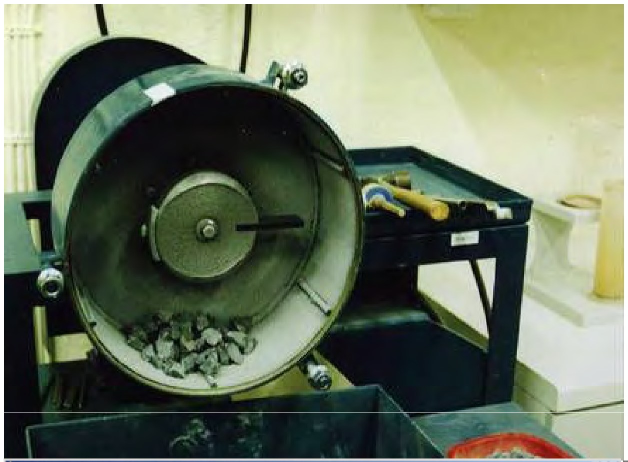
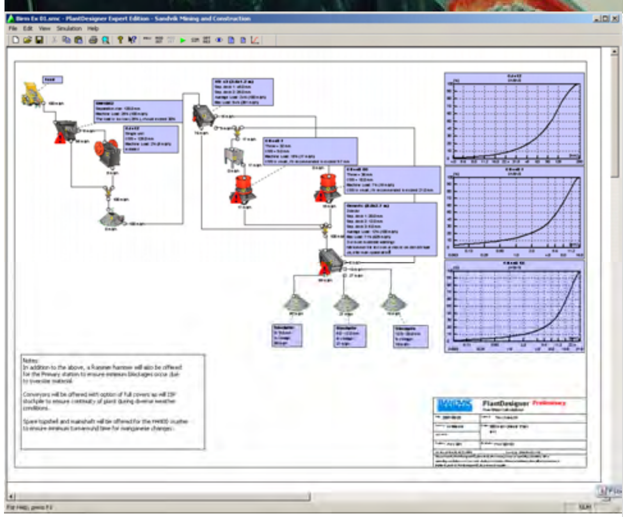
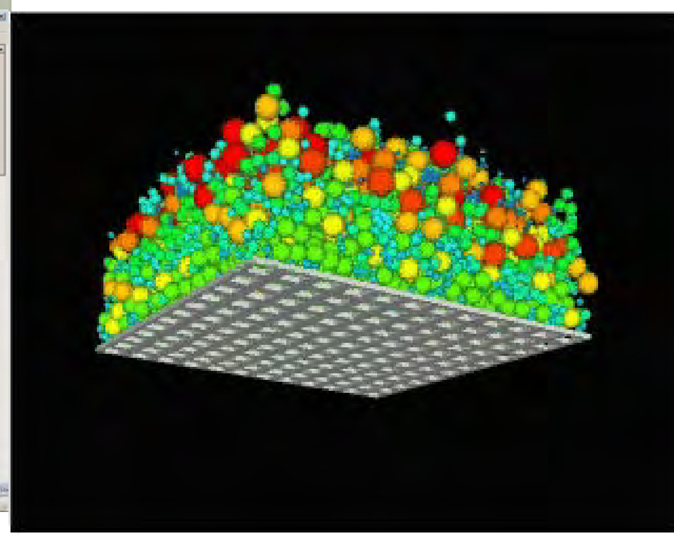
Crushing and Screening Process Expertise



- Raw Material Testing
- Process Expertise – Developing Crushing and Screening Processes
- PlantDesigner – Process Simulation
- Education and Training





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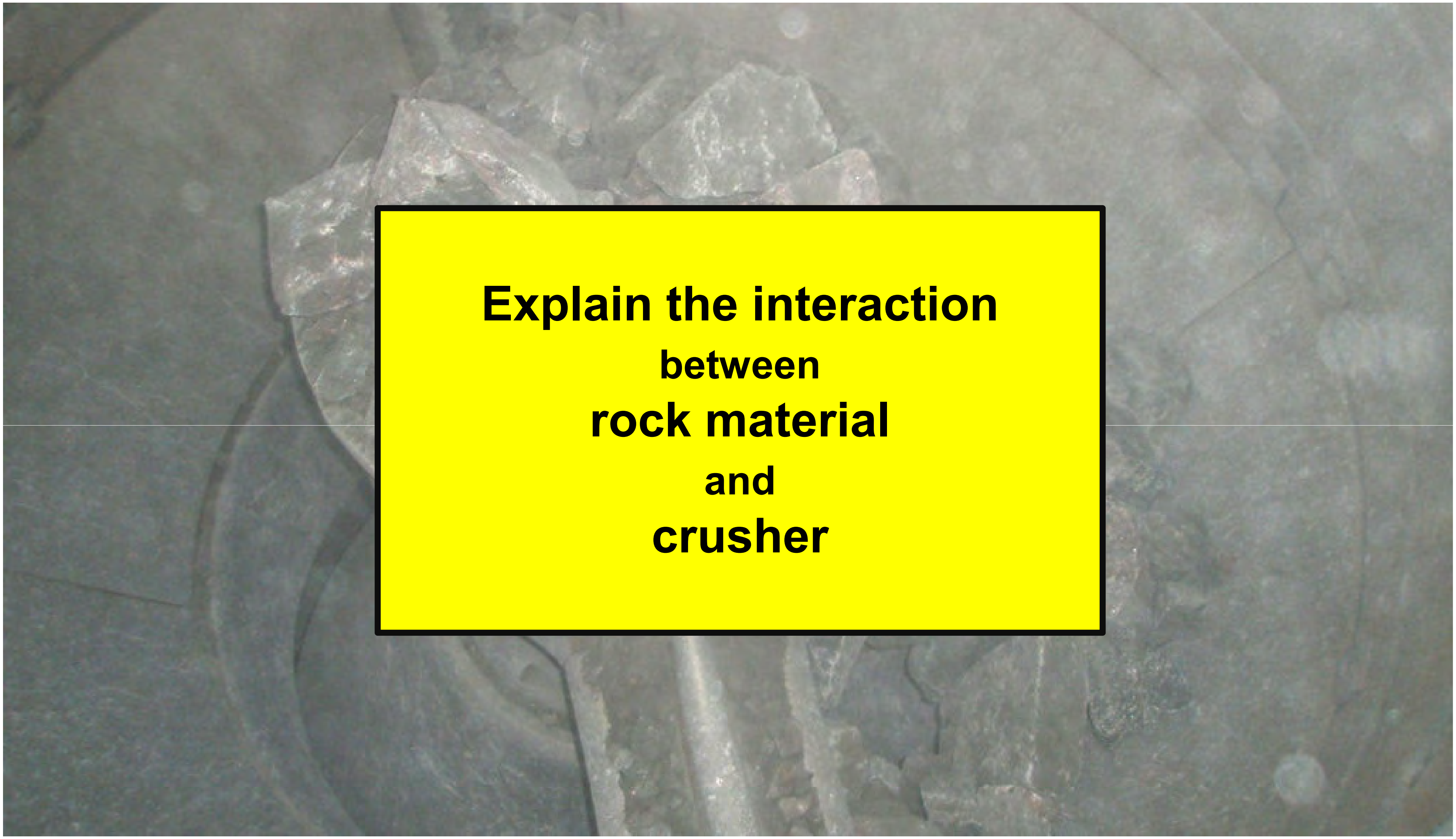
Objective



Explain the interaction

between

rock material

and

crusher

Agenda

- Background
- Crusher modeling
- Breakage and size reduction
- Simulations
- Verification (does it work?)
- Optimization
- Conclusions (theoretical and practical)

Take home messages

Take home messages will address:

- Information needed for problem solving
- How can product yield be improved?
- How can production costs be effected?
- How can particle shape be affected?
- How can machine parameters such as speed be utilized?

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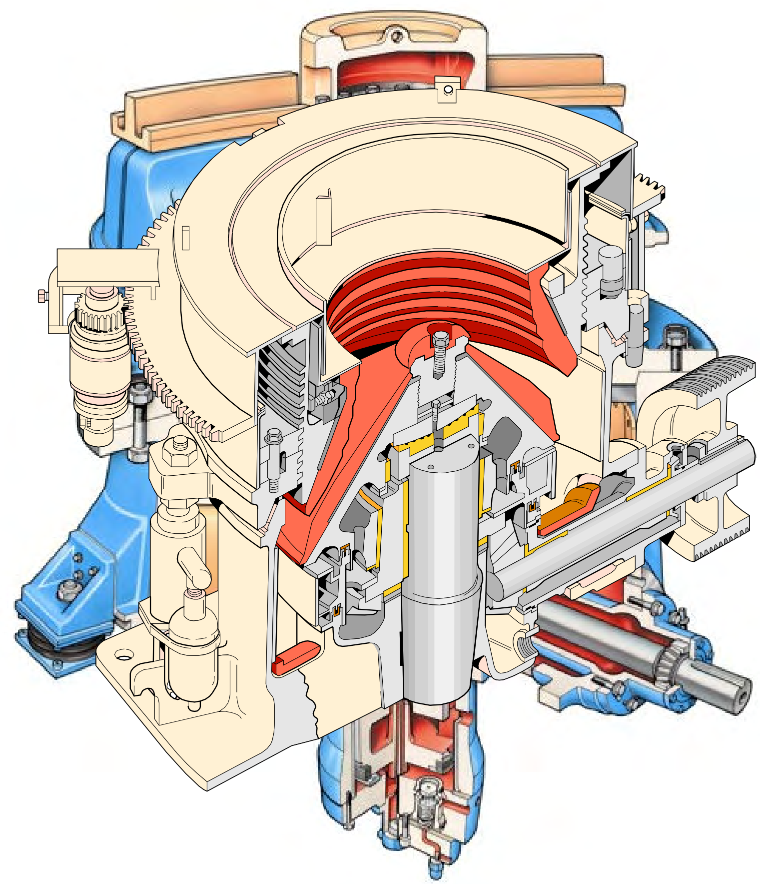
Cone Crushers

Why cone crushers?

The ***cone crusher*** design concept is an effective and smart way of realizing compressive crushing



- **Mechanical mineral liberation**
  - mining
- **Aggregate production**
  - quarries

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Objectives of Modeling

Fundamentals

- Particle size distribution
- Crushing pressure
- Crushing forces
- Power draw

Bond's formula only determines p_{80}

Design and operation considerations

- Utilization of compressive size reduction in chamber
- Energy efficient crushing
- Robust performance over total liner lifetime
- Maximizing product yield

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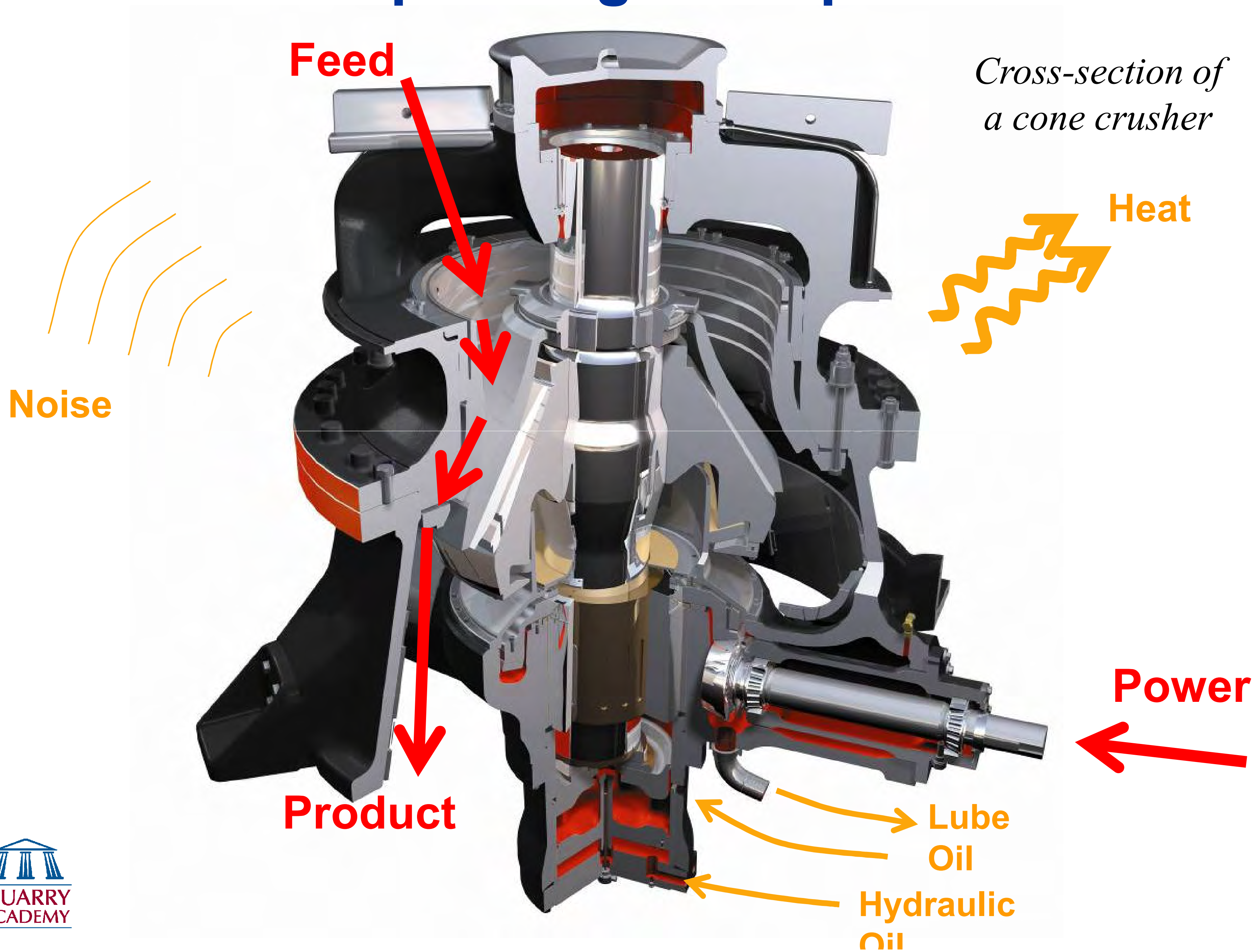
Operating Principle



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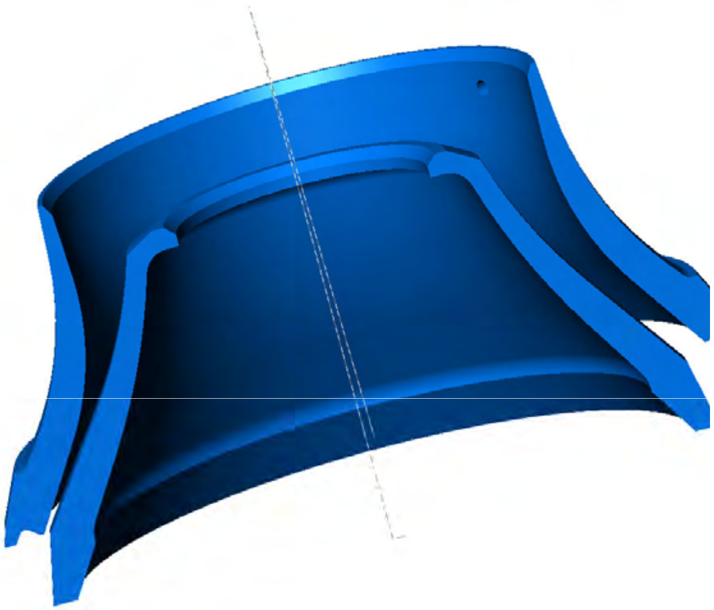
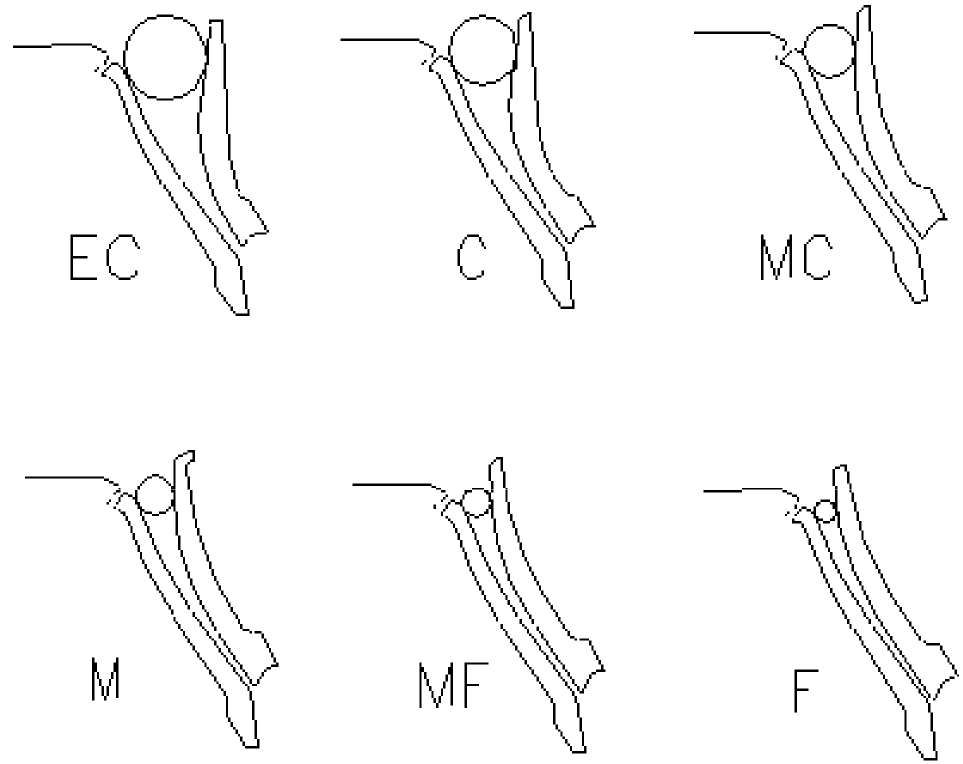
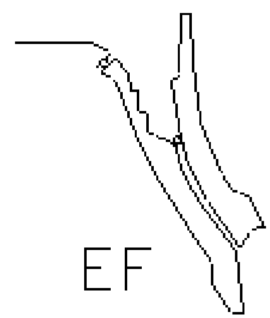
Operating Principle





All crushing starts with the chamber!



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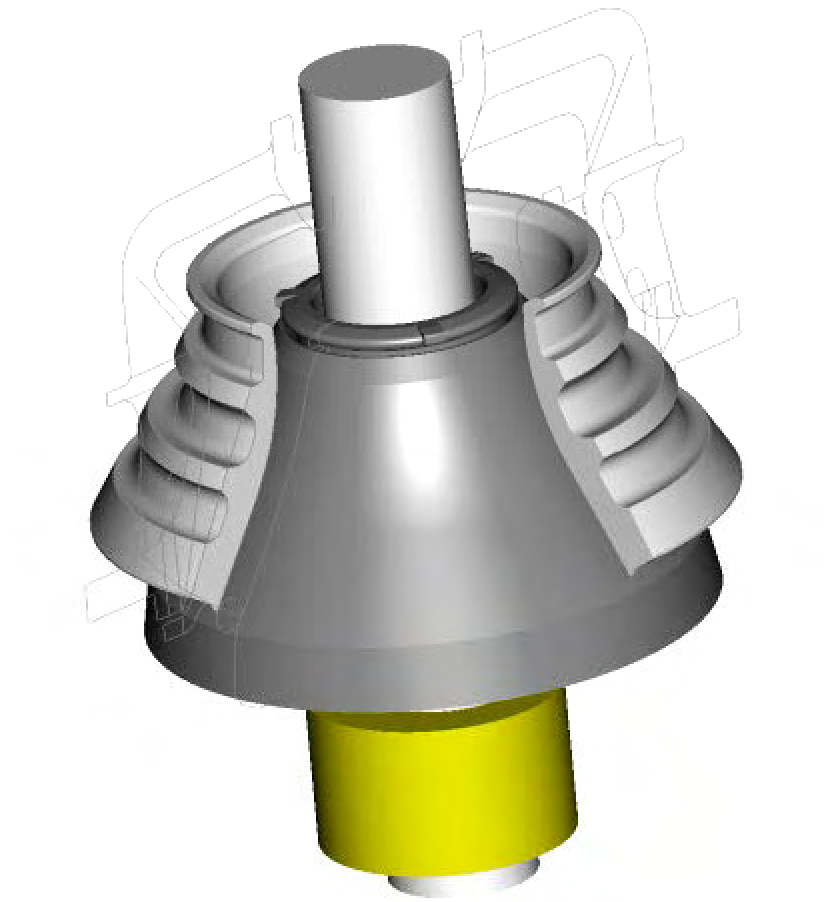
Operating Principle



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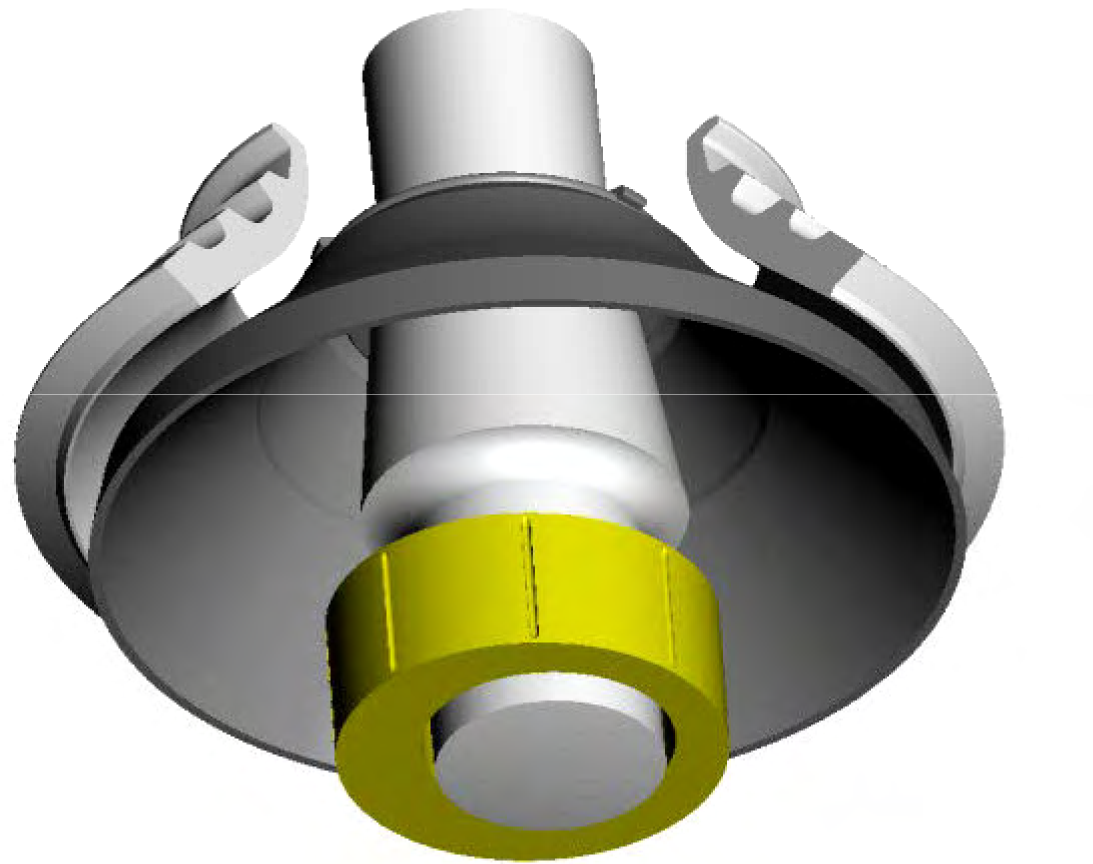
Operating Principle



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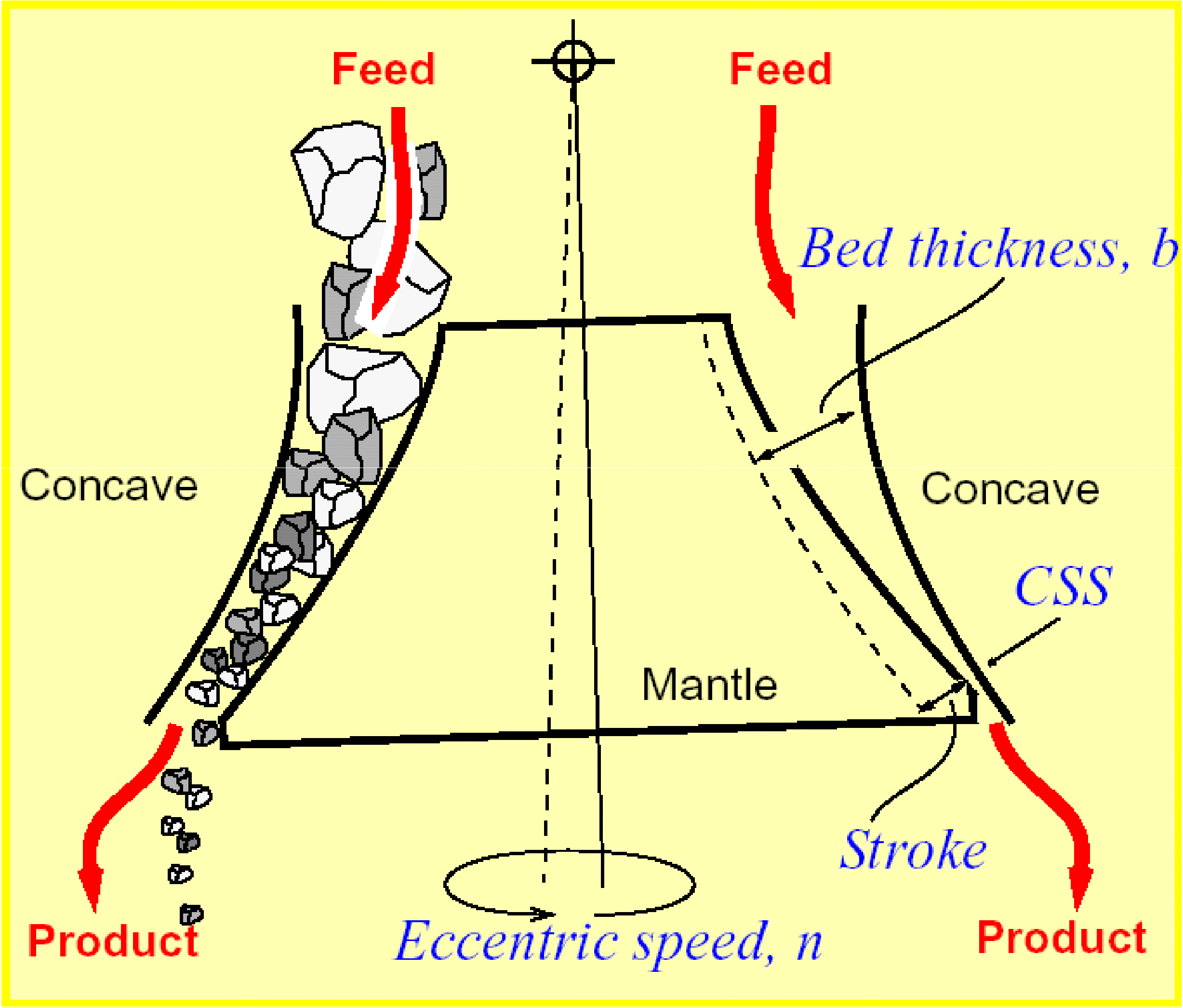
Operating Principle



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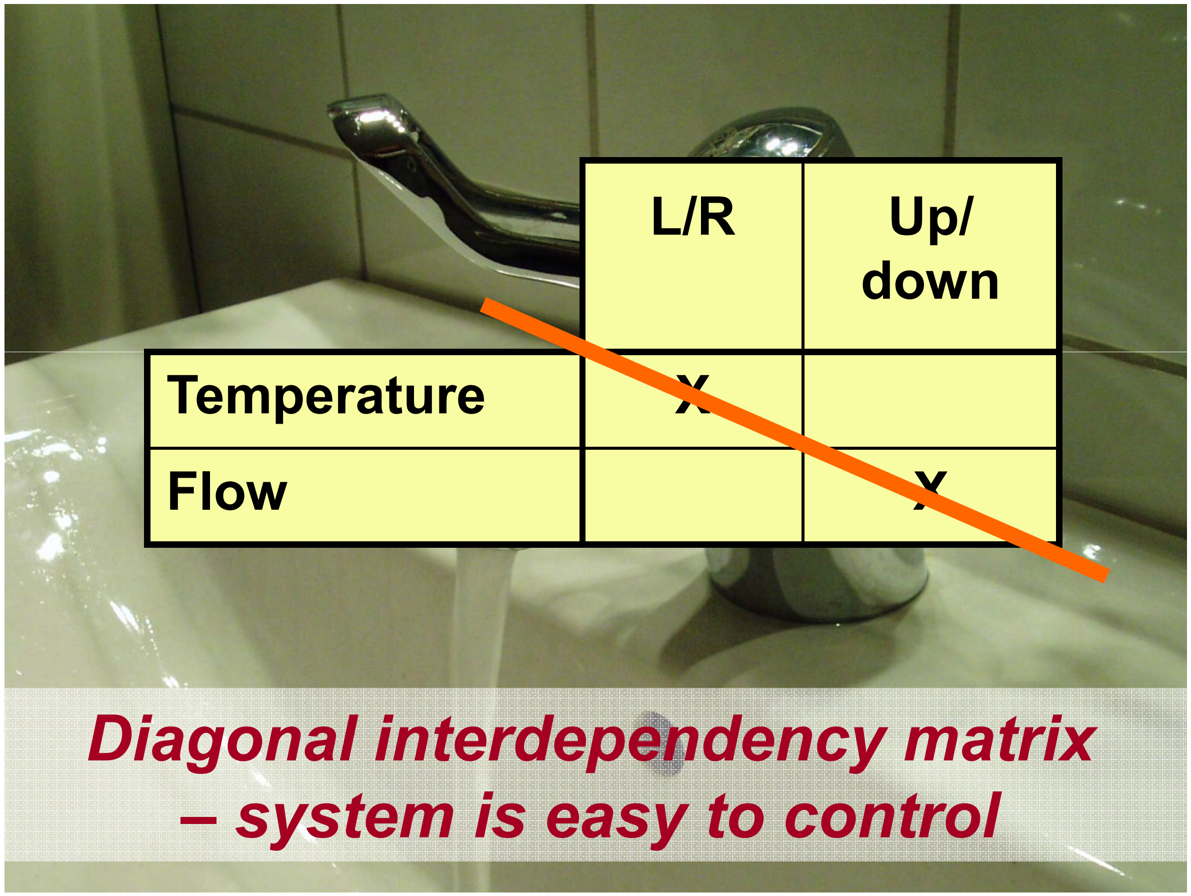
Operating Principle

Dependencies for a water tap...



	L/R	Up/ down
Temperature	X	
Flow		X

Diagonal interdependency matrix – system is easy to control

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Operating Principle

Dependencies for a cone crusher...

Input

X=Dependency

Output

	Eccentric speed	CSS	Stroke	Crushing chamber	Rock strength	Wear resistance	Feed particle size	Feed particle shape	Feed strength
Capacity	X	X	X	X			X		
Power	X	X	X	X	X	X	X	X	X
Hydraulic pressure	X	X	X	X	X	X	X	X	X
Product particle size	X	X	X	X	X	X	X	X	X
Product particle shape	X	X	X	X			X	X	X
Product strength	X	X	X	X	X	X			X

Many X = complex function

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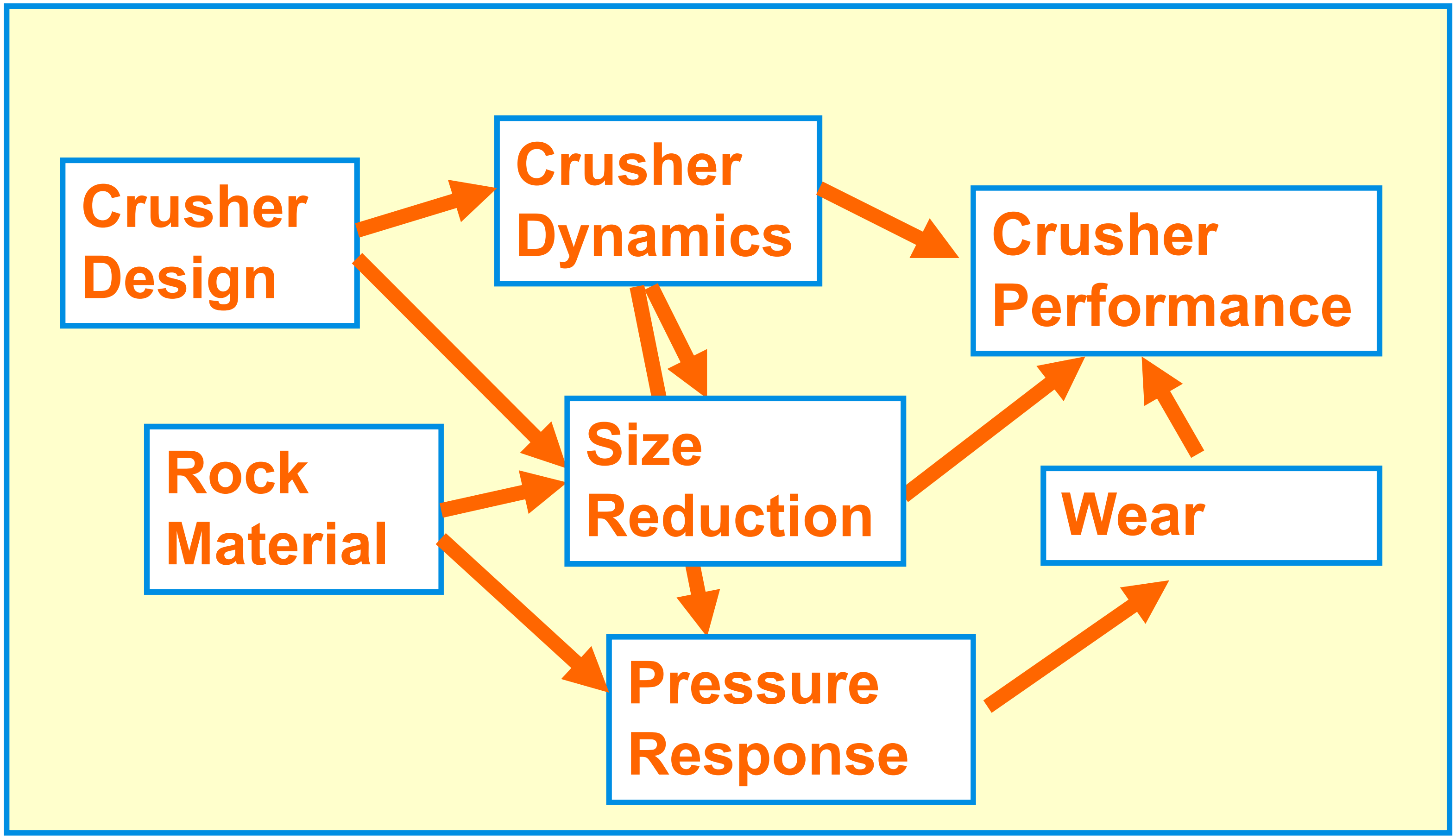
Crusher Model



Crusher Model

The compressive crushing process can be described with two functions.

Selection S **– which?**

Breakage B **– how?**

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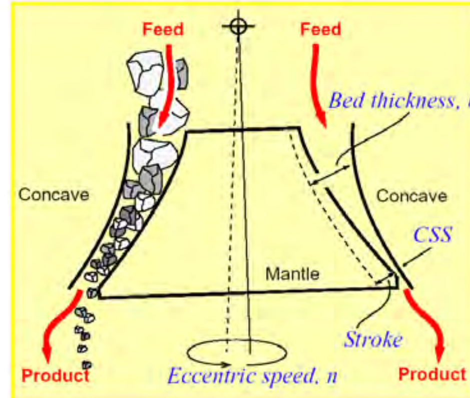
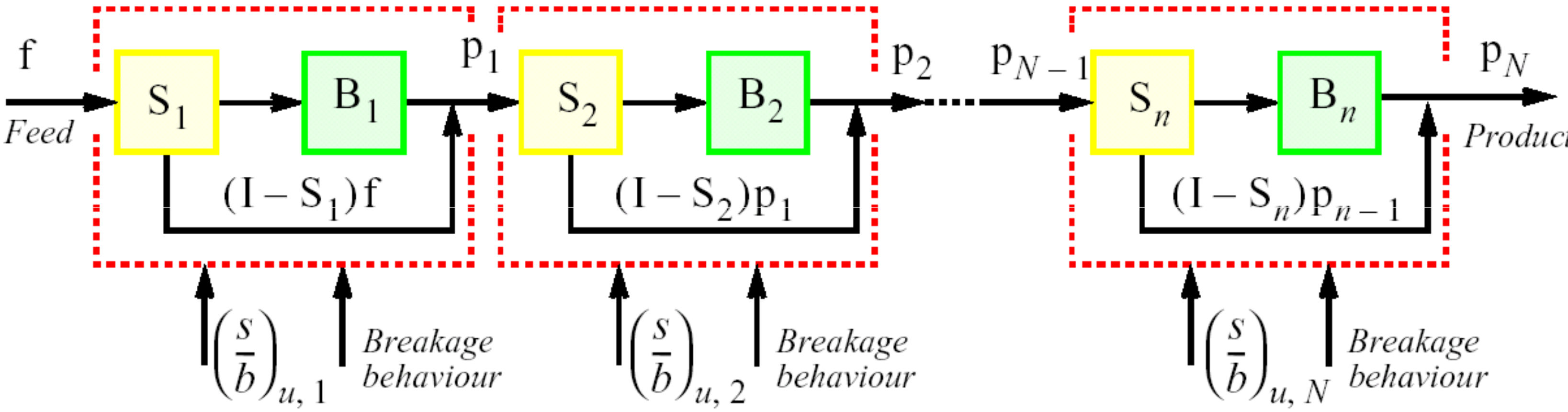
Crusher Model



Repeated size reduction steps



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

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

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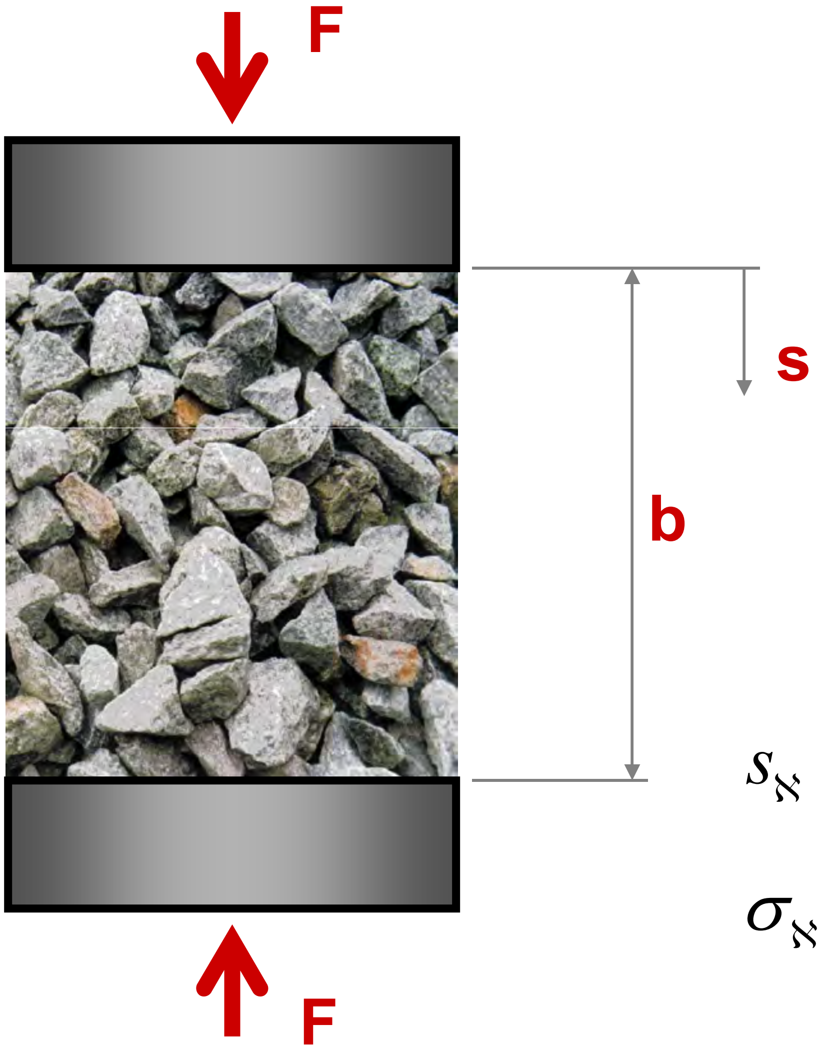
Rock Breakage Behavior



Form conditioned compression

-displacement controlled

$$F = F\left(s_{\aleph}, \sigma_{\aleph}\right)$$

$$s_{\aleph} = \frac{s}{b}$$

$$\sigma_{\aleph} = size\ distribution\ width$$

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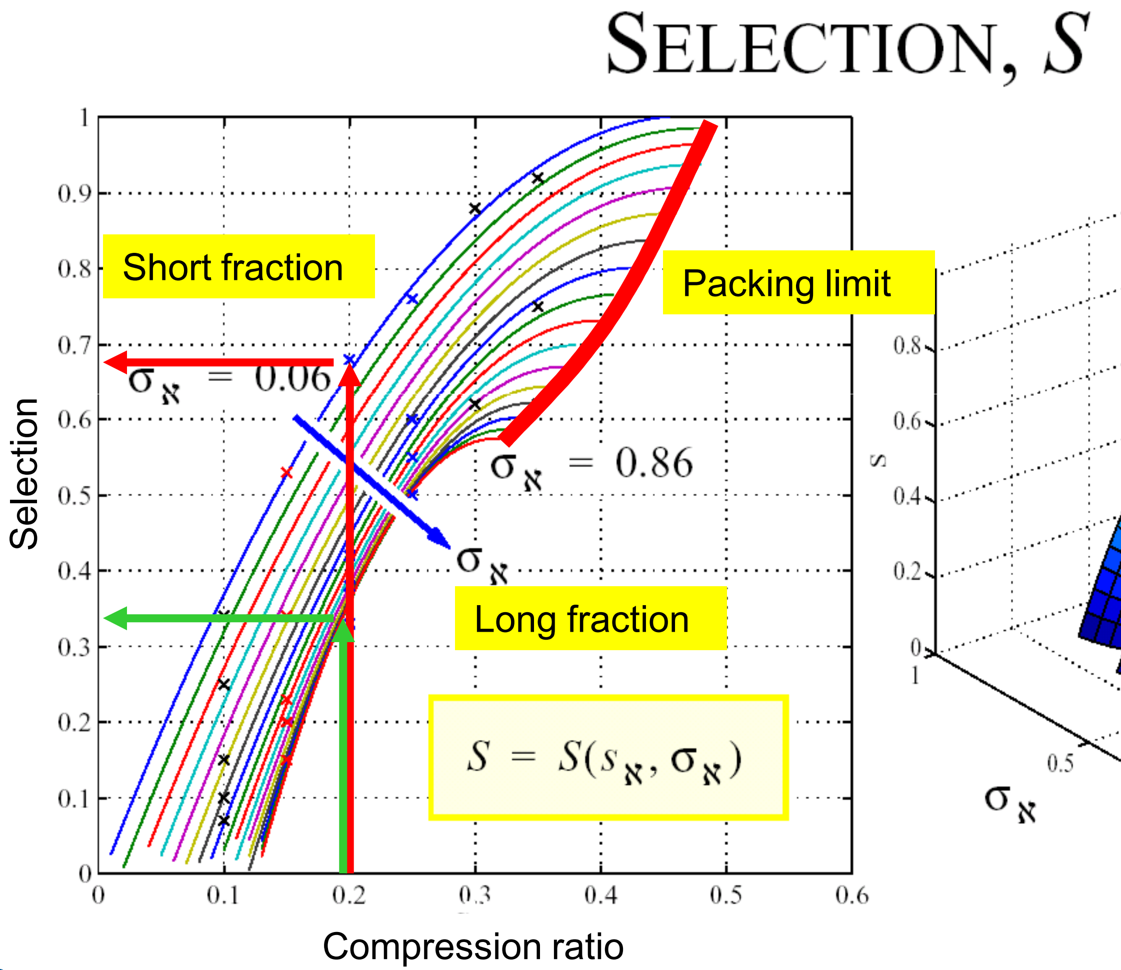
Rock Breakage Behavior



Take home message:

It is easier to crush short fractions than long fractions.

Packing limit is reach earlier with long fractions.

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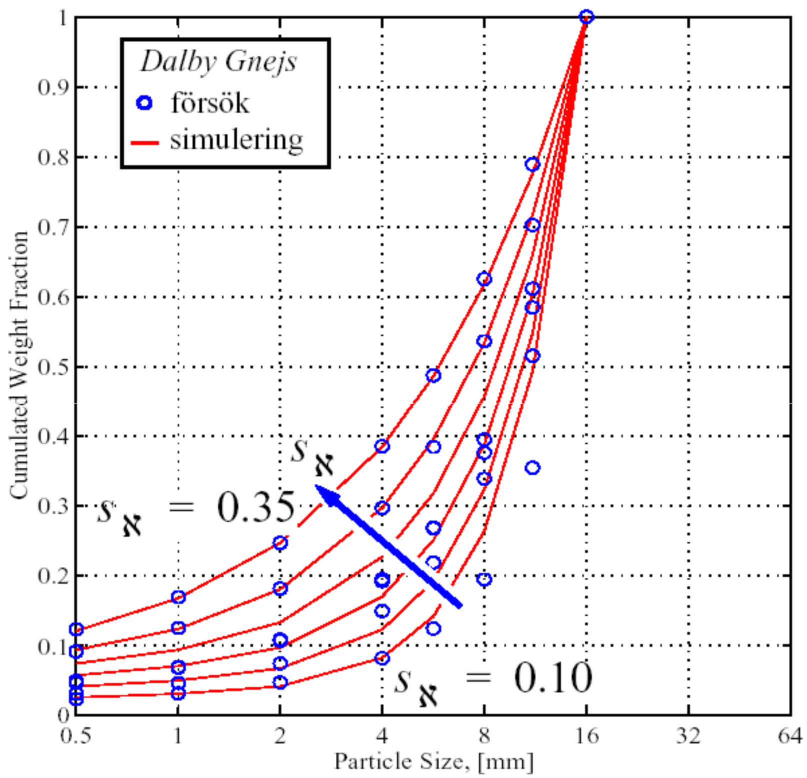
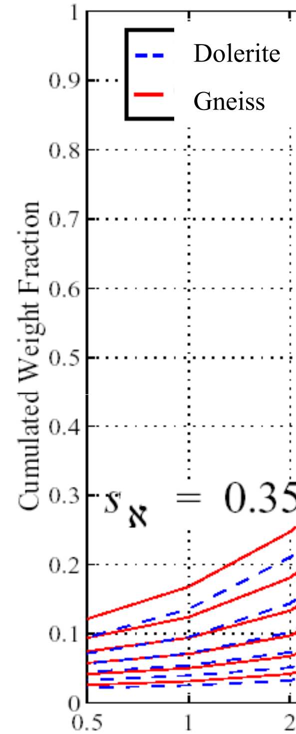
Rock Breakage Behavior

BREAKAGE, B





Take home message:

***Interparticle crushing* with high compression ratios crushing produces fines.**

$$B(x_{\aleph}, s_{\aleph}) = (1-(\alpha_3+\alpha_4 s_{\aleph}))x_{\aleph}^{\alpha_1+\alpha_2 s_{\aleph}} + (\alpha_3+\alpha_4 s_{\aleph})x_{\aleph}$$

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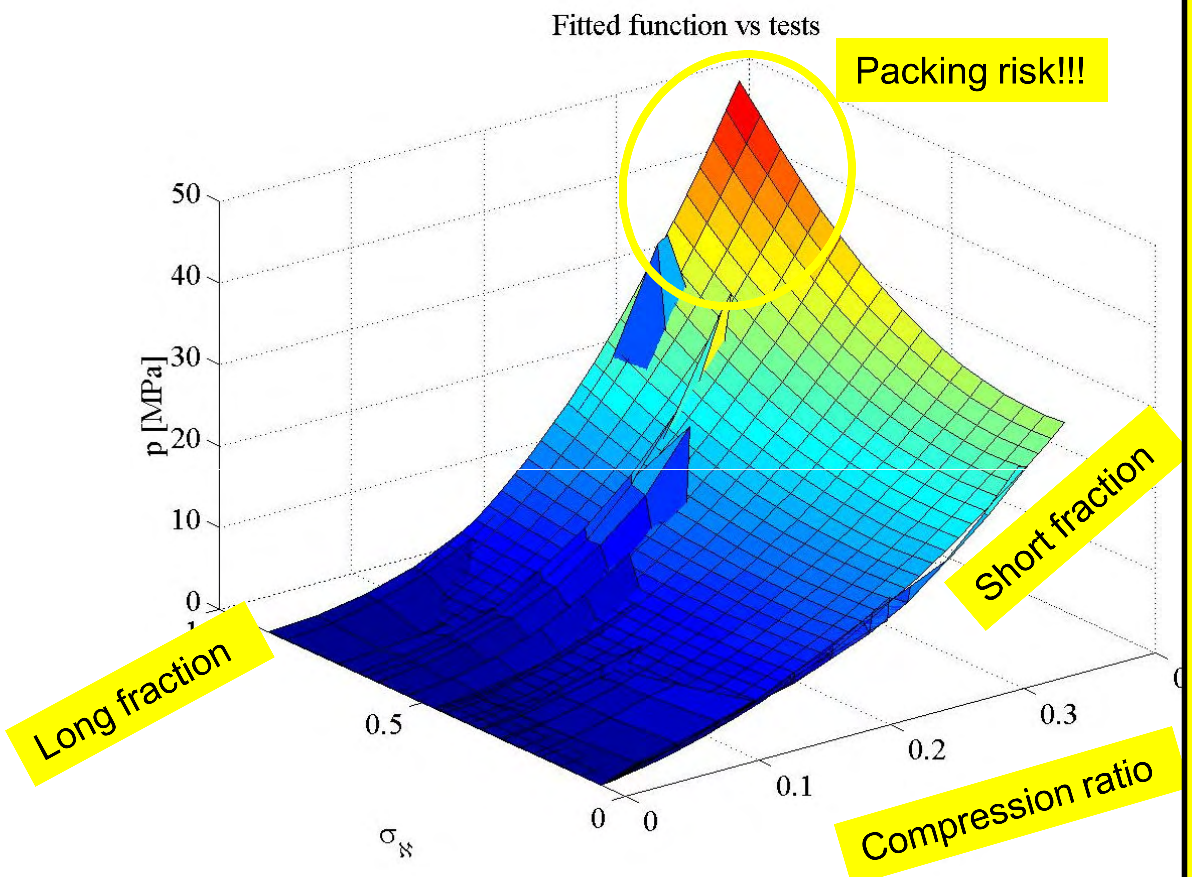
Rock Breakage Behavior



$$p\left(s_{\aleph},\sigma_{\aleph}\right)=a_1 s_{\aleph}^2\sigma_{\aleph}^2+a_2 s_{\aleph}^2\sigma_{\aleph}+a_3 s_{\aleph}^2+a_4 s_{\aleph}\sigma_{\aleph}^2$$

$\sigma_{\aleph} = size\ distribution\ width$

Take home message:

Interparticle breakage

Longer fractions results in higher crushing pressure and better particle shape.

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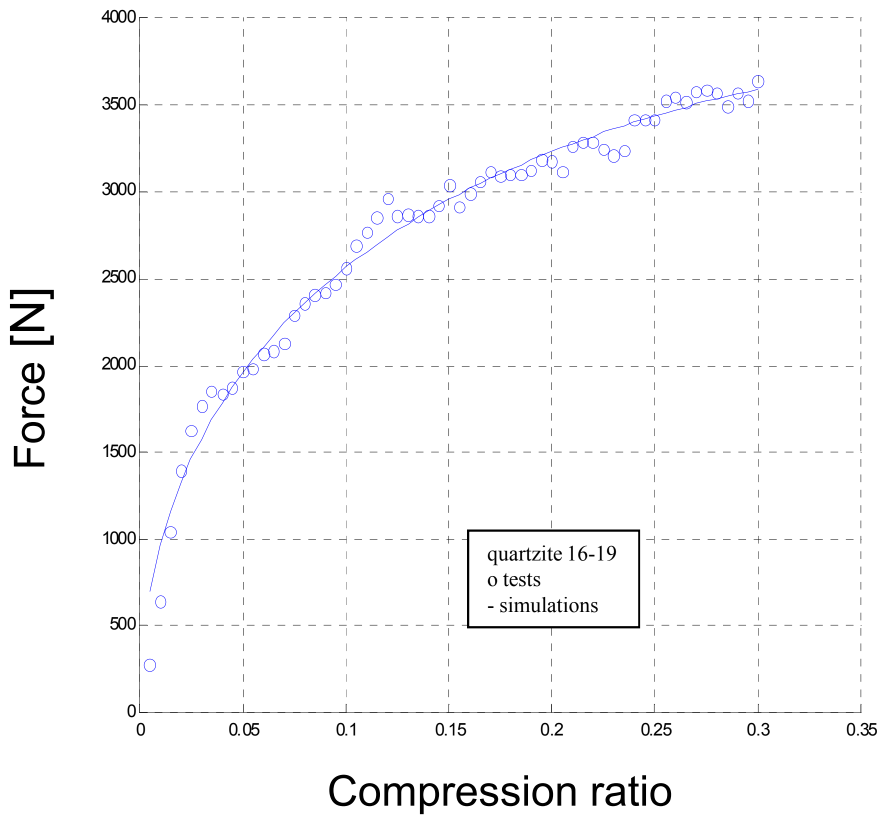
Rock Breakage Behavior

Single particle
-force response



Take home message:

Single particle breakage requires lower crushing force compared to interparticle.

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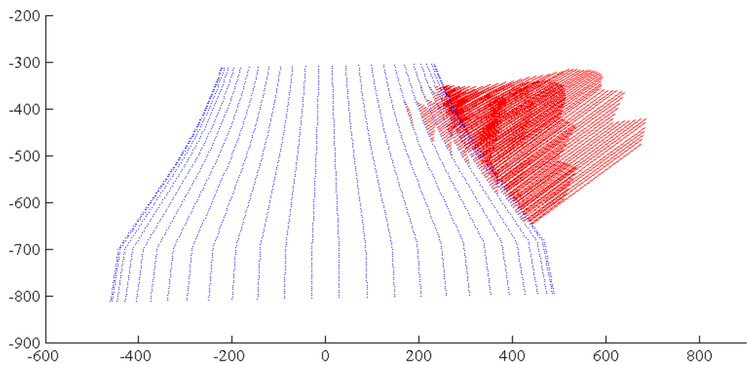
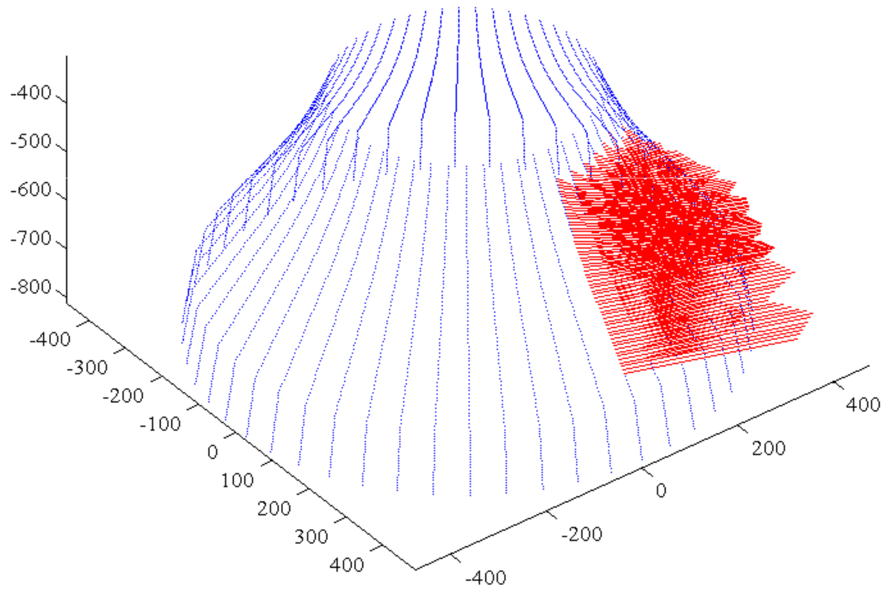
Crushing Pressure and Power Draw





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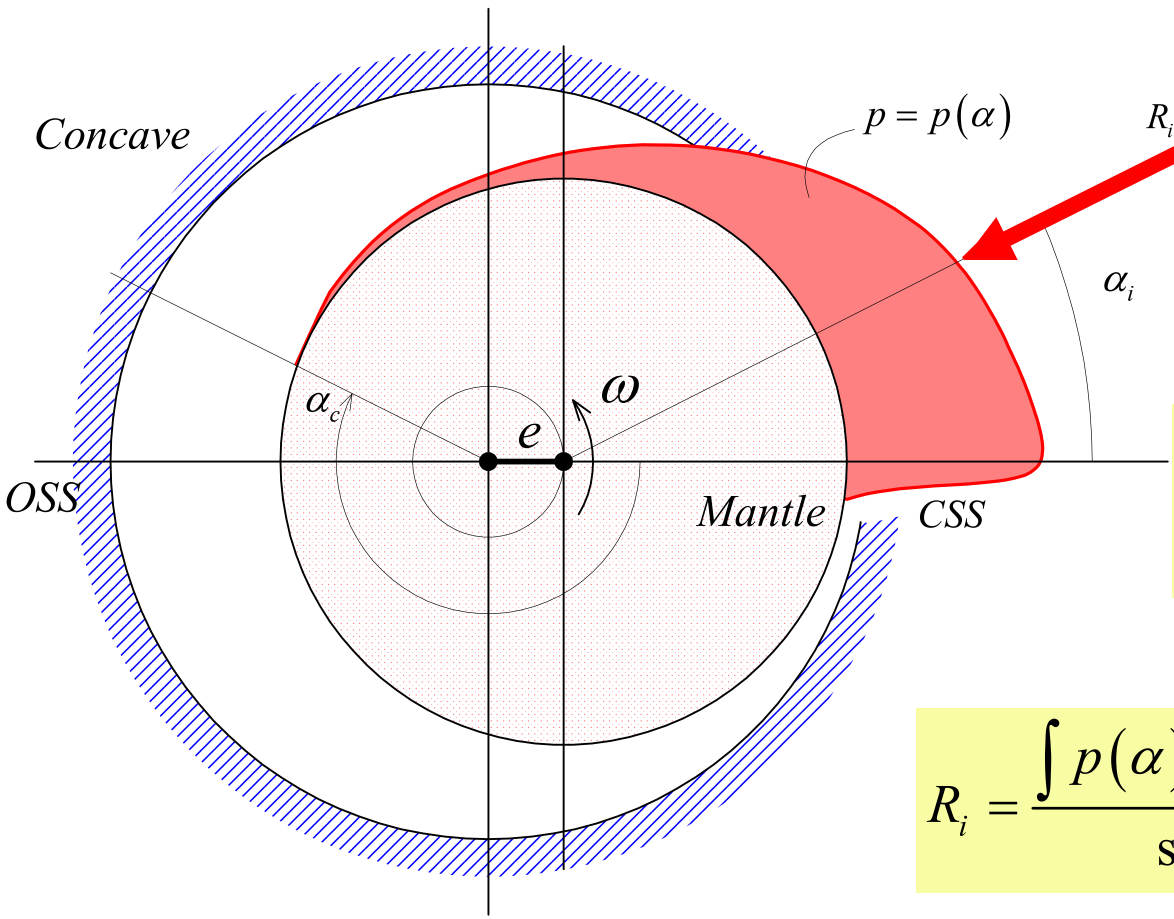
Crushing Pressure and Power Draw



$$\tan\alpha_i = \frac{\int p(\alpha)\sin\alpha\, d\alpha}{\int p(\alpha)\cos\alpha\, d\alpha}$$

$$R_i = \frac{\int p(\alpha)\, r\sin\alpha\, d\alpha}{\sin\alpha_i}$$

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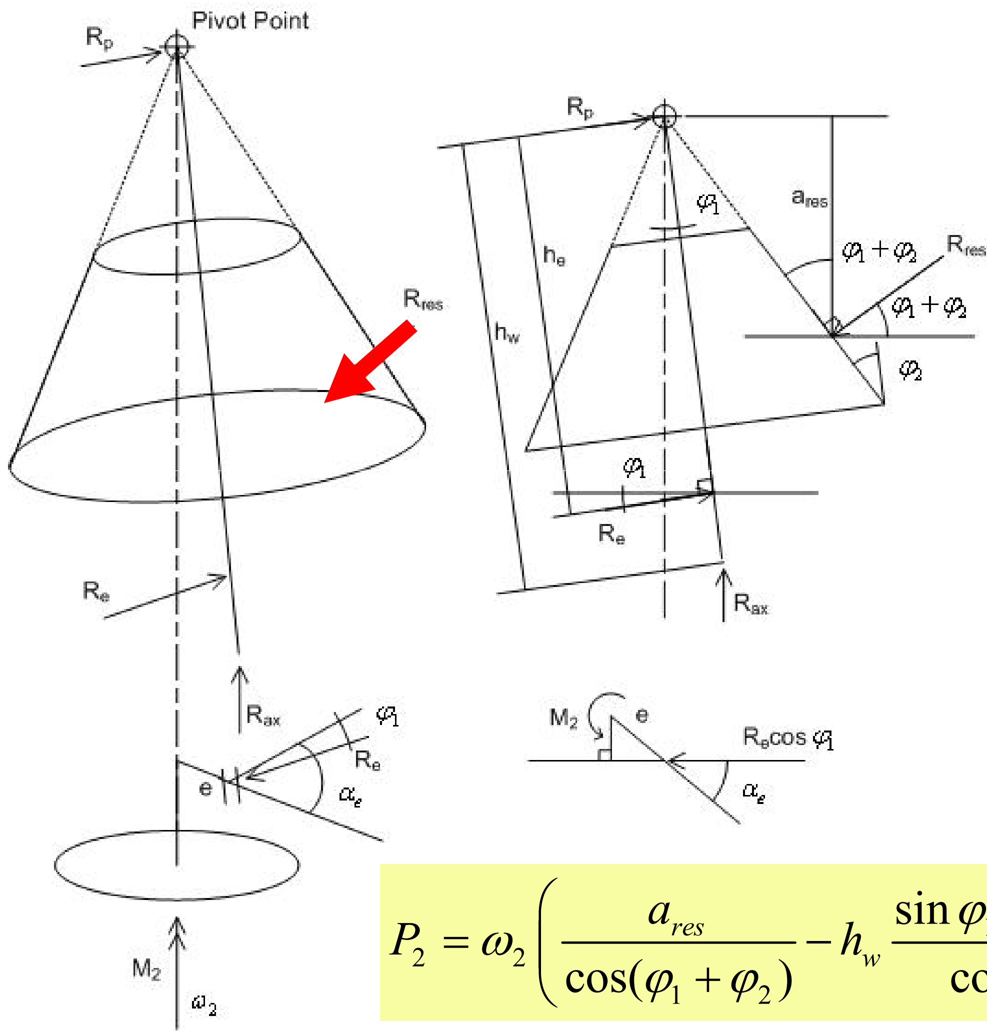
Crushing Pressure and Power Draw



$$P_2 = \omega_2 \left(\frac{a_{res}}{\cos(\varphi_1 + \varphi_2)} - h_w \frac{\sin\varphi_1 \sin\varphi_2}{\cos\varphi_1} \right) R_{res} \cos\varphi_1 \frac{e}{h_e} \sin\alpha_e$$

Take home message:

If the crushing angle is small you can experience packing even at low power draw.

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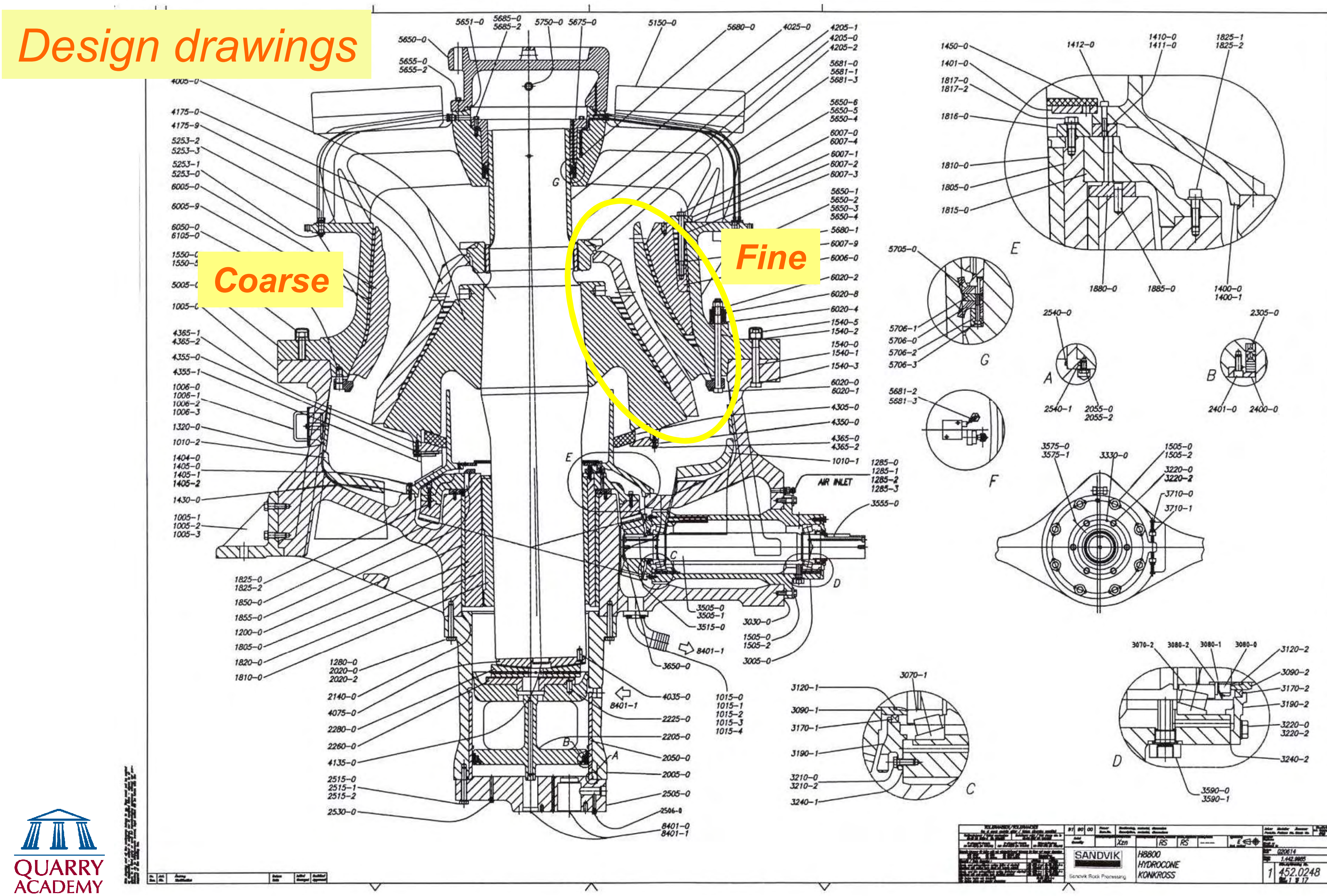
Geometry



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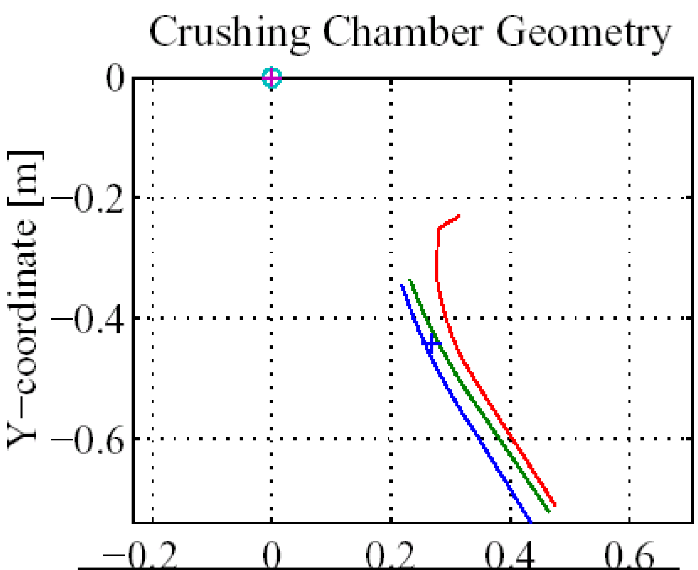
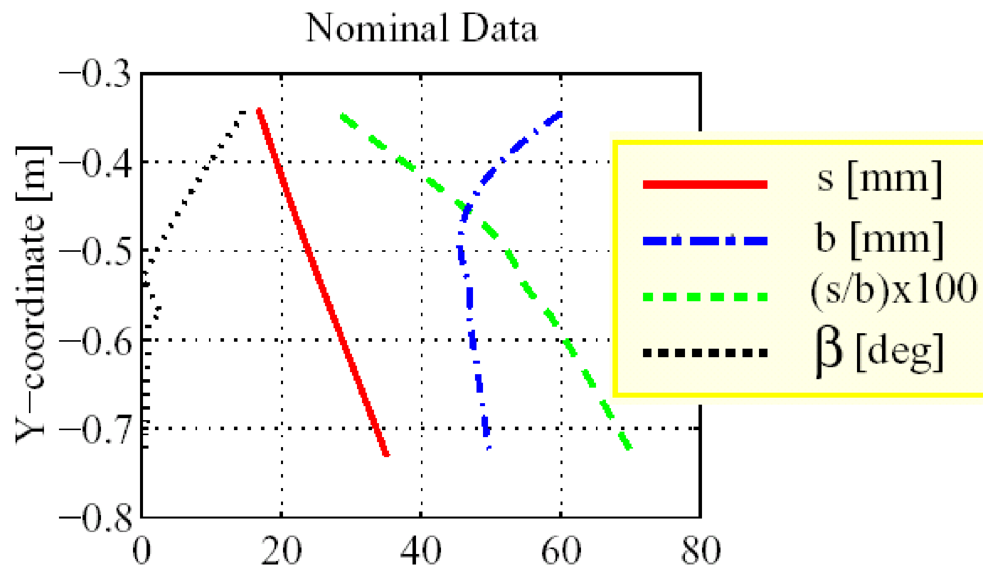
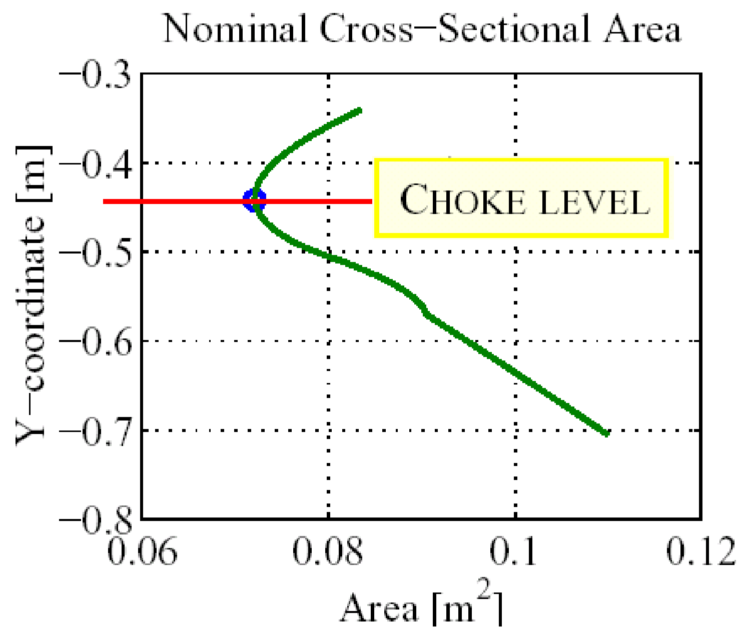
Geometry





Take home message:

Capacity is controlled by choke area.



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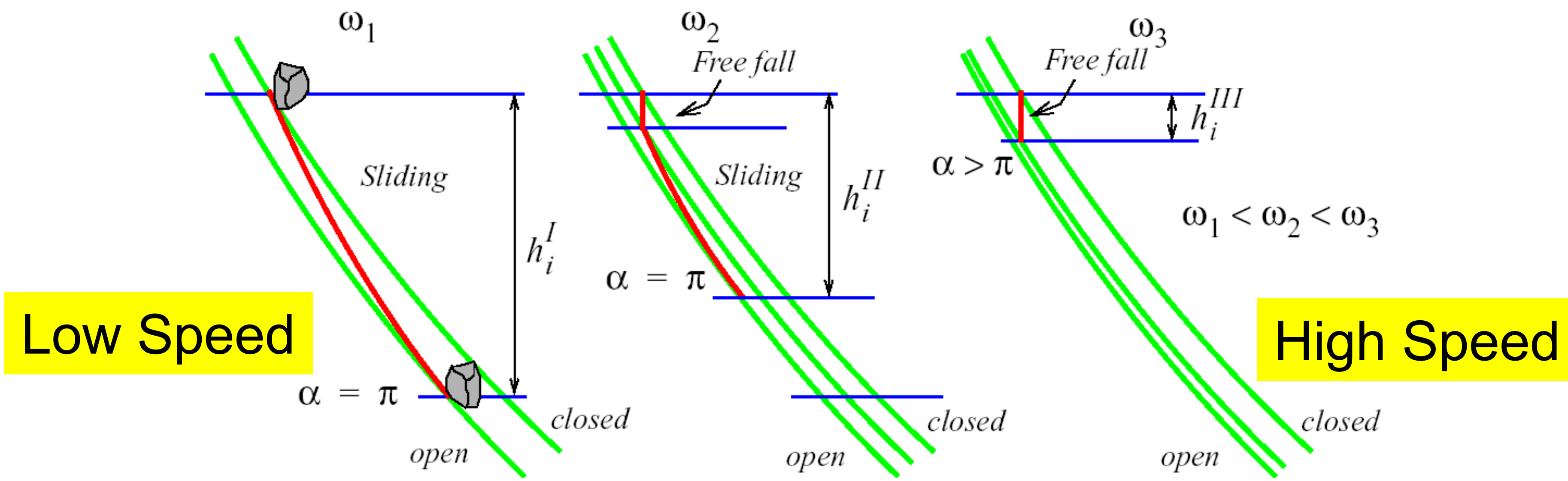
Flow model

Material flow mechanics

- Sliding
- Free fall
- Squeezing



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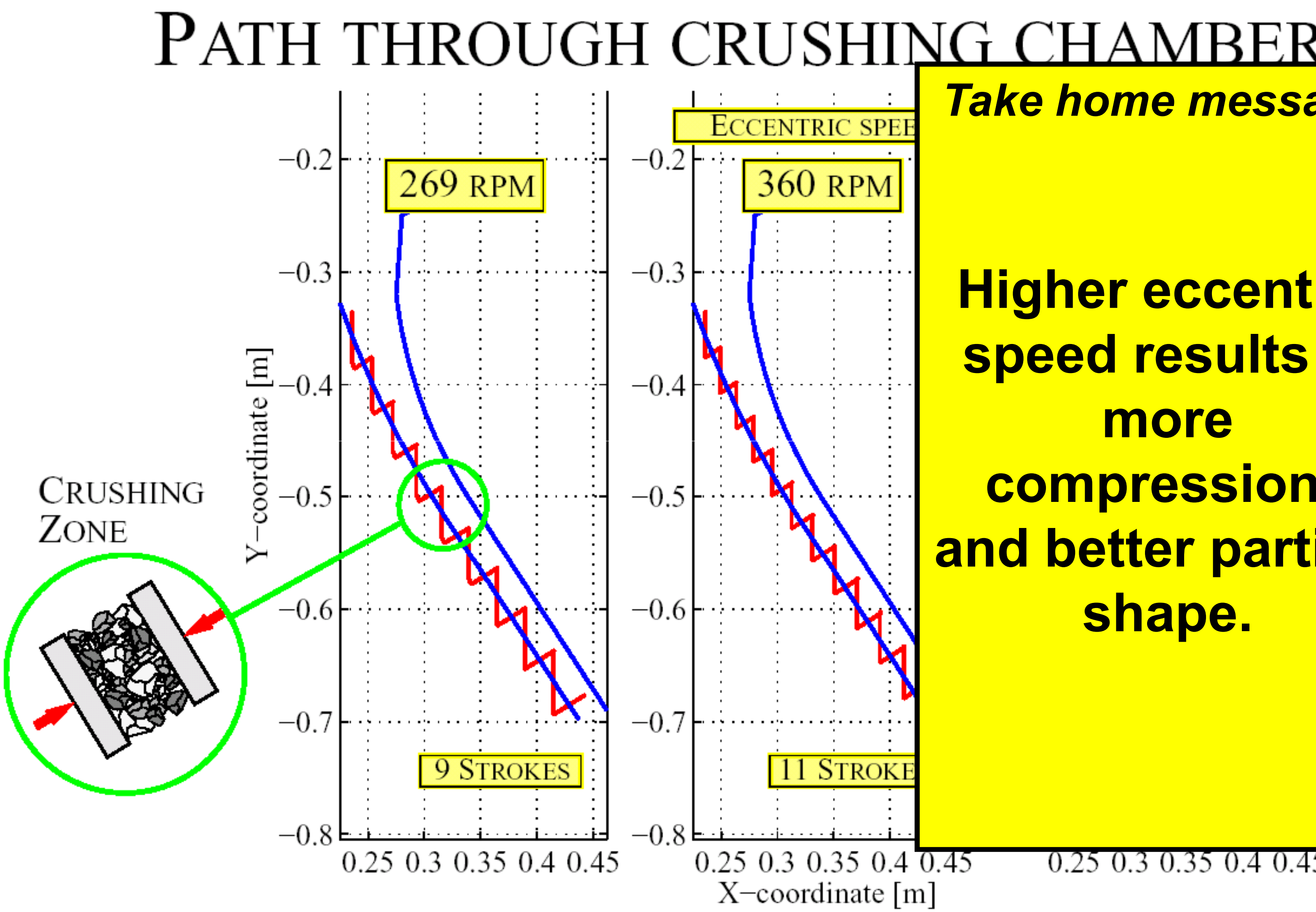
Flow model



Take home message:

Higher eccentric speed results in more compressions and better particle shape.

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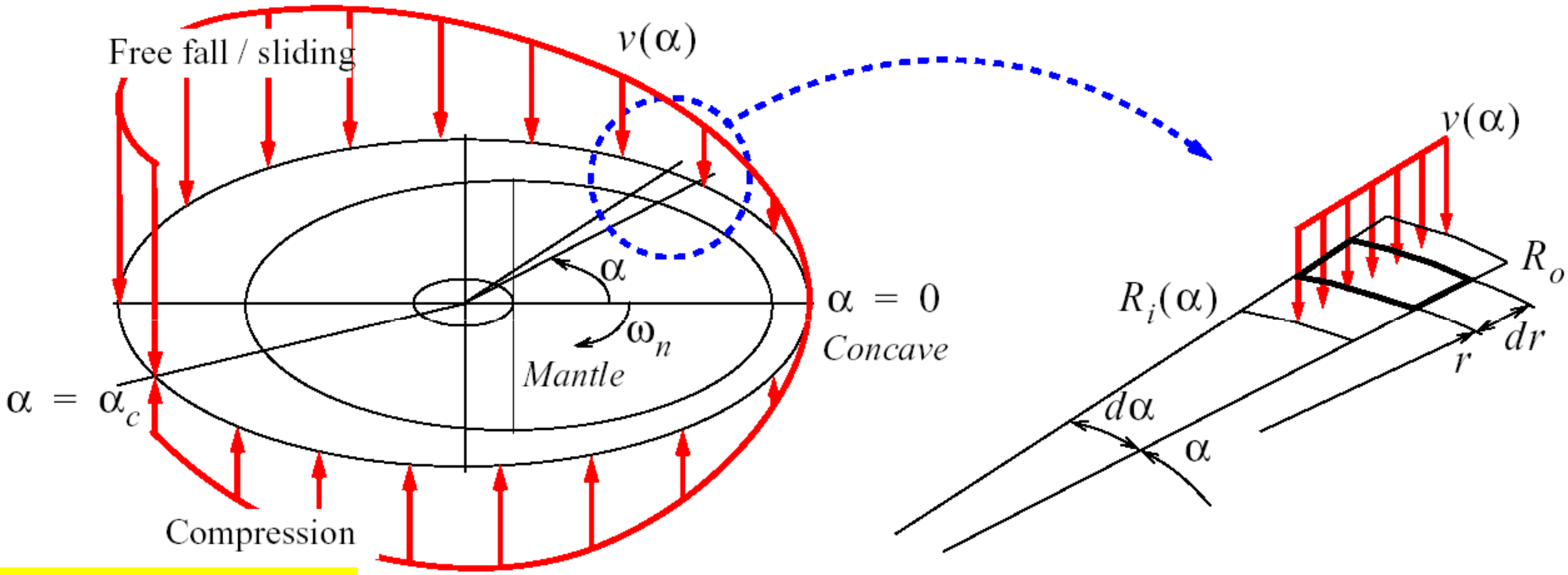
Flow model

Capacity is calculated at choke level



Upward flow !!!

Lost capacity

$$= \int_{0}^{\alpha_c} \int_{R_i(\alpha)}^{R_o} \rho(\alpha) v(\alpha) r\,dr\,d\alpha = \frac{1}{2} \int_{0}^{\alpha_c} \rho(\alpha)(R_o^2 - R_i^2(\alpha)) v(\alpha)\,d\alpha$$

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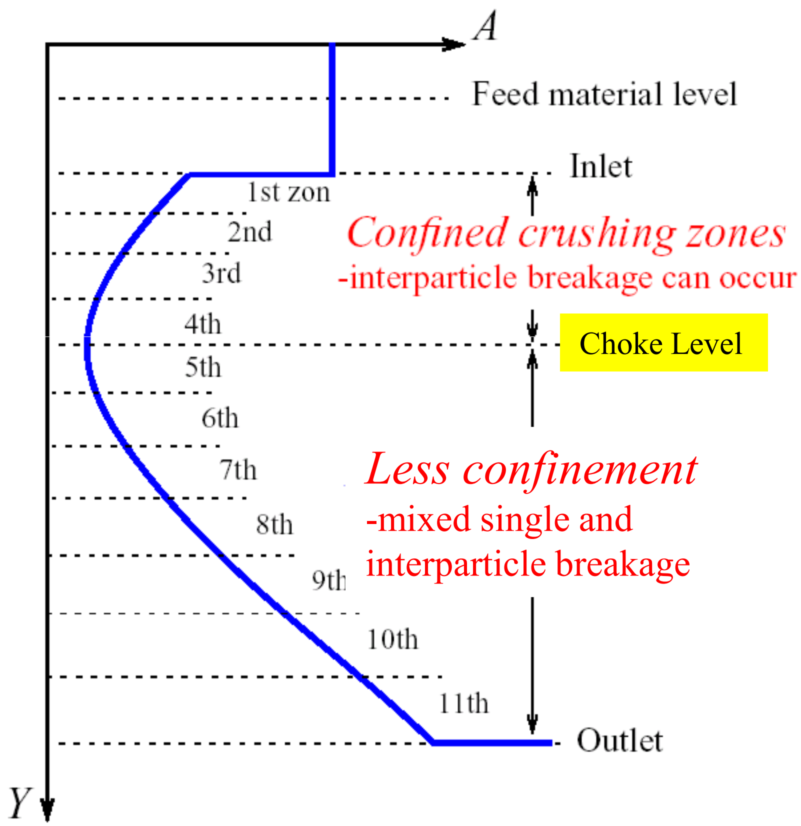
Breakage Modes



Take home message:

Chamber design affects breakage modes.

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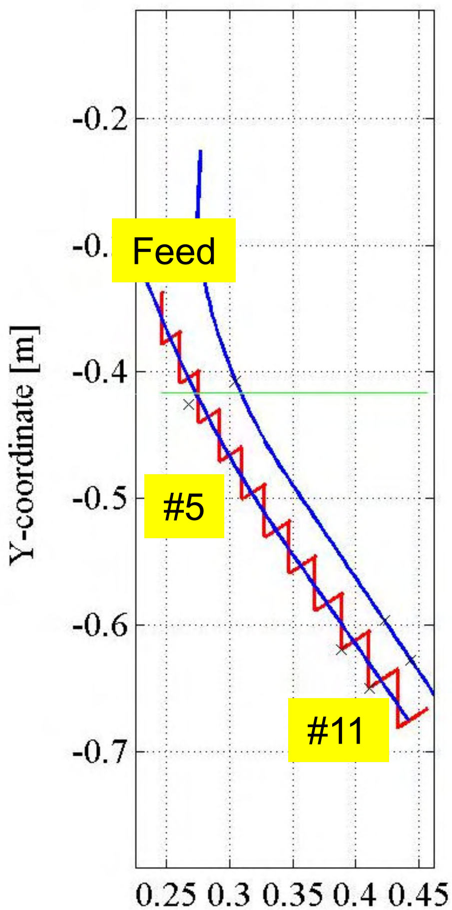
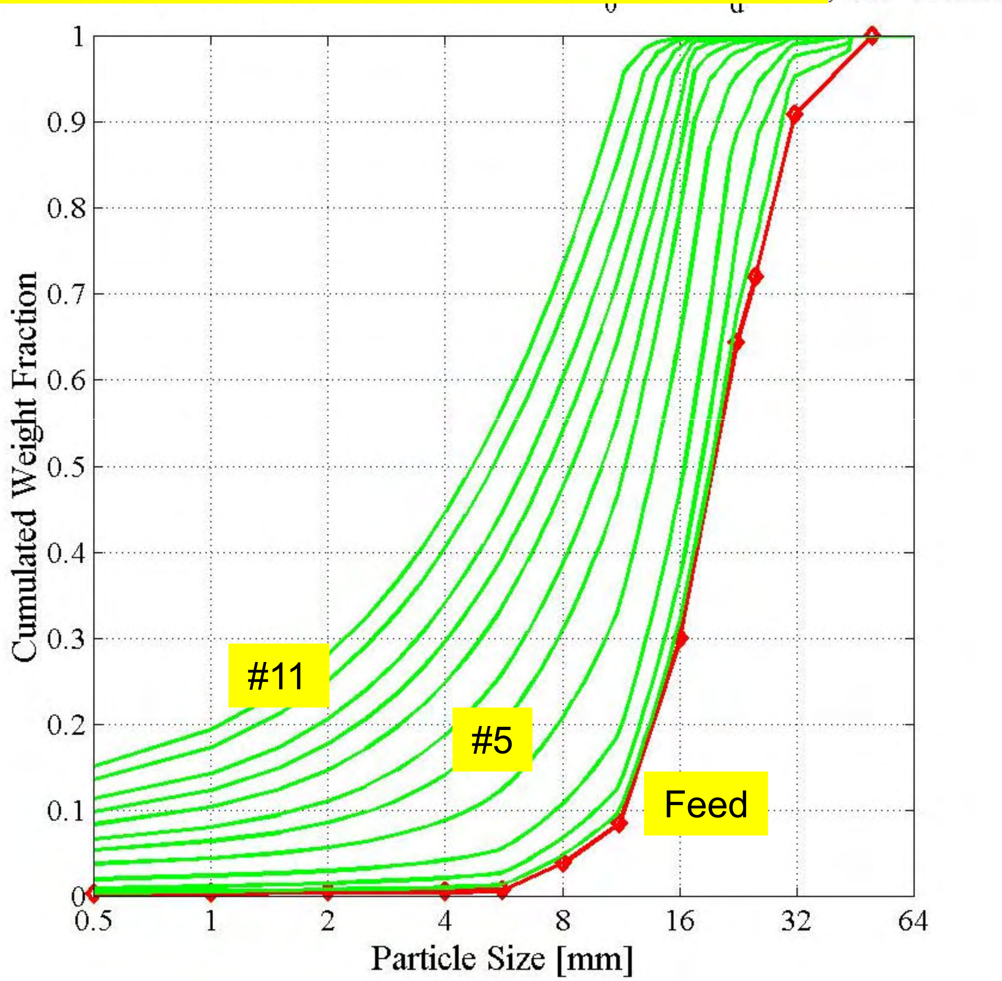
Results - *Particle size distributions*

Results from different CSS settings 8-16mm





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Results - *Particle size distributions*

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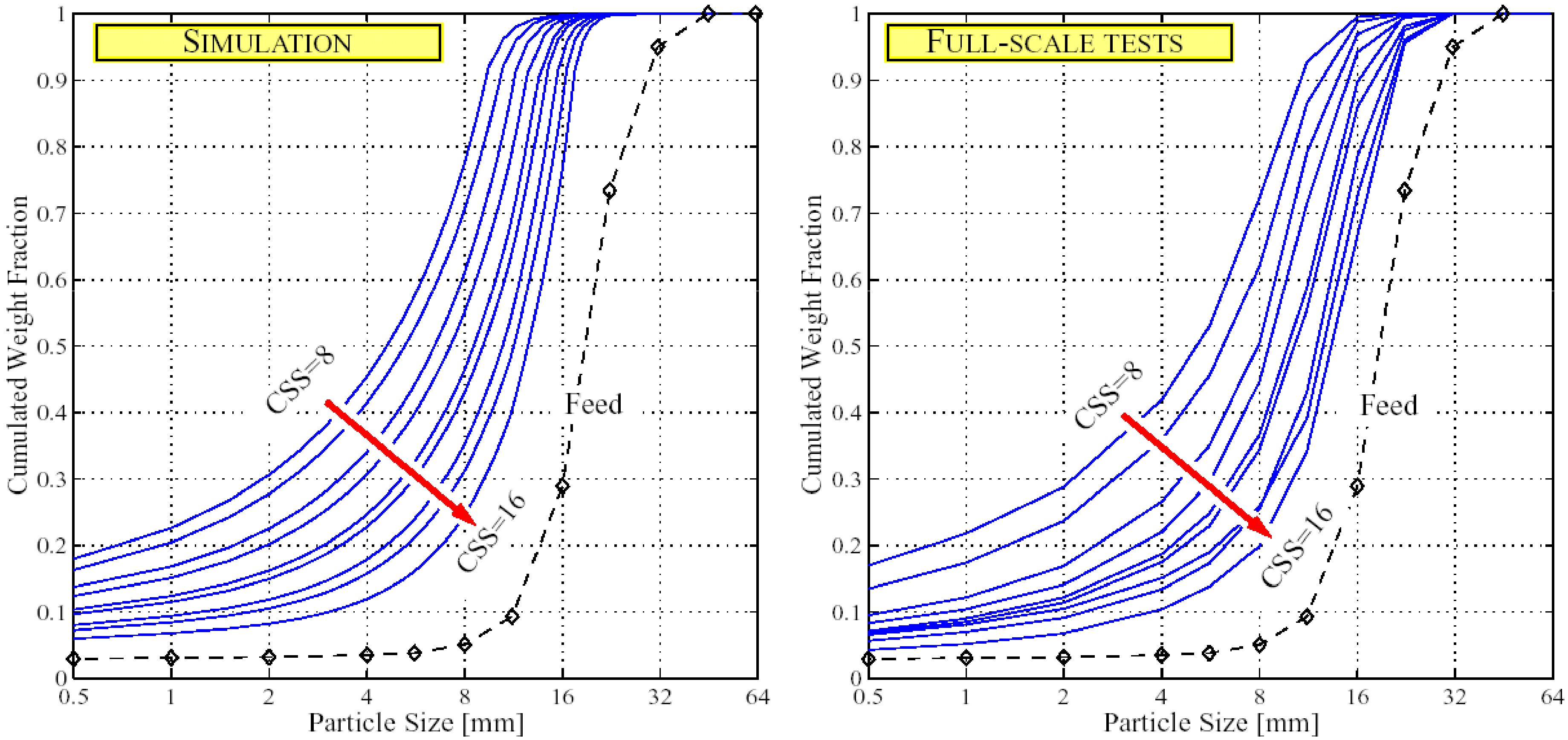
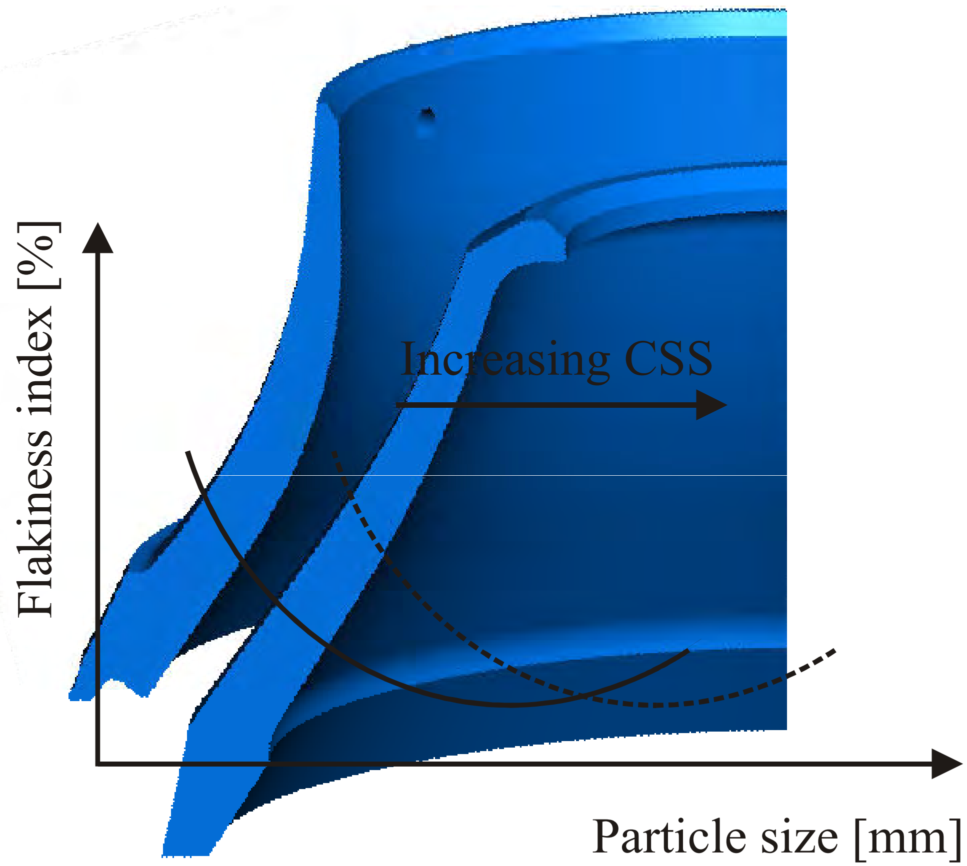


QUARRY ACADEMY

Crusher Operation
Compressive Crushing

- **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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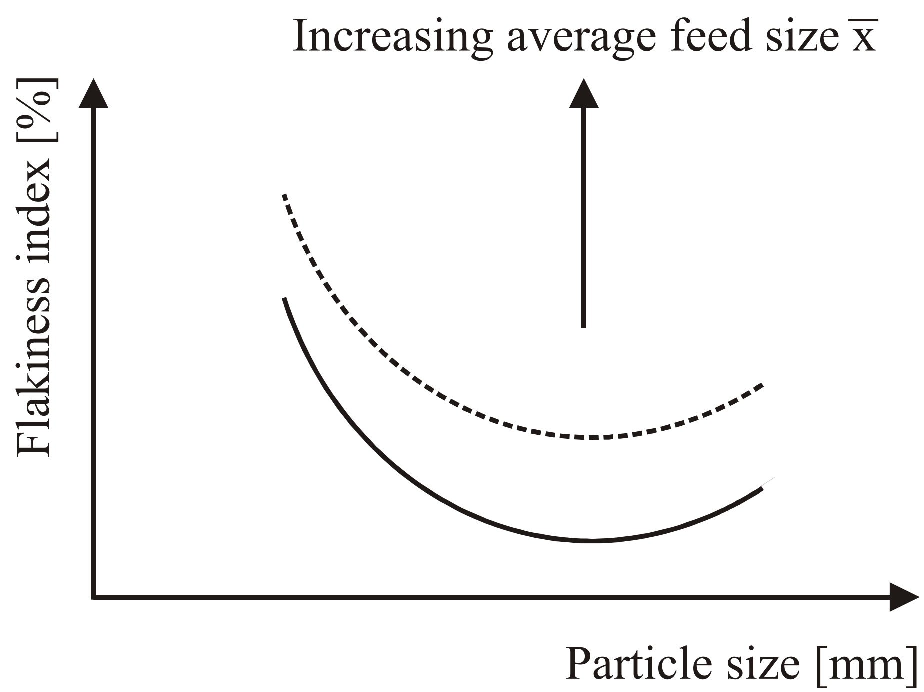
Crusher Operation
Compressive Crushing

- **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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Does it work?

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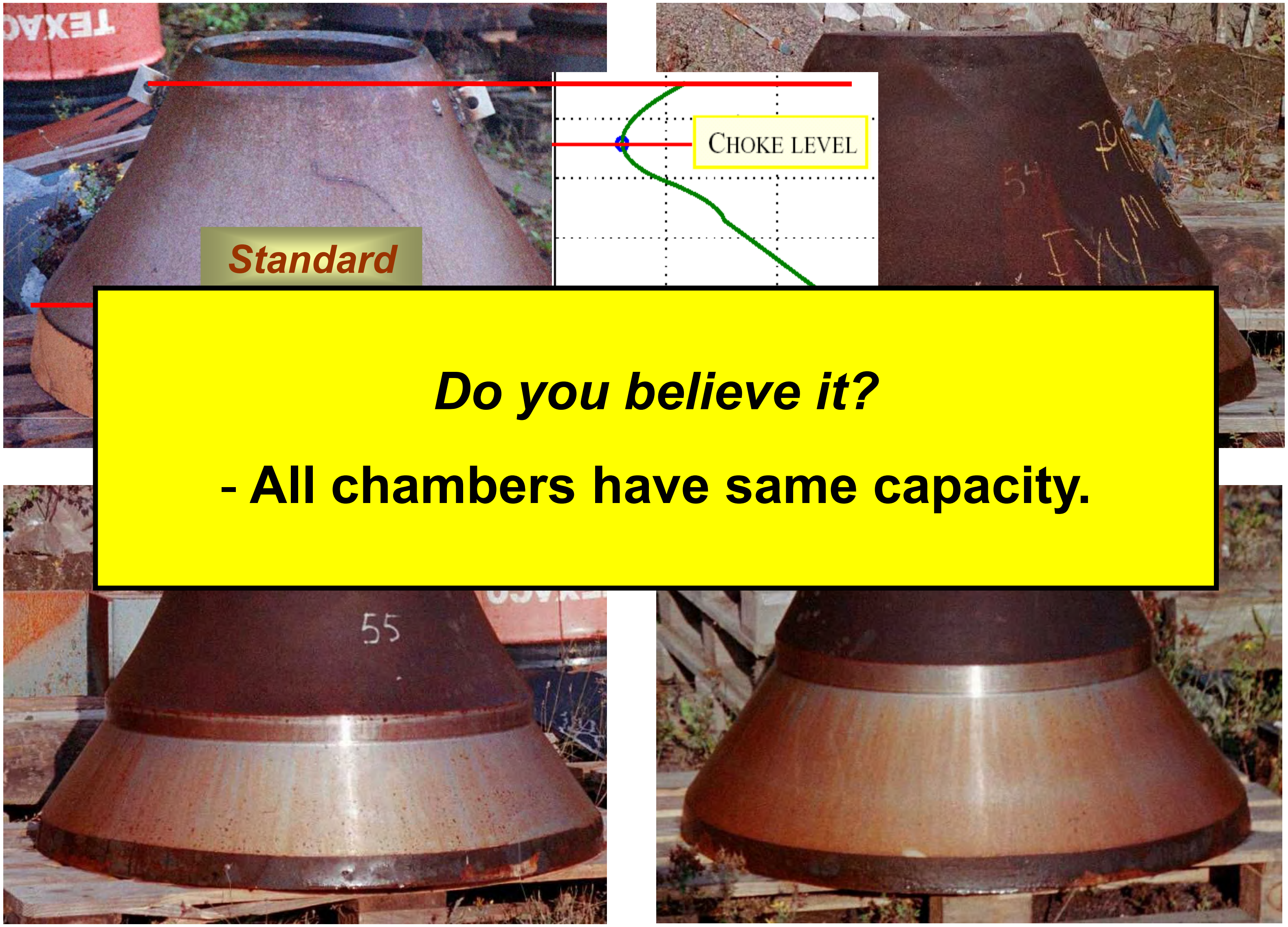
Verifying Tests

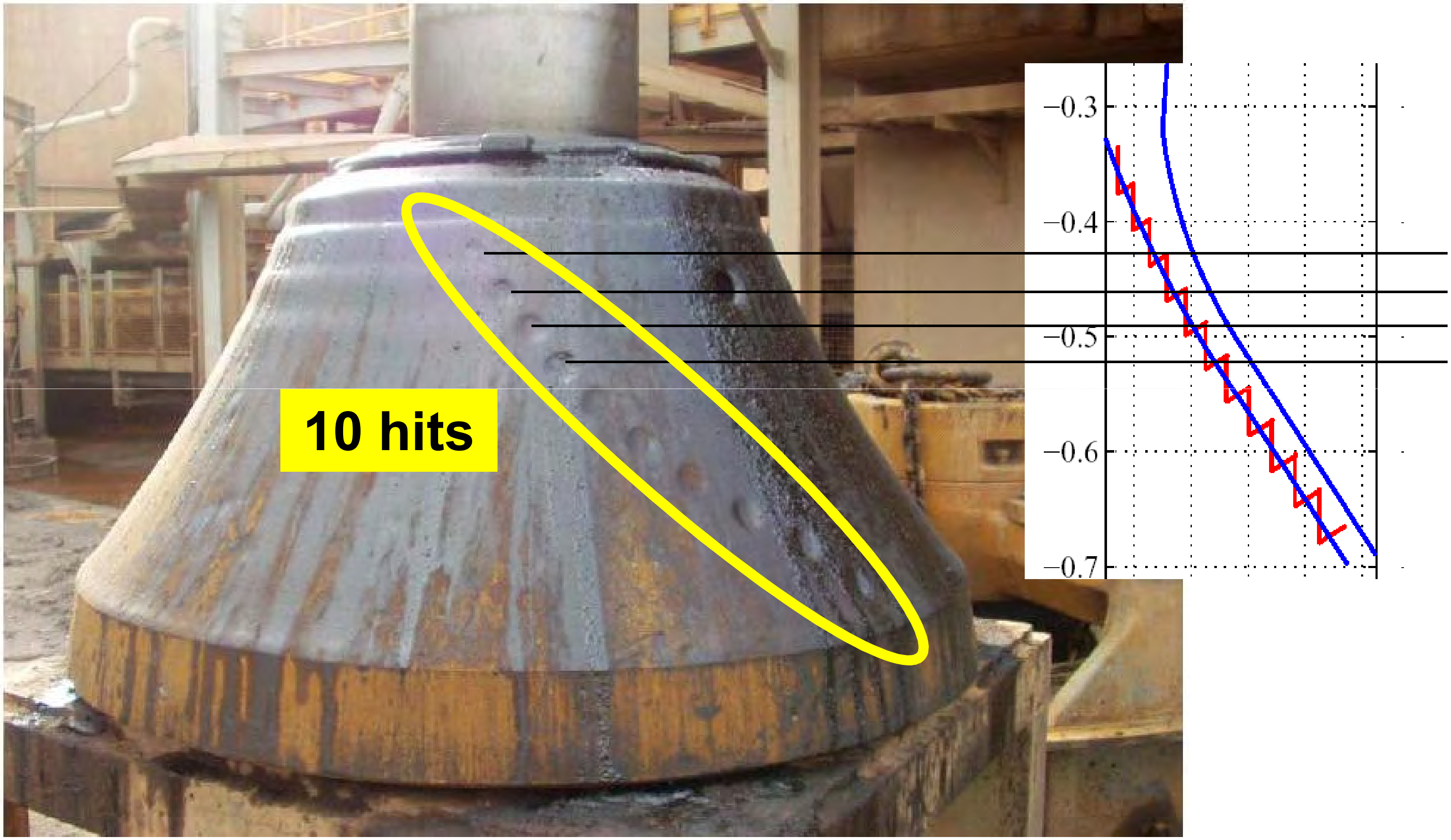


Do you believe it?

- All chambers have same capacity.

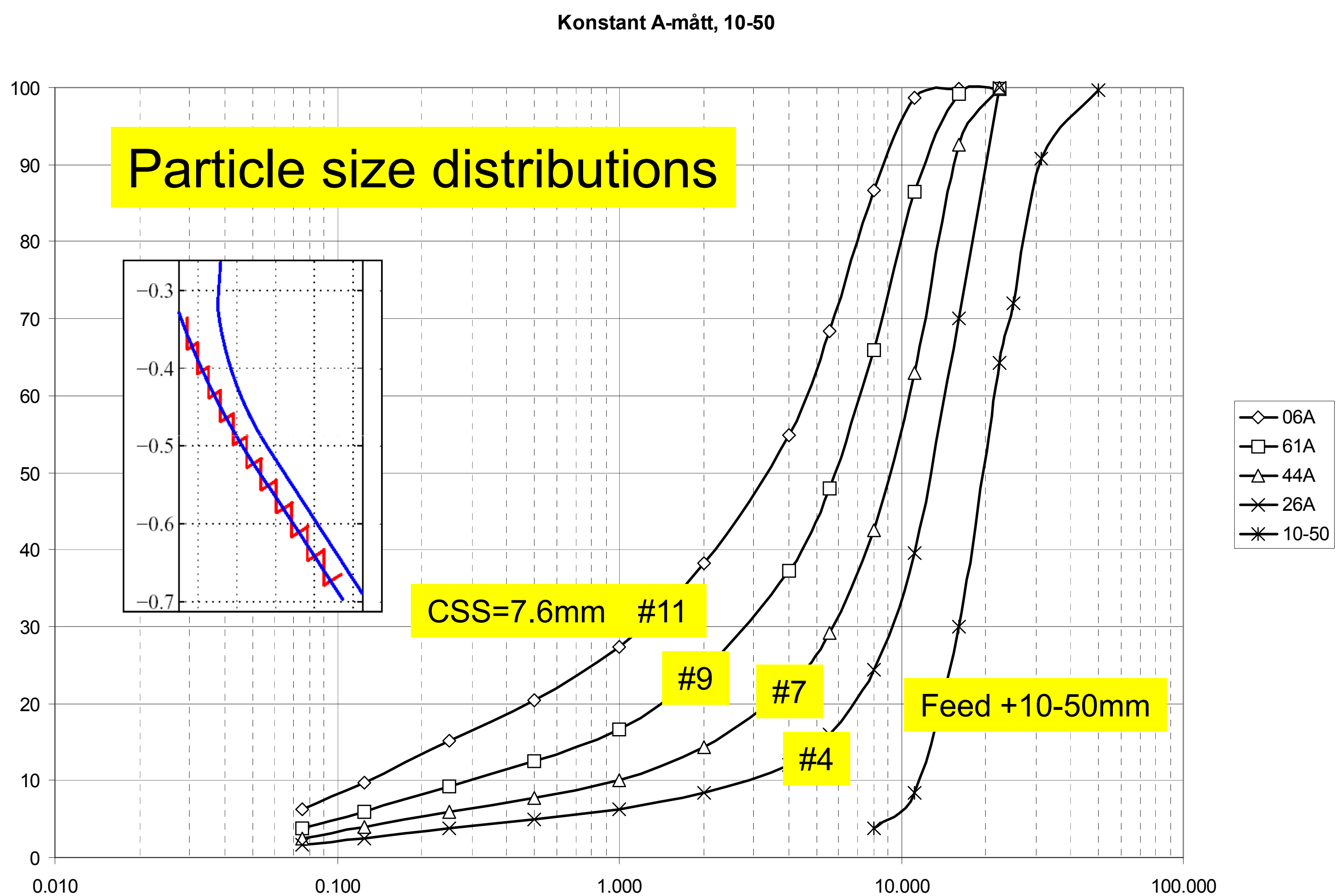
QUARRY ACADEMY

Verifying Tests…



QUARRY ACADEMY

Verifying tests



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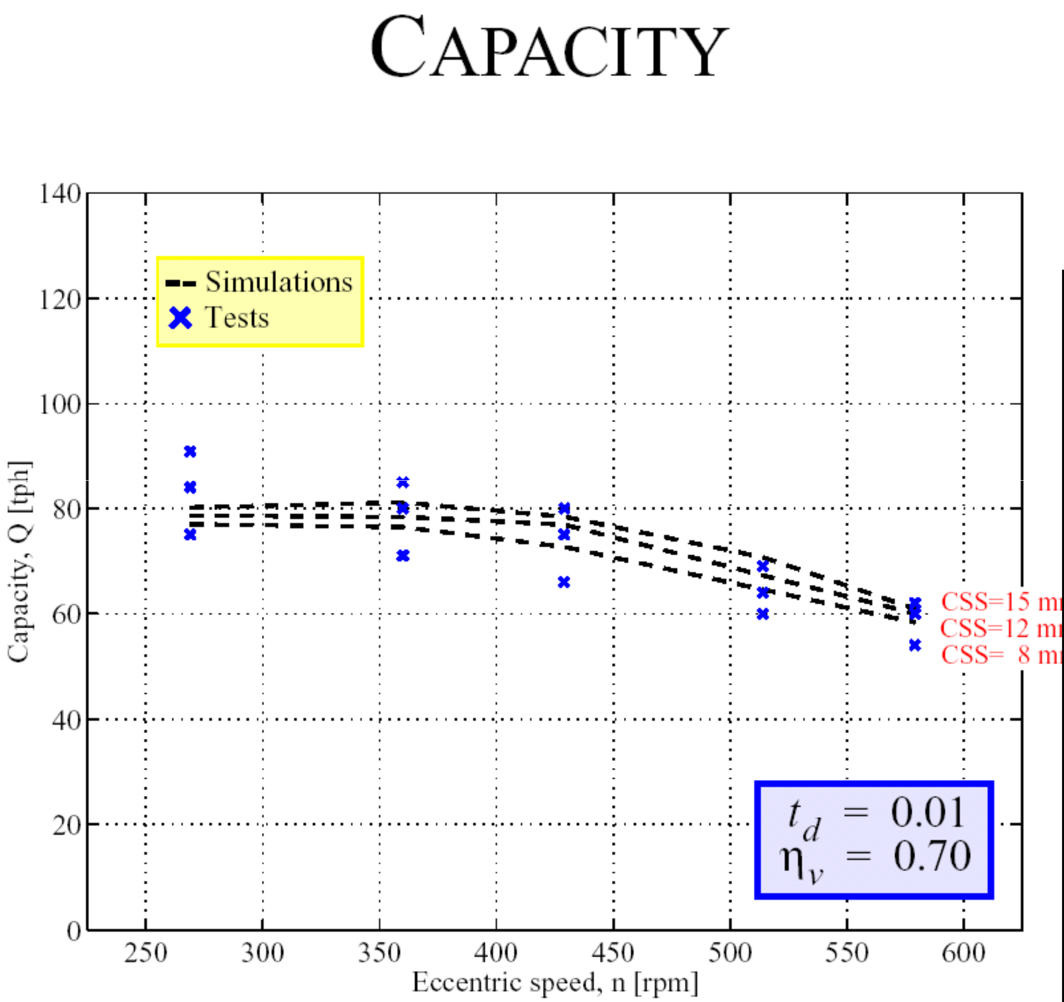
Results



Take home message:

Capacity normally decrease when eccentric speed increase.

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Conculsions

- Three (3) main factors influence the crushing result
  - ✓ Breakage modes – single or interparticle
  - ✓ The number of crushing zones
  - ✓ The compression ratio in each zone

- Design and operational parameters
  - ✓ Feed
  - ✓ Chamber design
  - ✓ Eccentric speed
  - ✓ Eccentric throw

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Optimization of a Final Crushing Stage

- The crushers are the last size reduction stage in the value chain.
- Over crushing is common.
- The rock cannot be repaired.
- We need to control the crusher carefully.

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Optimization of a Final Crushing Stage

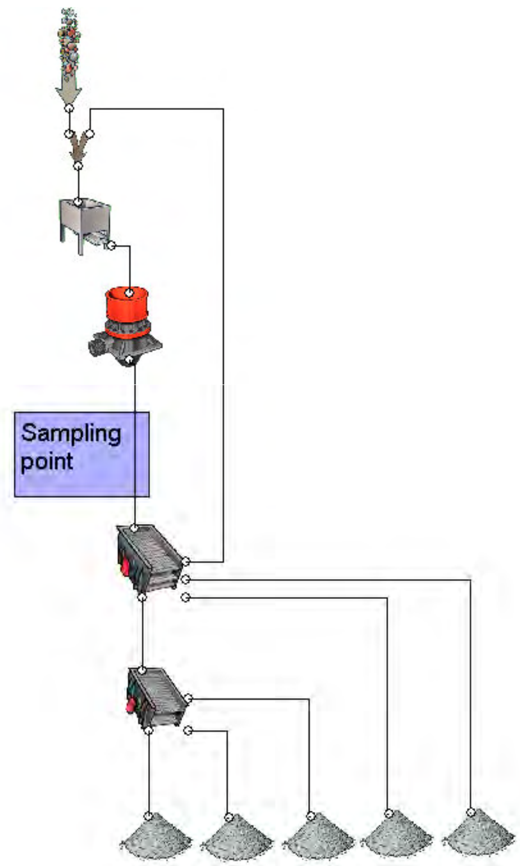
- What is the optimum CSS for the crusher?
- Optimize the setting for maximum production profit

- Combine product yield and economic aspects
- This can be done by taking samples and making the analysis in MS Excel

QUARRY ACADEMY

Optimization of a Final Crushing Stage
Taking Samples

- Material from crusher is sampled
- Production of 4 valuable products
  - ✓ 16-22 mm
  - ✓ 8-16 mm
  - ✓ 4-8 mm
  - ✓ 2-4 mm
- By-product with no value
  - ✓ 0-2 mm



Optimization of a Final Crushing Stage
Taking Samples

- Run the crusher at different settings
- Take at least one sample at each setting. (Multiple samples are often useful)
- Measure the capacity at each crusher settings. CSS will effect the final product capacity, especially in a closed circuit.

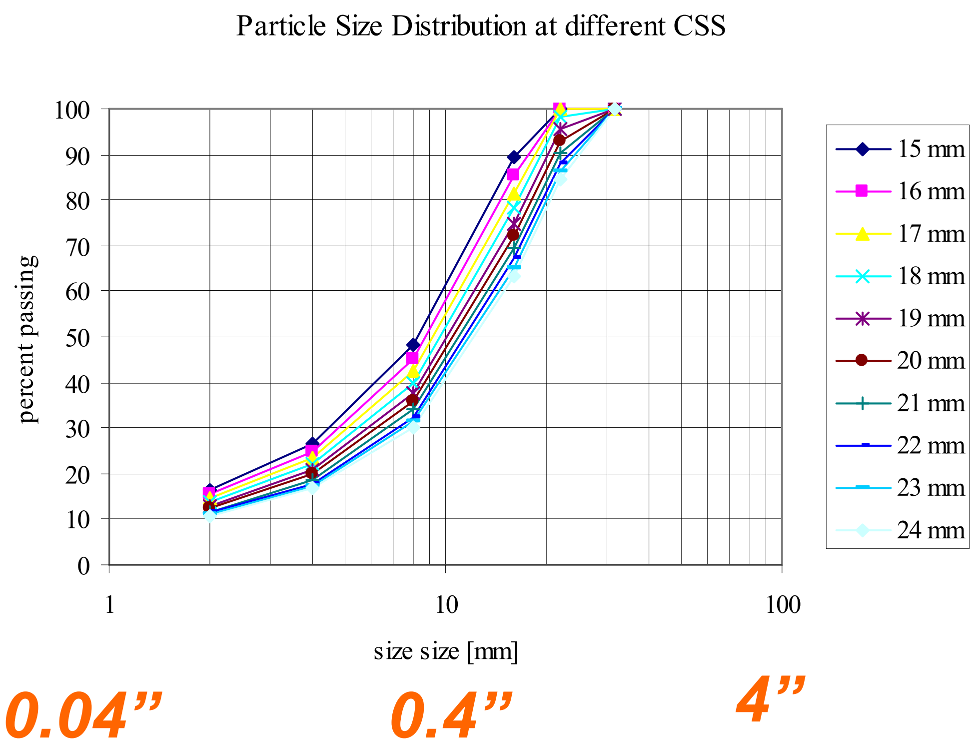
- Special Attention to Safety when taking samples!!
- Position of point were samples are taking.
- Ensure that the conveyor will not start by accident.

QUARRY ACADEMY

Optimization of a Final Crushing Stage Particle Size Distribution Analysis

- **Particle Size Distribution Plots**
- **If taking single samples on each CSS the risk of getting inconsistent results might make the graph look strange.**

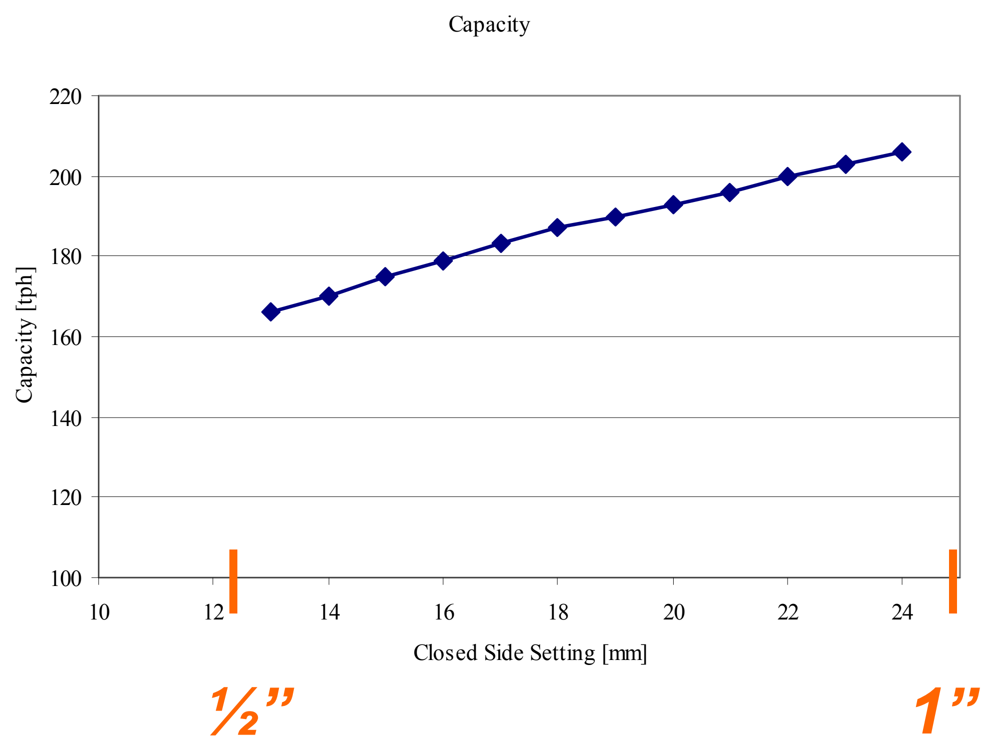
- **Impossible to determine optimum setting by only using particle size distribution graphs**



QUARRY ACADEMY

Optimization of a Final Crushing Stage
Crusher Capacity Analysis

- **If taking single samples on each CSS the risk of getting inconsistent results might make the graph look strange.**
- **Impossible to determine optimum setting by only using particle size distribution graphs**



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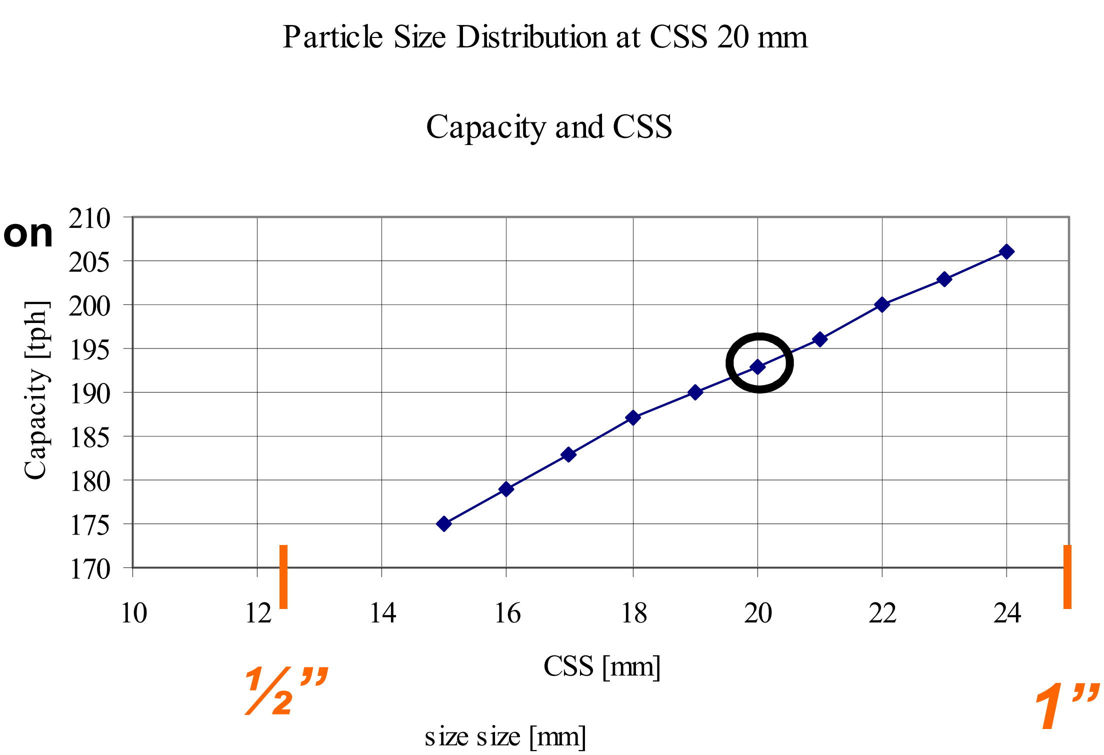
Optimization of a Final Crushing Stage
Making a useful analysis

- **Combine the particle size distribution and capacity.**
- **Percentage of final product times the capacity gives the production capacity of each product.**

- **Example 2-4 mm at CSS 20mm:**
  - ✓ **Percentage of crusher production**
  - ✓ **20% - 11% = 9%**
  - ✓ **Crusher capacity**
  - ✓ **193 tph**

  - ✓ **Total Production:**
  - ✓ **193 tph x 9% = 17 tph**



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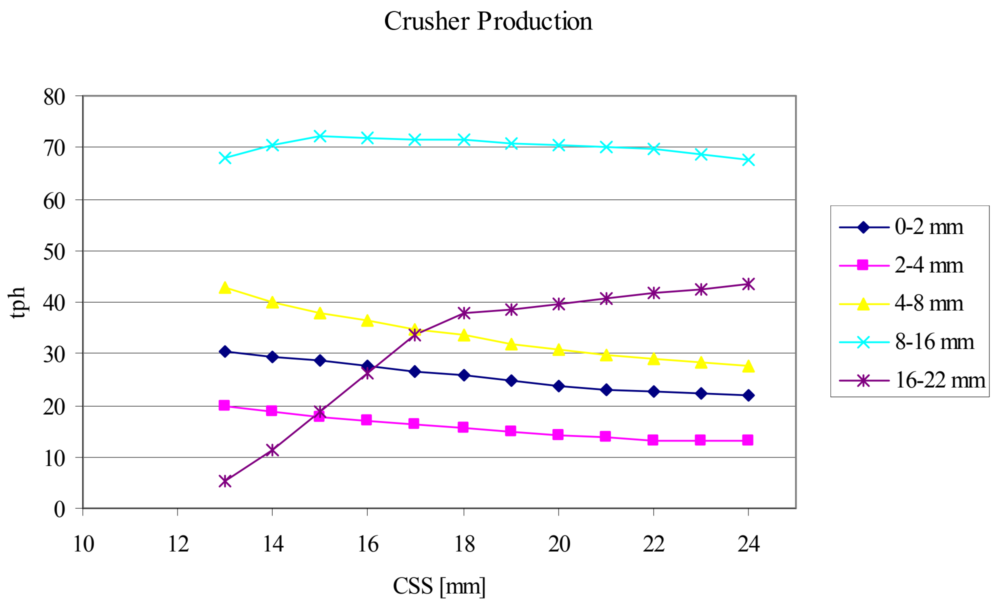
Optimization of a Final Crushing Stage
Putting it all together

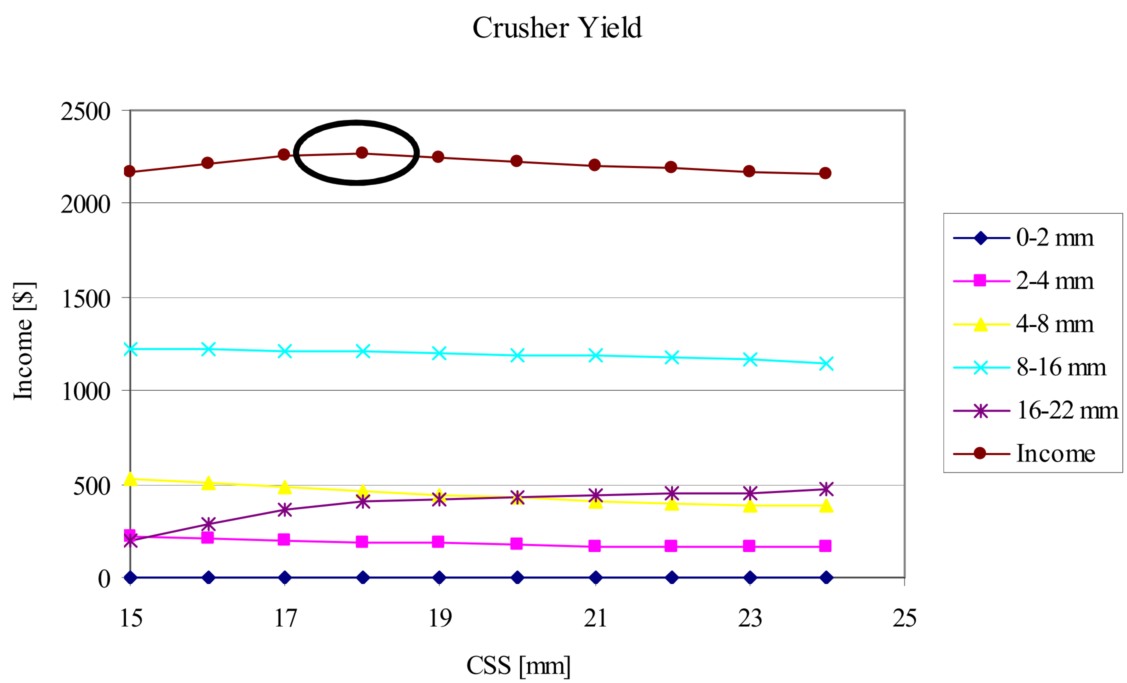
- **Entering all the values into MS Excel makes this easy to get production capacities.**
- **Still difficult to determine the optimal setting**



QUARRY ACADEMY

Optimization of a Final Crushing Stage
Putting it all together

- **Use the price per ton for all products*:**
  - ✓ **0-2 mm: $ 0 (by-product)**
  - ✓ **2-4 mm: $ 12.30**
  - ✓ **4-8 mm: $ 13.85**
  - ✓ **8-16 mm: $ 16.90**
  - ✓ **16-22 mm: $ 10.80**



- **Make an income graph by combining prices with capacity**

**** Prices are estimates based on publicly available information***

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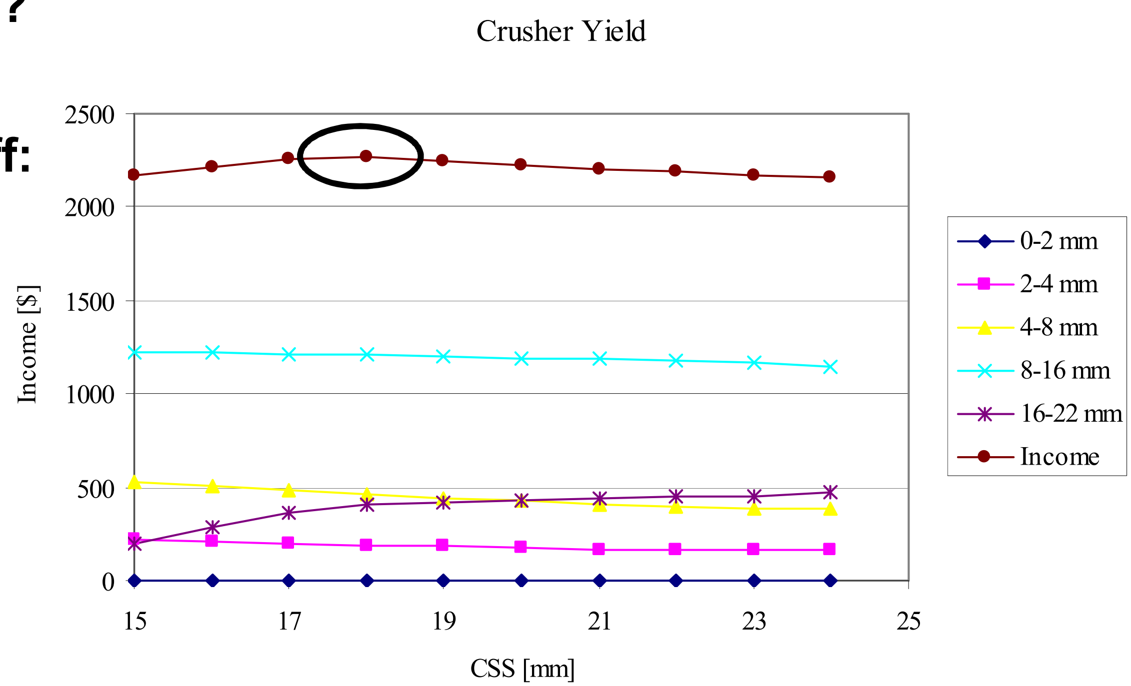
Optimization of a Final Crushing Stage
Putting it all together

- **What difference does it make?**
- **Running the crusher 2 mm off:**
  - ✓ **Decrease the profit by $49**
  - ✓ **Running the crusher at 1600 hours per year: 49*1600=$78400**



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Take home messages

- It is easier to crush short fractions than long fractions.
- Packing limit is reach earlier with long fractions.
- Longer fractions results in higher crushing pressure and better particle shape.
- Single particle breakage requires lower crushing force compared to interparticle.
- If the crushing angle is small you can experience packing even at low power draw.
- Capacity is controlled by choke area.
- Higher eccentric speed results in more compressions and better particle shape.
- Chamber design affects breakage modes.
- Use ”Crusher Performance Maps” for manual optimization of crushers.
- Capacity normally decrease when eccentric speed increase.

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Thank you for listning!

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