Principles of Mechanical Crushing

Per Svedensten

QUARRY ACADEMY

Per Svedensten

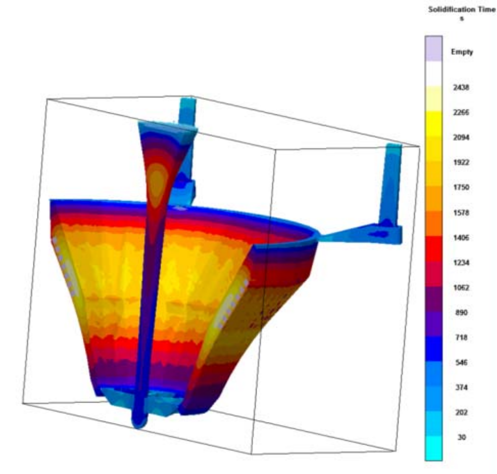
- **Manager Crushing Chamber and Materials Development**
  - ✓ **Product Development Center Crushing (R&D)**
- **Master of Science in Mechanics, specialized in mechatronics**
- **Ph.D 2007, Chalmers University**
  - ✓ **Partly funded by Sandvik**
  - ✓ **Modeling, simulation and optimization of crushing plants**
  - ✓ **Technical-Economic Optimization**
- **Sandvik employee since 2004**
  - ✓ **Manager Crushing and Screening Process Experise**

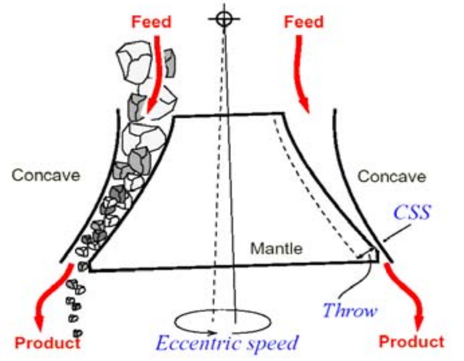
QUARRY ACADEMY

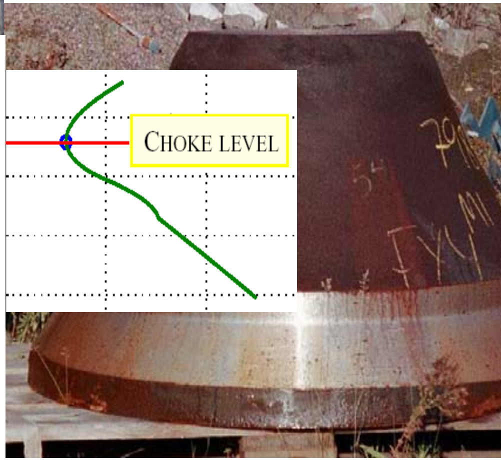
Crushing Chamber And Materials Development

- Crushing Chamber Geometry
- Crushing Chamber Materials
- Other Machine Parts Material

- Our Three Values
  - ✓ Safe!
  - ✓ Customer Values
  - ✓ Scientific Approach







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Objective

Explain the interaction
between

rock material

and

crusher

Take home messages

The Take Home Messages will adress:

- *Trouble Shooting*
- *Improve Yield*
- *Improve Performance*

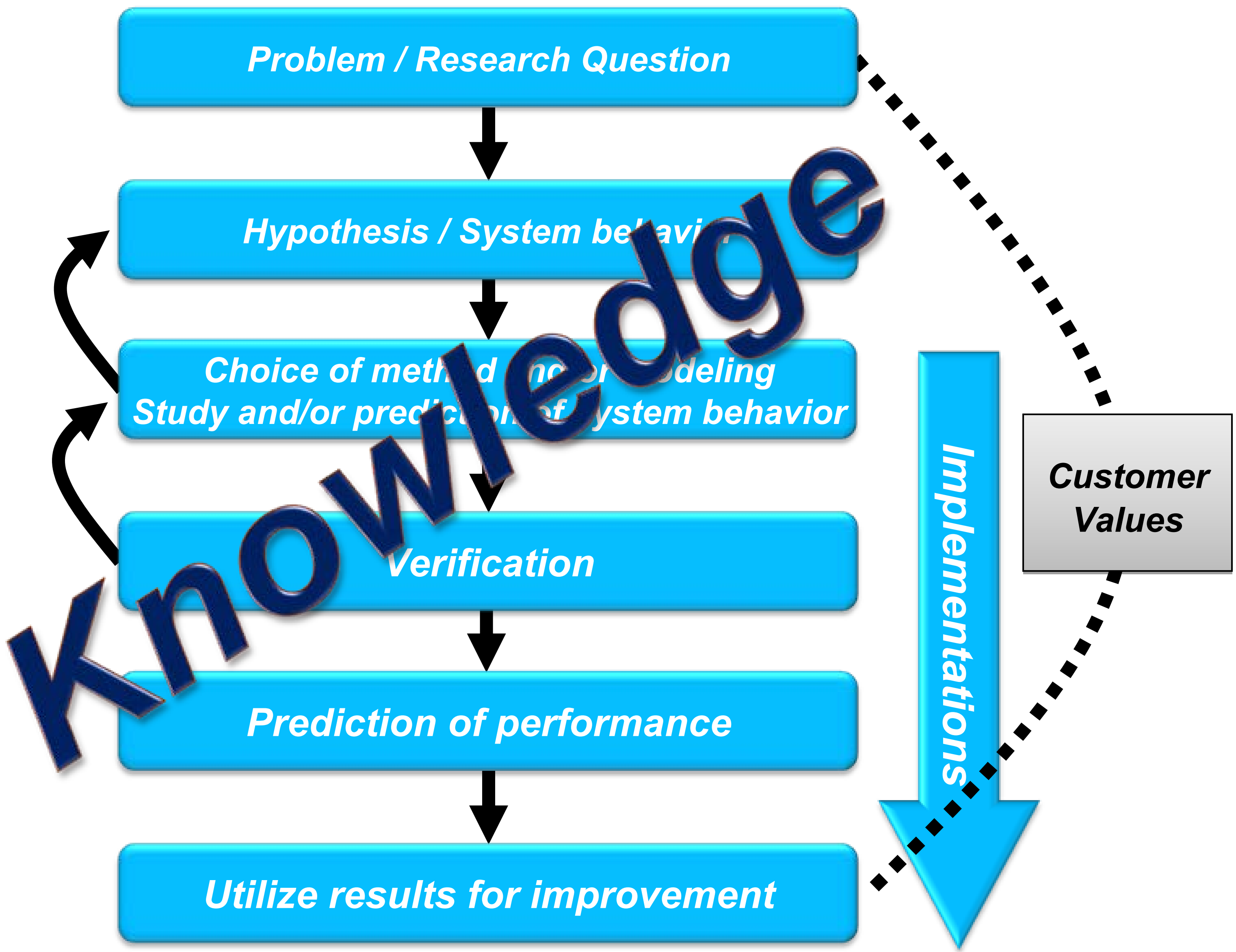
QUARRY ACADEMY

Agenda

- Cone Crusher Operating Principal
- Crusher and Rock Interaction
- Forces and Power Draw
- Capacity
- Operating the Crusher in a Process
- Optimization
- Conclusions

NCC, Borås, Sweden

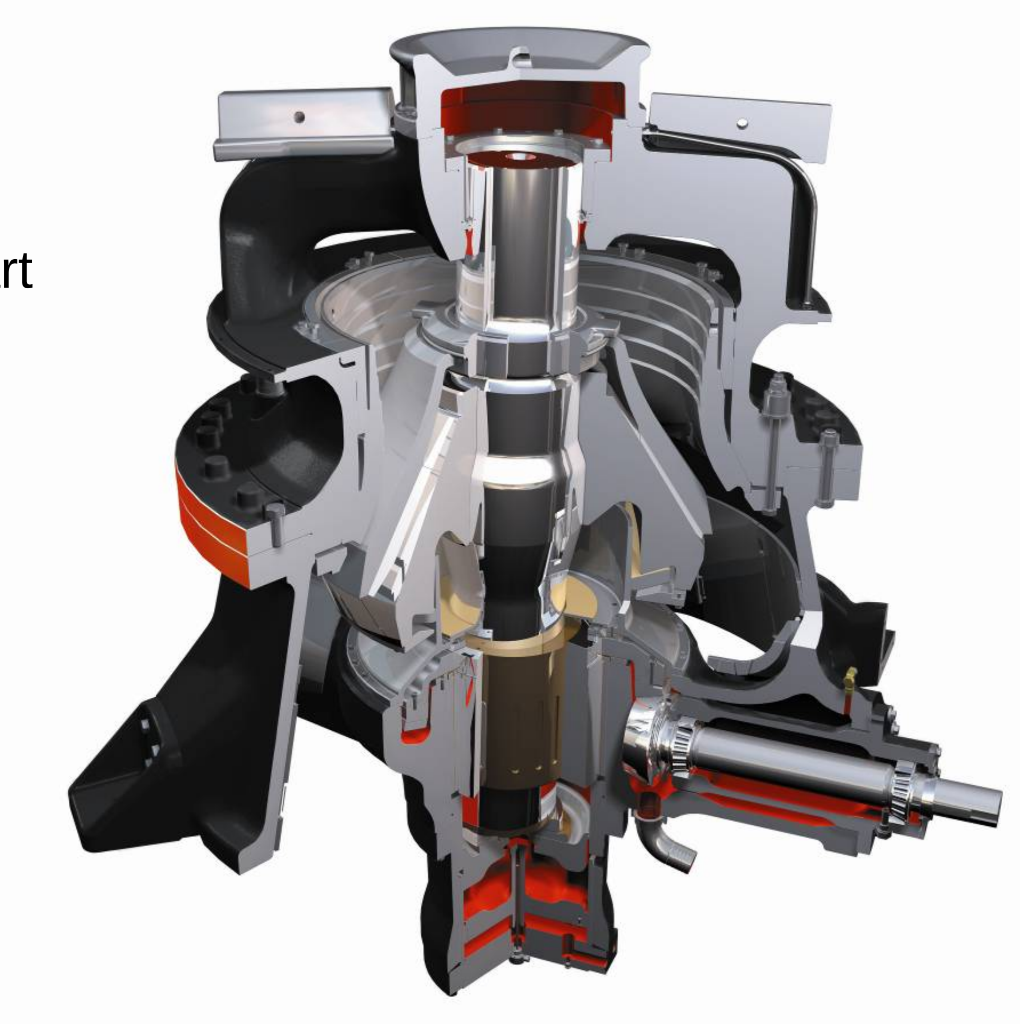
Scientific Approach



QUARRY ACADEMY

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**

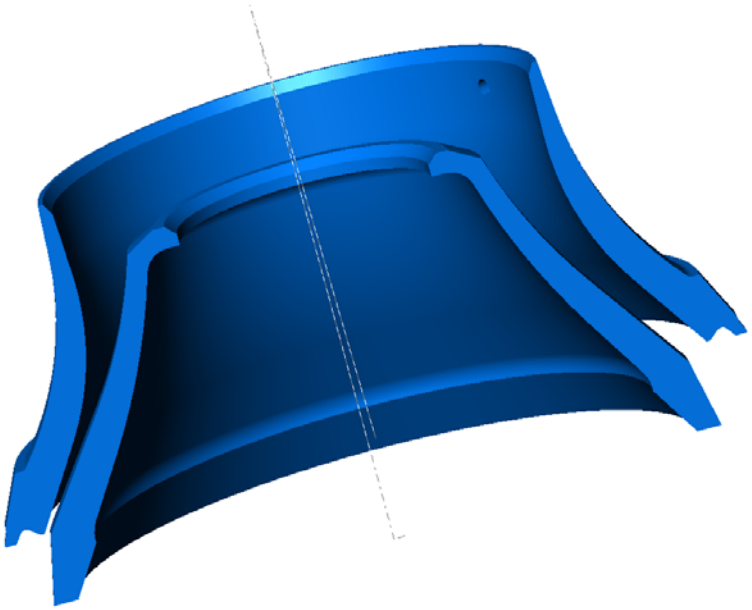


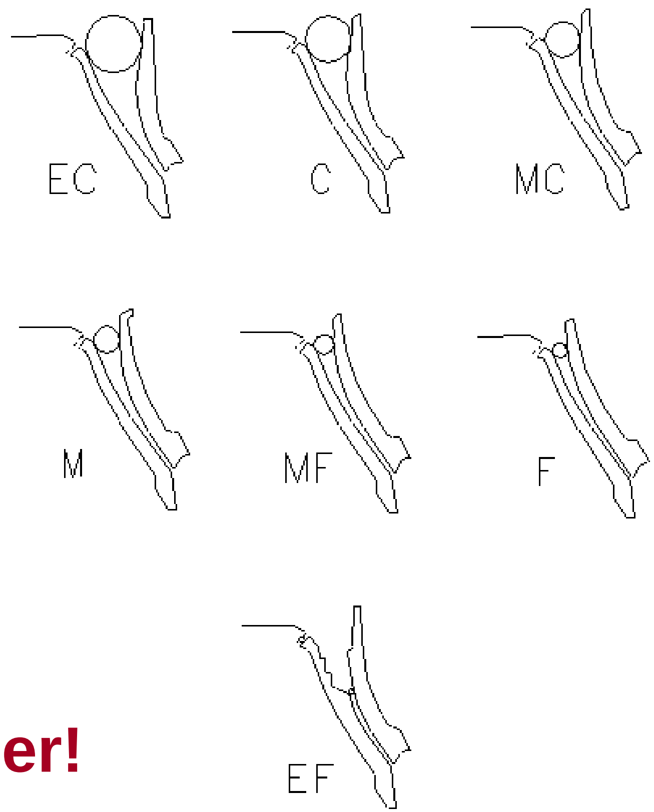
QUARRY ACADEMY

Operating Principle

QUARRY ACADEMY

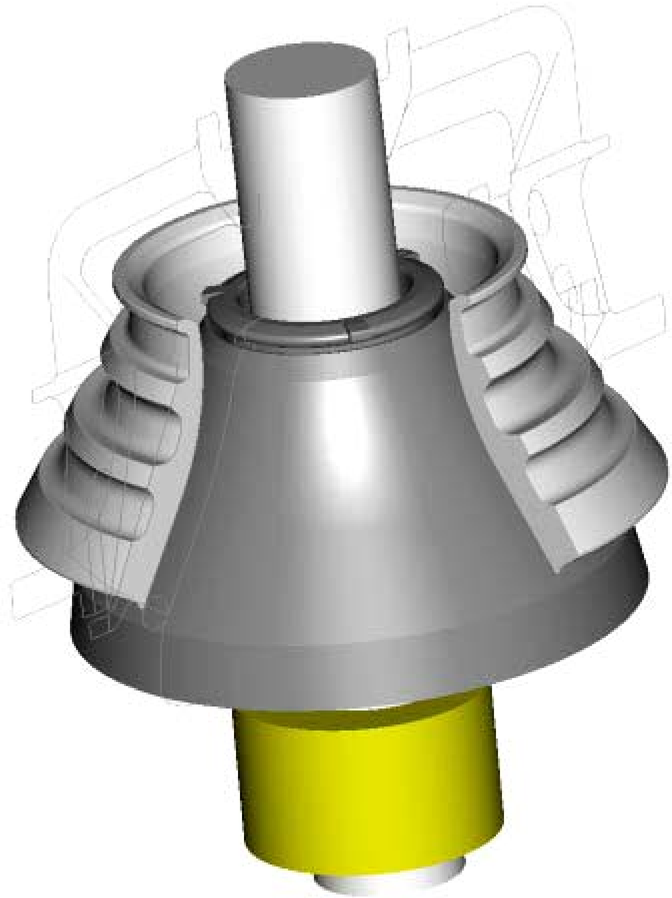
Operating Principle



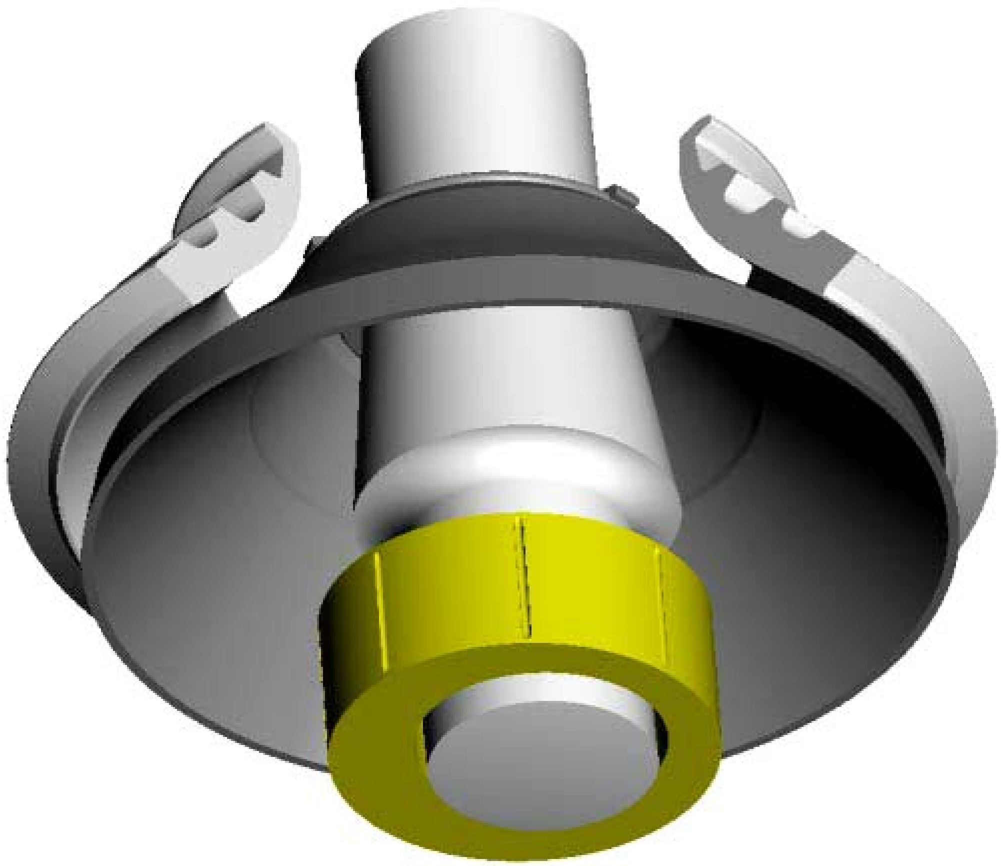


All crushing starts with the chamber!

Operating Principle

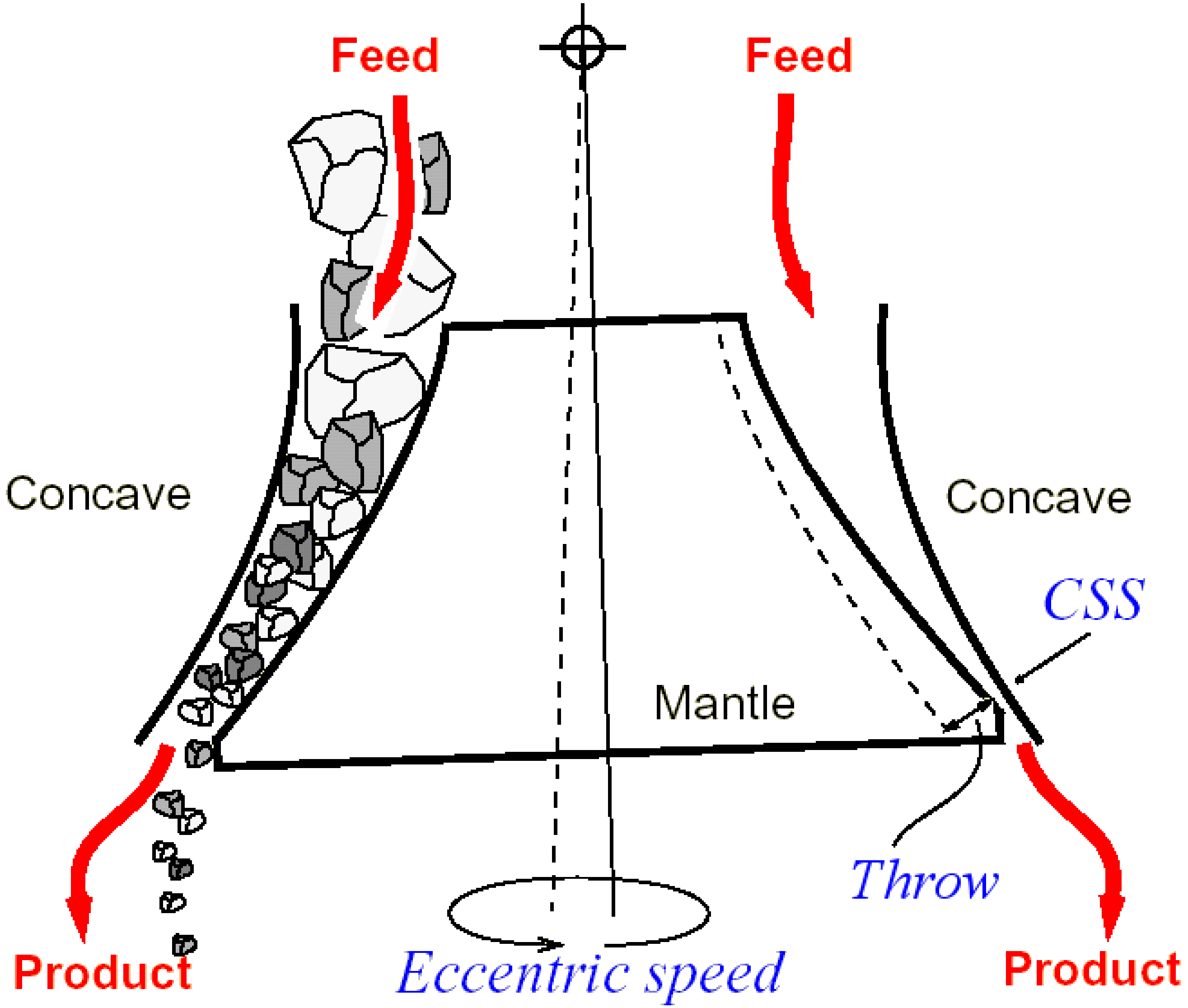


Operating Principle

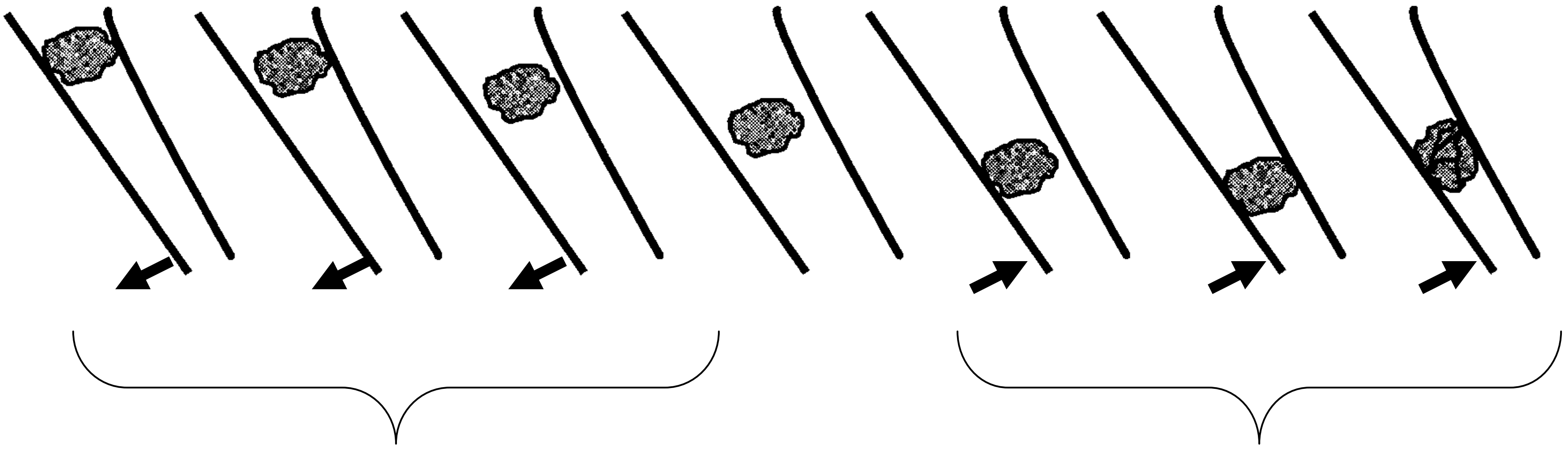


QUARRY ACADEMY

Operating Principle



Operating Principal



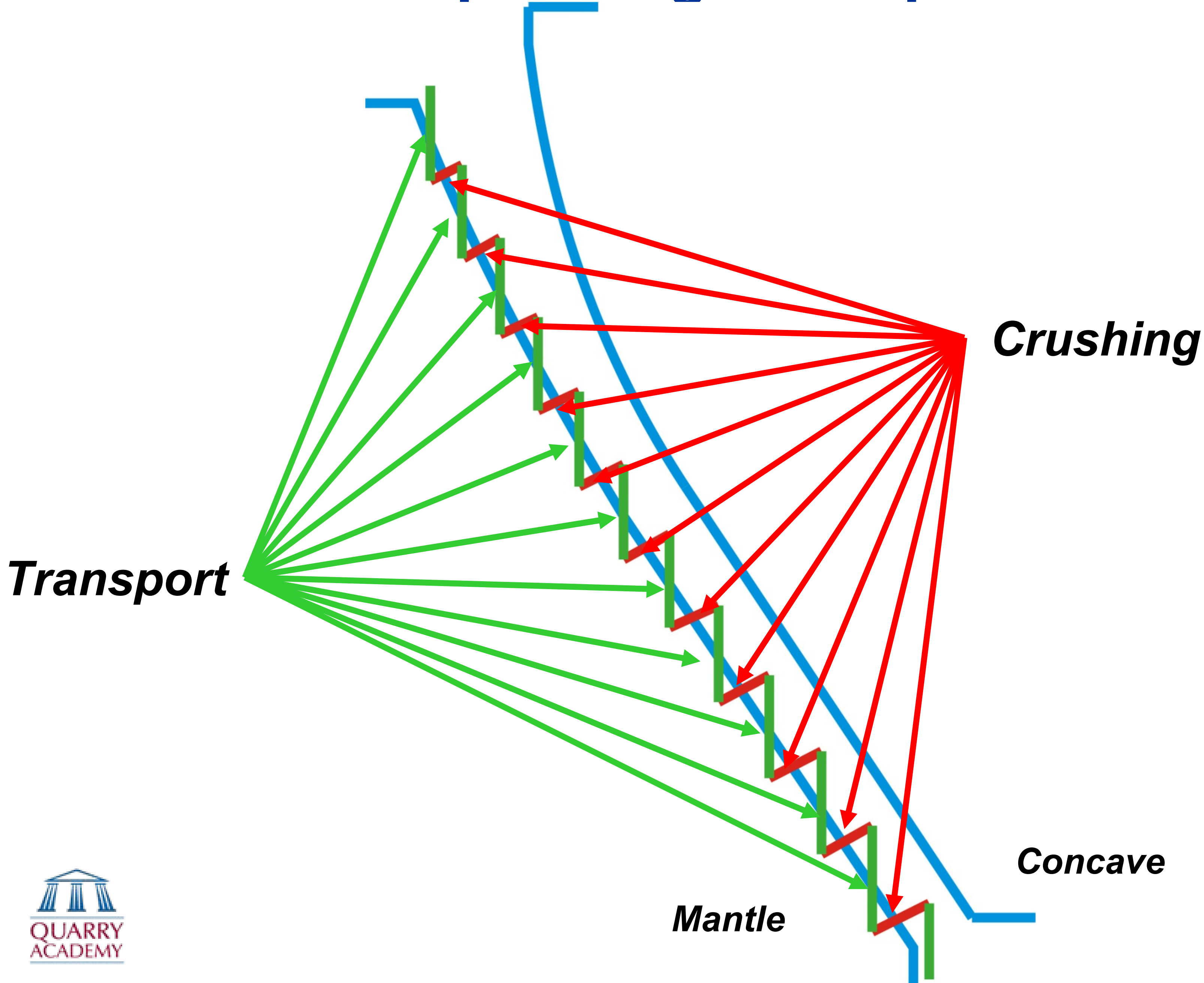
Opening Phase =

= Transport

Closing Phase =

= Crushing

Operating Principal



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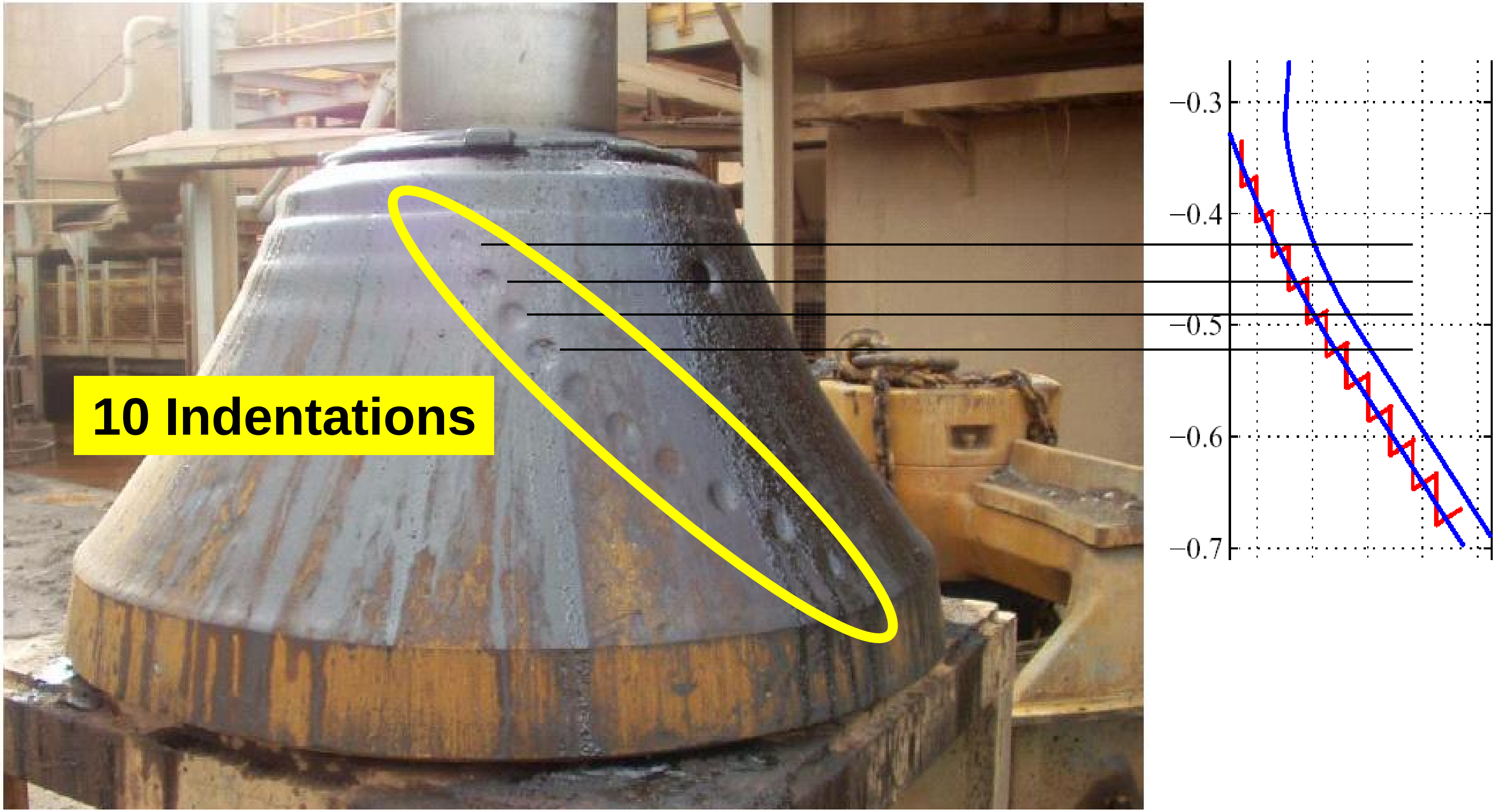

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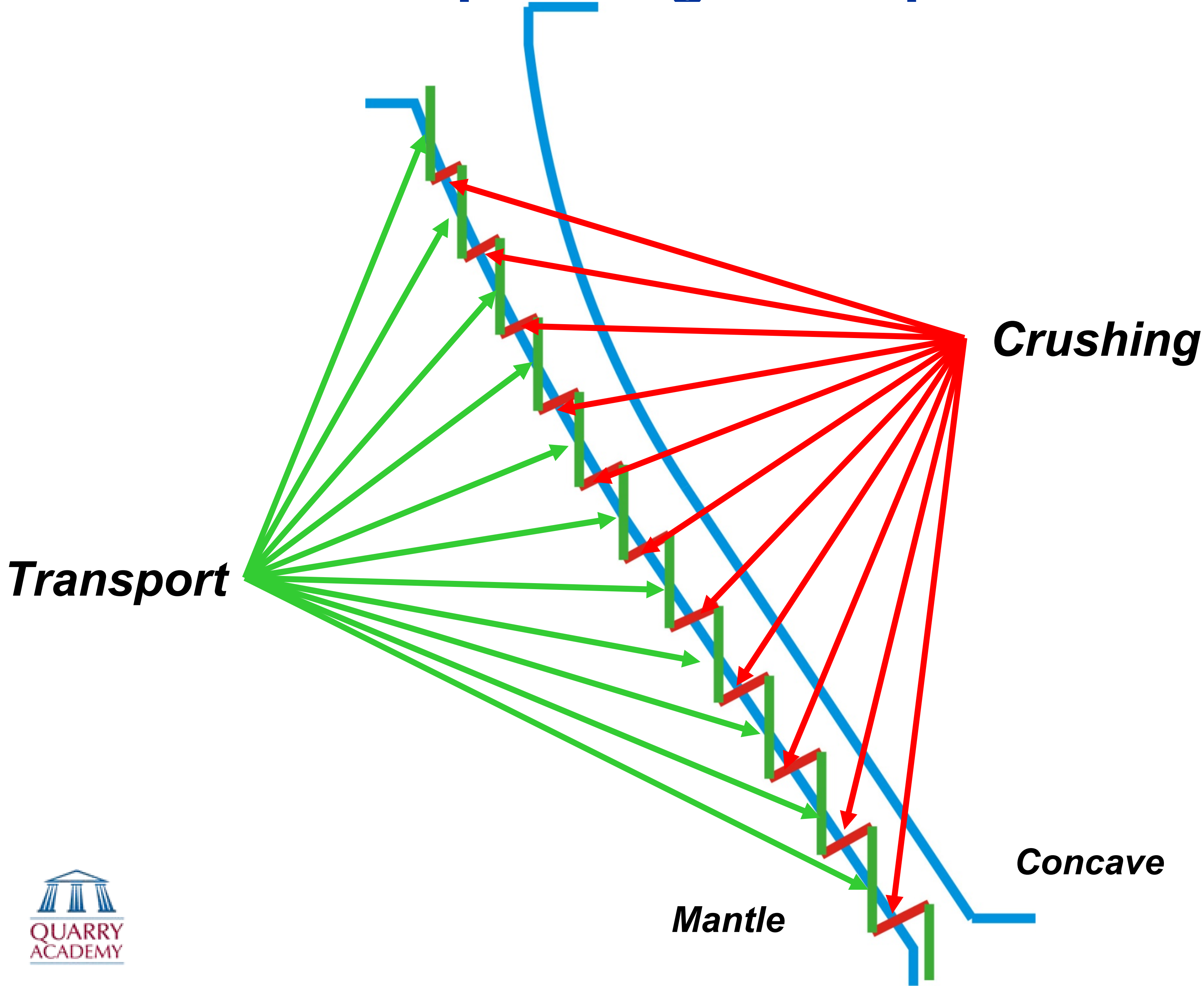
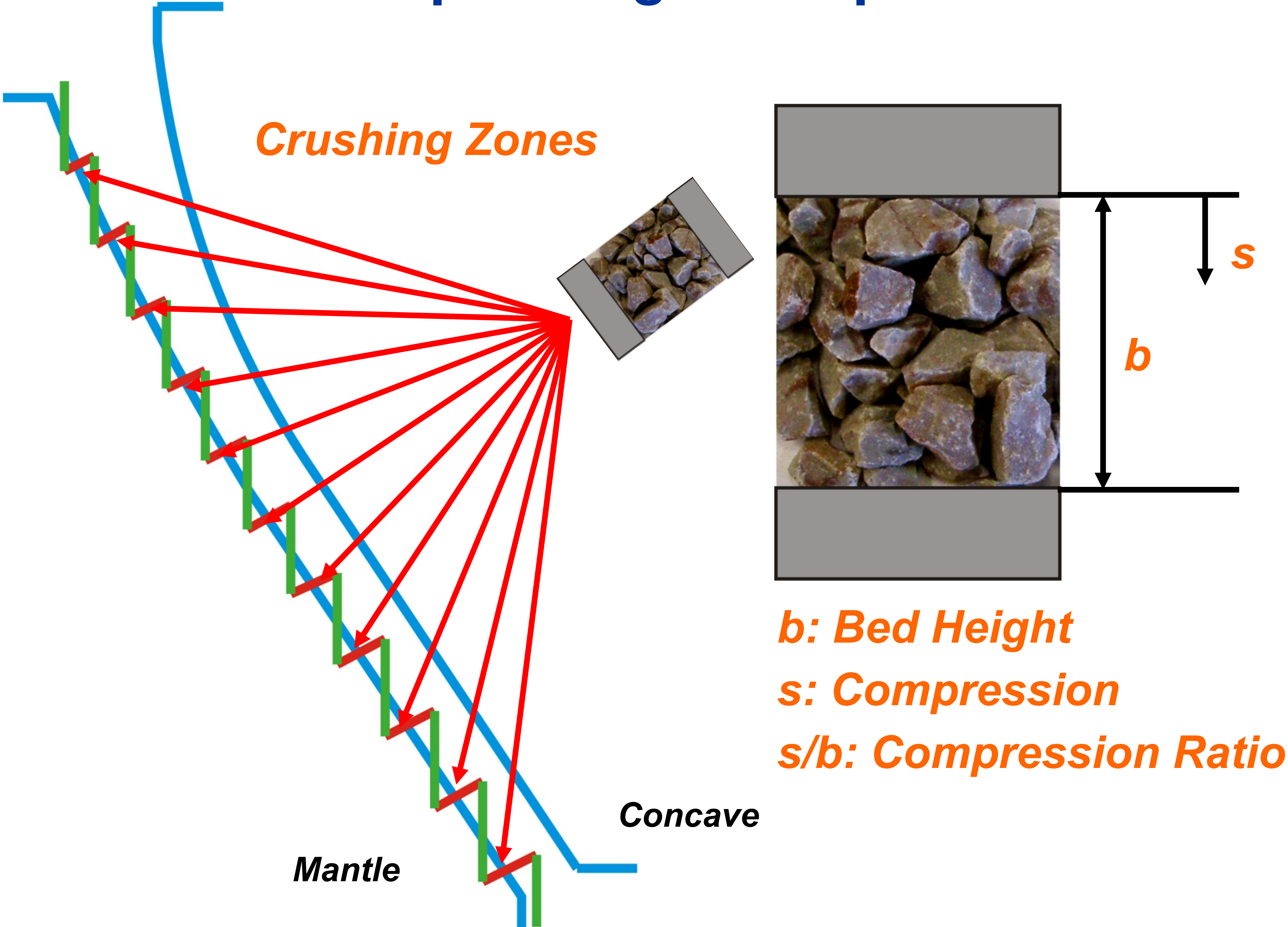
Operating Principal



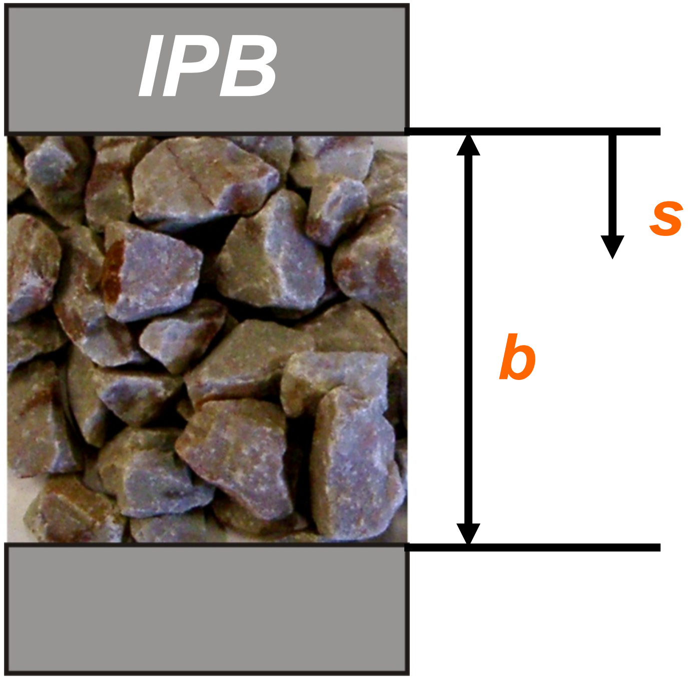
QUARRY ACADEMY

Operating Principal



Operating Principal

Single Particle Breakage



Inter Particle Breakage

QUARRY ACADEMY

Crusher Modeling

The compressive crushing process can be described with two functions.

Selection S **– which?**

Breakage B **– how?**

QUARRY ACADEMY

Crusher Modeling

Prediction of:

- Product Particle Size Distribution
- Capacity
- Crushing Force
- Hydraulic Pressure
- Power Draw

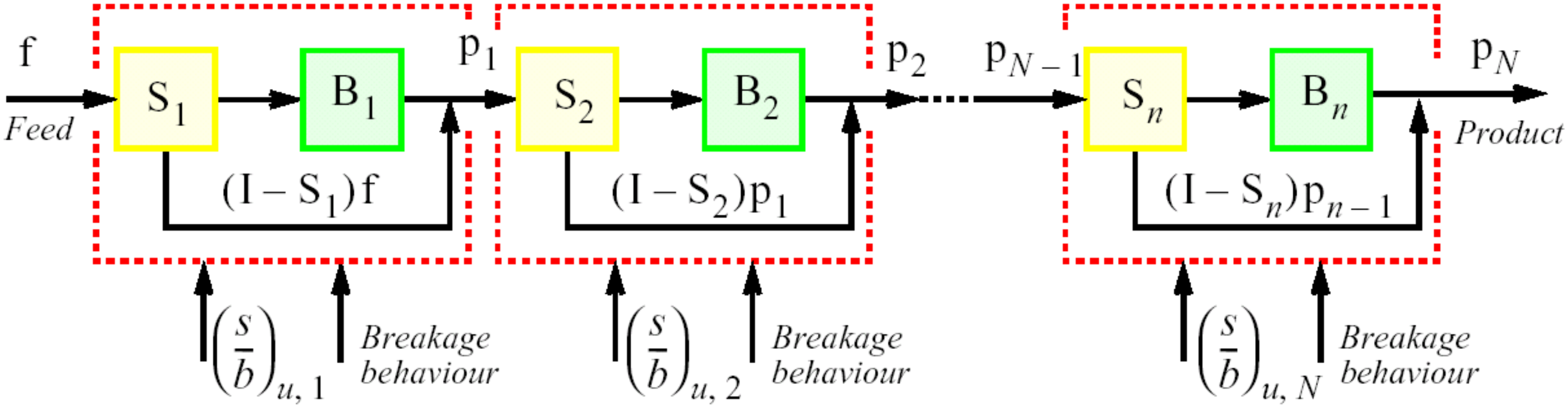
Design and Operation

- Computer Calculation Model of Cone Crushers
- Utilize the crusher as efficient as possible
- Energy efficient crushing
- Robust performance during the entire wear part life
- Maximize product yield

QUARRY ACADEMY

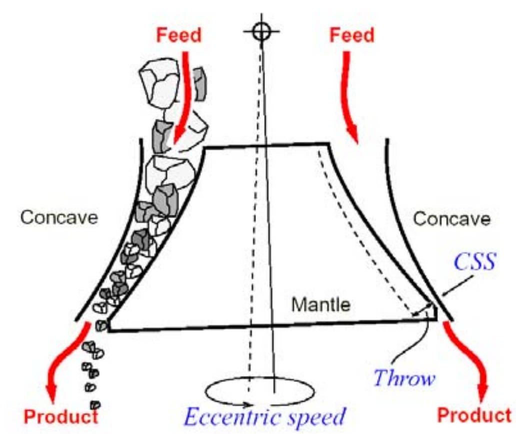
Crusher Modeling

Repeated size reduction steps



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

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



Crusher Modeling

Laboratory investigation of breakage modes

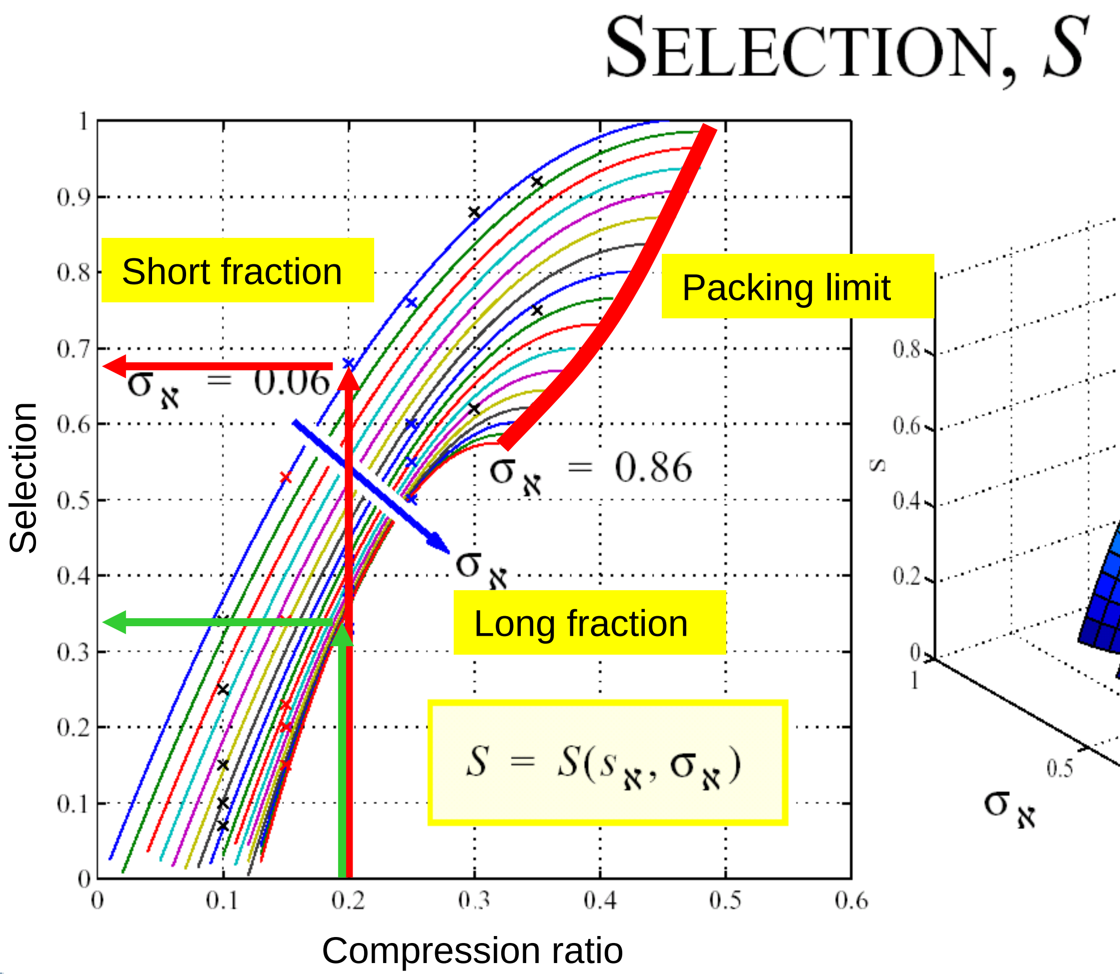
Compressive crushing with hydraulic press.

Compression ratio

Compression ratio

Distribution width

Rock Breakage Behavior



Take home message:

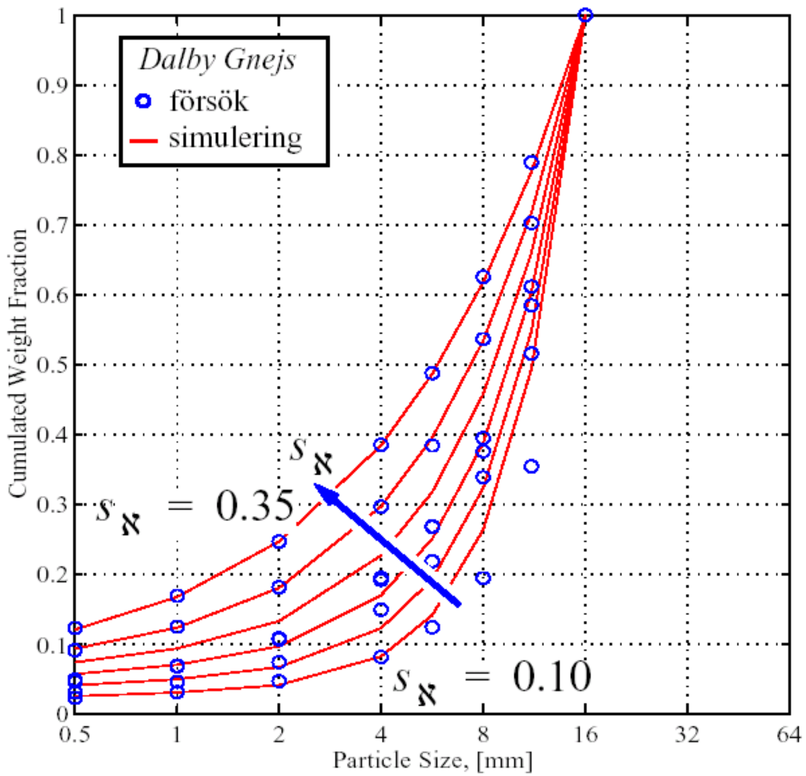
It is easier to crush short fractions than long fractions.

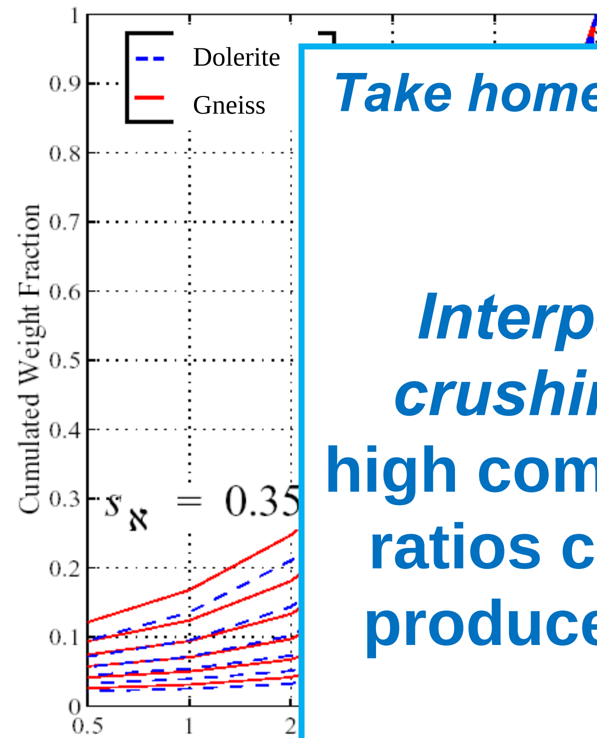
Packing limit is reach earlier with long fractions.

QUARRY ACADEMY

Rock Breakage Behavior

BREAKAGE, *B*





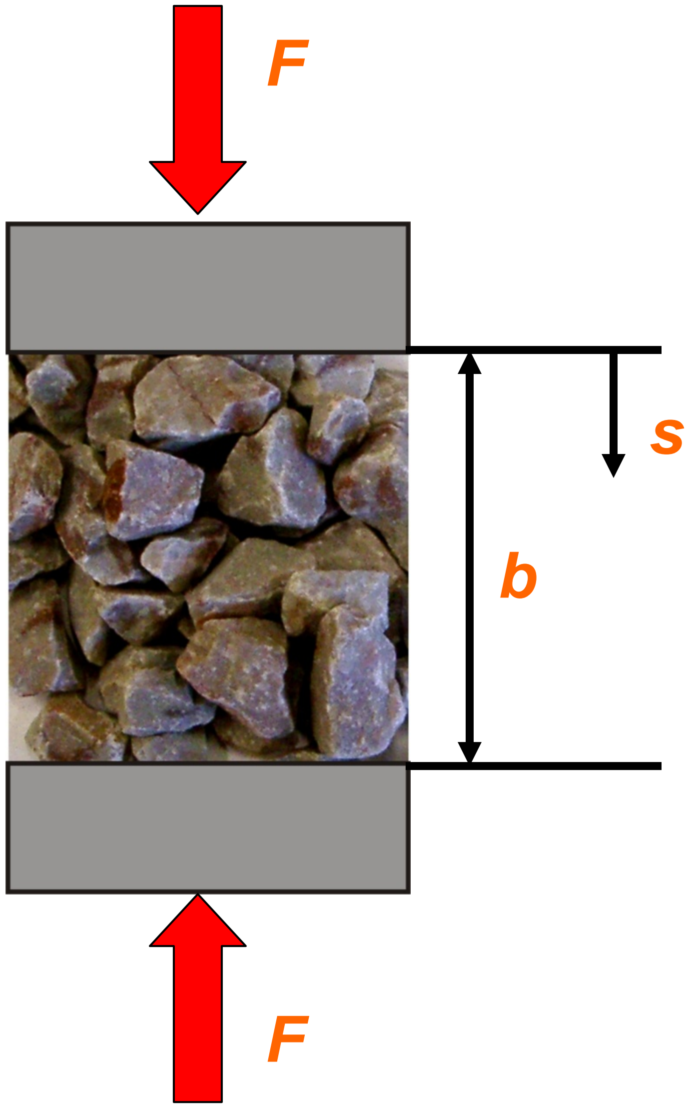
Take home message:

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

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

QUARRY ACADEMY

Crushing Force and Power Draw



b: Bed height

s: compression

s/b: compression ratio

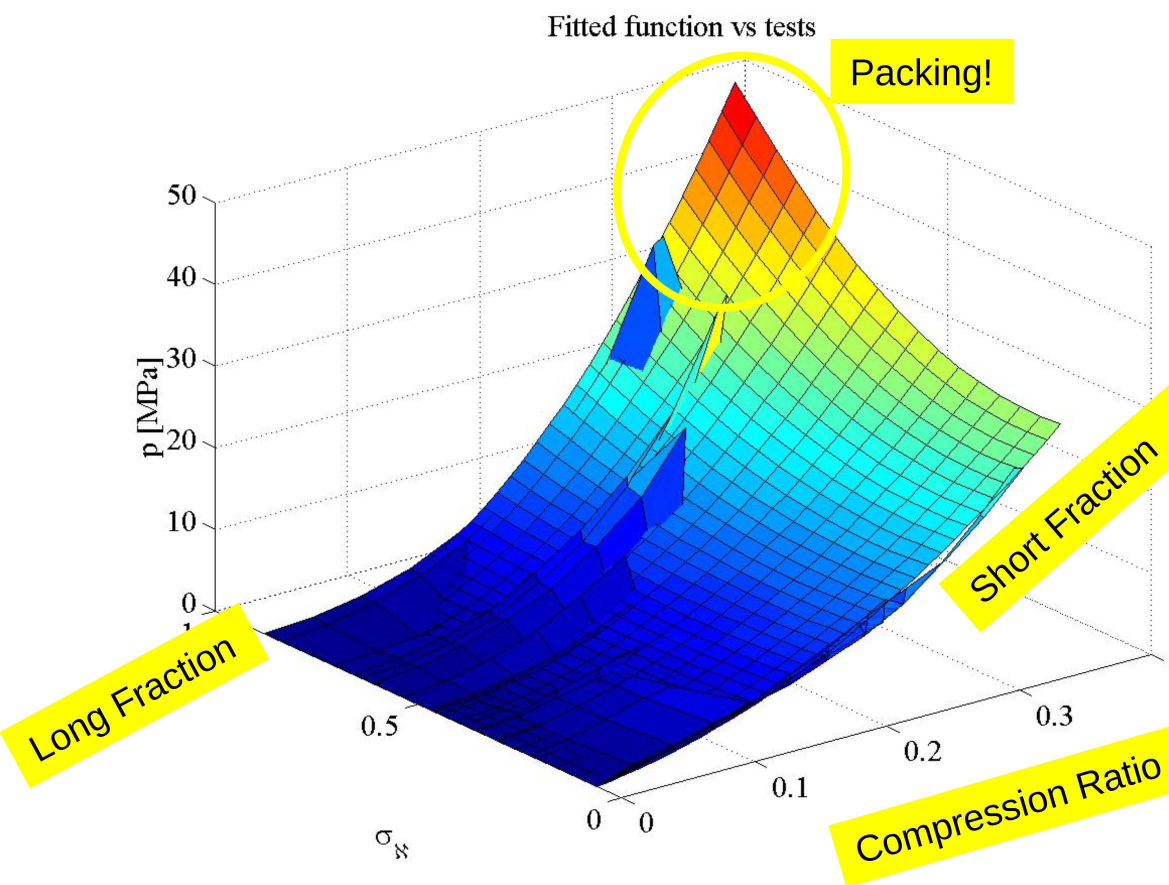
F: Force

F = f(s/b, σ)

σ: Fraction length

QUARRY ACADEMY

Crushing Force and Power Draw



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

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

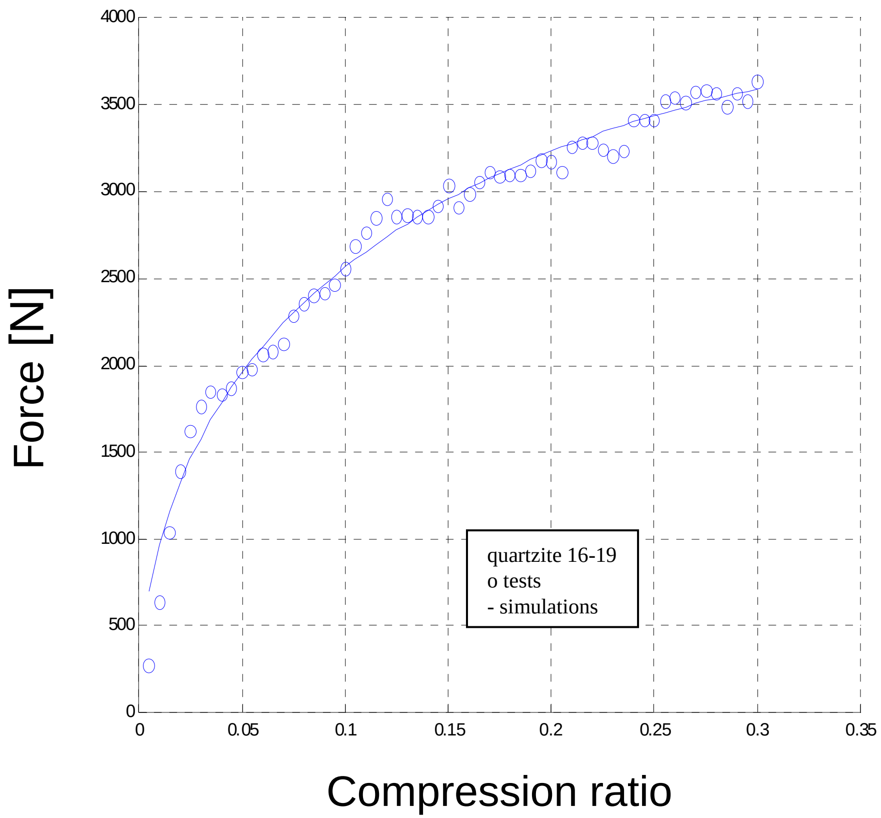
Take home message:

Interparticle breakage

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

Crushing Force and Power Draw

Single particle
-force response

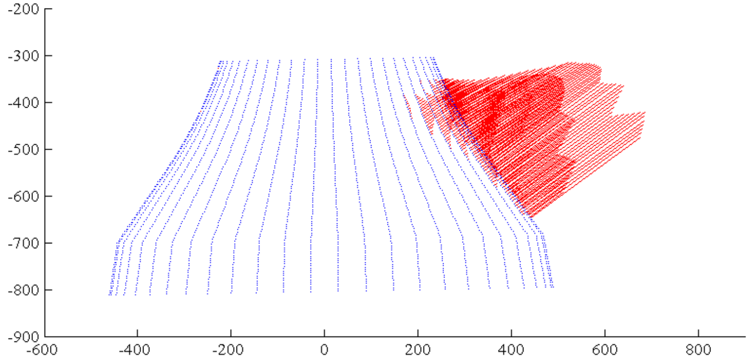


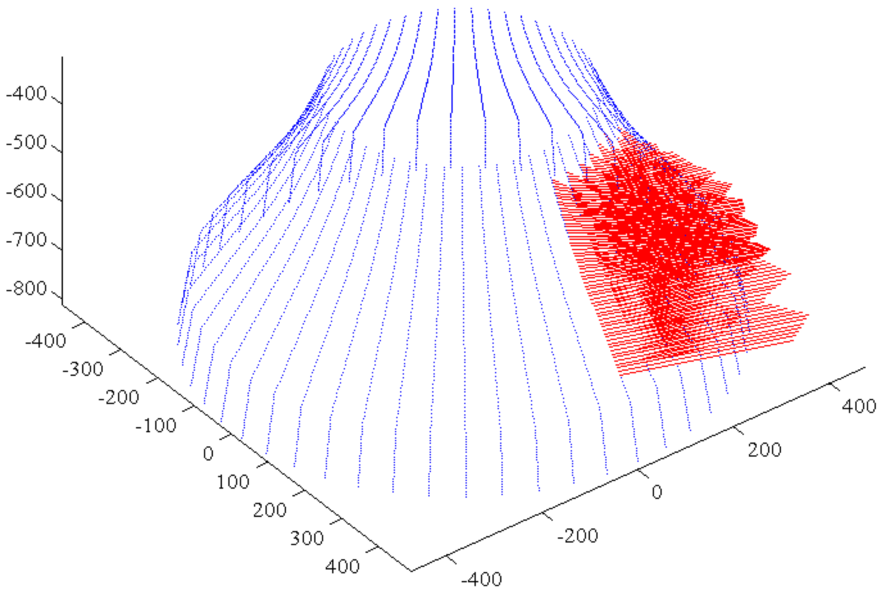
Take home message:

Single particle breakage requires lower crushing force compared to interparticle.

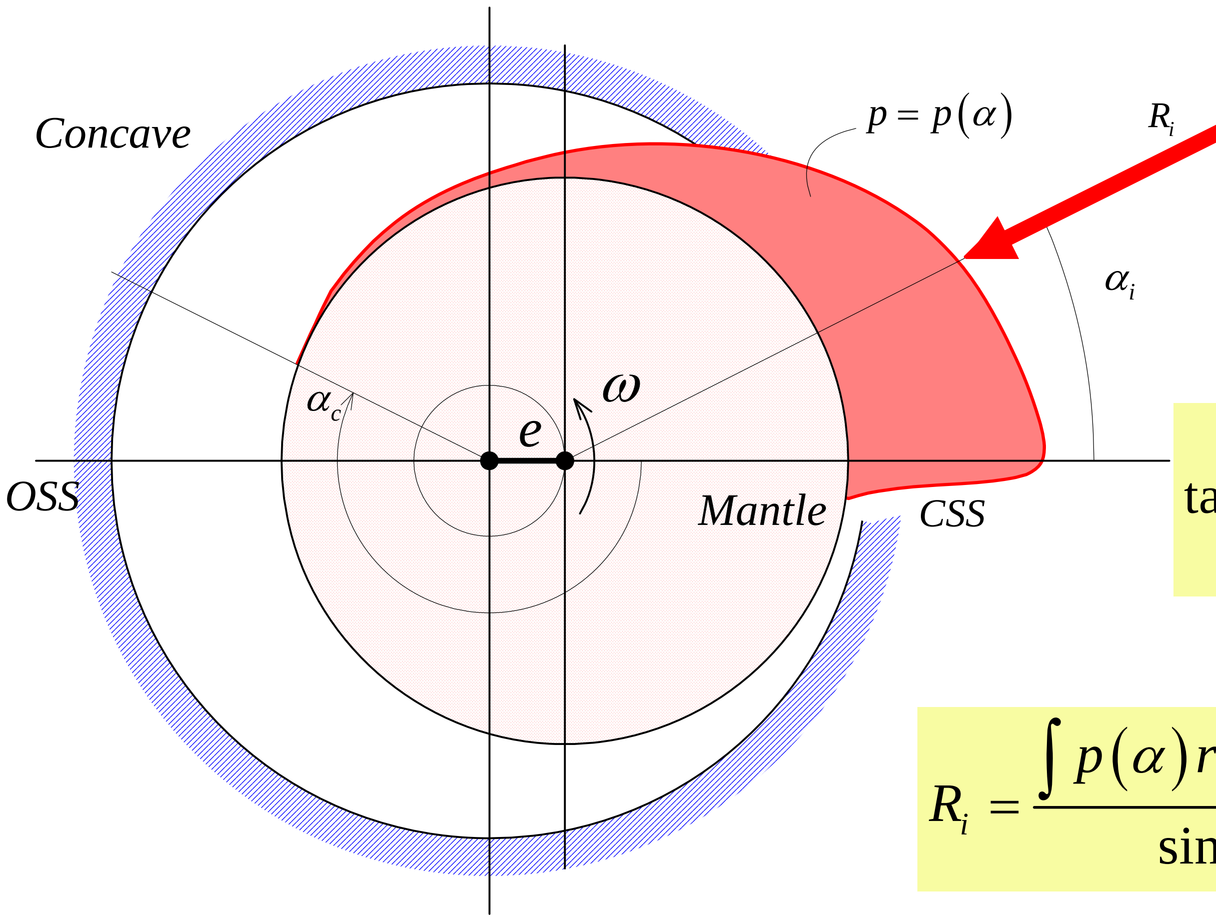
QUARRY ACADEMY

Crushing Force and Power Draw





Crushing Force and Power Draw



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

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

QUARRY ACADEMY

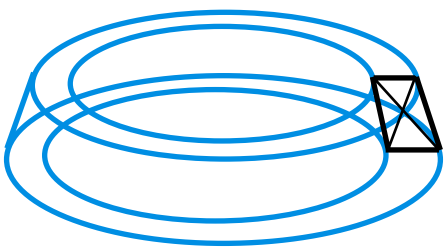
Crusher Capacity

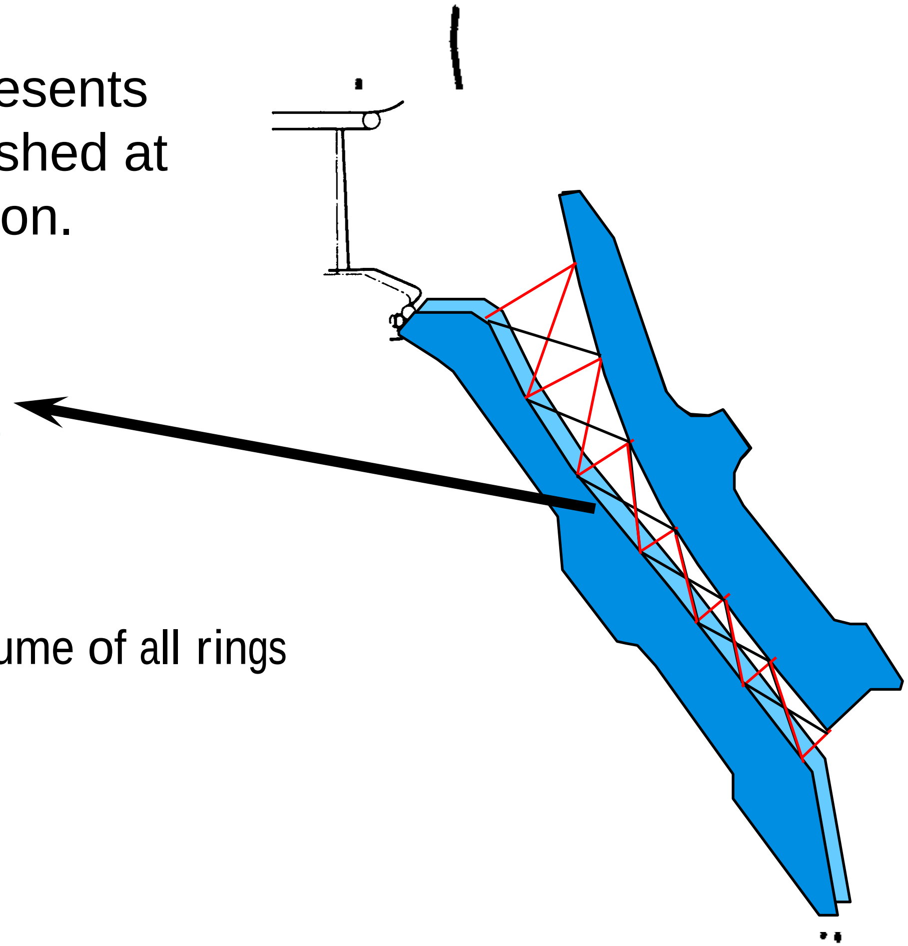
- **What is determining the crusher capacity?**
- **Machine parameters:**
  - ✓ **CSS**
  - ✓ **Throw**
  - ✓ **Chamber Design**
- **Environmental parameters**
  - ✓ **Moisture**
  - ✓ **Feed particle size distribution**
  - ✓ **and some others…**

QUARRY ACADEMY

Crusher Capacity

Each ring volume represents the material that is crushed at each eccentric revolution.

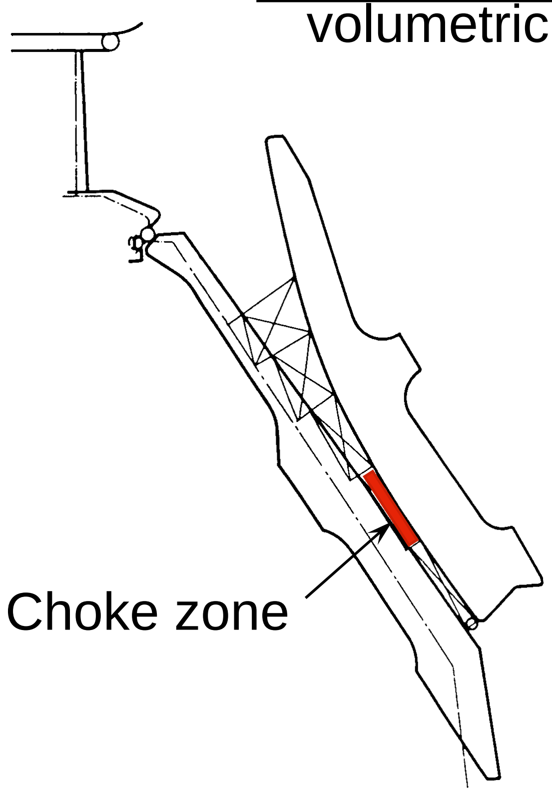


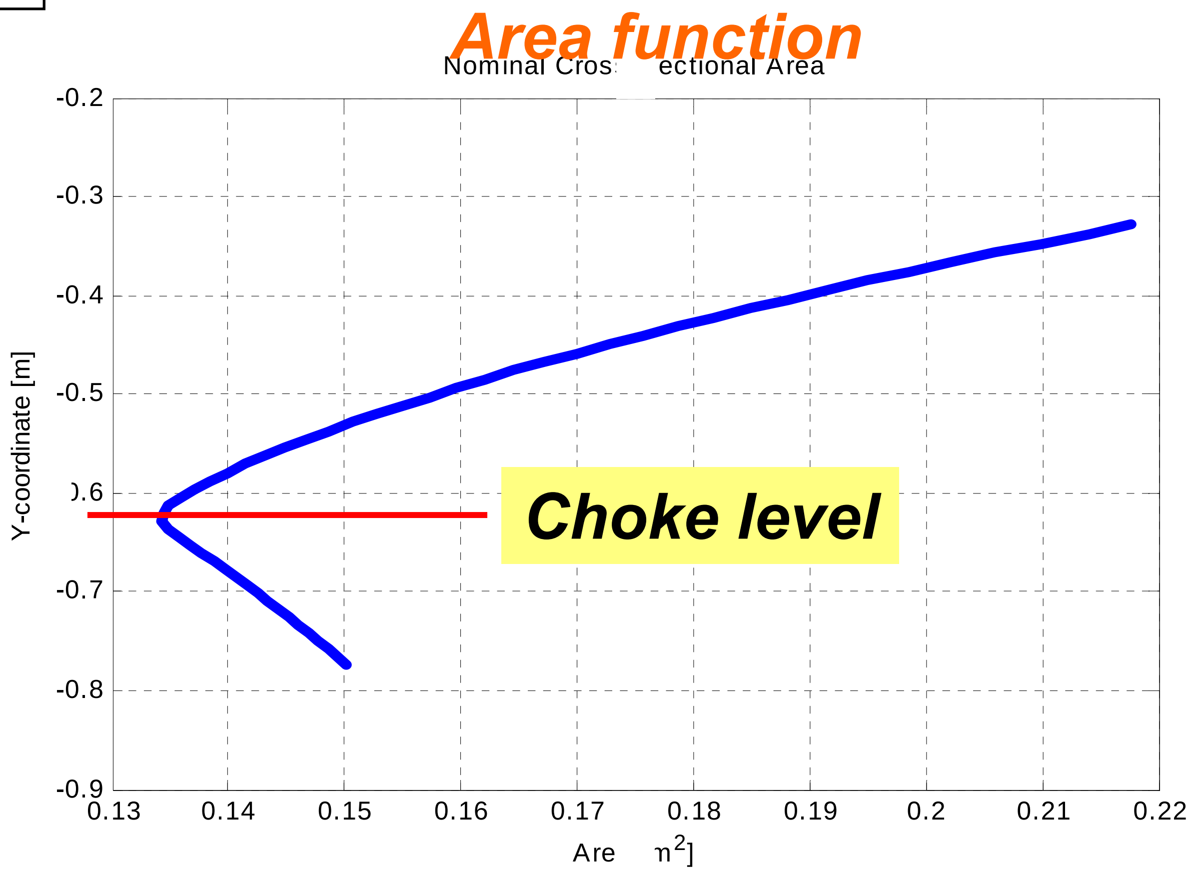


CSS and Throw will affect the volume of all rings

Crusher Capacity

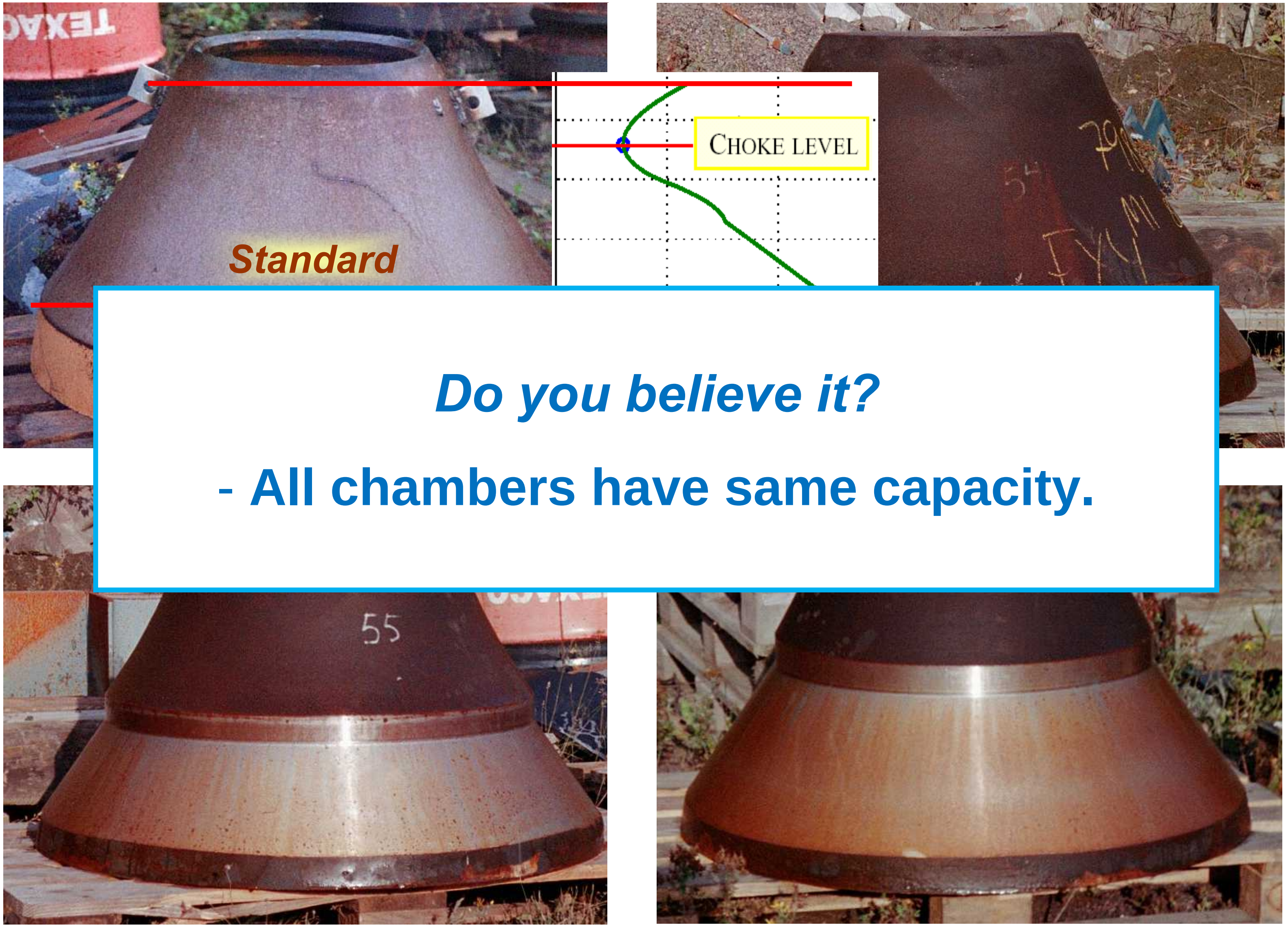
The capacity is volumetric





QUARRY ACADEMY

Crusher Capacity

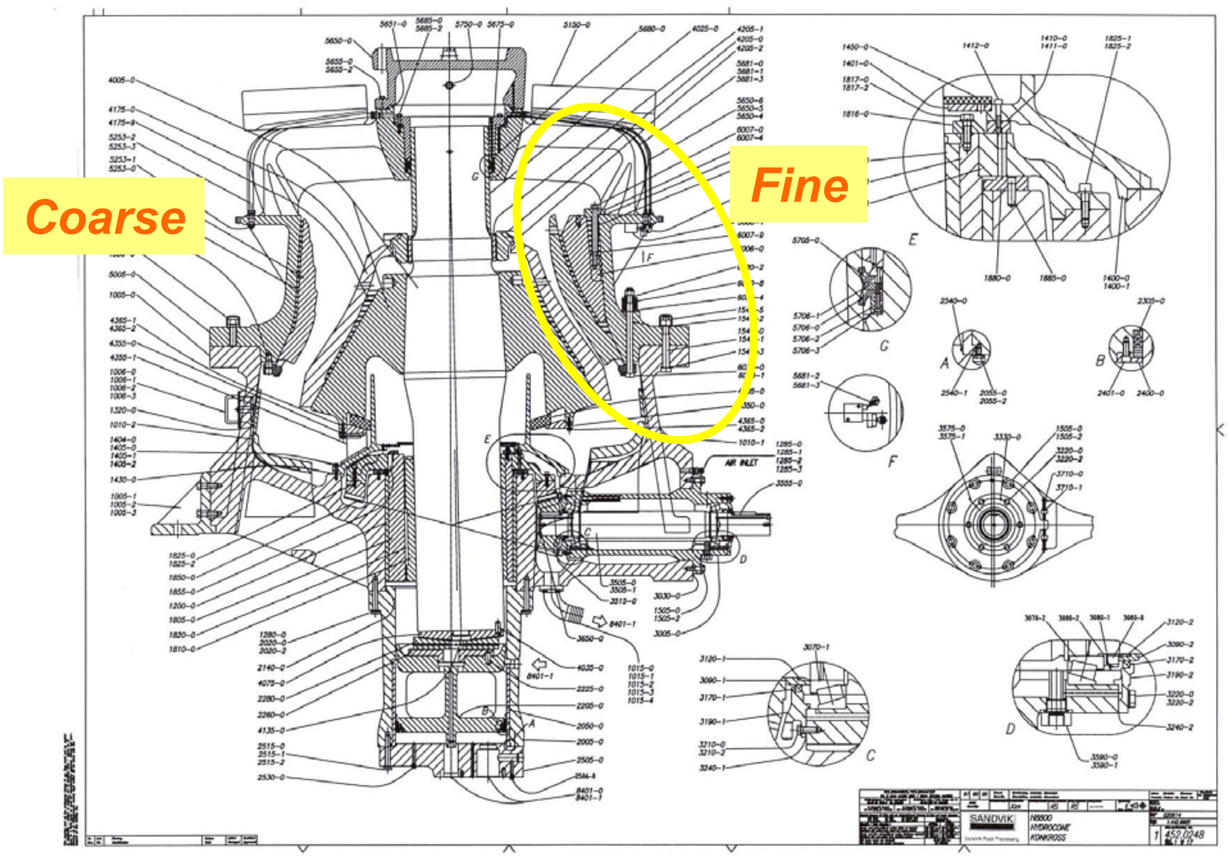


Do you believe it?

- All chambers have same capacity.

Chamber Design

Design drawings



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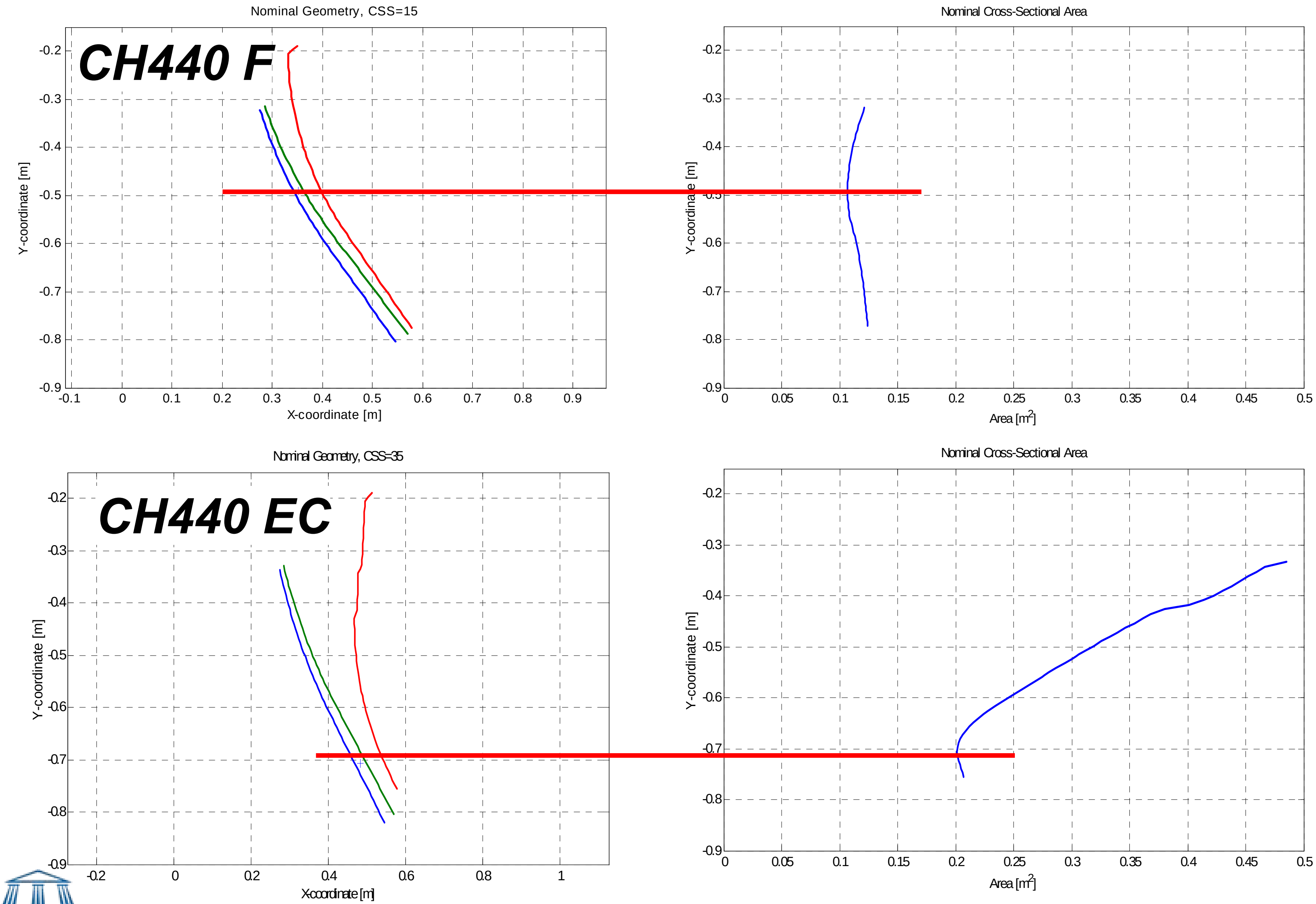
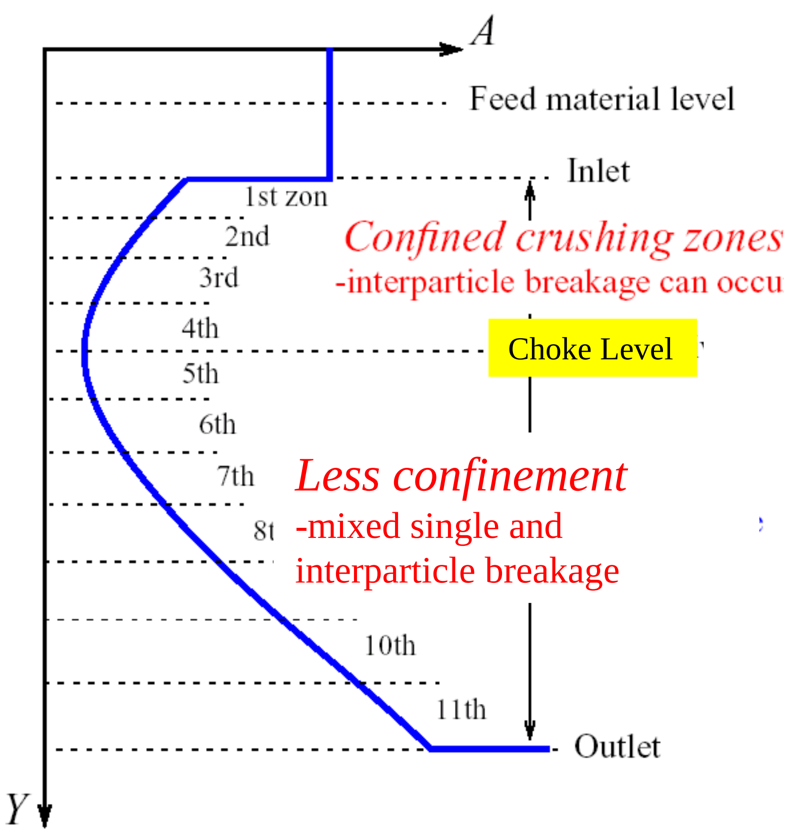
Chamber Design



QUARRY ACADEMY

Chamber Design

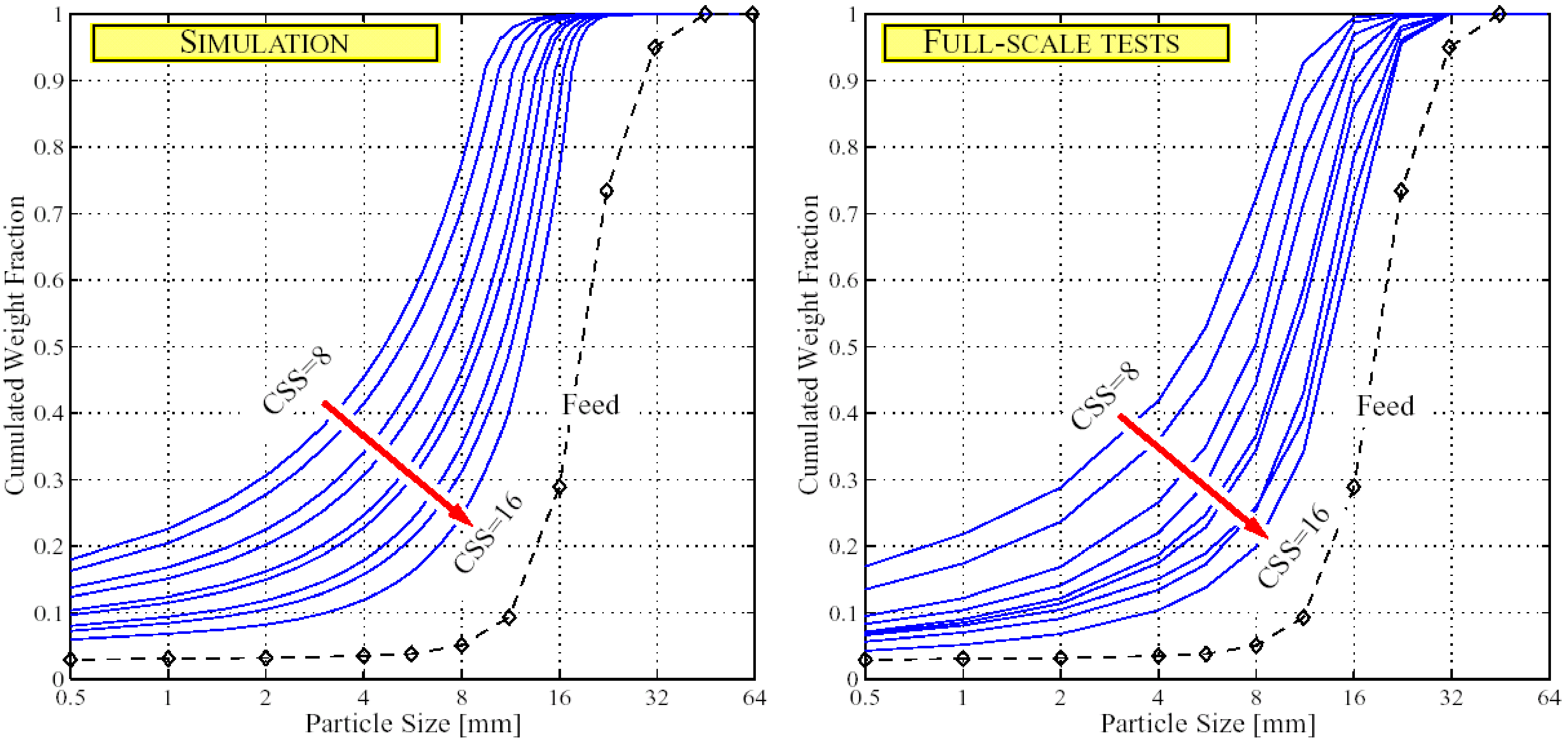


Take home message:

Chamber design affects breakage modes.

Results - *Particle size distributions*

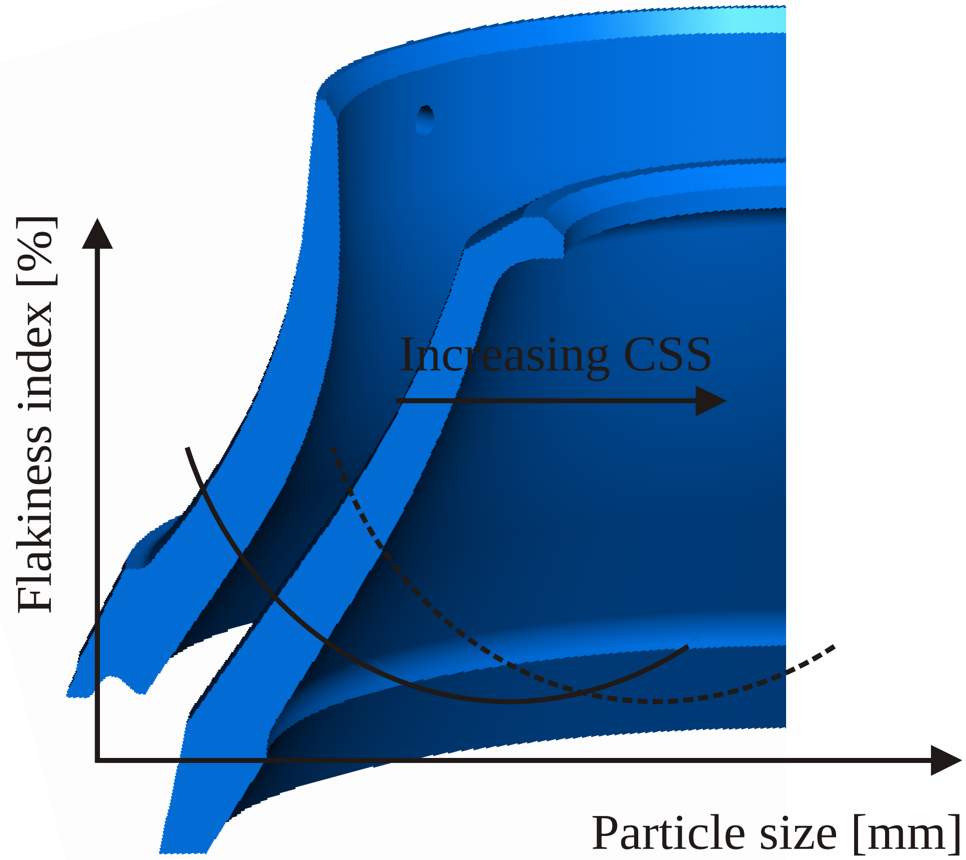
Results from different CSS settings 8-16mm



QUARRY ACADEMY

Crusher Operation

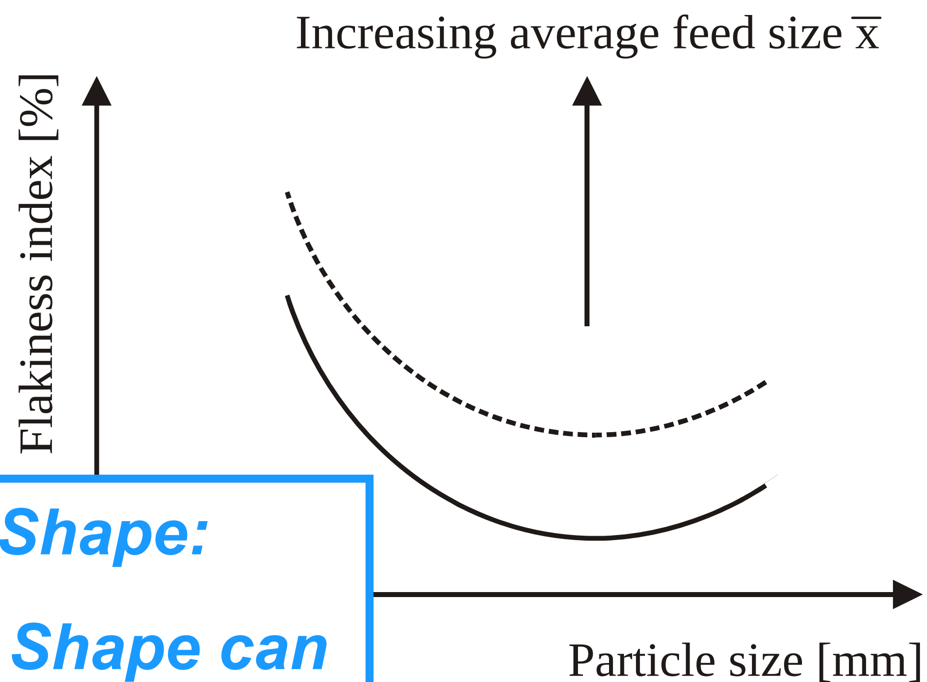
- **Relation between CSS and Shape**
  - ✓ **The size were the best shape can be found is at CSS**
  - ✓ **It is very difficult for cubical stones larger then CSS to pass the chamber**
  - ✓ **Breakage of stones creates flaky particles. Smaller flaky stones will more easily find its way through the chamber**



QUARRY ACADEMY

Crusher Operation

- **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 w round.**
  - ✓ **Breaking roun flaky material.**

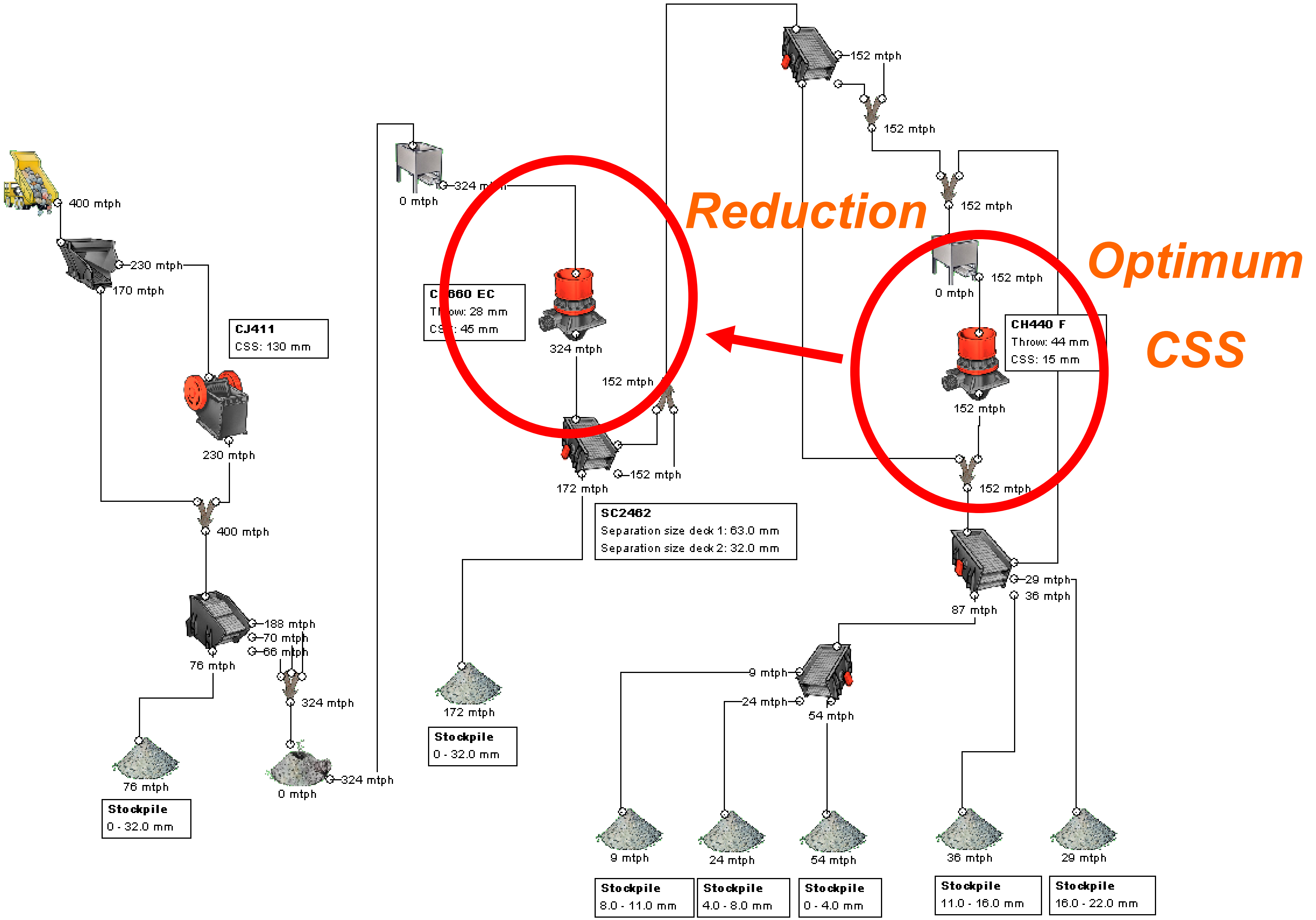


Particle Shape:

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

QUARRY ACADEMY

Crusher Operation



QUARRY ACADEMY

Process Capacity

Capacity:

Process Capacity and Crusher Capacity must correspond

Design capacity: 200 tph

Crusher Capacity: 300 tph

Choke fed Crusher operation(300 tph):

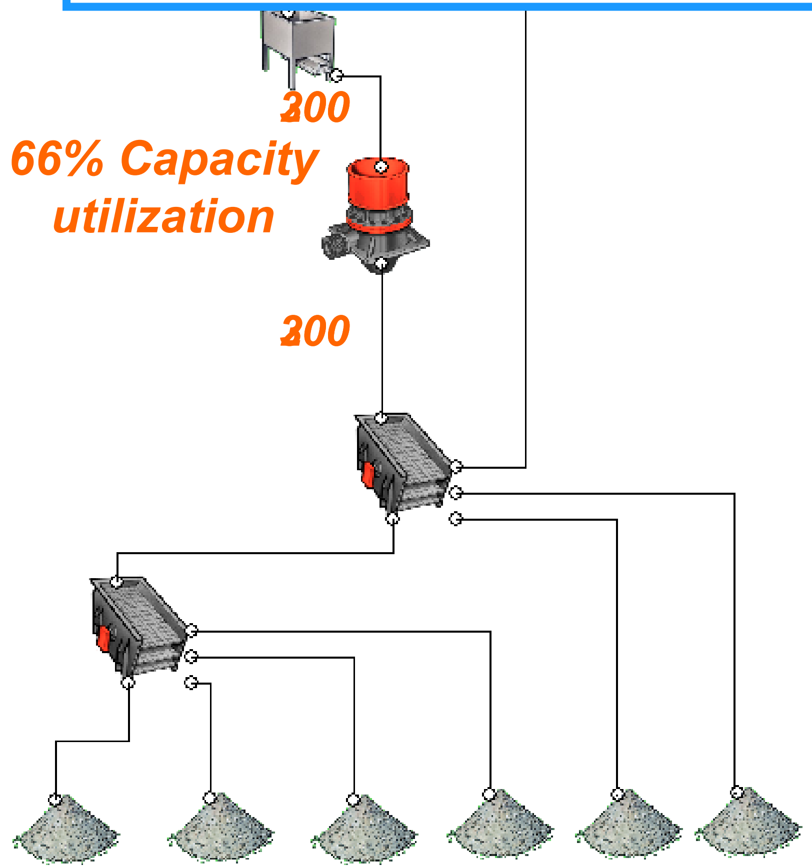
Material in surge bin runs out at even intervals

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

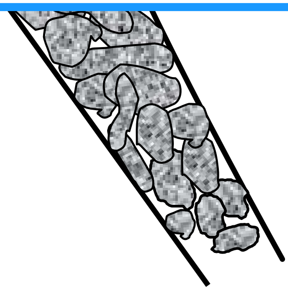


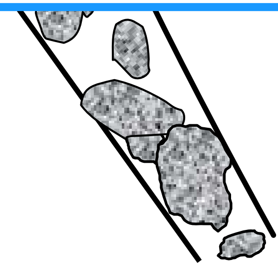
Feeding, the key to successful operation

Feeding:

Choke feeding yields more inter particular crushing

Choke feeding makes the liners wear evenly



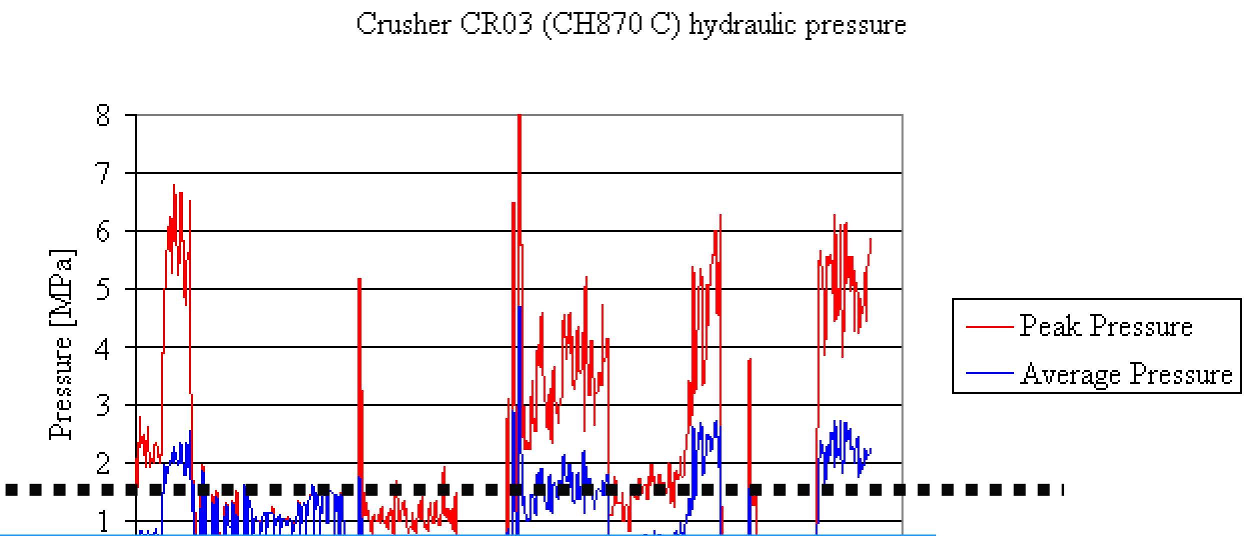


- Bed of rock gives smoother operation.
- The rocks are gradually crushed as they are transported through the crushing chamber.
- The entire chamber is utilized for crushing.

- The rocks falls/slides through the chamber until they are crushed directly between the concave and mantle.
- The rocks are crushed in one strike which yields big forces
- Most of the crushing in the lower part of the chamber

QUARRY ACADEMY

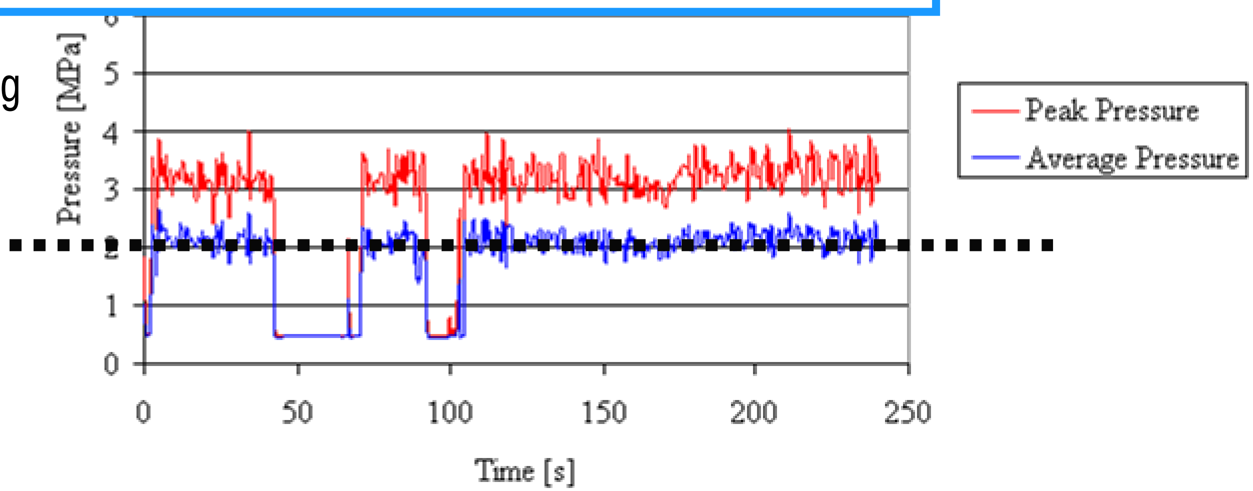
Mis-aligned feed and trickle fed crusher



Feeding:

Feeding condition affects the forces in the crushers and thereby has a direct effect on maintenance cost

Crusher with good feeding conditions



QUARRY ACADEMY

Optimization of a Final Crushing Stage

- The crushers are the last size reduction stage in the value chain.
- Over crushing is common.
- The connection between crusher setting and yield is often unknown
- The rock cannot be repaired.
- We need to control the crusher carefully.

QUARRY ACADEMY

Optimization of a Final Crushing Stage

Planning → Sampling → Analysis → Optimization

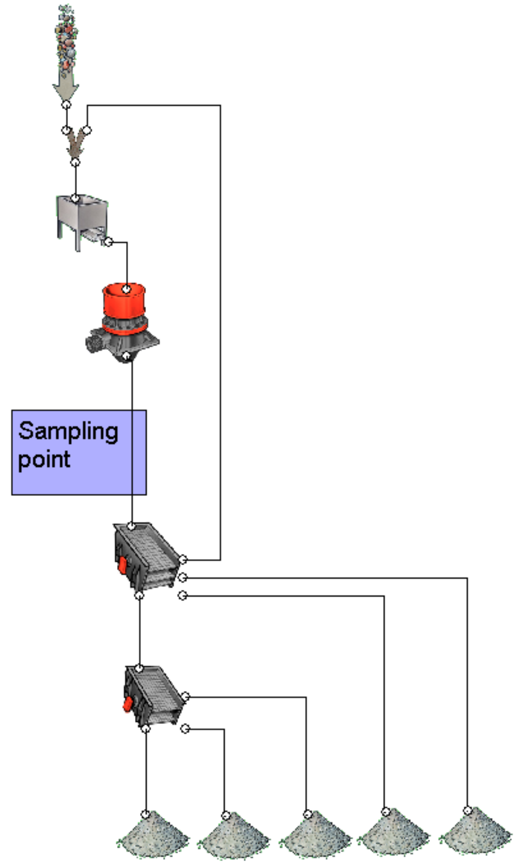
- Optimization of one parameter (CSS) can be done by sampling and analysis
- The invested time and lost production will quickly be repaid by increased productivity
- Combine product yield and economic aspects
- This can be done by taking samples and making the analysis in MS Excel

QUARRY ACADEMY

Optimization of a Final Crushing Stage

Planning → Sampling → Analysis → Optimization

- Material from crusher is sampled
- Measure the capacity at each crusher settings. CSS will effect the final product capacity, especially in a closed circuit.
- Production of 4 valuable products
  - ✓ 0.08-0.16'' (2-4 mm)
  - ✓ 0.16-0.32'' (4-8 mm)
  - ✓ 0.32-0.64'' (8-16 mm)
  - ✓ 0.64-0.87'' (16-22 mm)
- By-product with no value
  - ✓ 0-0.08'' (0-2 mm)



Optimization of a Final Crushing Stage

Planning → Sampling → Analysis → Optimization

- Run the crusher at different settings
- Take at least one sample at each setting. (Multiple samples are often useful)

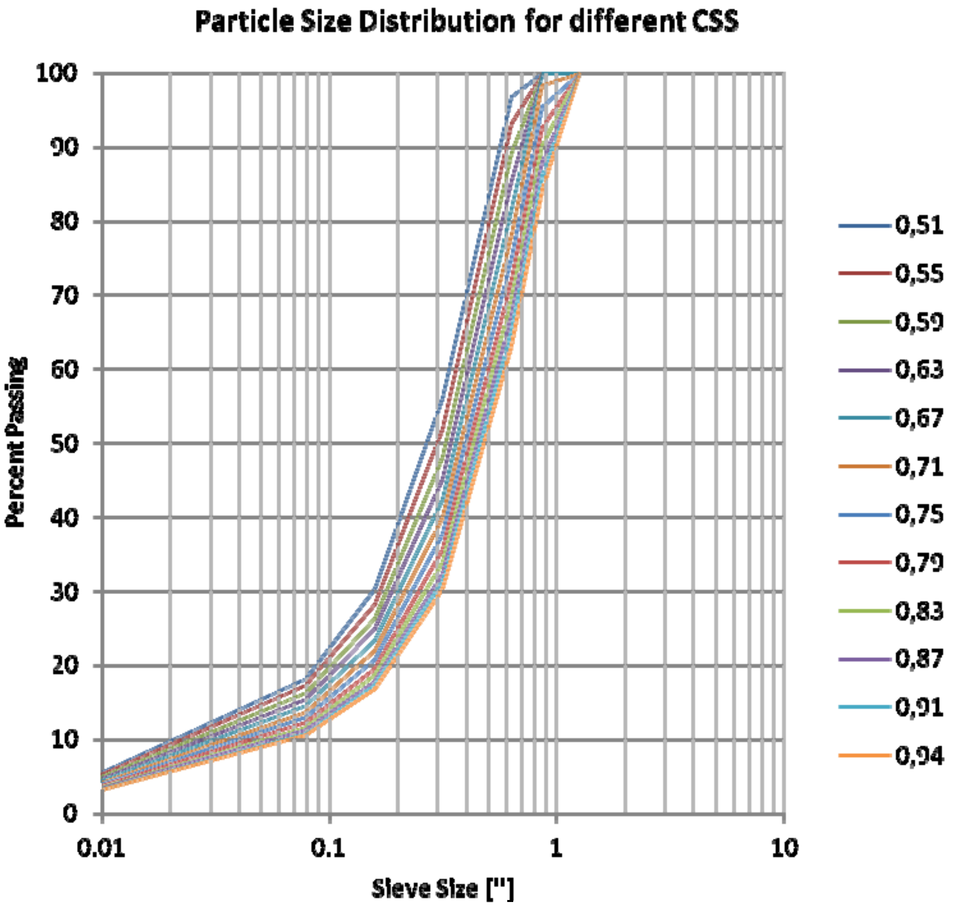
- Special Attention to Safety when taking samples!!
- Position of point were samples are taking.
- Ensure that the conveyor will not start by accident.

QUARRY ACADEMY

Optimization of a Final Crushing Stage

Planning | Sampling | **Analysis** | Optimization

- **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

Planning → Sampling → Analysis → Optimization

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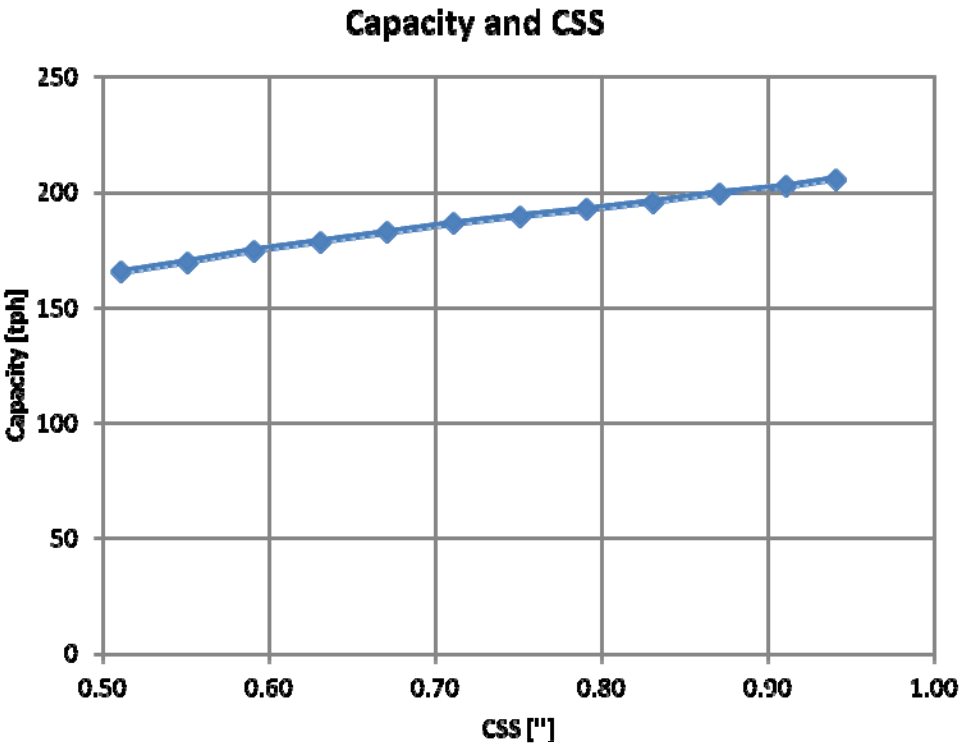
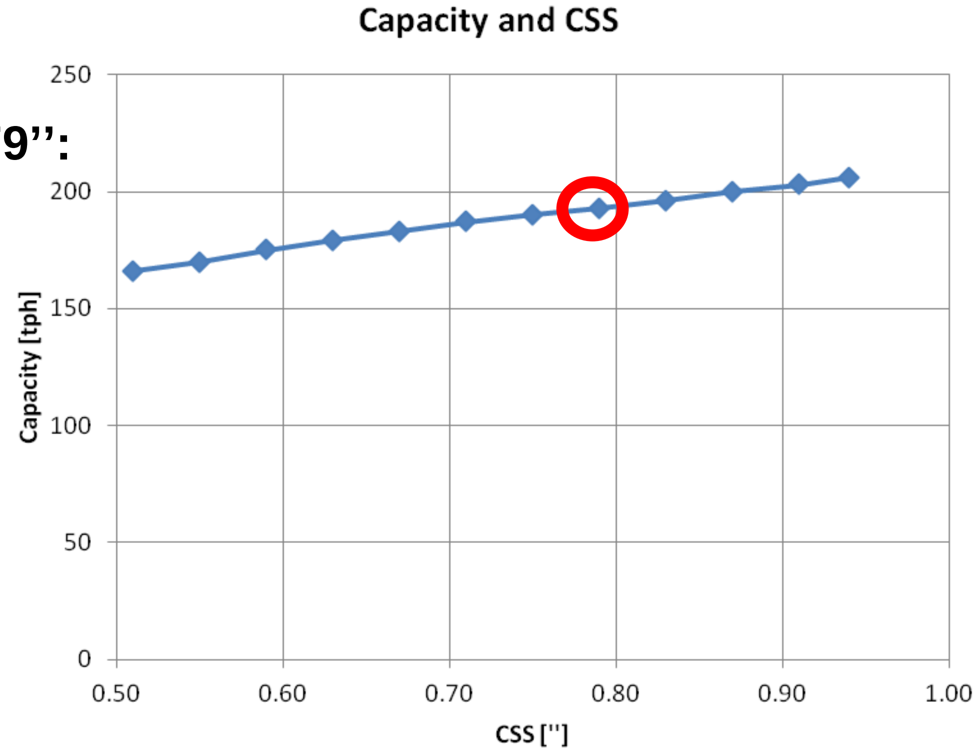


QUARRY ACADEMY

Optimization of a Final Crushing Stage

Planning | Sampling | **Analysis** | Optimization

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



- Example 0.08’’-0.16’’ mm at CSS 0.79’’:
  - ✓ Percentage of crusher production
  - ✓ 20% - 11% = 9%
  - ✓ Crusher capacity
  - ✓ 193 tph
  - ✓ Total Production:
  - ✓ 193 tph x 9% = 17 tph

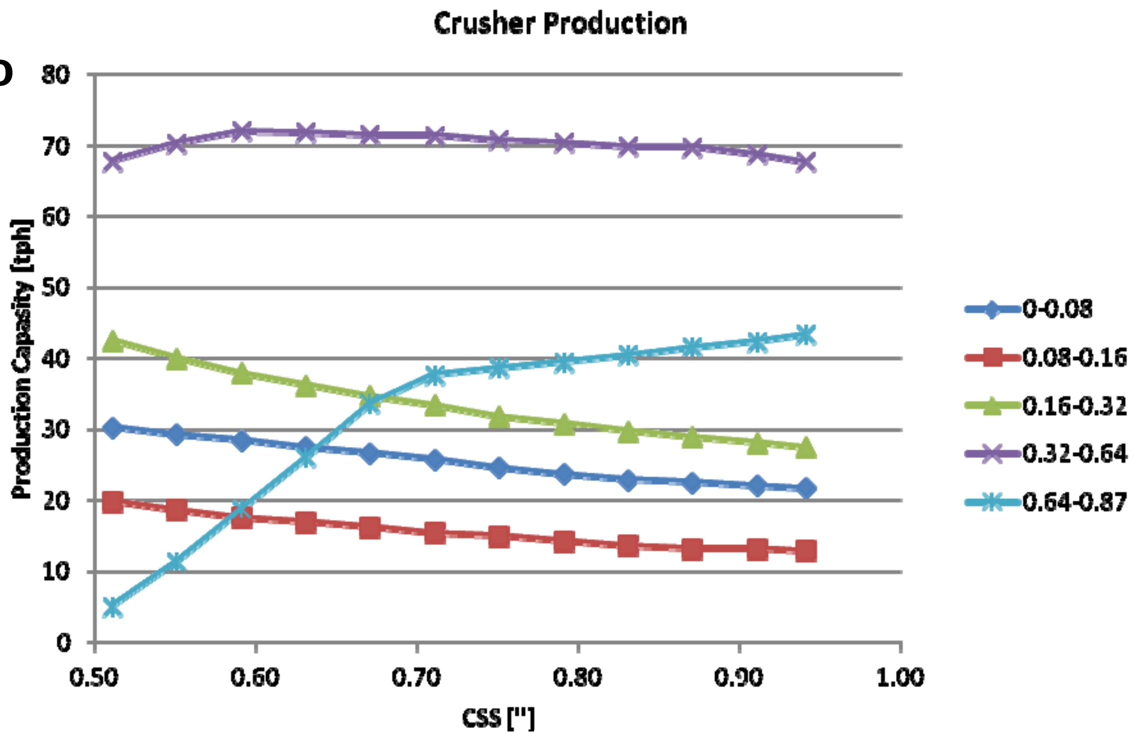
QUARRY ACADEMY

Optimization of a Final Crushing Stage

Planning → Sampling → **Analysis** → Optimization

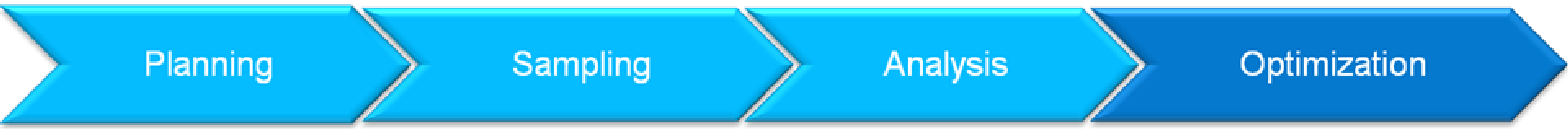
- **Entering all the values into MS Excel makes this easy to get production capacities.**

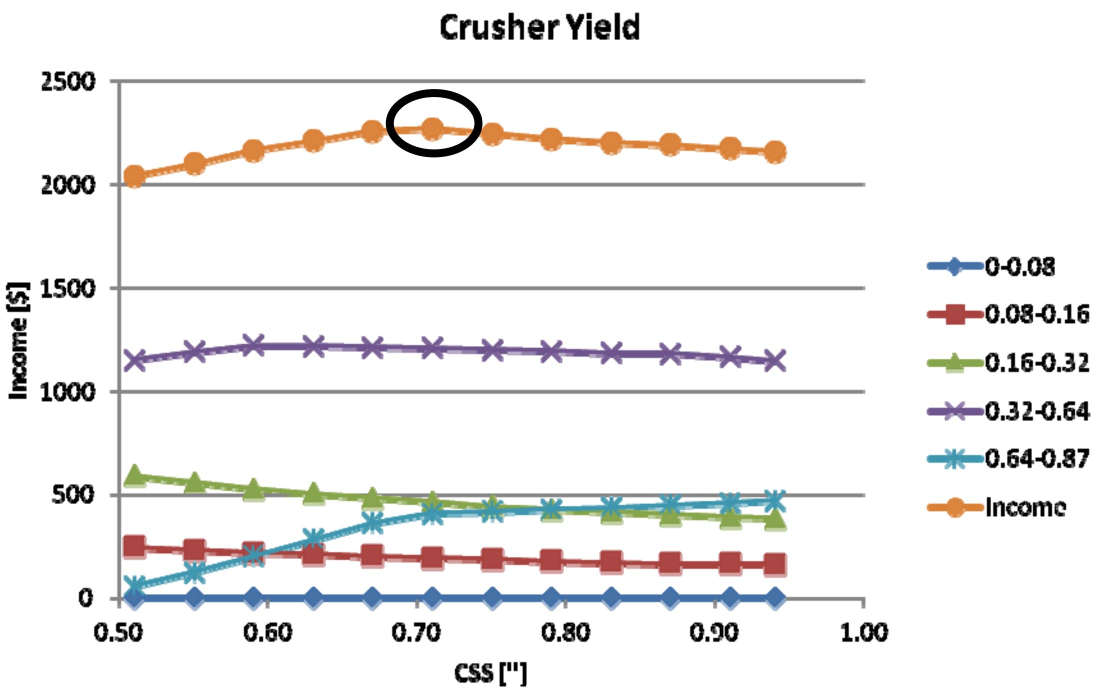
- **Still difficult to determine the optimal setting**



QUARRY ACADEMY

Optimization of a Final Crushing Stage





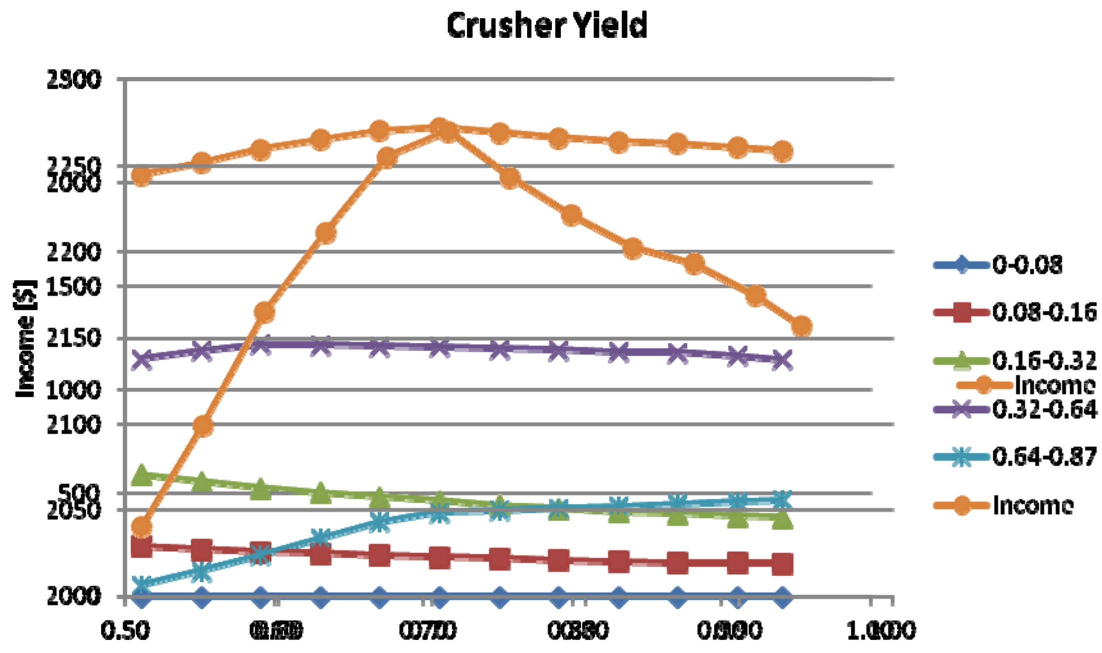
- Use the price* per ton for all products:
  - ✓ 0-0.08'': $ 0 (by-product)
  - ✓ 0.08-0.16'': $ 12.30
  - ✓ 0.16-0.32'': $ 13.85
  - ✓ 0.32-0.64'': $ 16.90
  - ✓ 0.64-0.87'': $ 10.80
- Make an income graph by combining prices with capacity

All prices are estimates based on publicly available data

Optimization of a Final Crushing Stage

Planning | Sampling | Analysis | **Optimization**

- **What difference does it make?**
- **Running the crusher 0.08’’ off:**
  - ✓ **Decrease the profit by 58.5 $/h**
  - ✓ **Running the crusher at 1600 hours per year: 58.5*1600=$93600**



Optimization:

The effort put in to optimization will repay itself quickly

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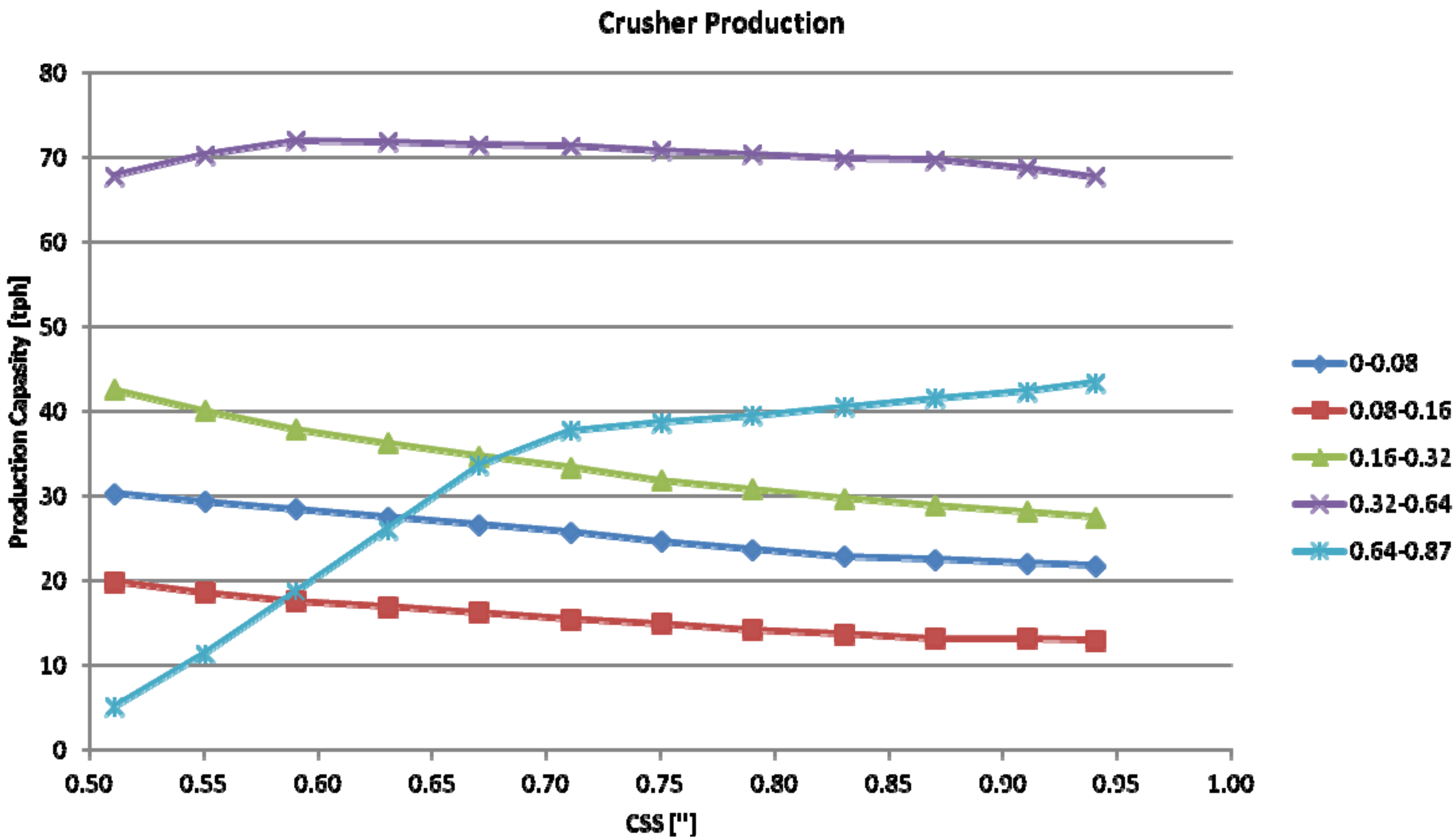
Crusher Performance Map

Planning | Sampling | Analysis | Optimization



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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 inter particle breakage.
- Capacity is controlled by choke area.
- Chamber design determines breakage mode
- CSS and reduction ratio effects particle shape
- Crusher capacity and process capacity should match each other.
- Feeding conditions are important for efficient crusher operation
- Optimization of a crusher is easy and profitable.

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LIGHTEN UP!