Crusher Dynamics, Design and Performance

Magnus Evertsson

QUARRY ACADEMY

Improving Processes. Instilling Expertise.

DYNO Dyno Nobel

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SANDVIK

Agenda

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

NCC, Borås, Sweden

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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Audience Survey

What is the most important crusher parameter?

A. Closed Side Setting
B. Feeding
C. Chamber selection
D. Capacity
E. Eccentric speed

Background

Aggregate producers in Sweden required more knowledge and fundamental understanding about crushing

Modeling of cone crushers started at Chalmers University of Technology in 1993.

Background

Why compressive crushing?
(hard rock types)

- ✓ **Energy efficient**
- ✓ **Acceptable yield of p**
- ✓ **Acceptable particle**
- ✓ **Low fines generatio**
- ✓ **Low wear on manga**

Take home message:

Compressive crushing is energy efficient.

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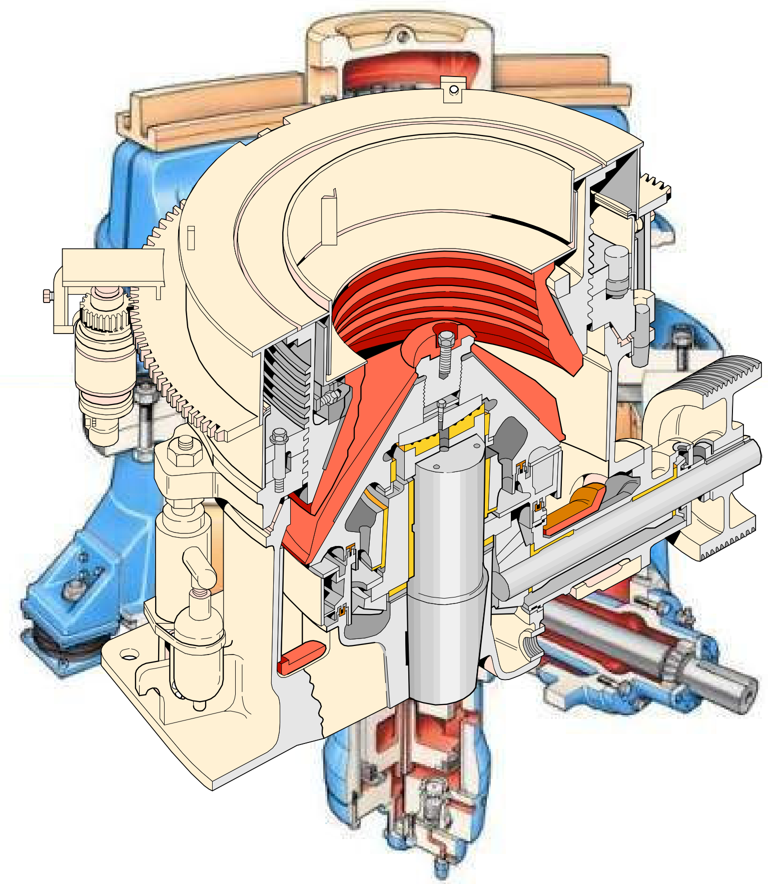
Cone Crushers

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

Should the crusher be the same?

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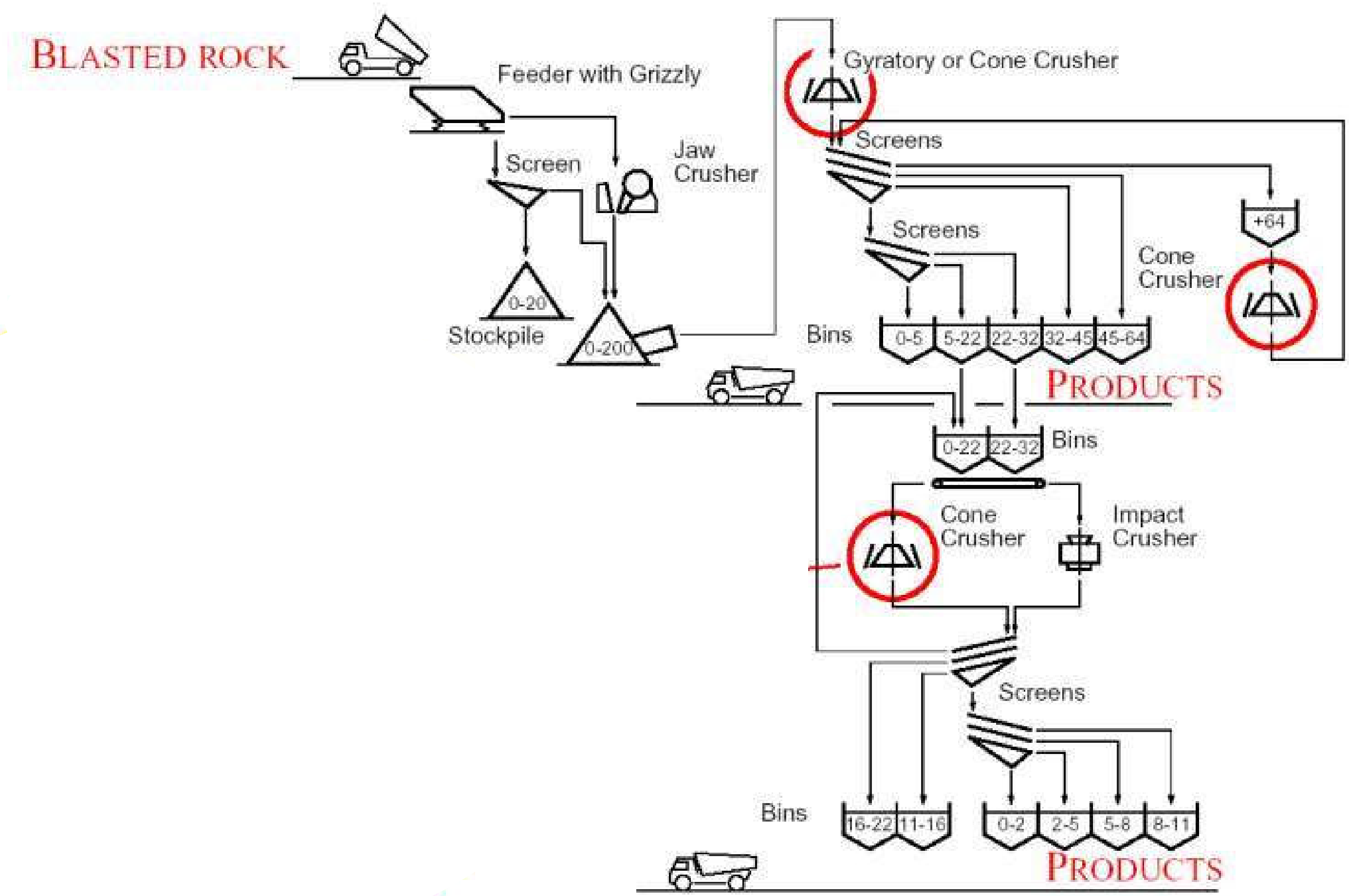
Cone Crushers

Crushing plant - Aggregates



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How OLD is the cone crusher concept?

A. Older than 10 years (but younger than 50)

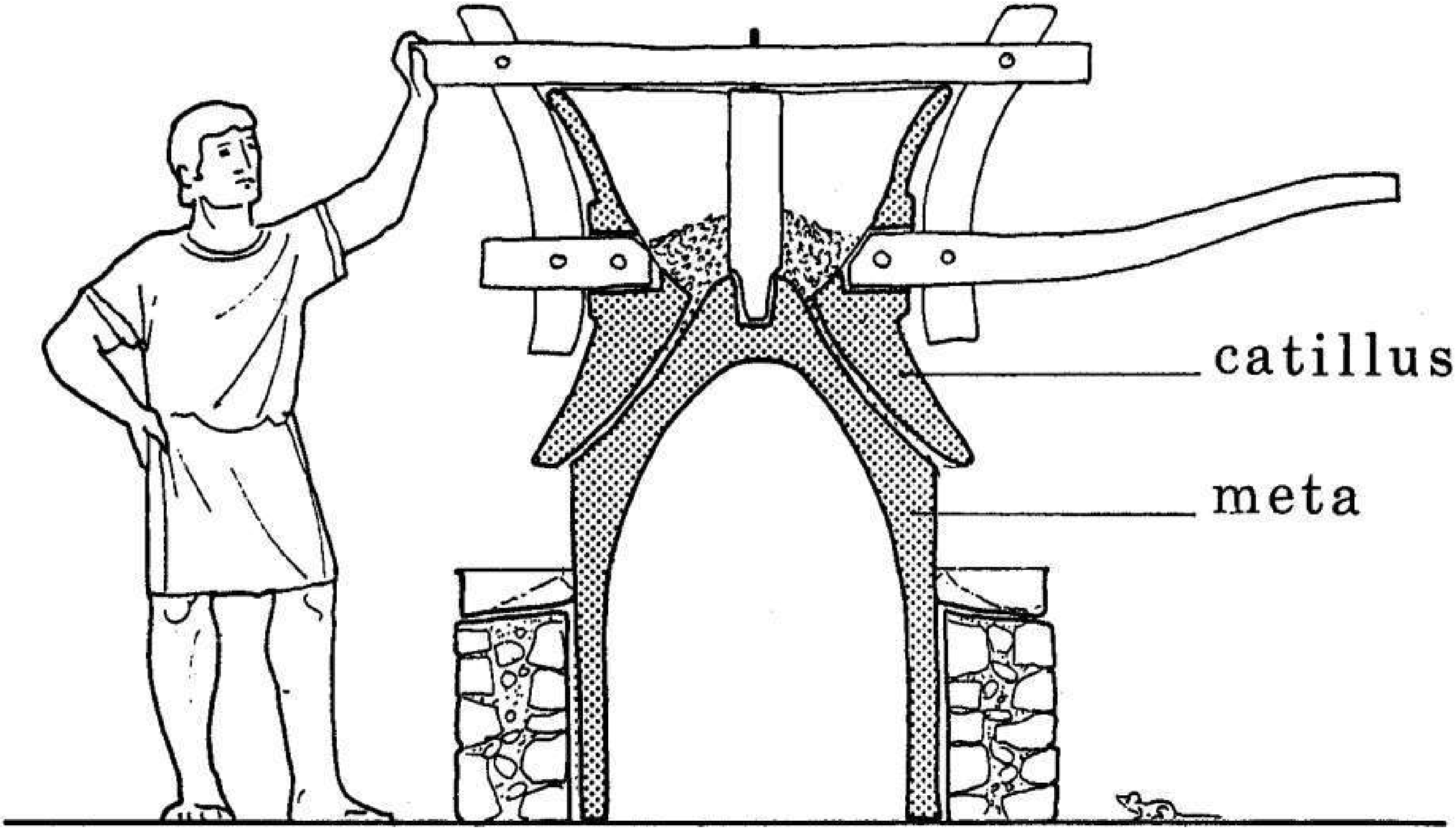
B. Older than 50 years (but younger than 100)

C. Older than 100 years (but younger than 1000)

D. Older than 1000 years

History

History



From Jan Theo Bakker et. al. 1999, *The Mills-Bakeries of Ostia. Description and Interpretation*, Amsterdam.

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The interior of a bakery on a relief from Rome, now in the Vatican Museums

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History

Size reduction and crusher modeling theories

- **…**
- **1954 Fred Bond's WI**
- **1954 Gauldie**
- **1970 Bill Whiten**
- **1991 Ted Bearman**
- **…**

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Why a Crusher Model?

MVI_0980.AVI

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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 considerations

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

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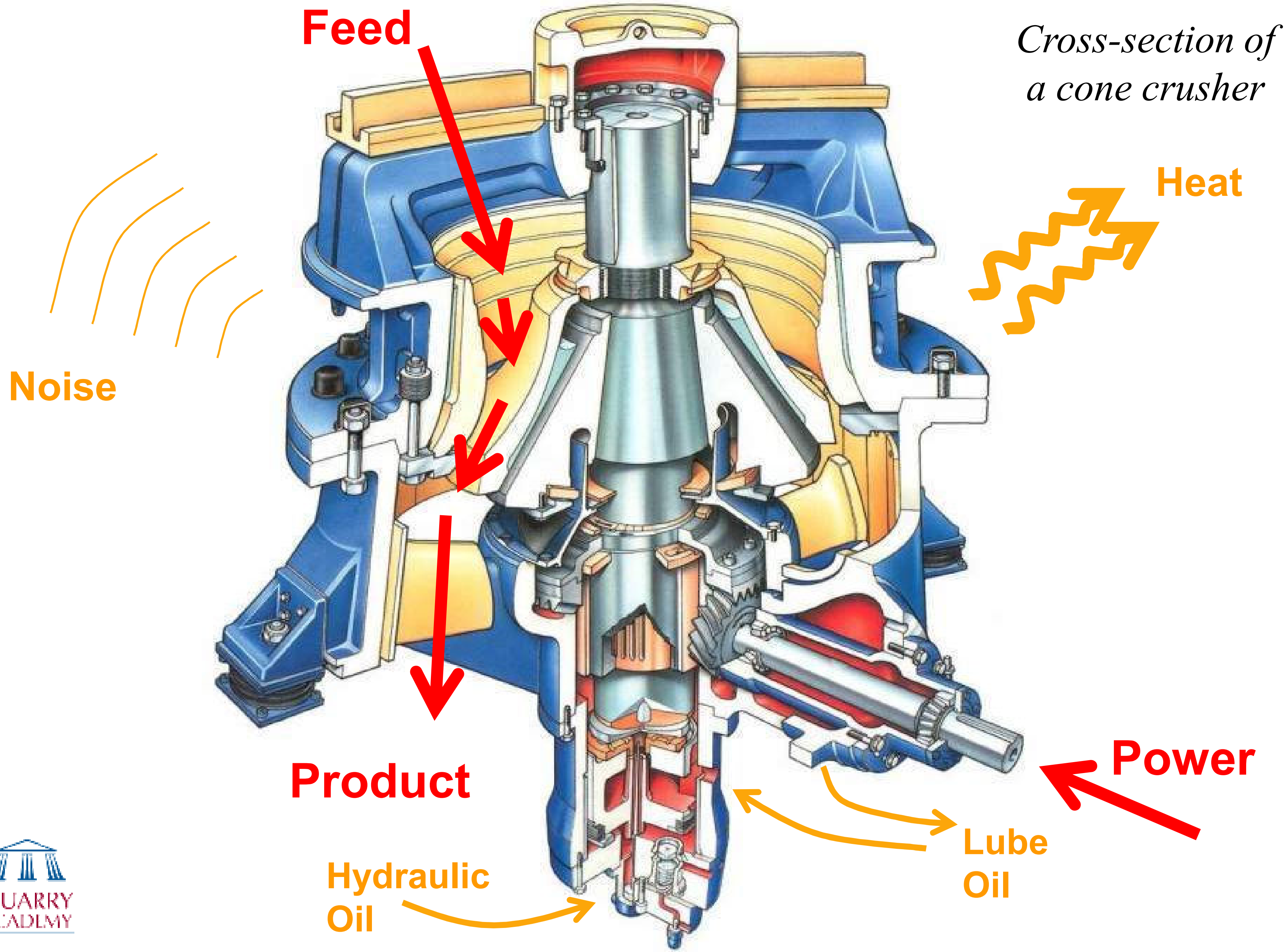
Operating Principle



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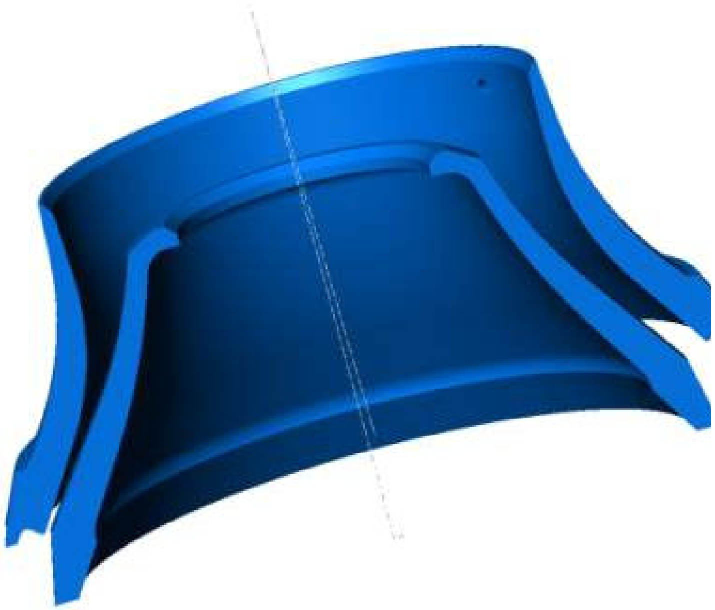
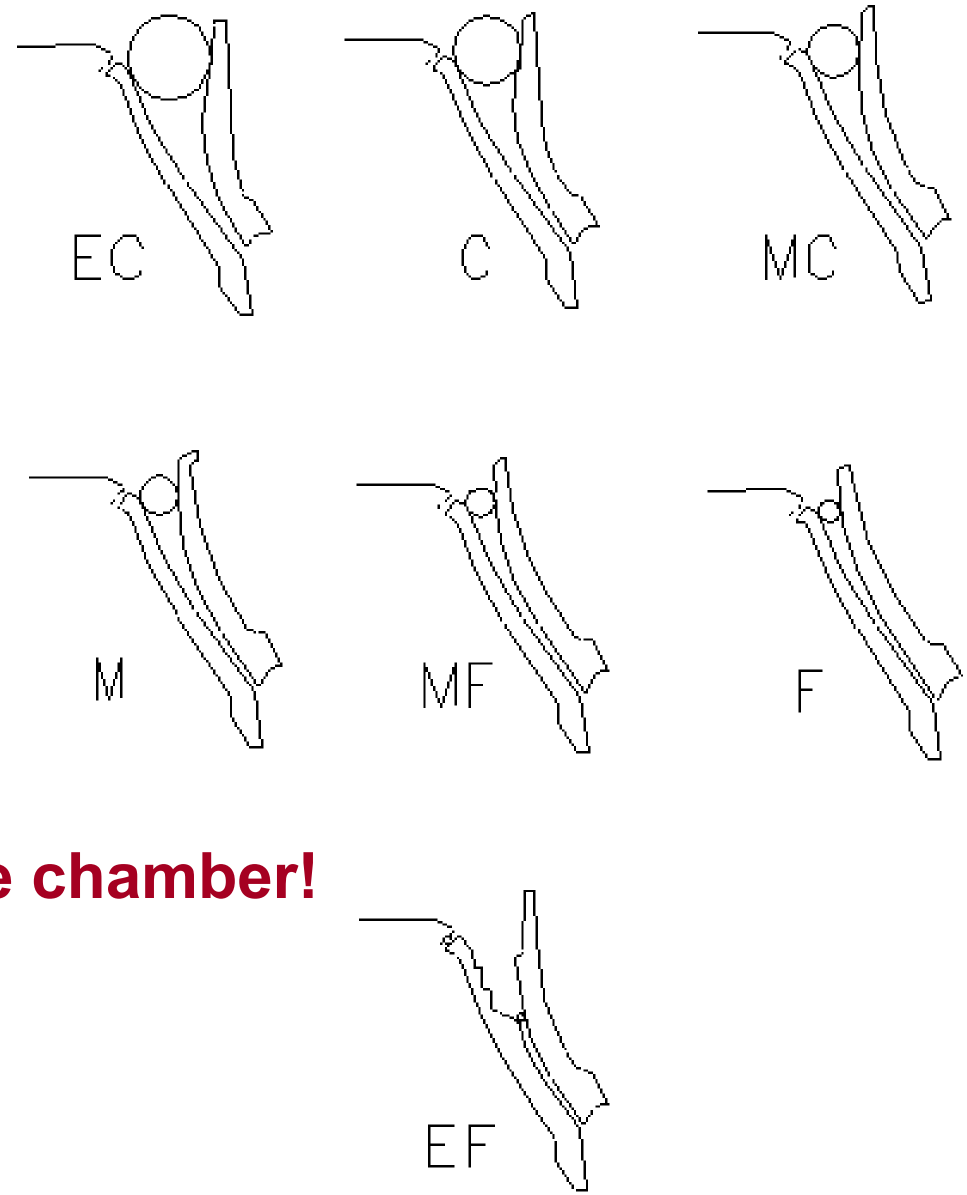
Operating Principle





All crushing starts with the chamber!

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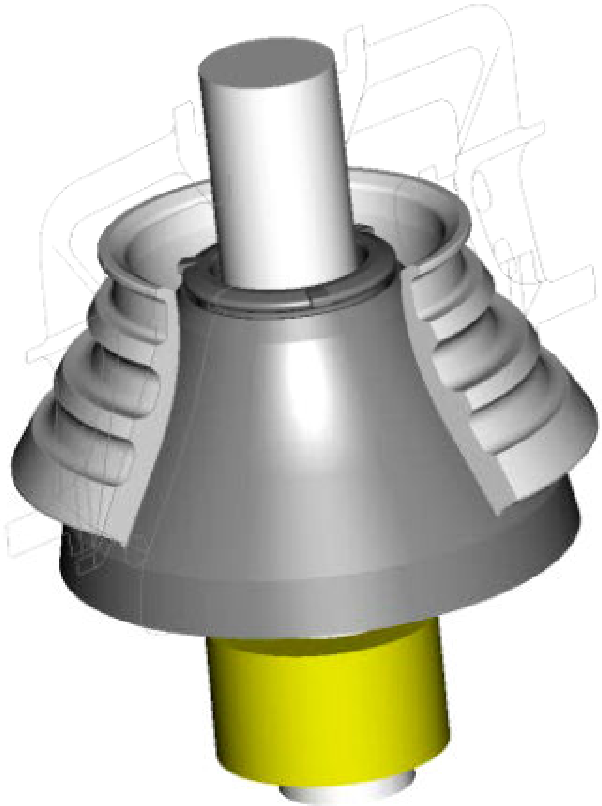
Operating Principle



H3000.mpg

Operating Principle

H3000 2.mpg

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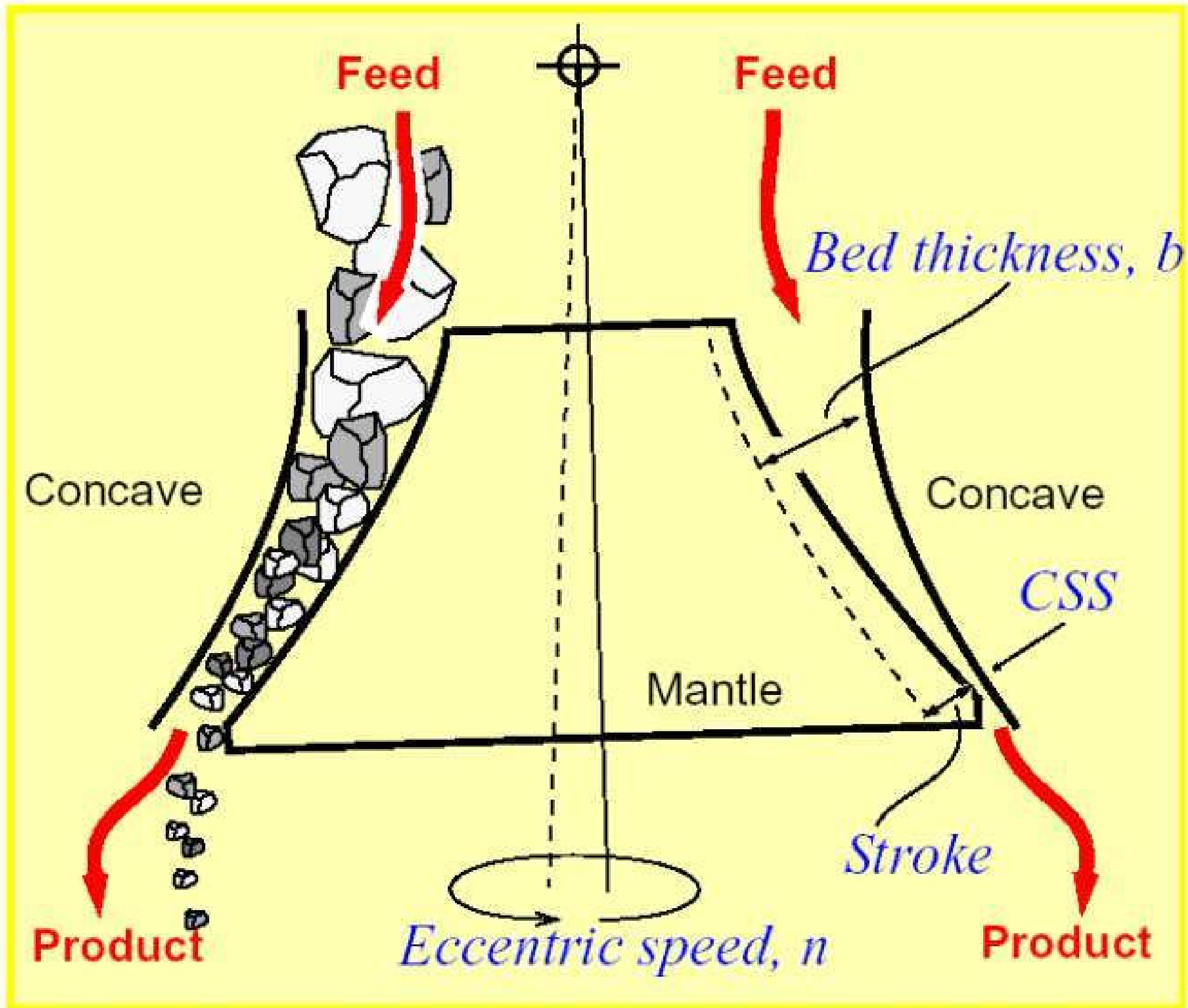
Operating Principle



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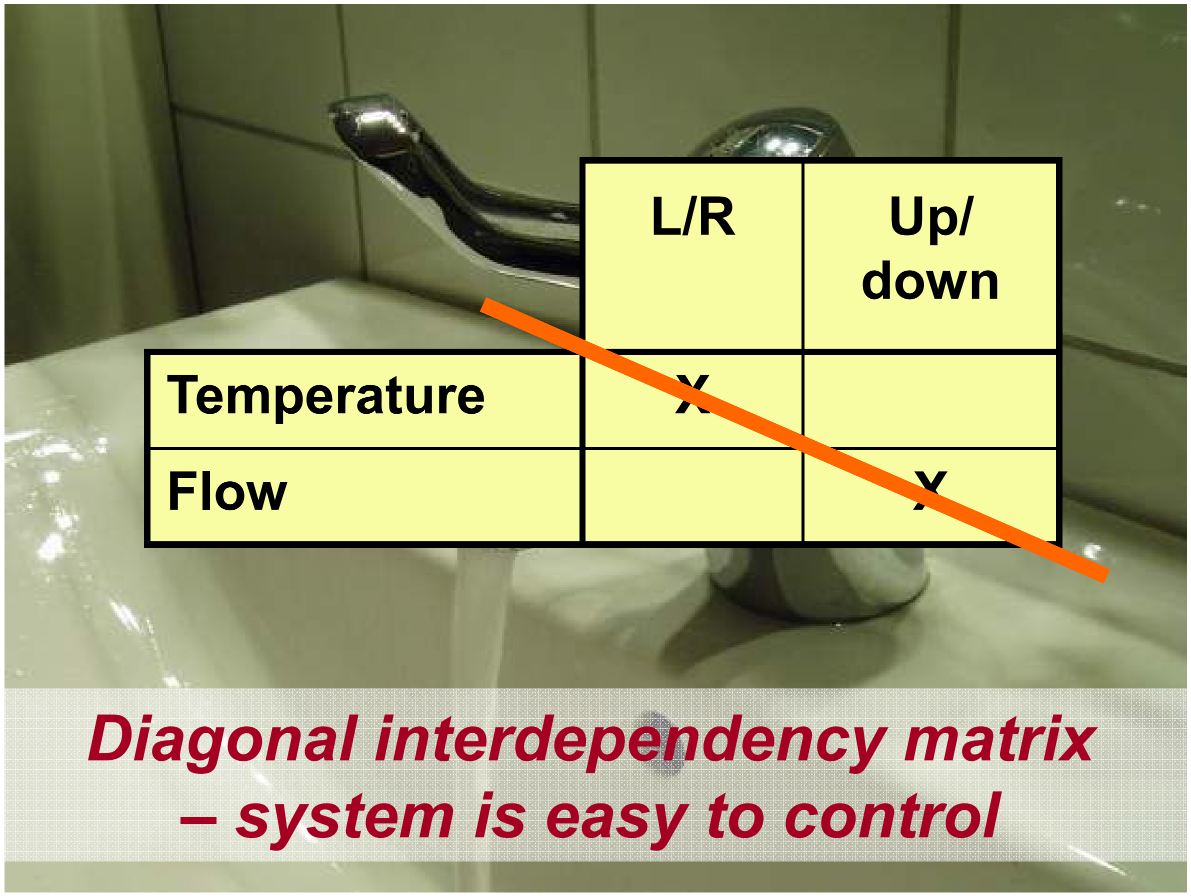
Operating Principle

Dependencies for a water tap...



	L/R	Up/ down
Temperature	X	
Flow		X

Diagonal interdependency matrix – system is easy to control

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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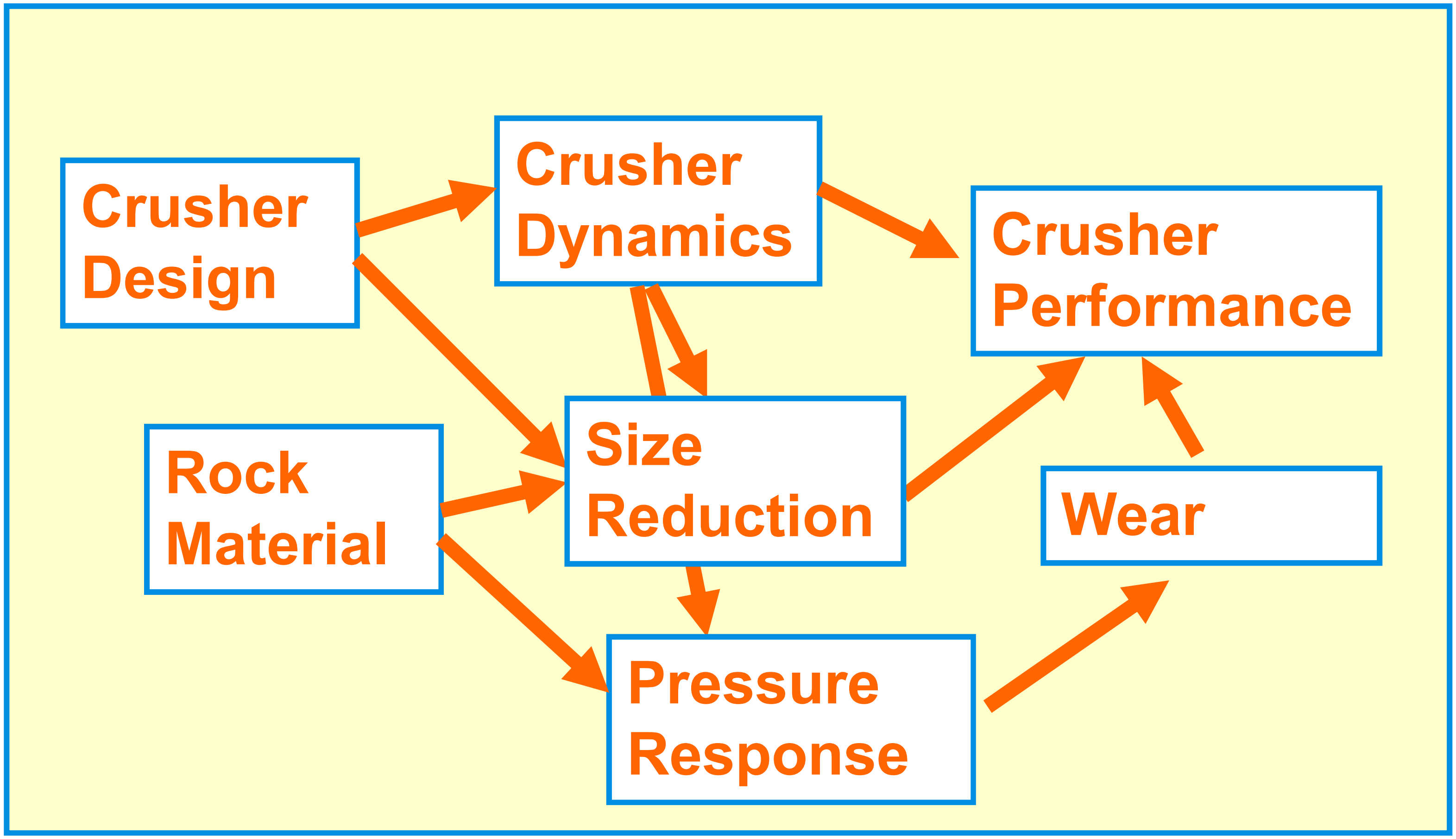
Crusher Model



Crusher Model

The compressive crushing process can be described with two functions.

Selection S **– which?**

Breakage B **– how?**

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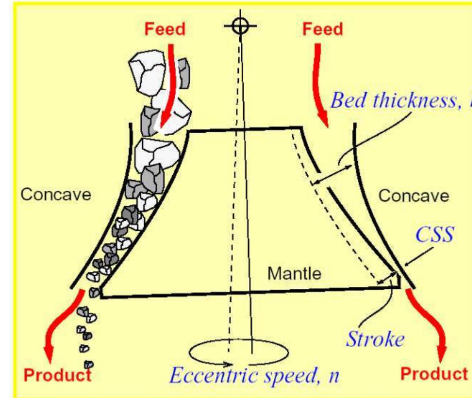
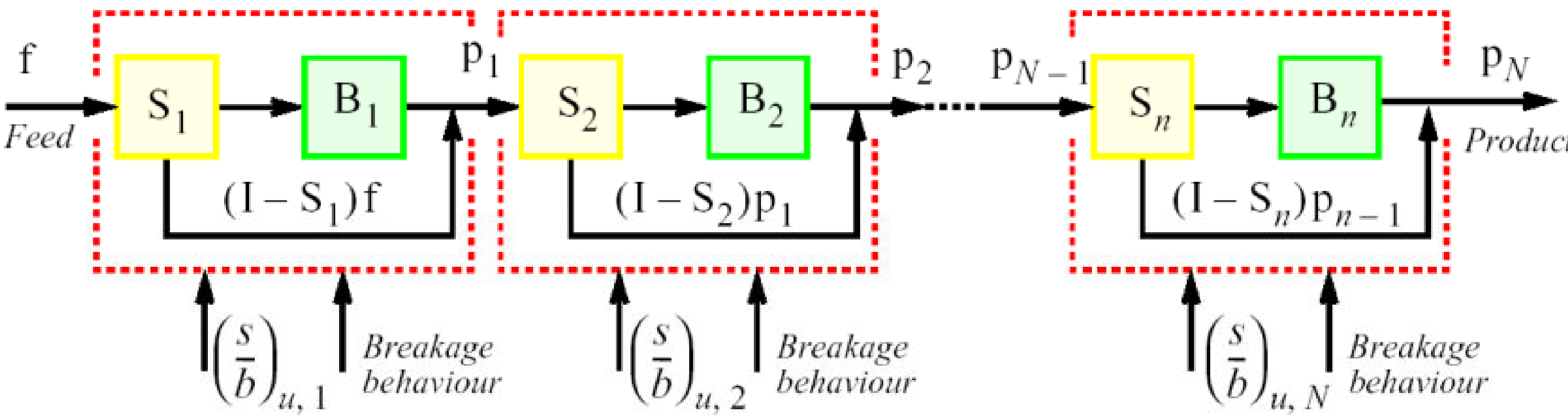
Crusher Model



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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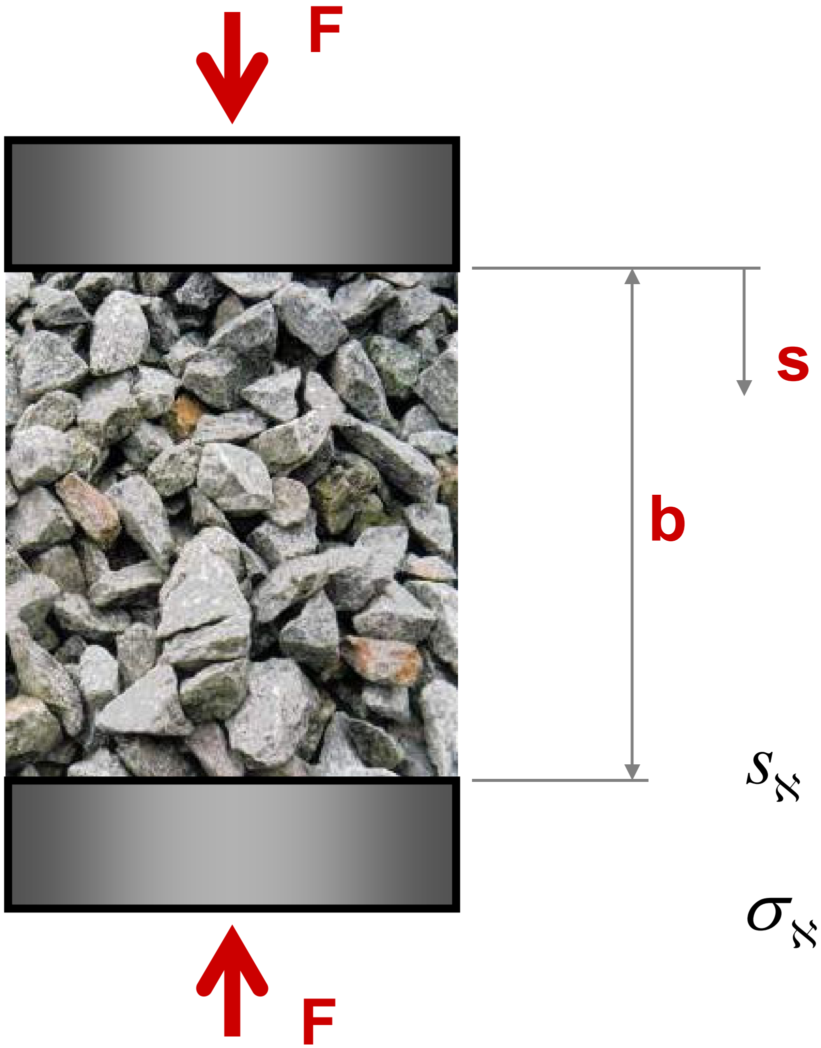
Rock Breakage Behavior



Form conditioned compression

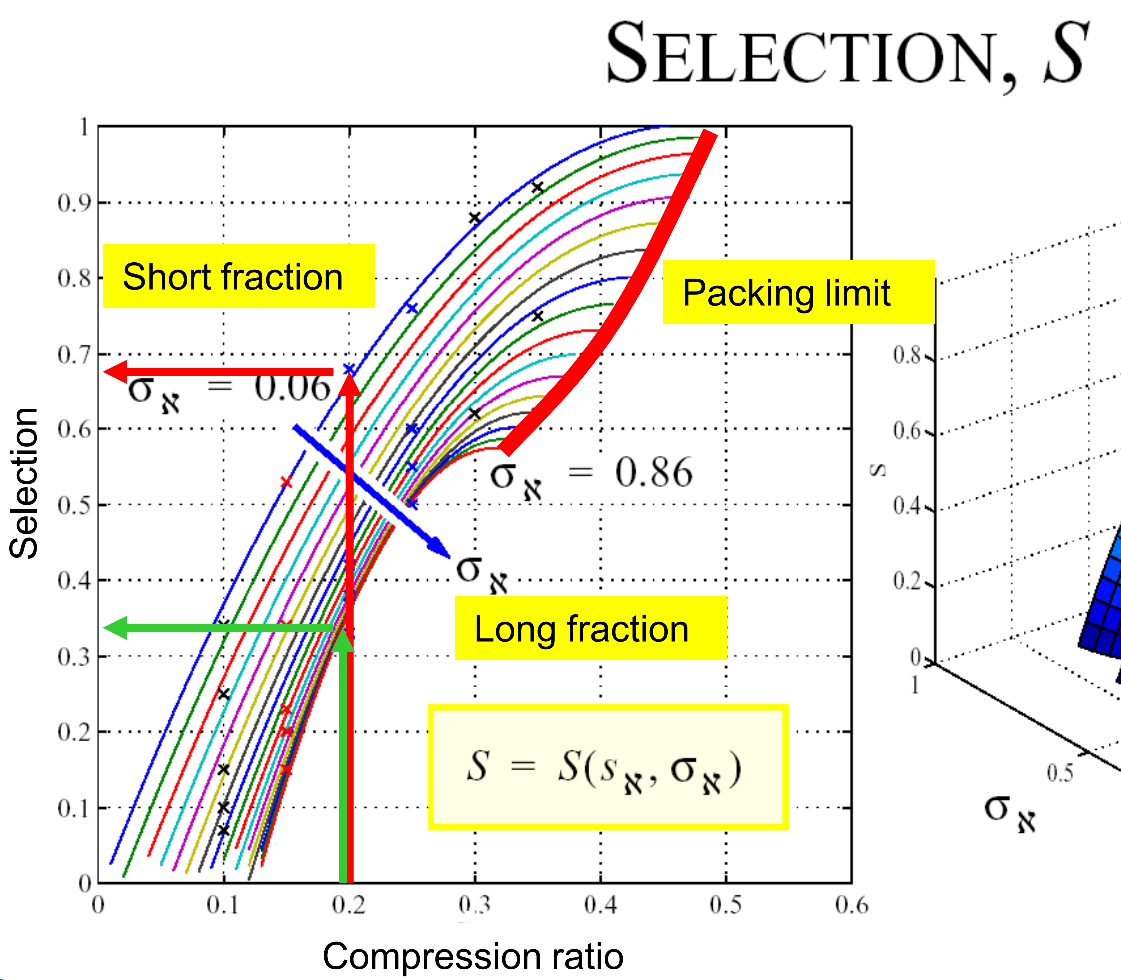
-displacement controlled

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

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

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

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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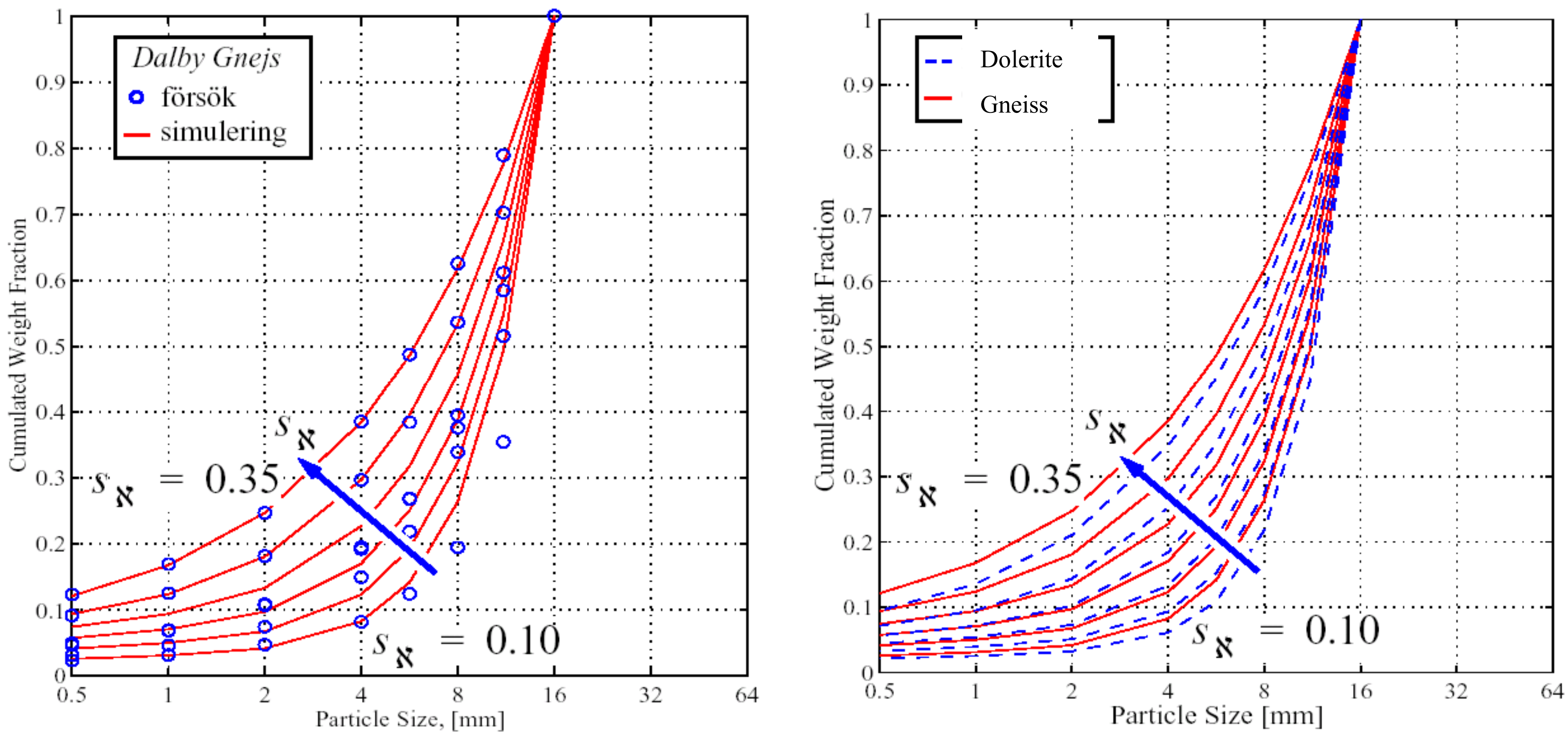
Rock Breakage Behavior

BREAKAGE, *B*



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

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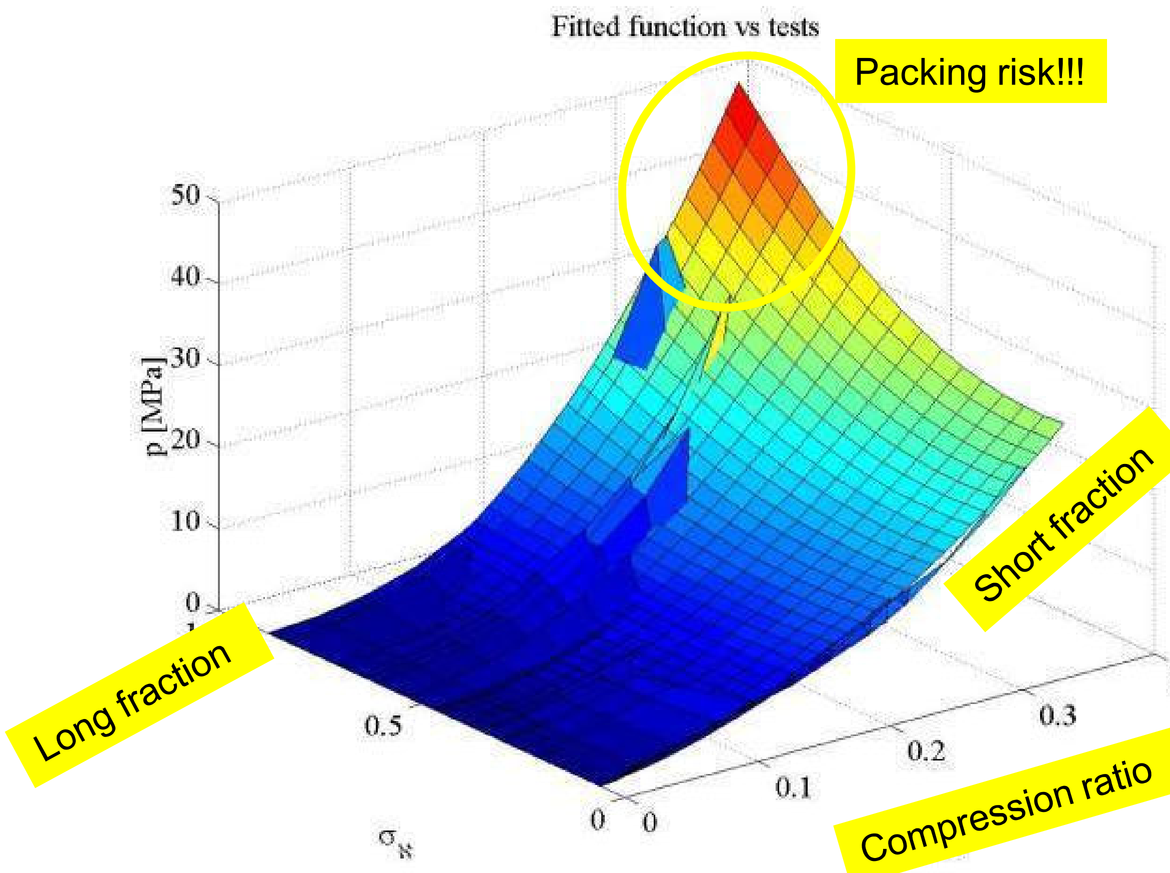
Rock Breakage Behavior



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

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

Take home message:

Interparticle breakage

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

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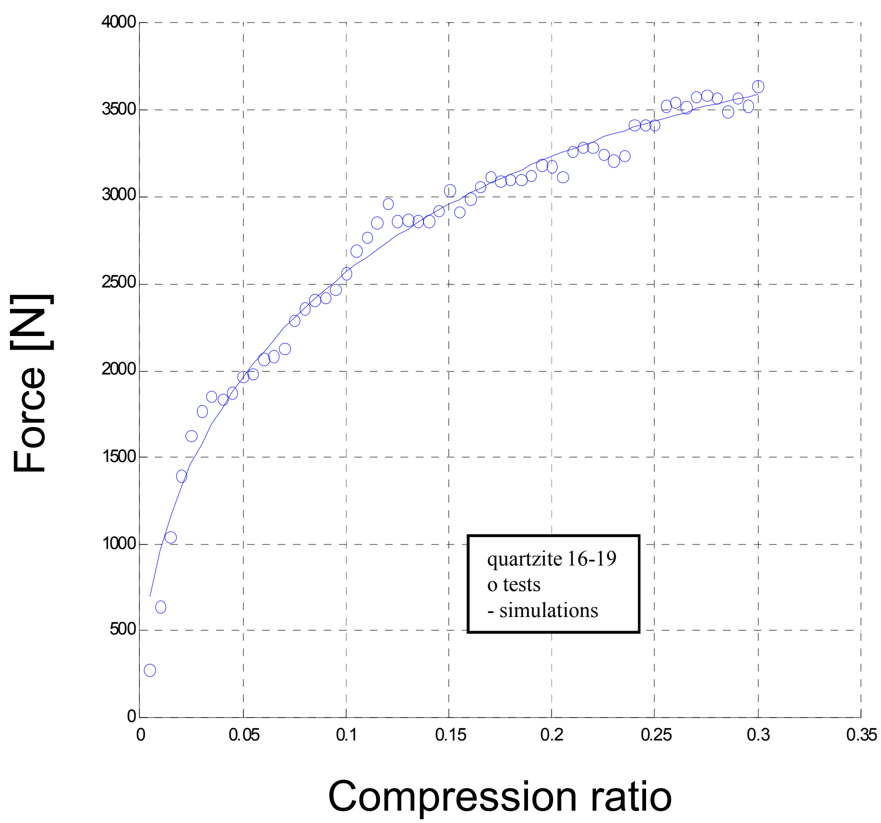
Rock Breakage Behavior

Single particle
-force response



Take home message:

Single particle breakage requires lower crushing force compared to interparticle.

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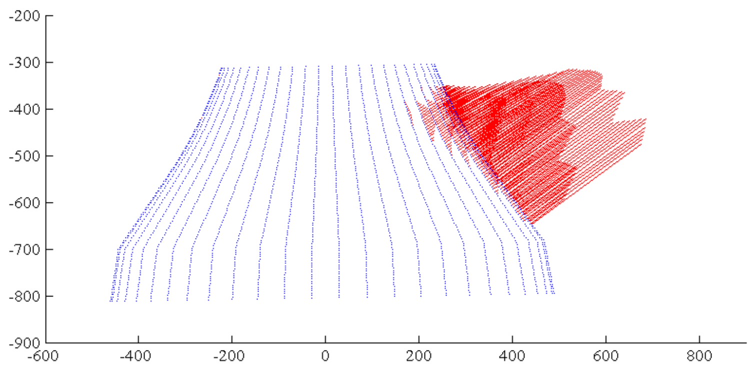
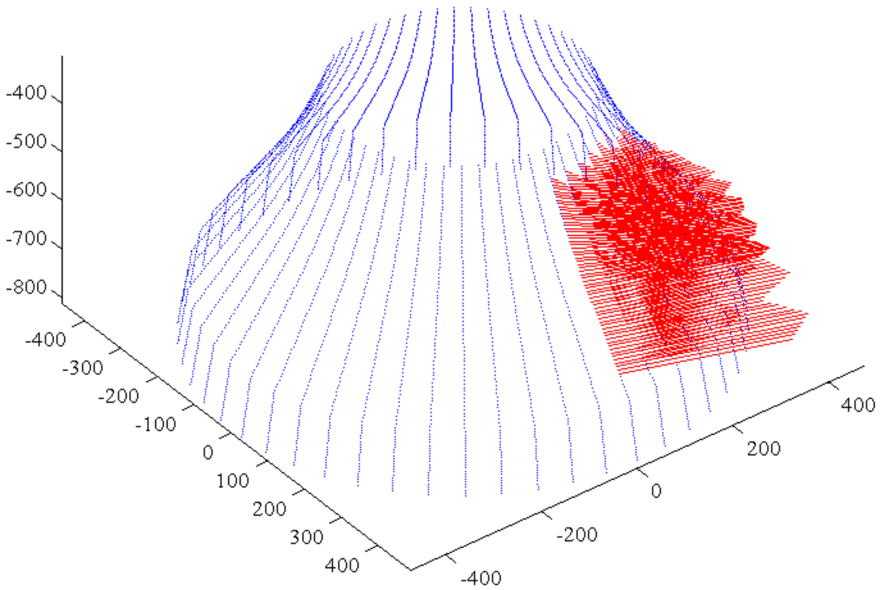
Crushing Pressure and Power Draw





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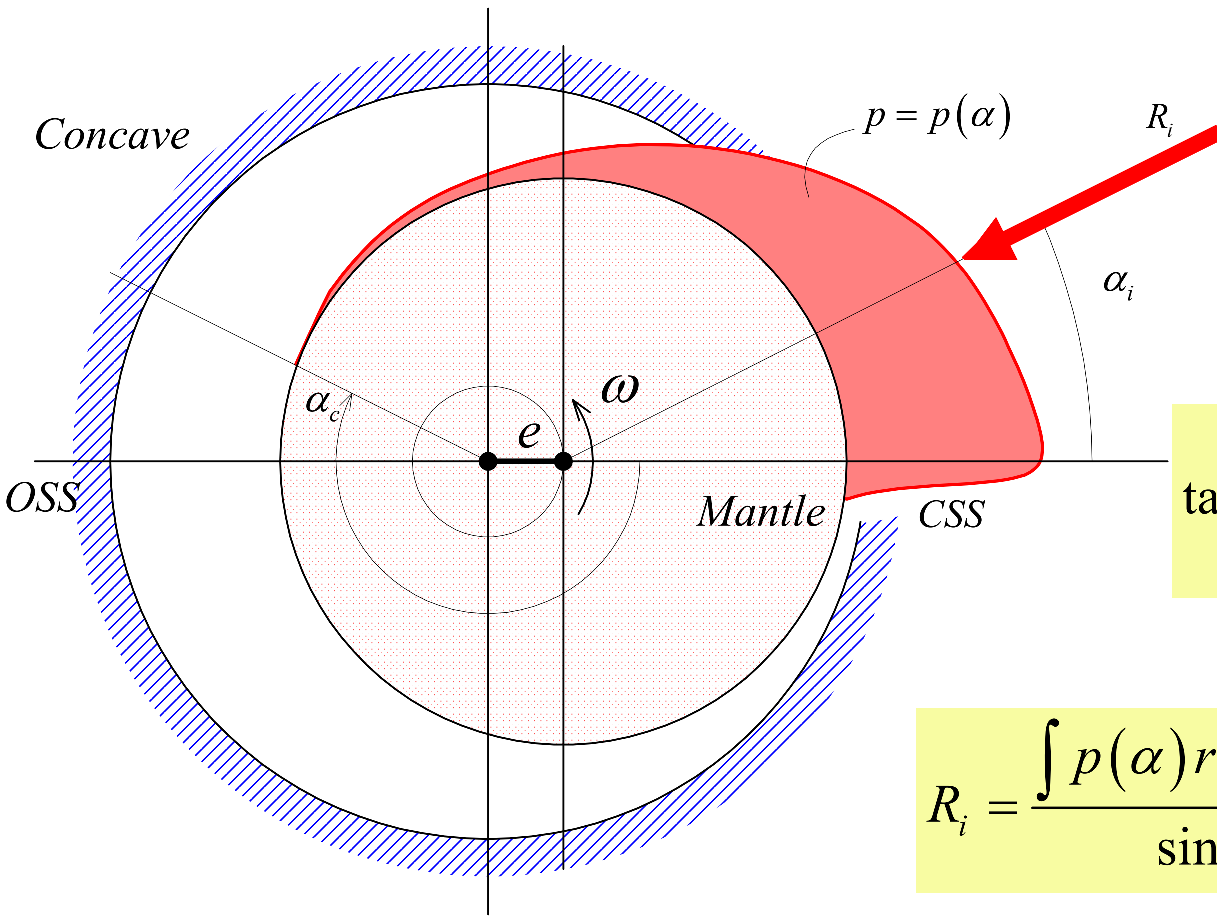
Crushing Pressure and Power Draw



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

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

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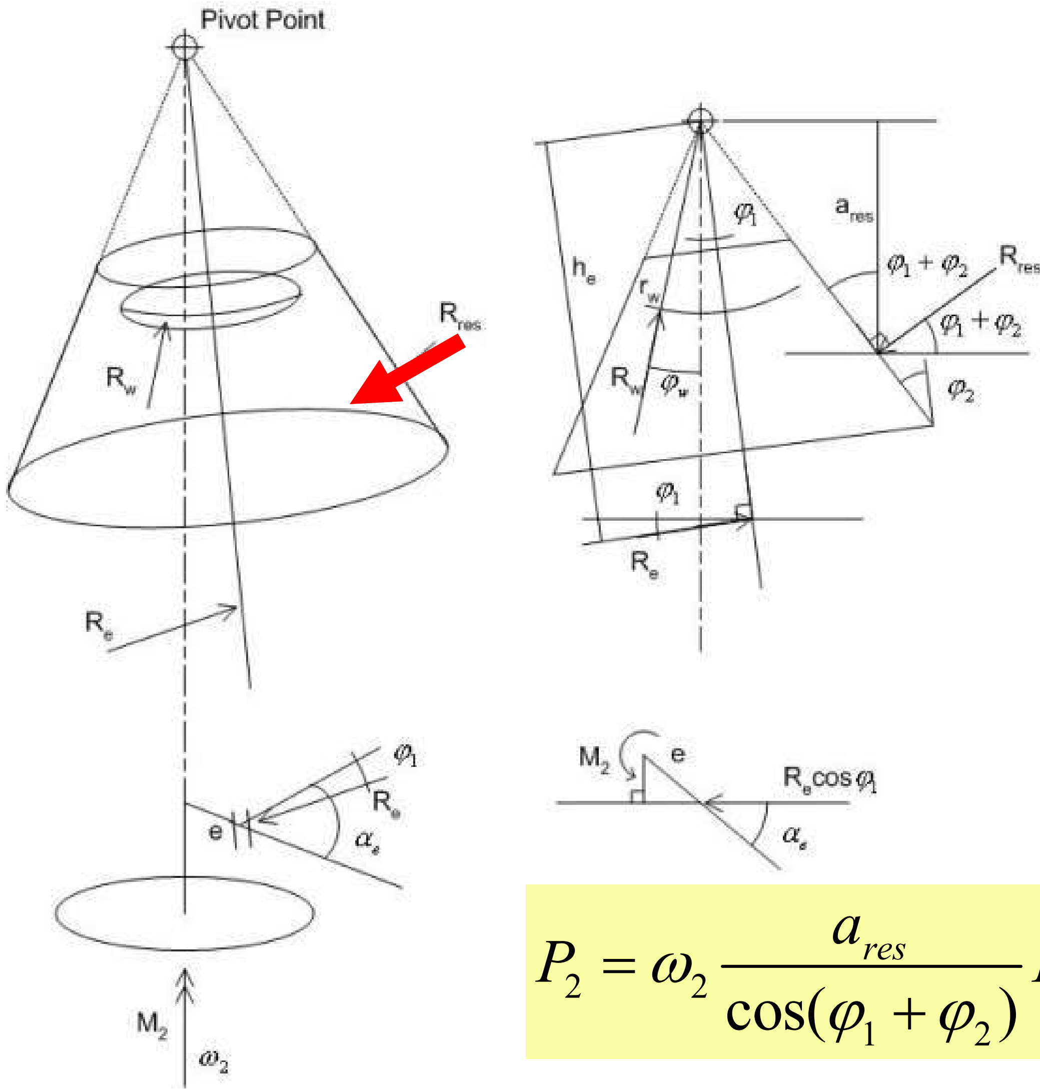
Crushing Pressure and Power Draw

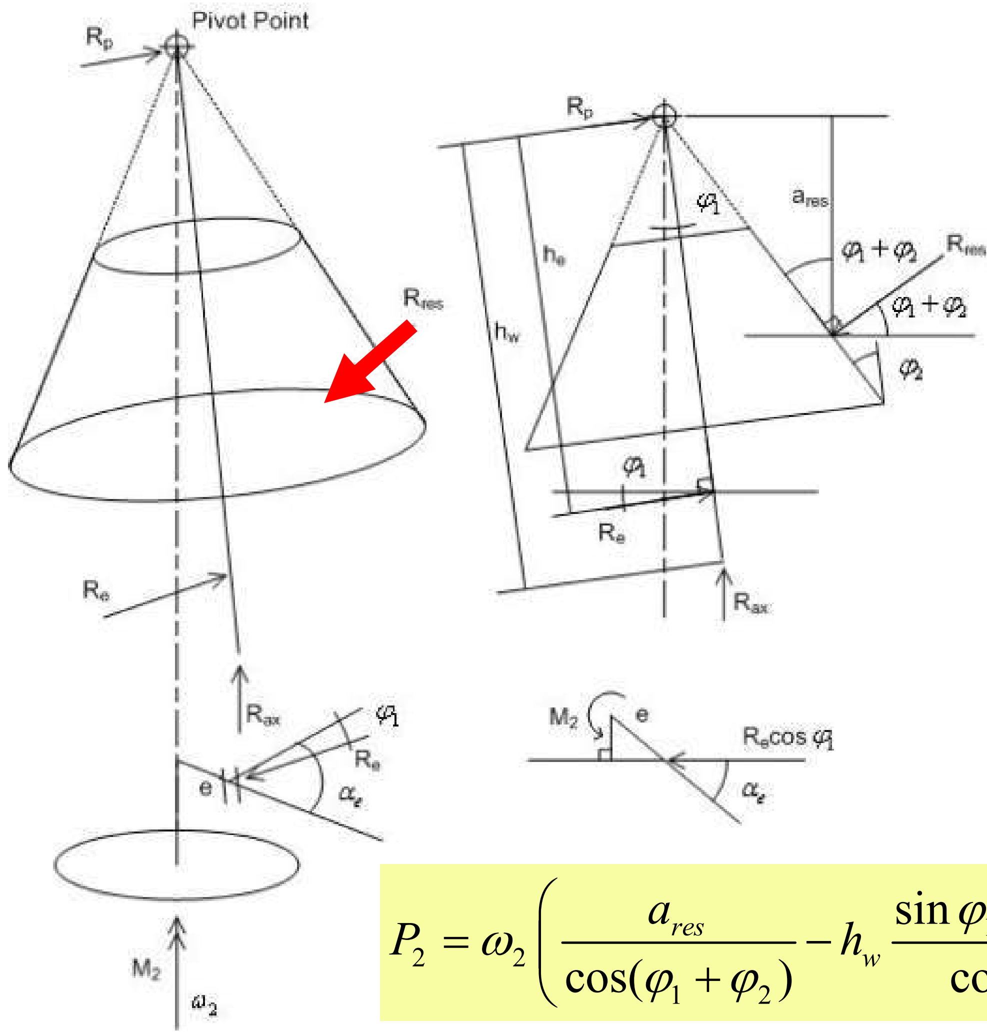


Mechanical model of spiderless cone crusher

SYMONS-type

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

Crushing Pressure and Power Draw



Take home message:

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

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

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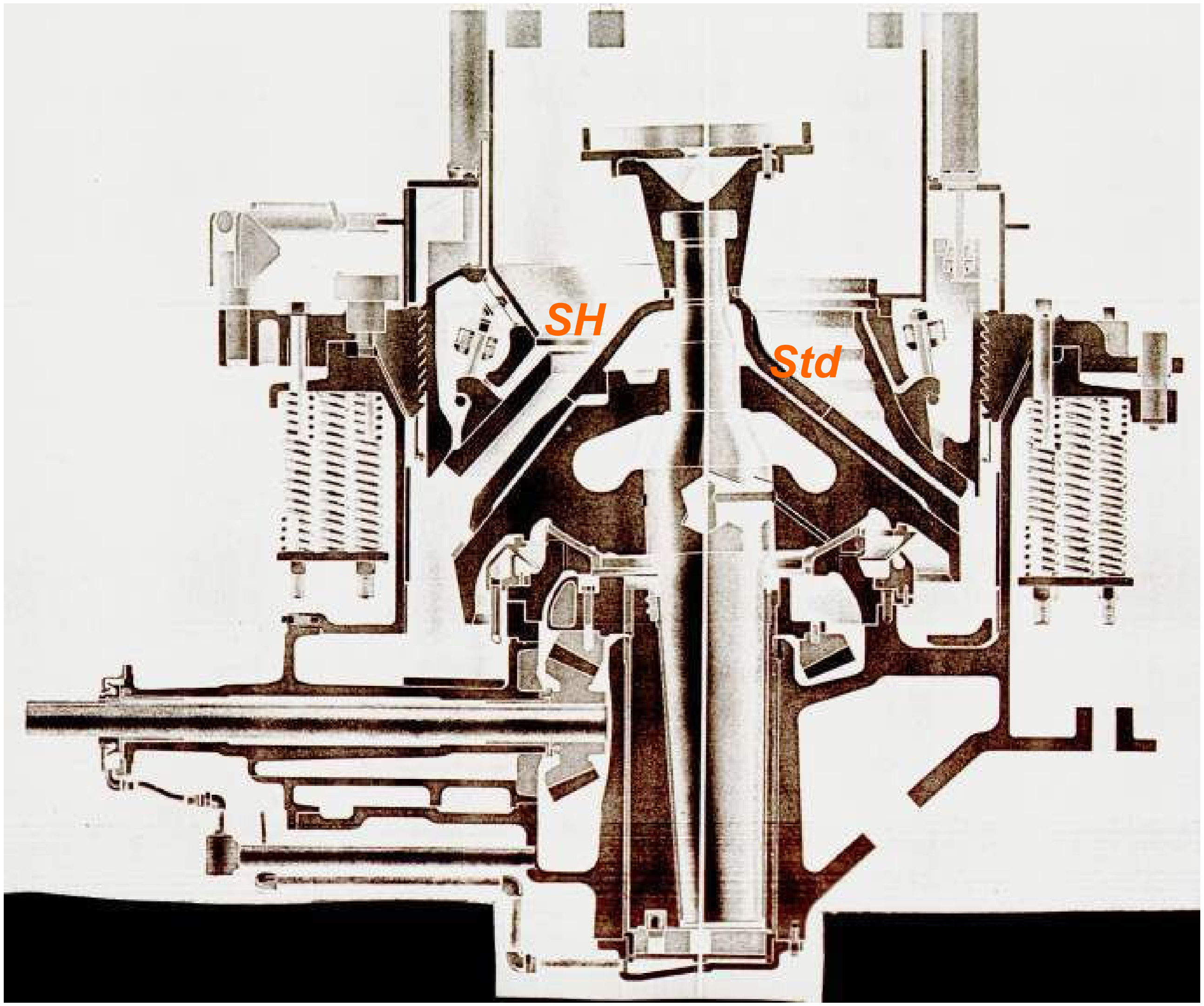
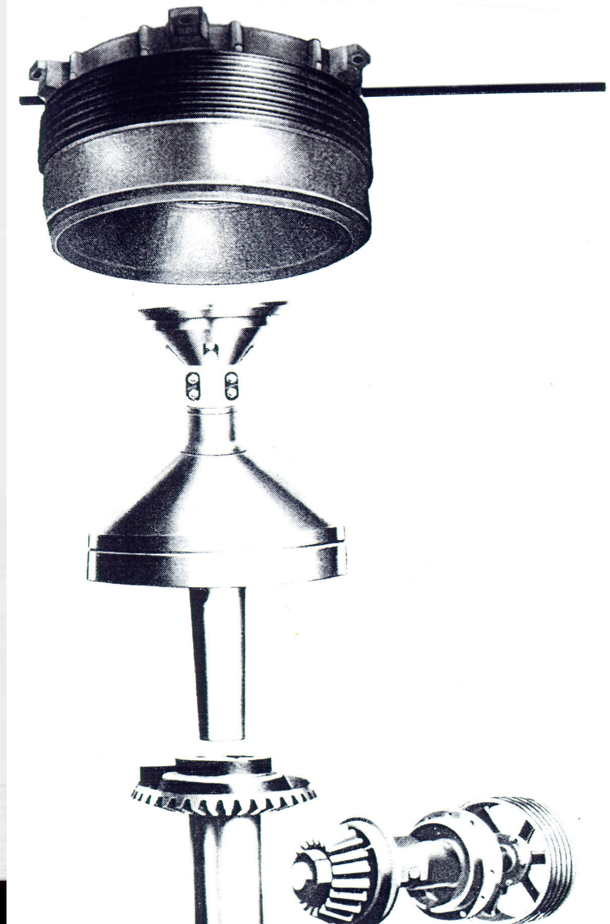
Geometry





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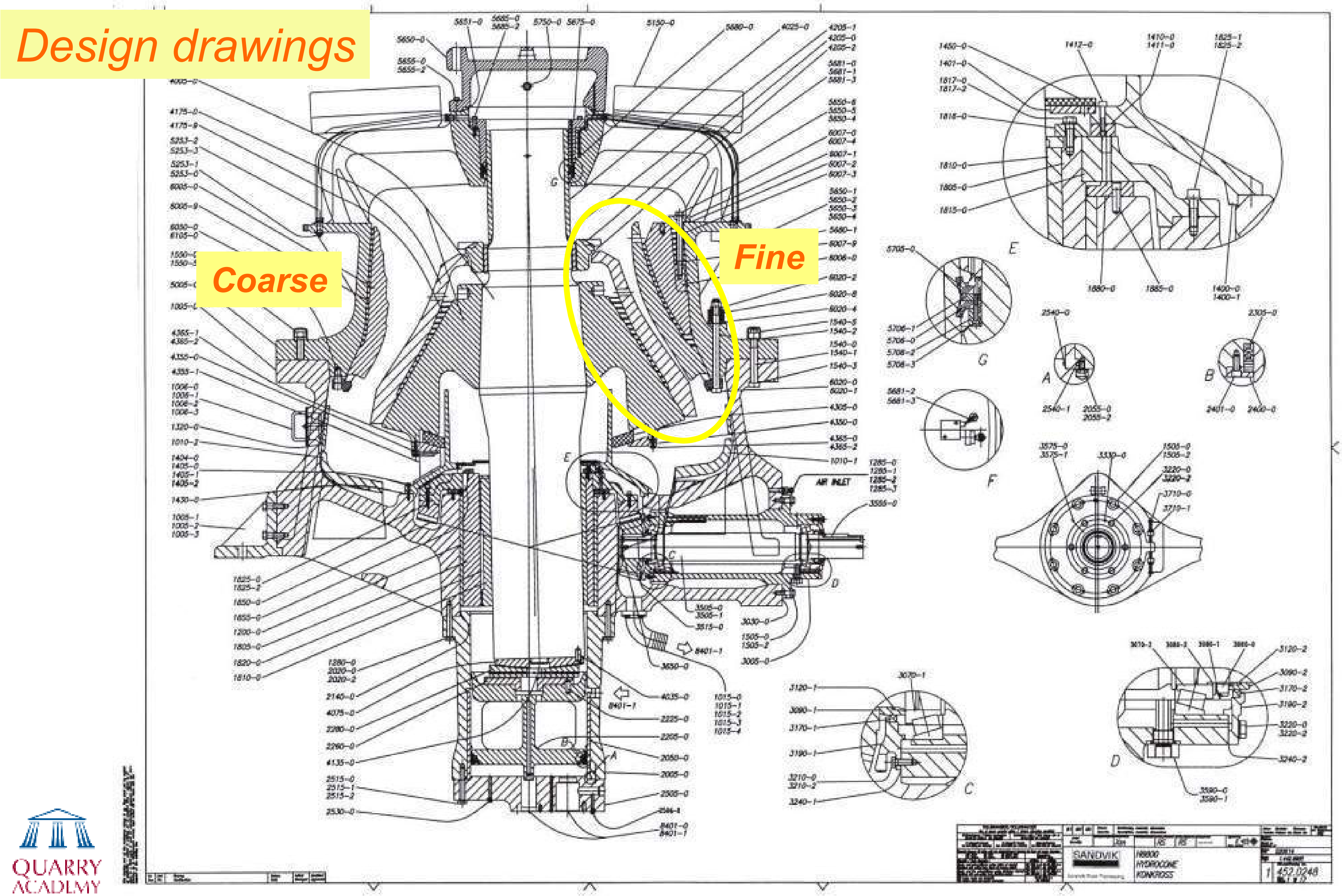
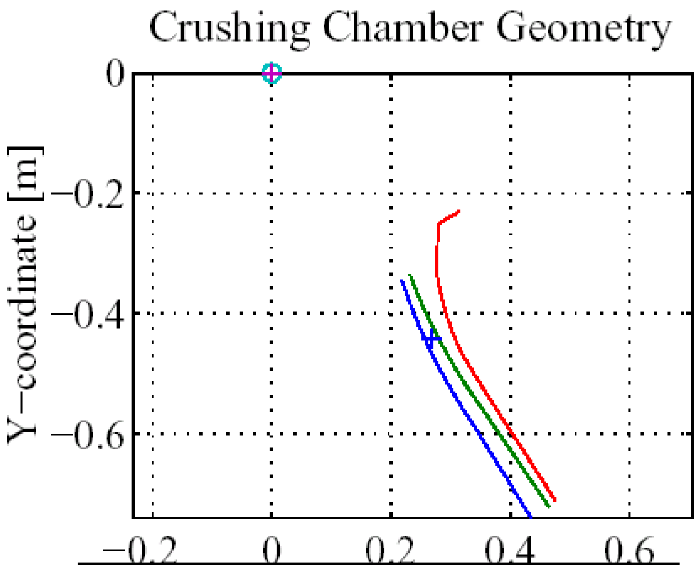
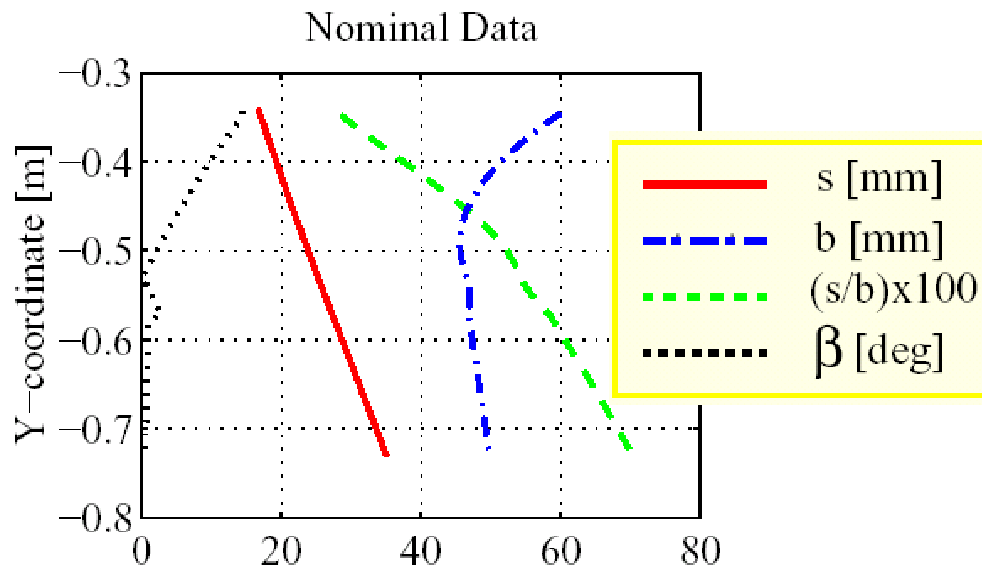
Geometry



QUARRY ACADEMY

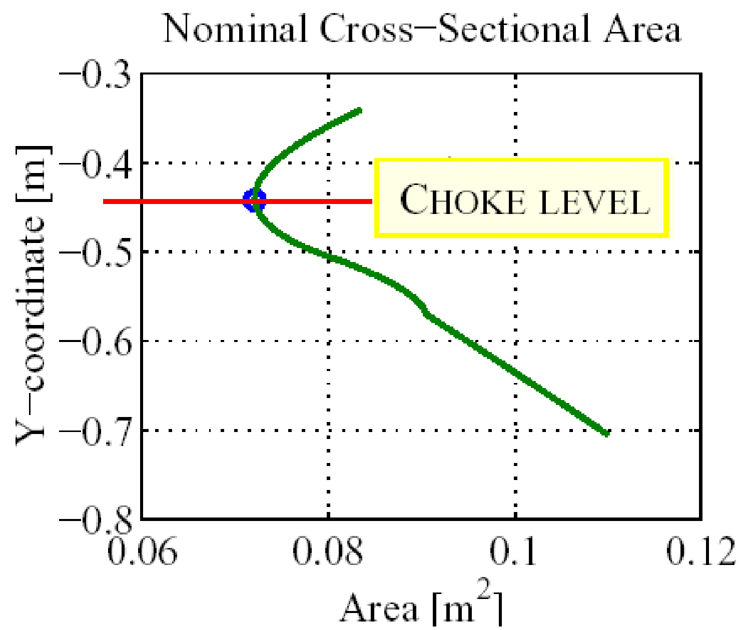
Geometry





Take home message:

Capacity is controlled by choke area.



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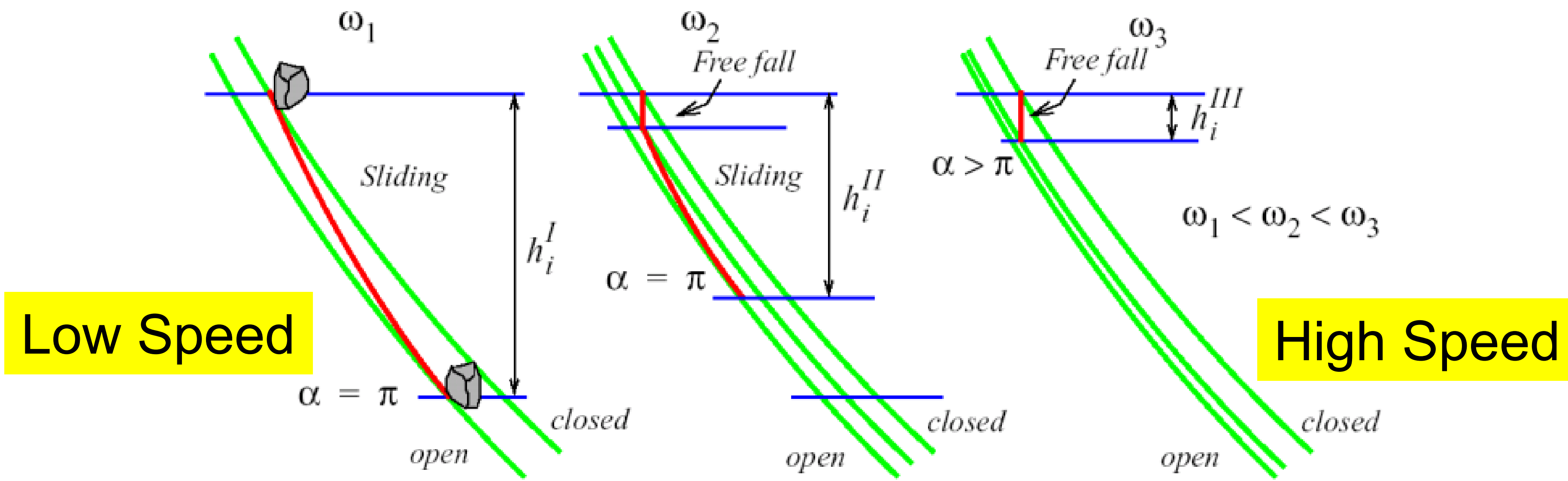
Flow model

Material flow mechanics

- Sliding
- Free fall
- Squeezing



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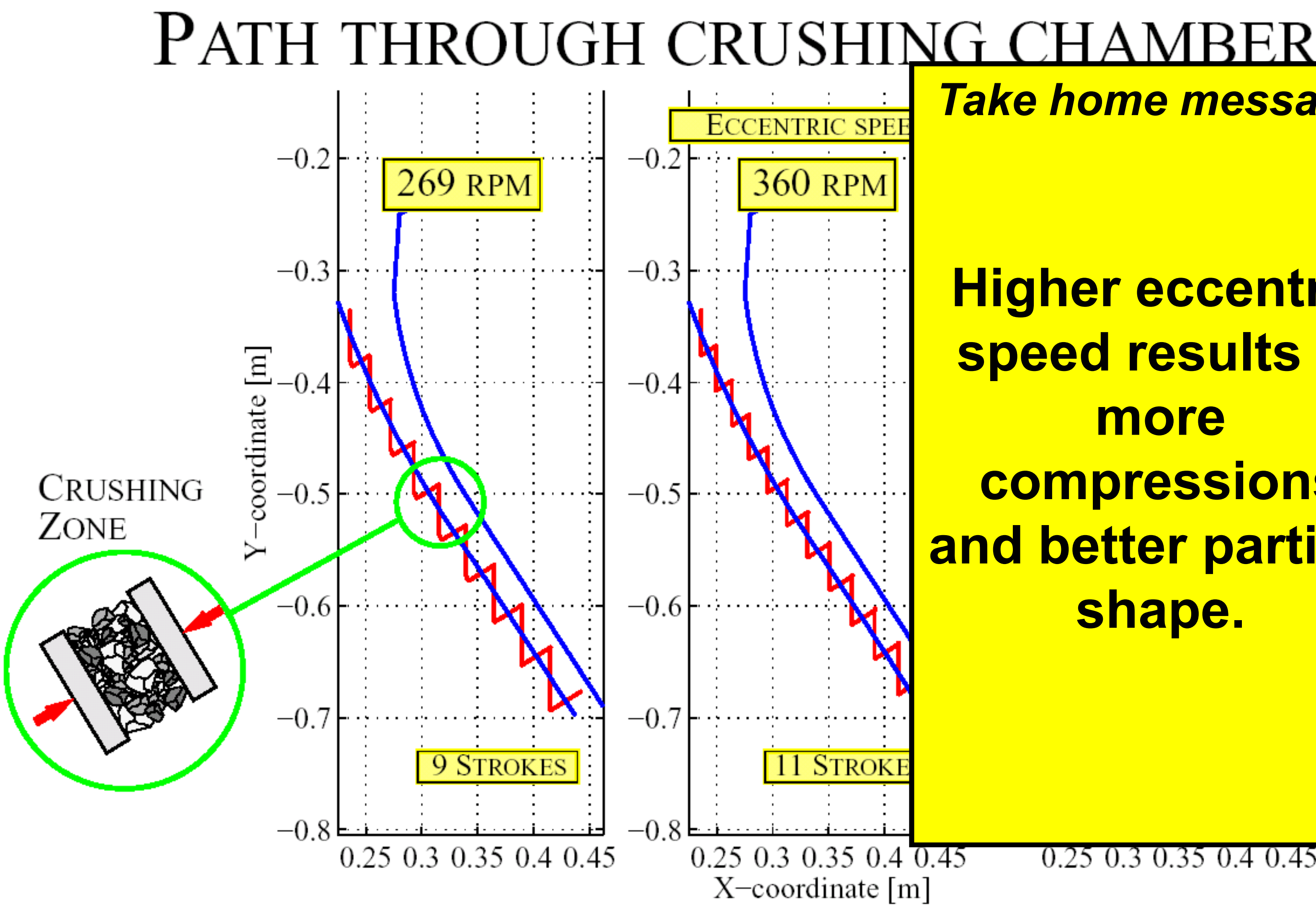
Flow model



Take home message:

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

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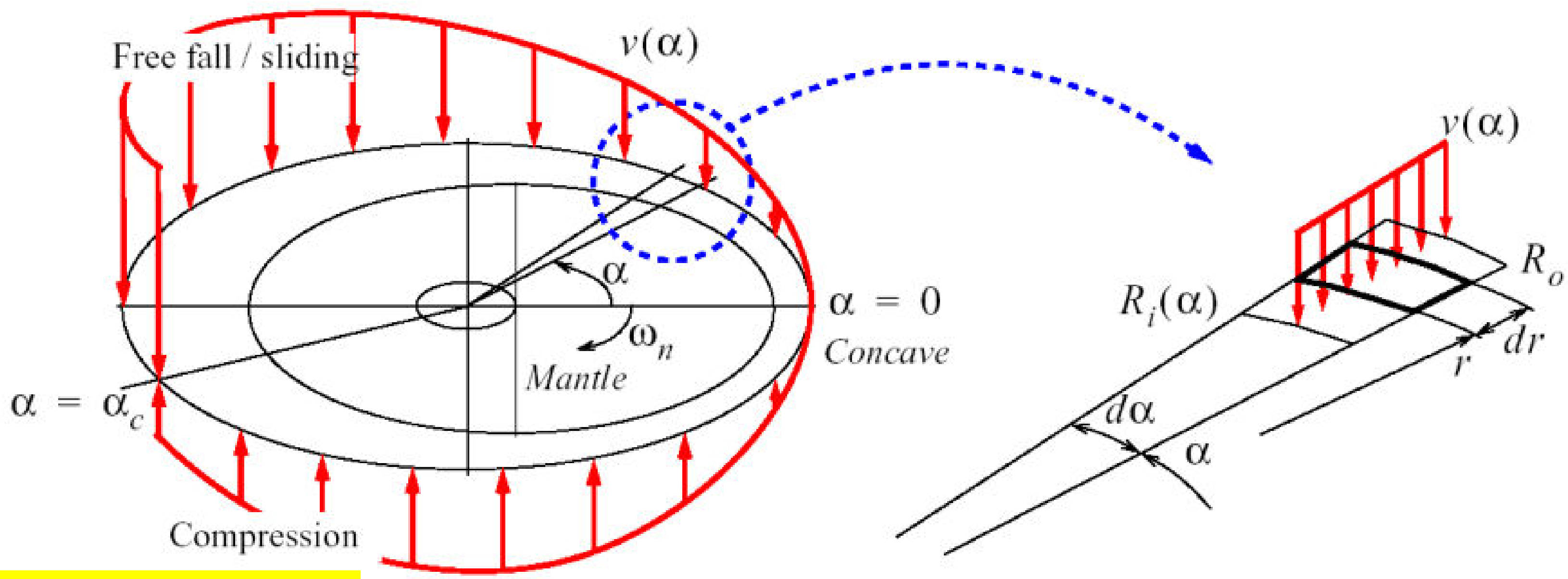
Flow model

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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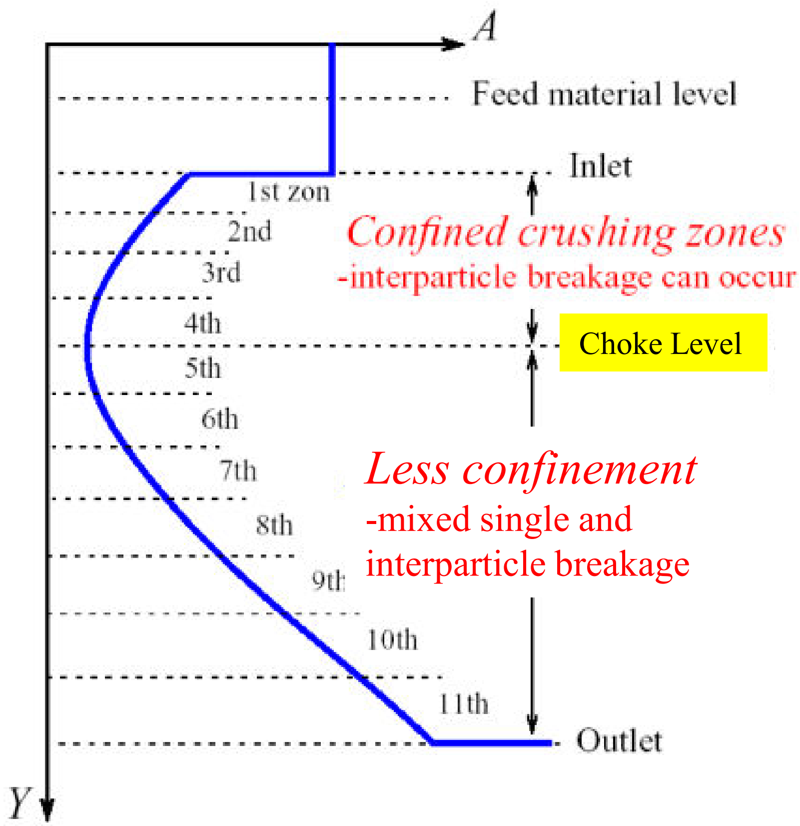
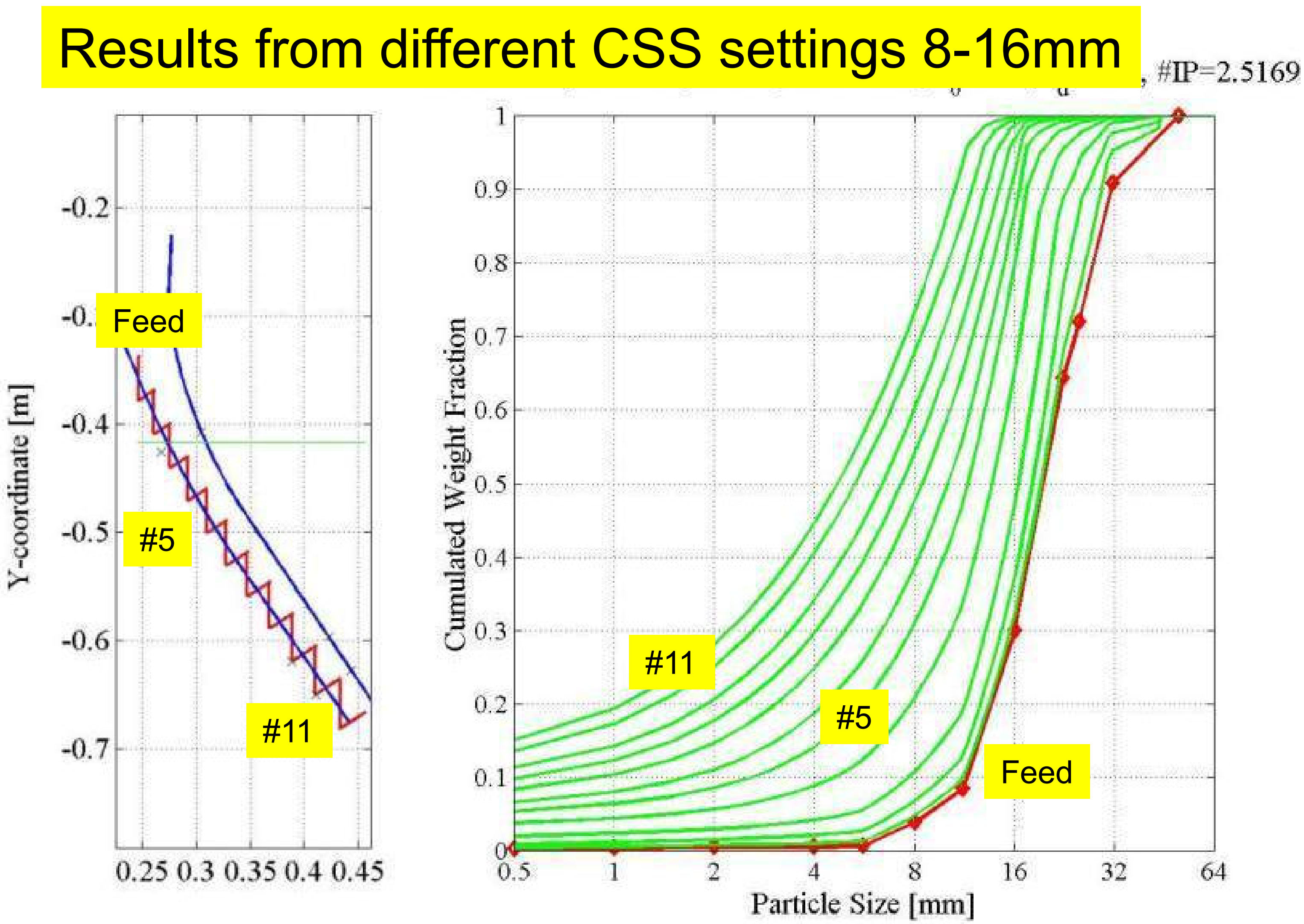
Breakage Modes



Take home message:

Chamber design affects breakage modes.

Results - *Particle size distributions*



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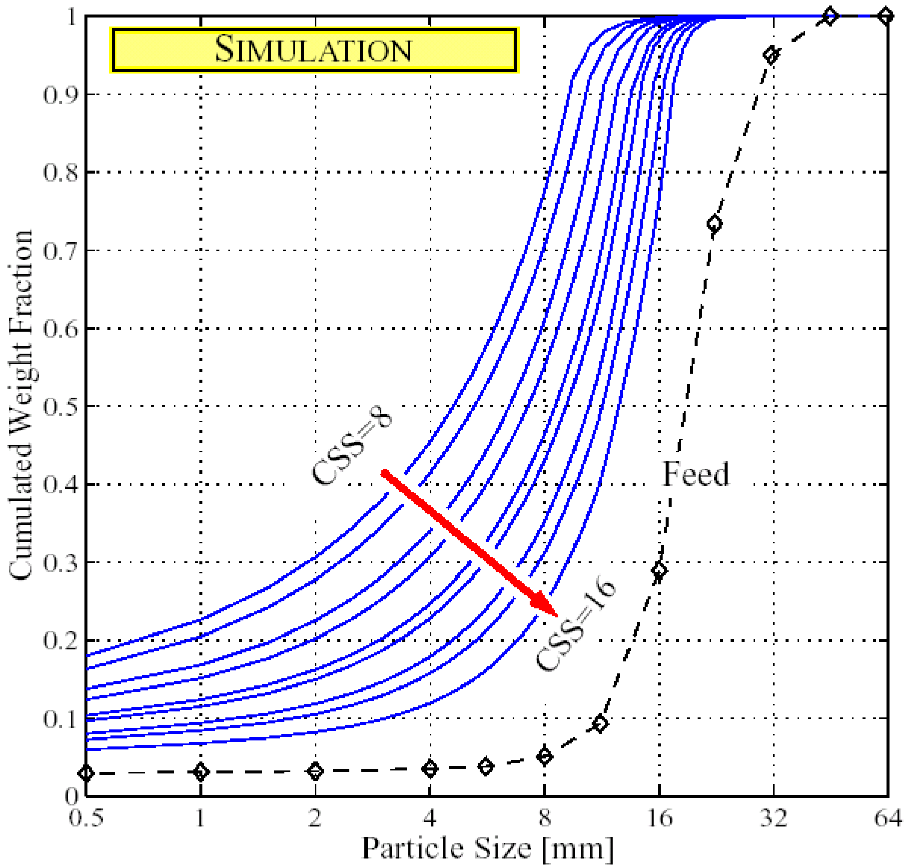
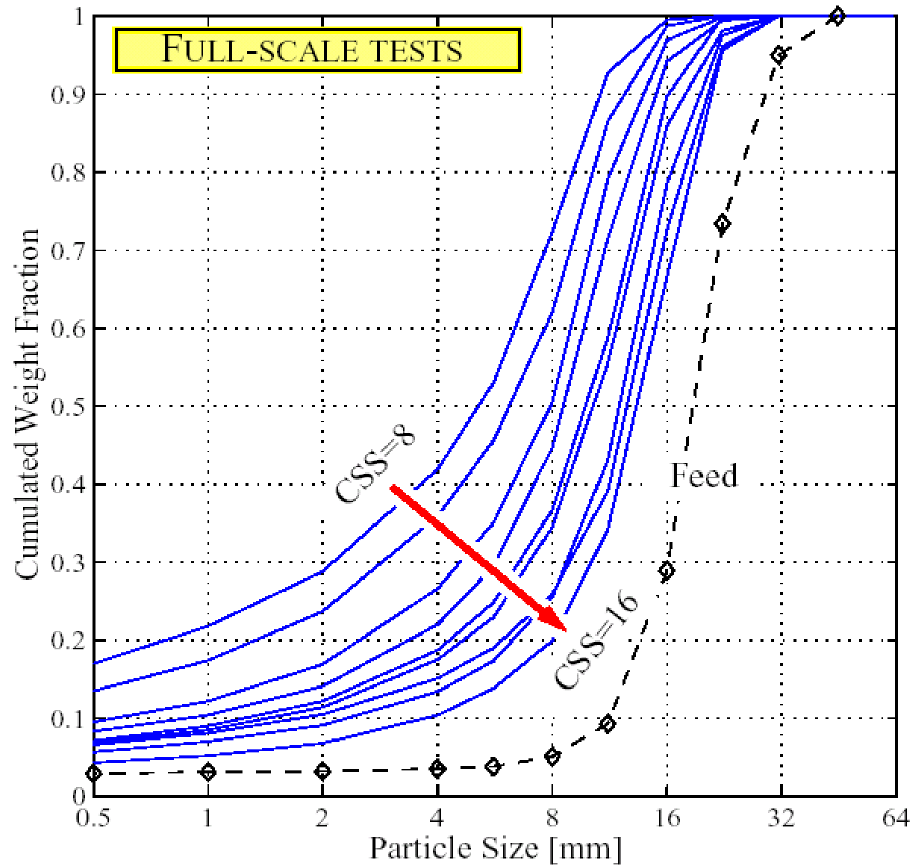
Results - *Particle size distributions*

Results from different CSS settings 8-16mm





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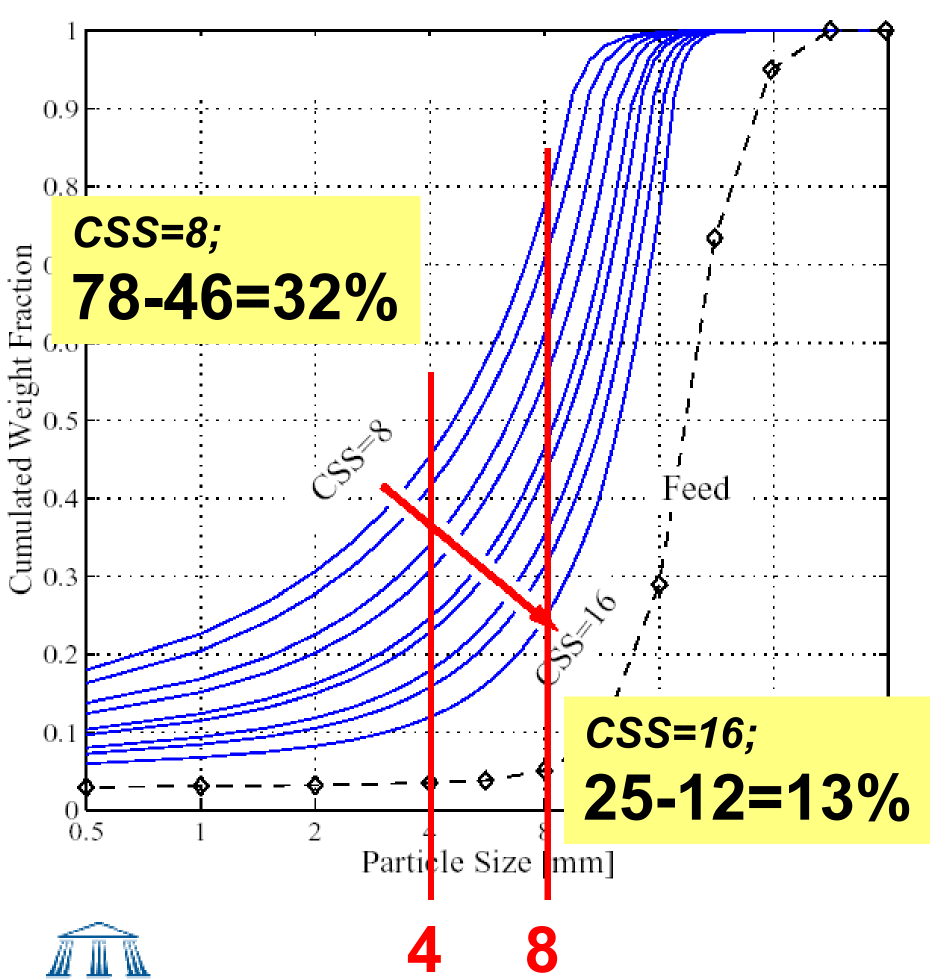
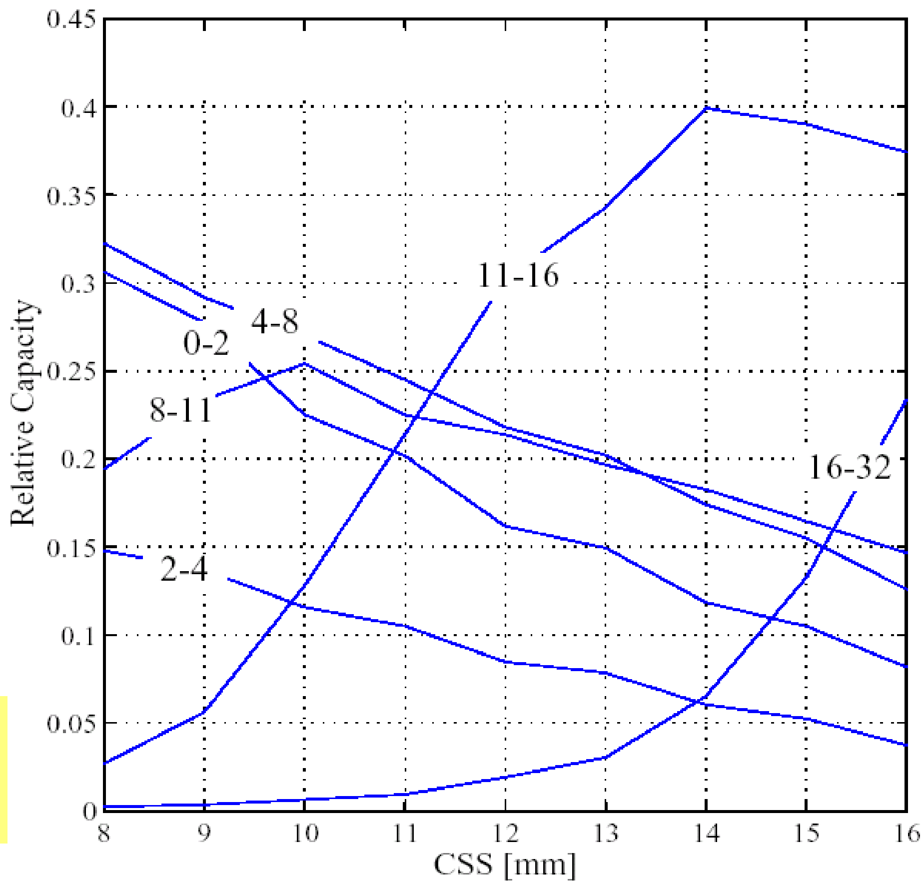
Product Yield Graphs





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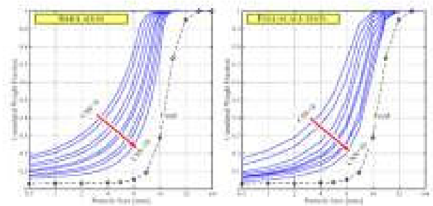
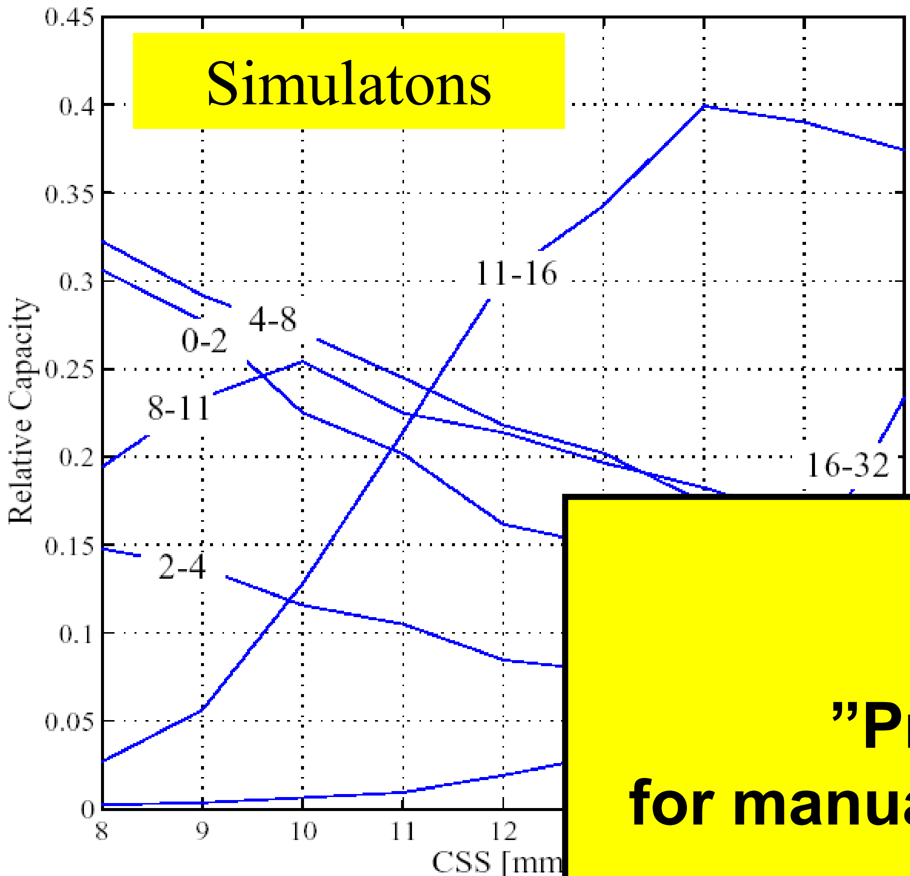
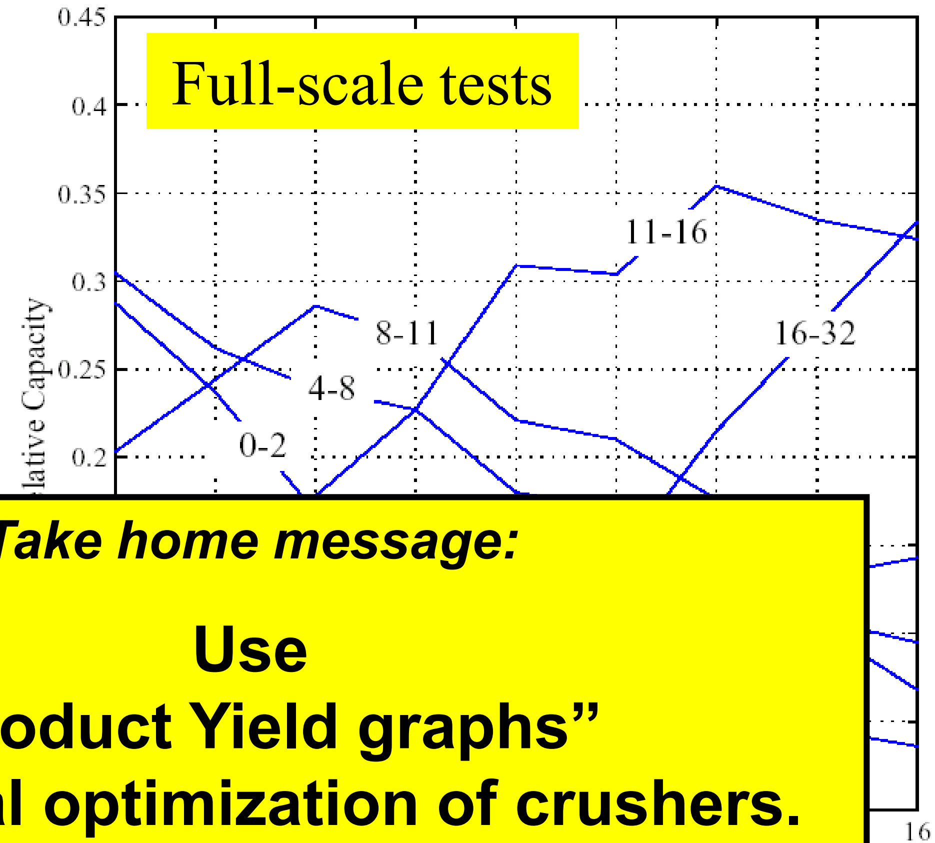
Results – *Product Yield*







Take home message:

Use
”Product Yield graphs”
for manual optimization of crushers.

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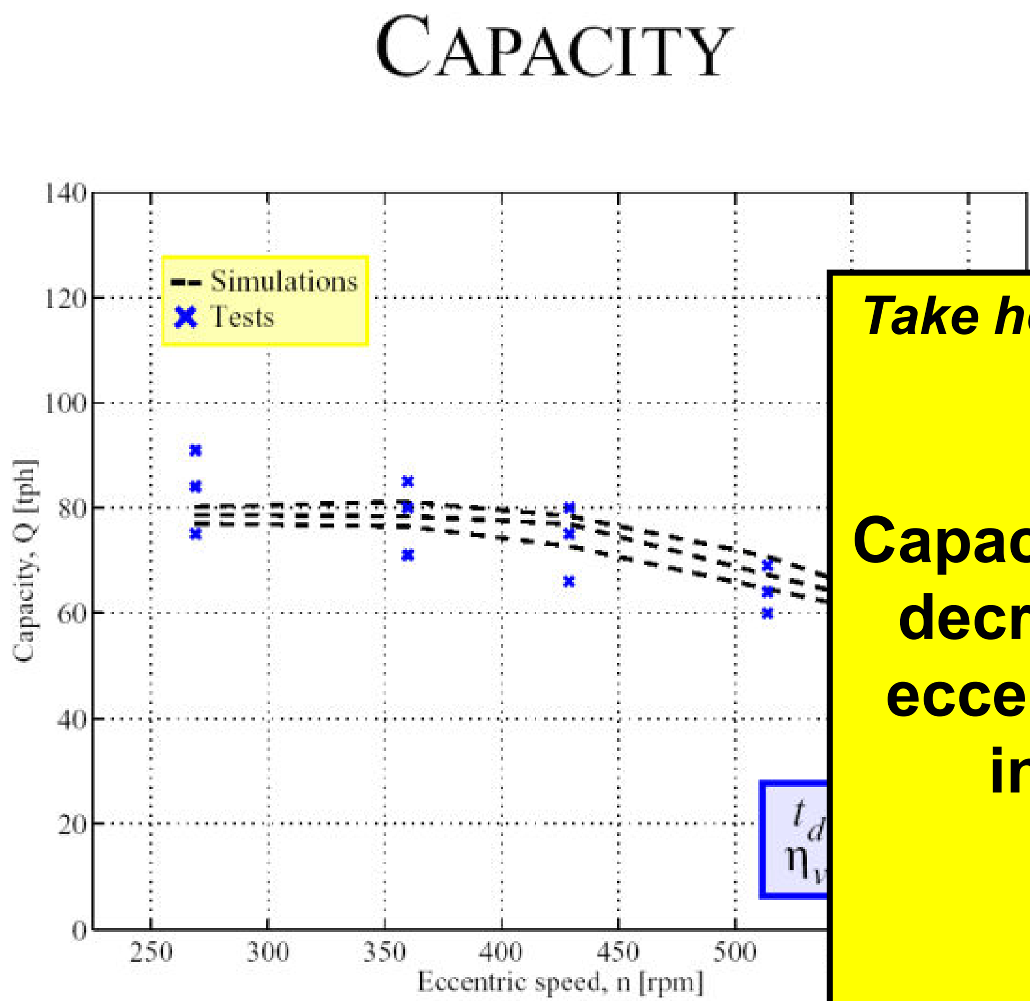
Results



Take home message:

Capacity normally decrease when eccentric speed increase.

Conclusions

- **Cone crushers are complex machines and can not satisfactory be described by empirical models.**

- **Analytical model for cone crushers:**
  - ✓ General - works for all type of cone crushers
  - ✓ Simulation
  - ✓ Optimization
  - ✓ Trouble shooting

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Conculsions

- Three (3) main factors influencing the final results was identified
  - ✓ Breakage modes – single or interparticle
  - ✓ The number of crushing zones
  - ✓ The compression ratio in each zone
- Detailed understanding of the crushing process on a fundamental level

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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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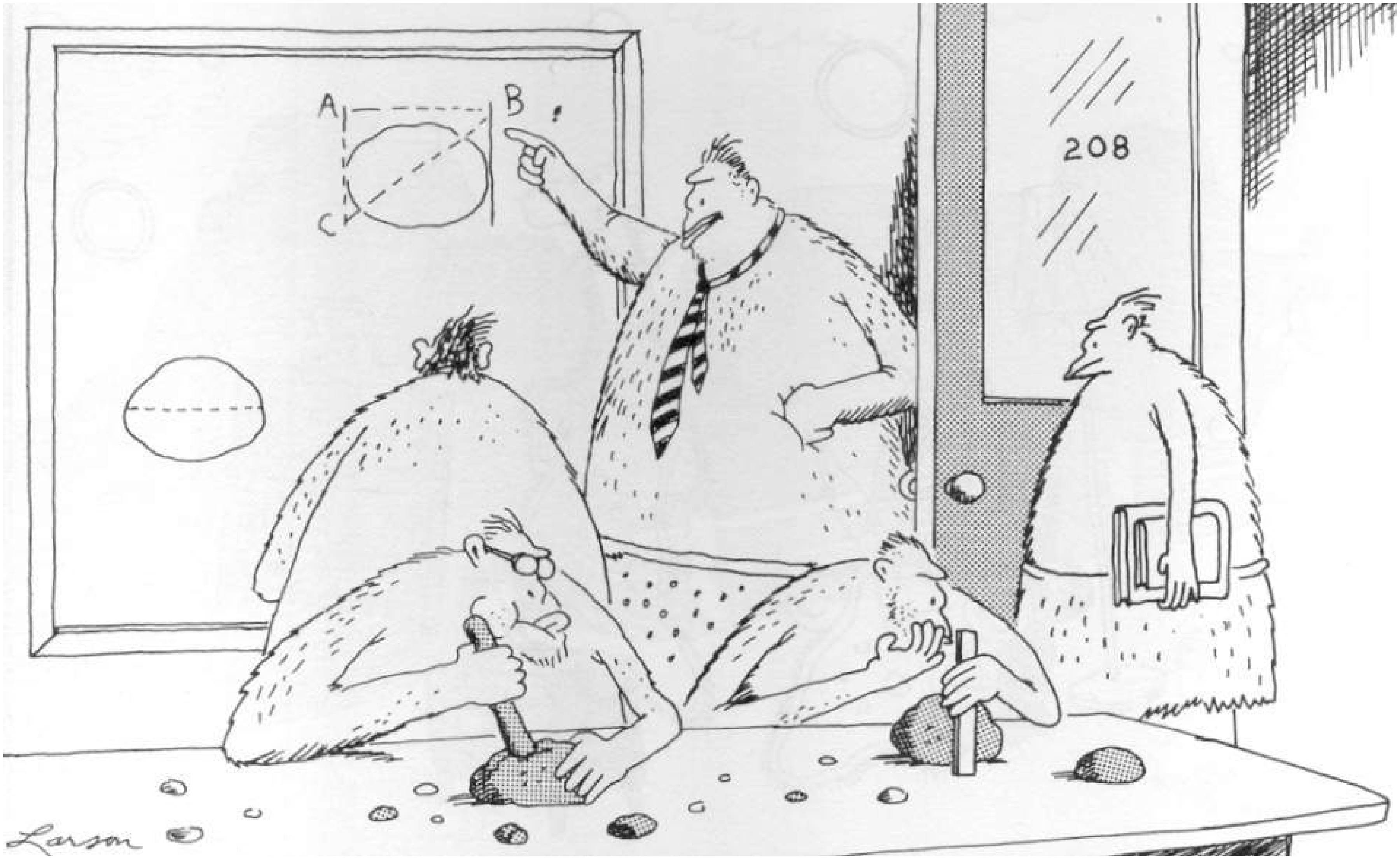

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