Cone Crusher Modelling

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Background

Aggregate producers on the Swedish west-coast required more knowledge about crushing…

Modelling of cone crushers started in December 1993.

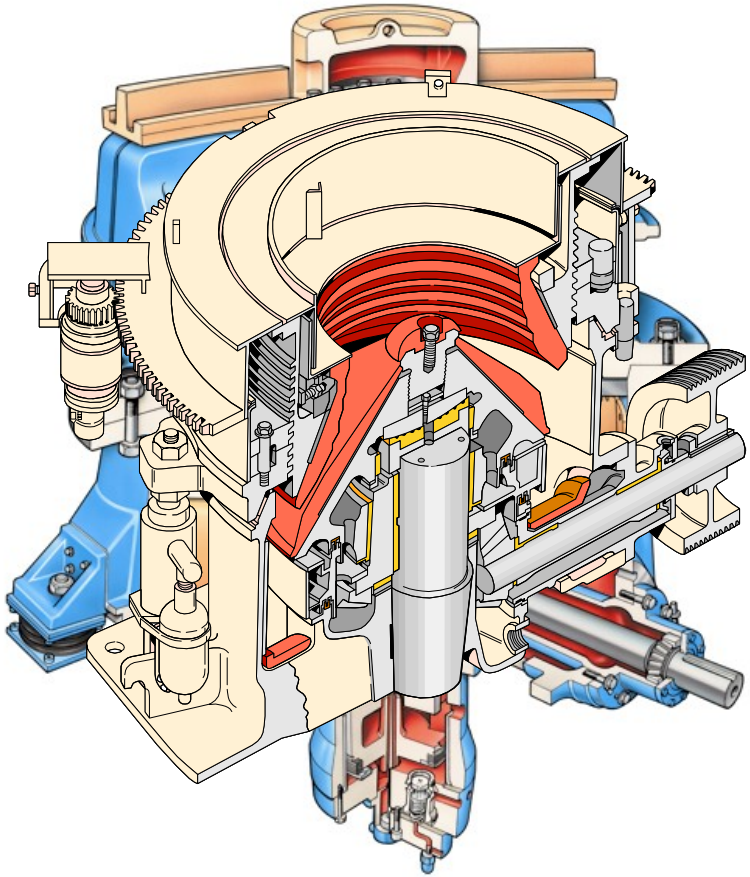
Cone Crushers

Cone Crushers

=

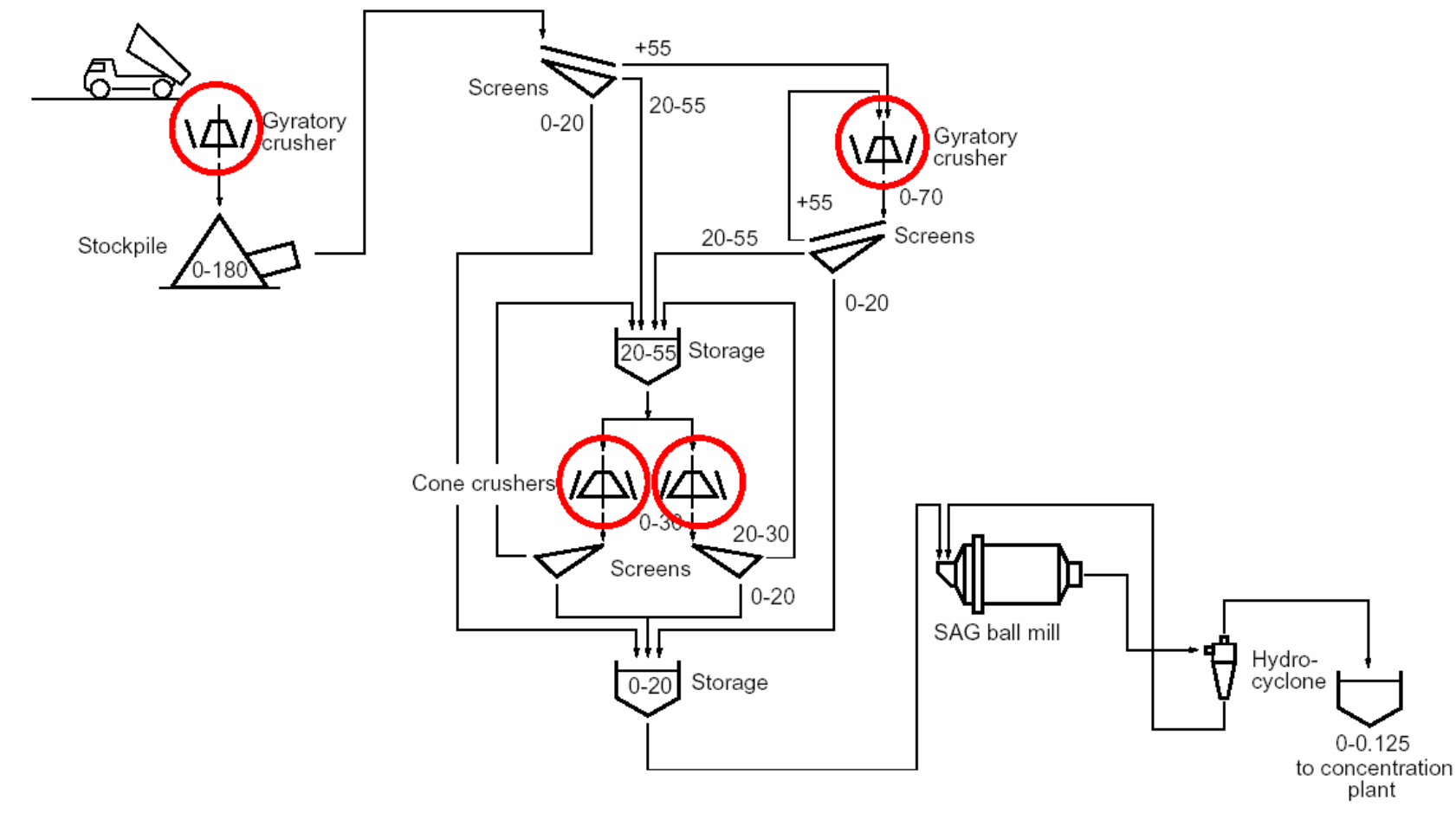
Size Reduction

- Mechanical mineral liberation
  - mining
- Aggregate production
  - quarries



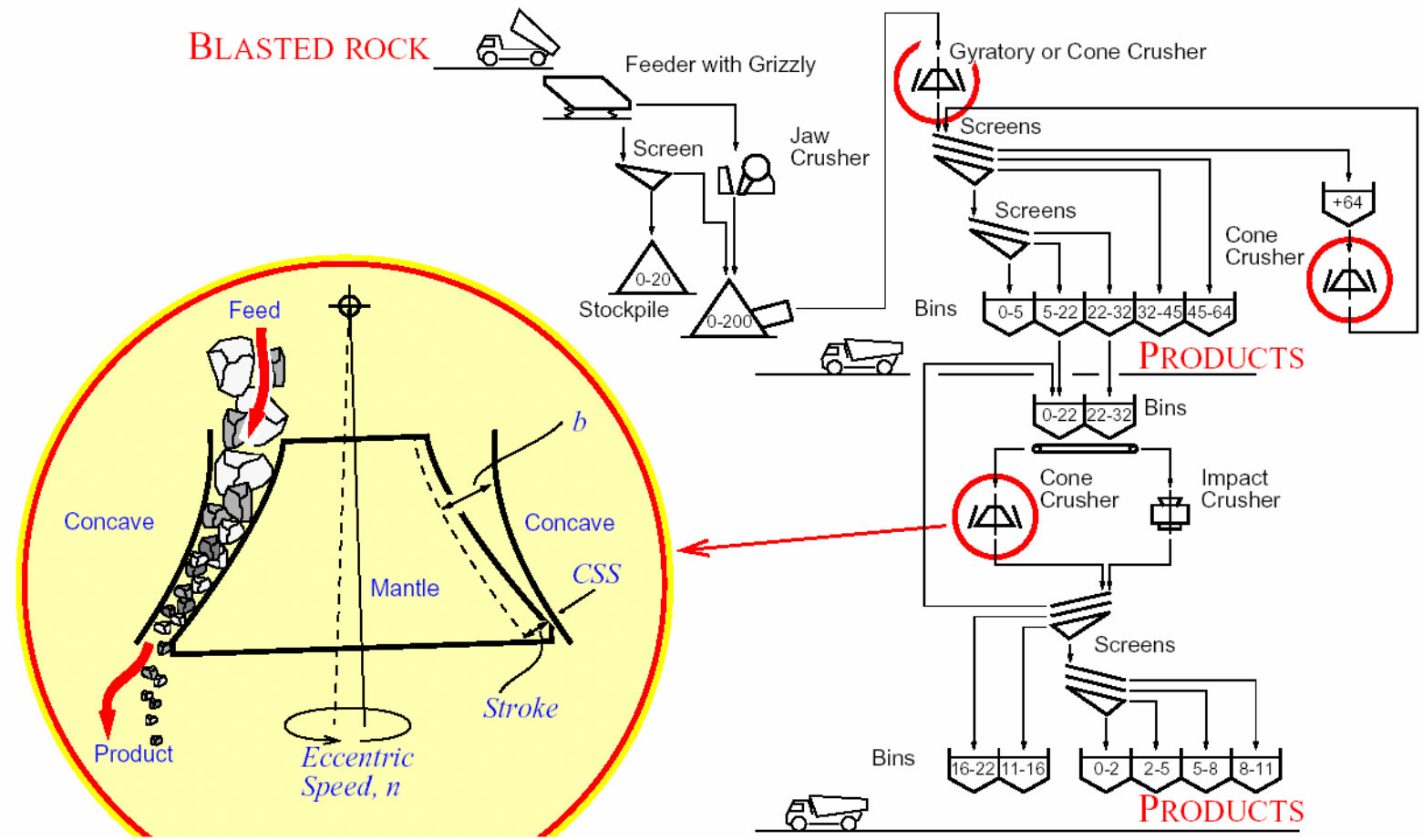
Cone Crushers

Crushing plant - Mining



Cone Crushers

Crushing plant - Aggregate



History

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

Objectives

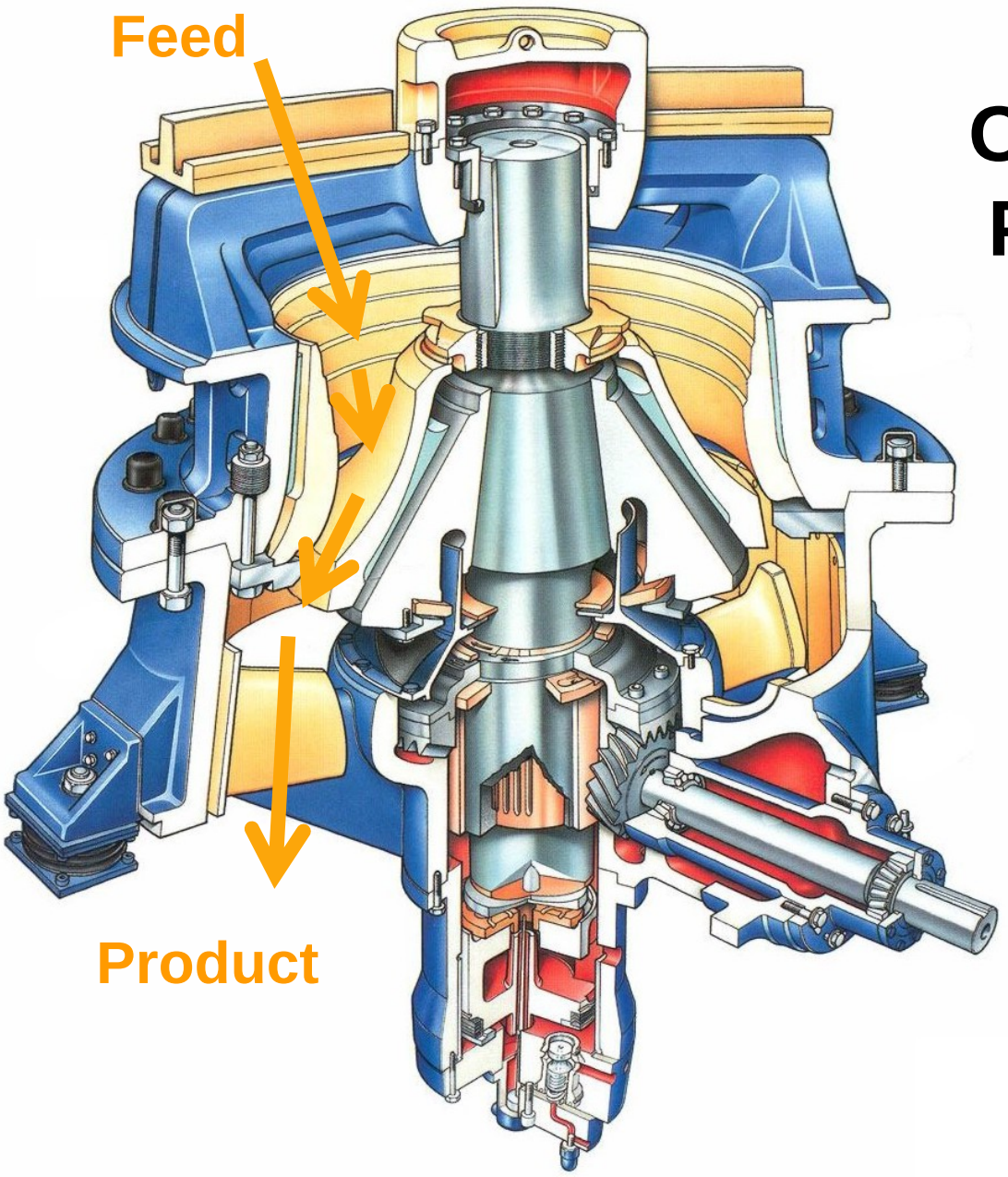
Fundamentals

- Prediction of particle size distribution
- Prediction of crushing pressure distributions
- Prediction of crushing forces
- Prediction of power draw

Design considerations

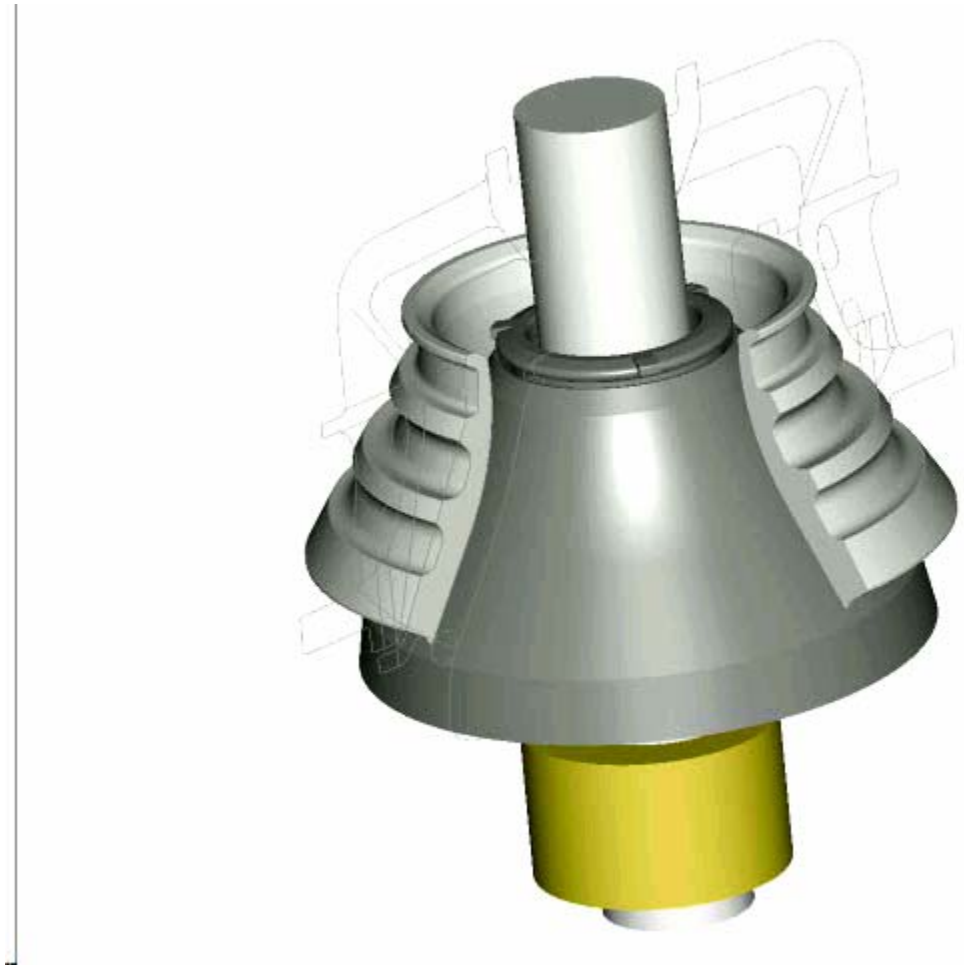
- Utilization of compressive size reduction in cone crushers
- Energy efficient crushing
- Robust performance over total liner lifetime

Operating Principle

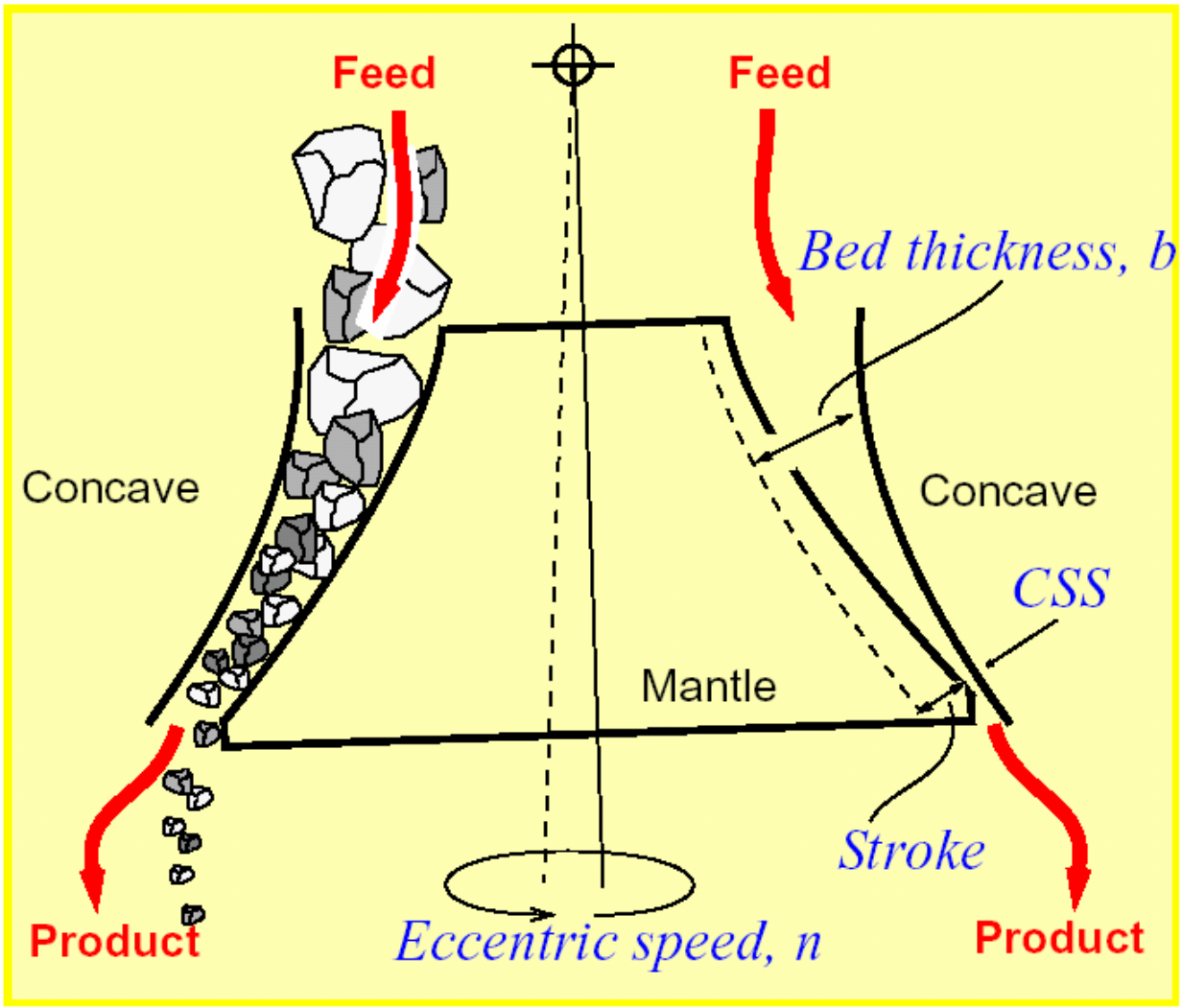


Cross-section of a cone crusher

Operating Principle

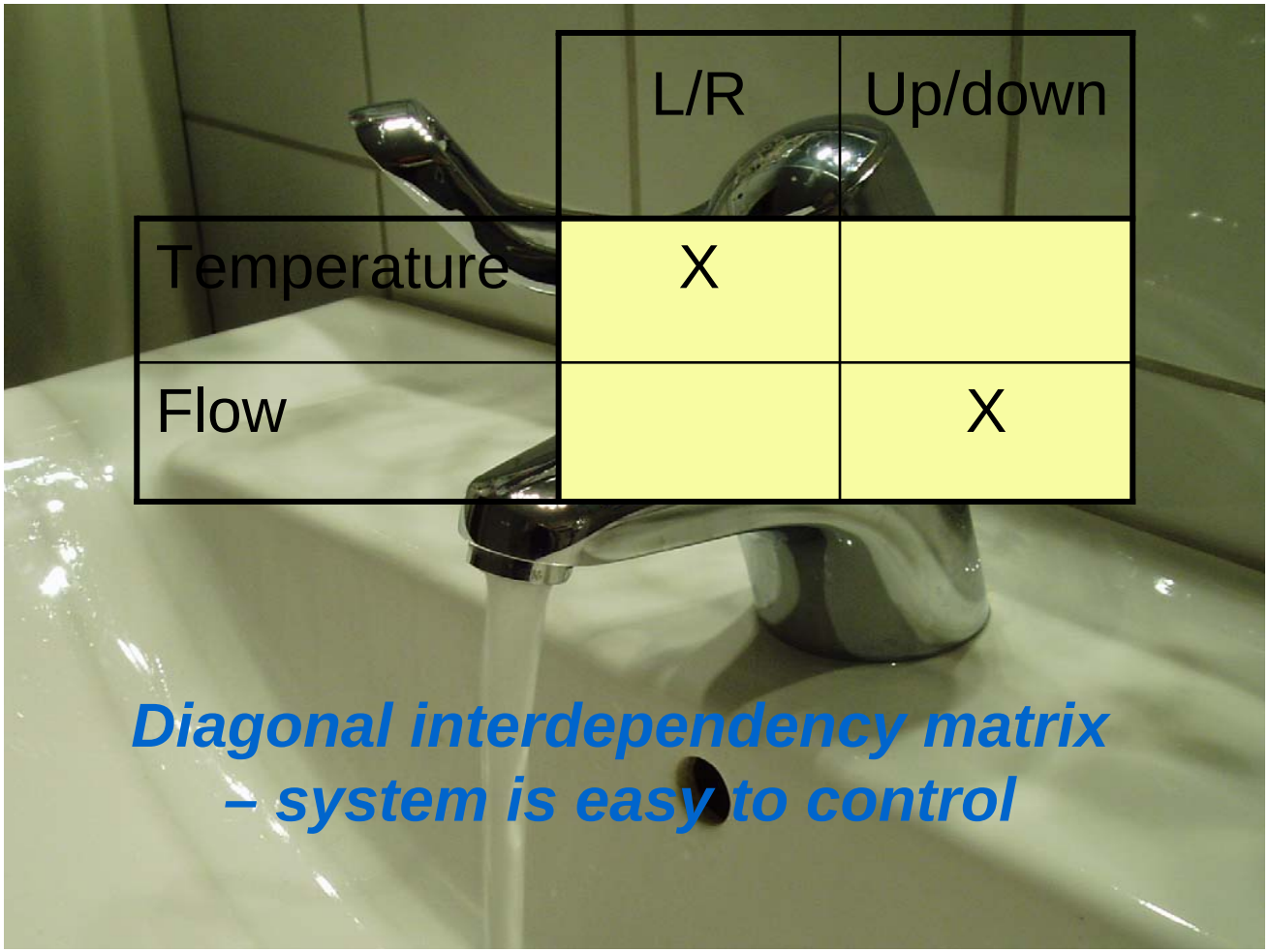


Operating Principle



Operating Principle

Dependencies for a water tap...



	L/R	Up/down
Temperature	X	
Flow		X

Diagonal interdependency matrix – system is easy to control

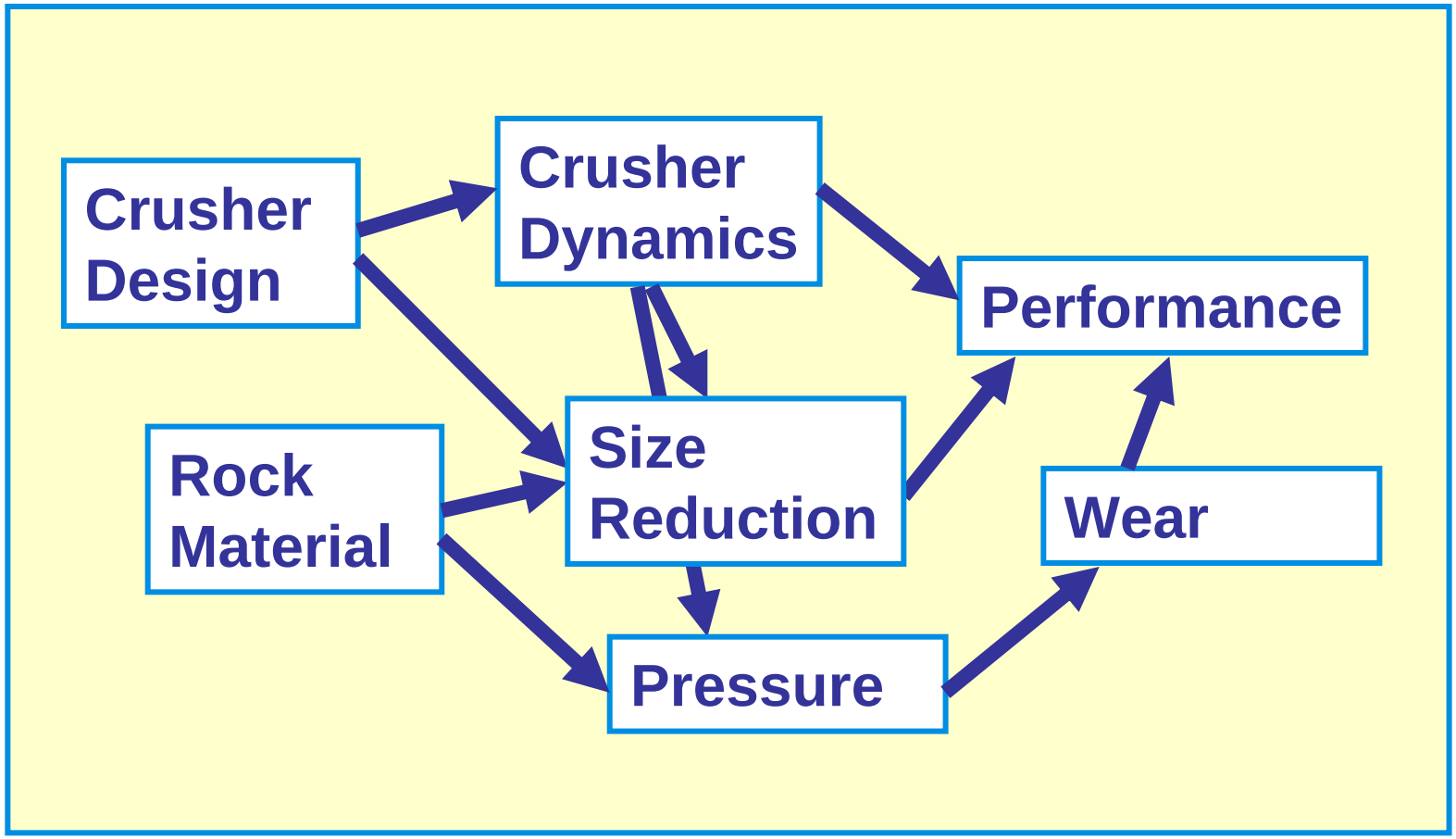
Operating Principle

Dependencies for a cone crusher...

X=Dependency	Input: Eccentric speed	CSS	Stroke	Crushing chamber	Rock strength	Wear resistance	Feed particle size	Feed particle shape	Feed strength
Output: 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

Crusher Model



Crusher Model

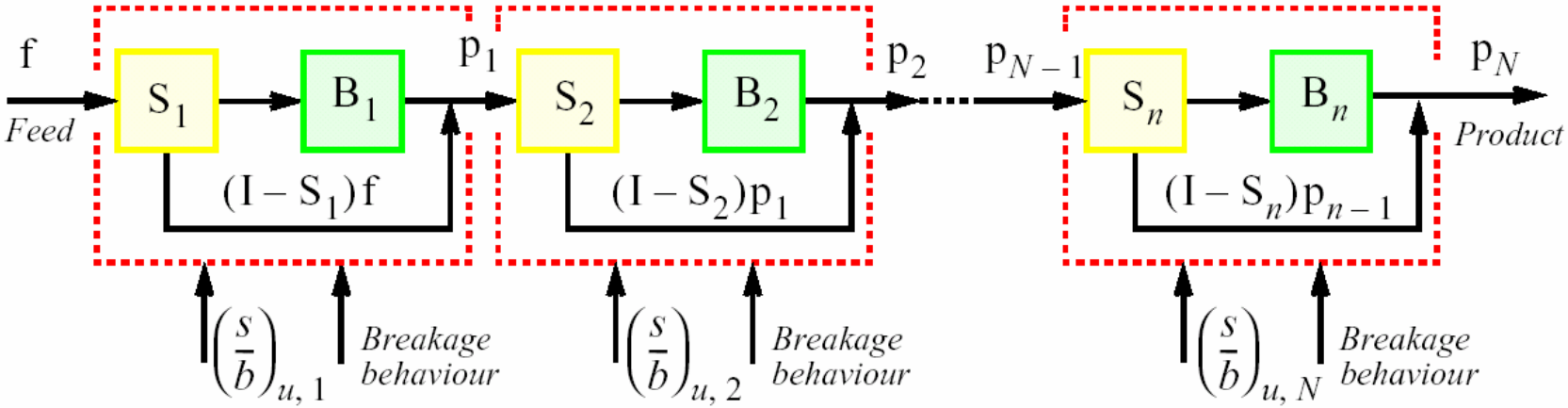
The crushing process can be described with two functions.

Selection S – which?

Breakage B – how?

Crusher Model

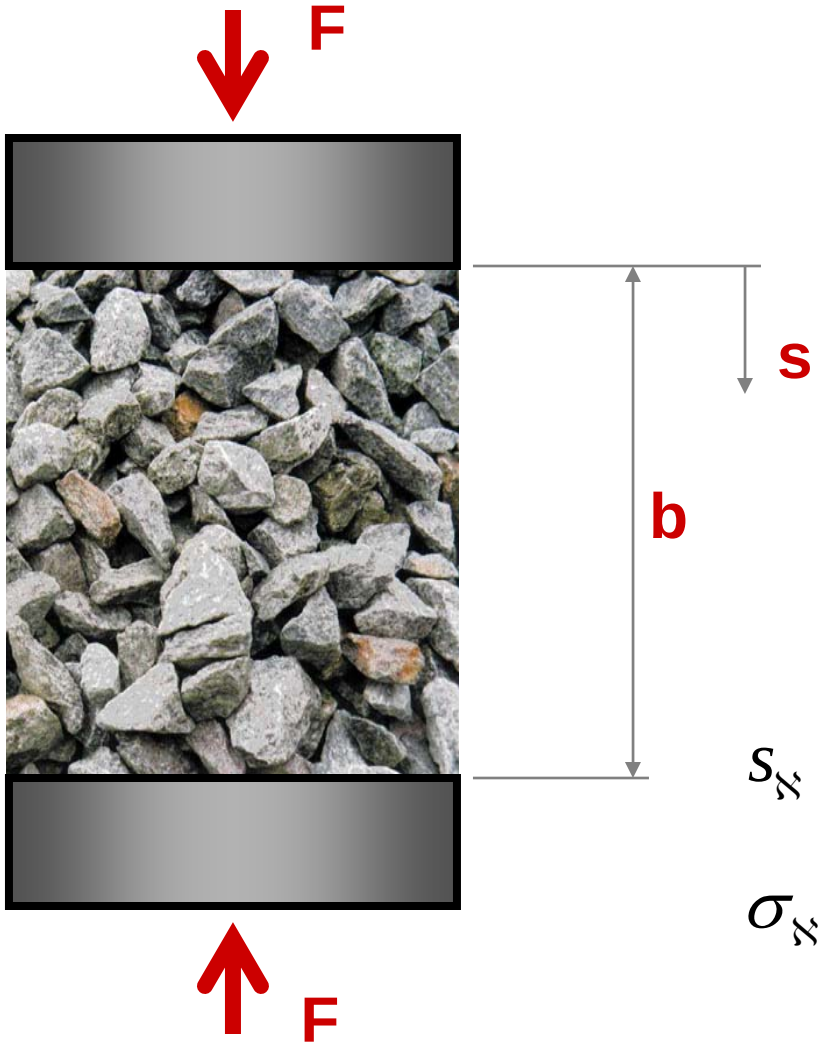
CONE CRUSHER- REPEATED CRUSHING



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

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

Rock Breakage Behavior



Form conditioned compression

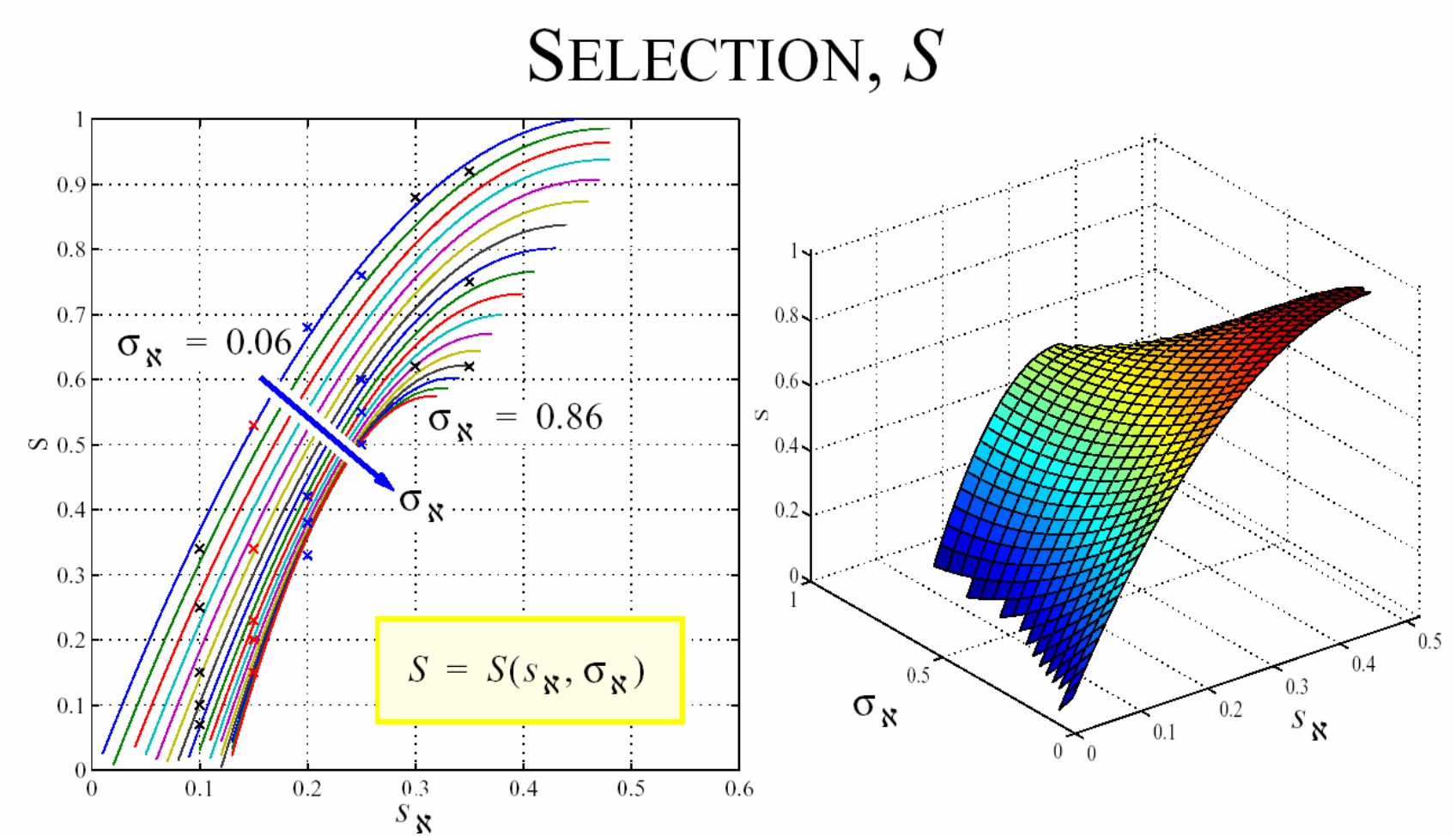
-displacement controlled

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

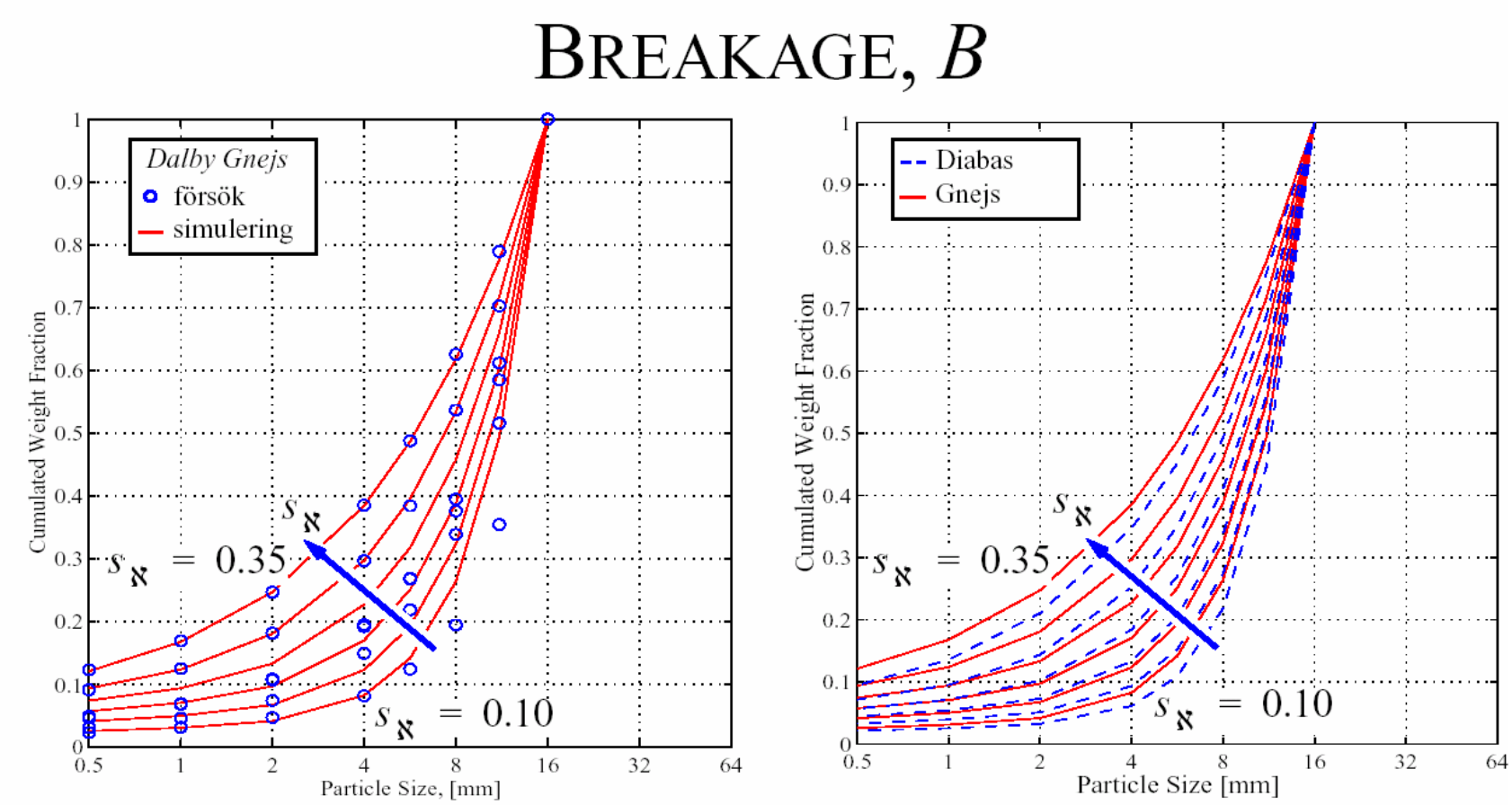
$$s_{\aleph} = \frac{s}{b}$$

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

Rock Breakage Behaviour

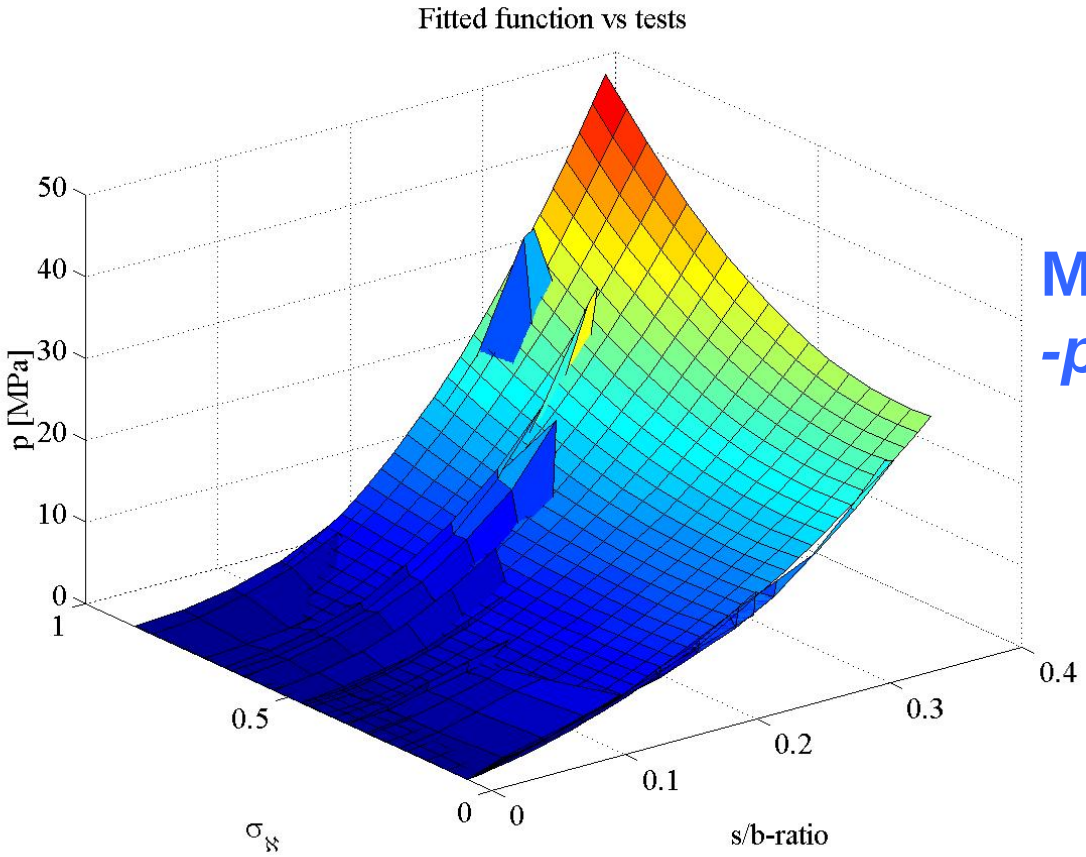


Rock Breakage Behaviour



$$B(x_x, s_x) = (1 - (\alpha_3 + \alpha_4 s_x)) x_x^{\alpha_1 + \alpha_2 s_x} + (\alpha_3 + \alpha_4 s_x) x_x$$

Rock Breakage Behavior



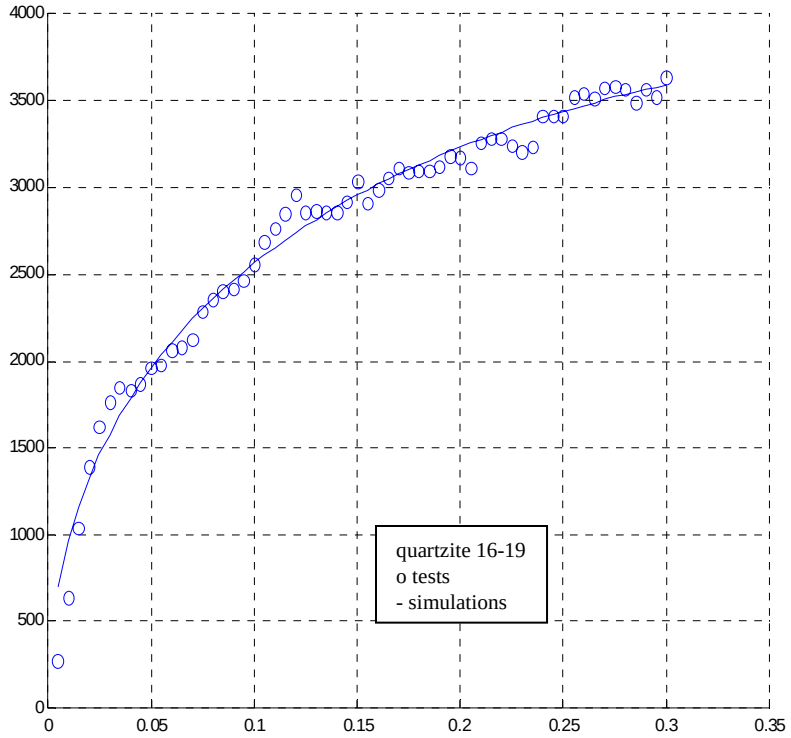
Multi (inter) particle
-pressure response

$$p\left(s_{s'},\sigma_{s'}\right) = a_1 s_{s'}^2 \sigma_{s'}^2 + a_2 s_{s'}^2 \sigma_{s'} + a_3 s_{s'}^2 + a_4 s_{s'} \sigma_{s'}^2 + a_5 s_{s'} \sigma_{s'} + a_6 s_{s'}$$

$\sigma_{s'}$ = *size distribution width*

Rock Breakage Behavior

F [N]



s/b

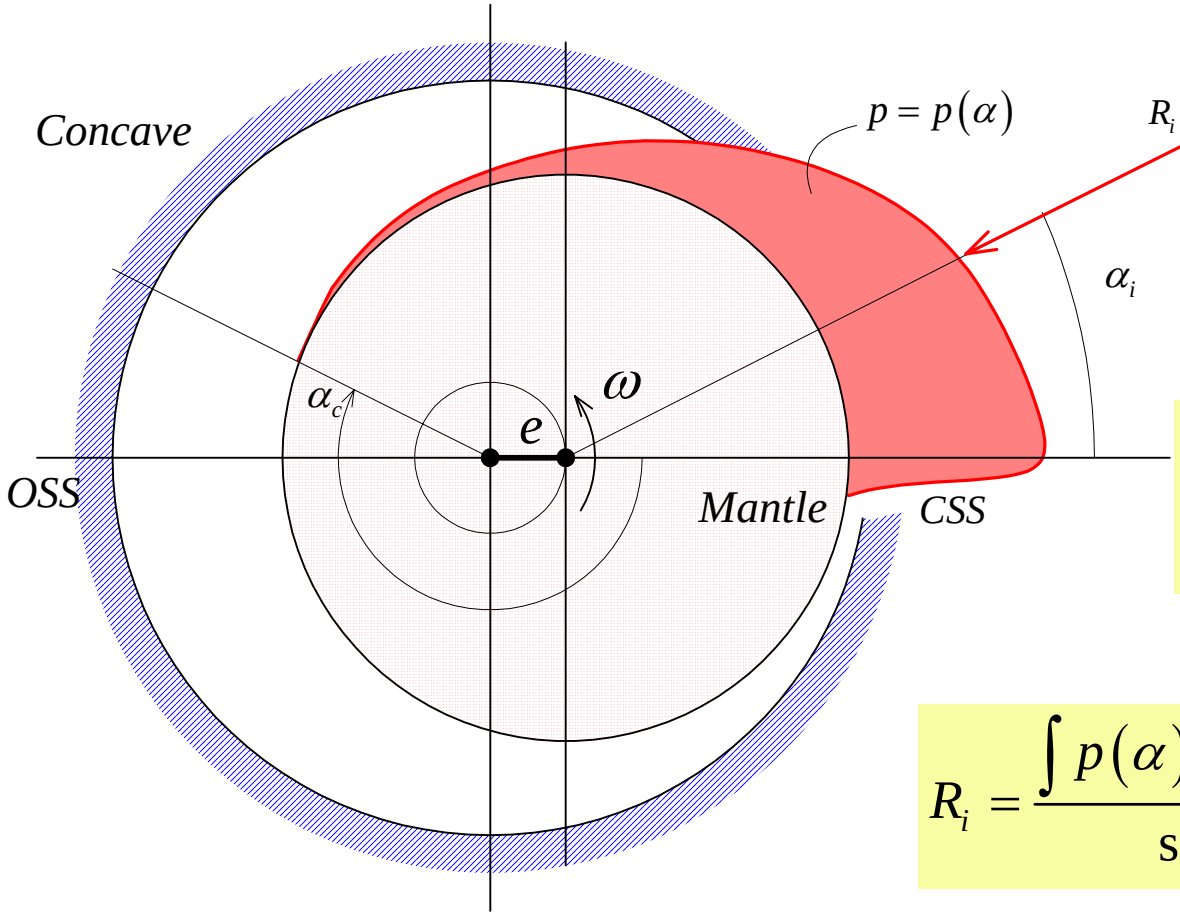
Single particle
-force response

$$F\left(s_{\%}, d\right) = d^2\left(k_1 s_{\%} + k_2 s_{\%}^{k_3}\right)$$

$s_{\%} = compression\ ratio$

$d = particle\ size$

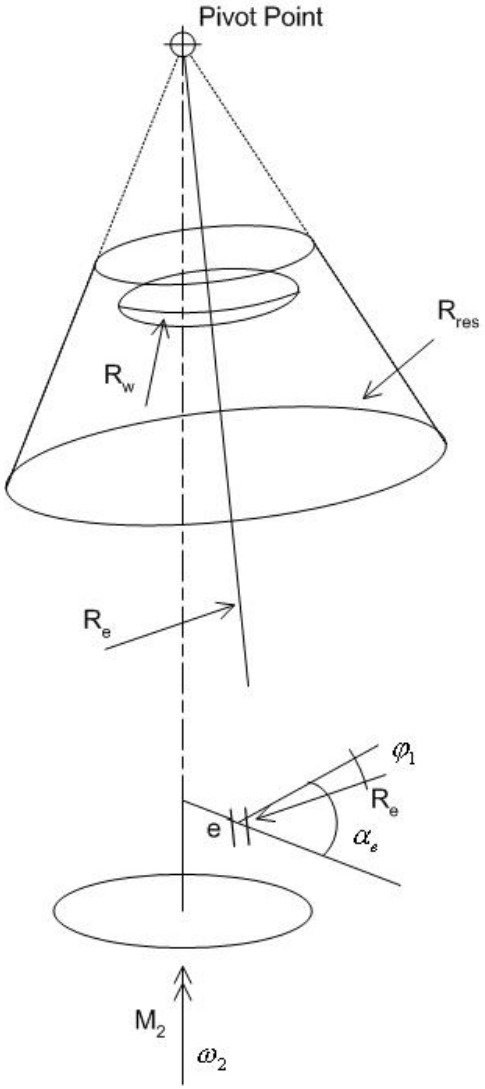
Crushing Pressure and Power Draw

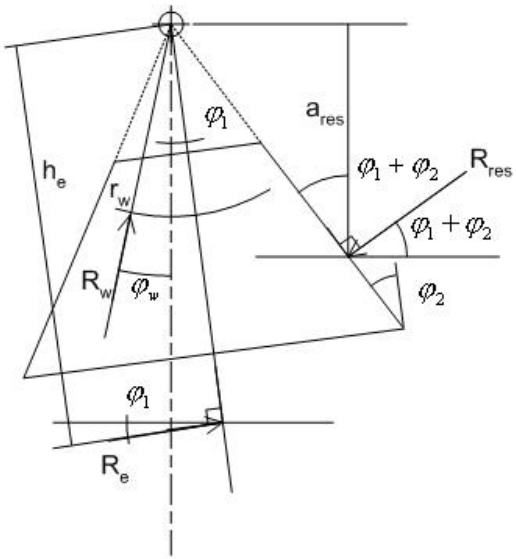


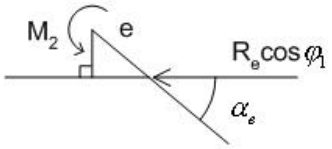
$$\tan\alpha_i = \frac{\int p(\alpha)\sin\alpha d\alpha}{\int p(\alpha)\cos\alpha d\alpha}$$

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

Crushing Pressure and Power Draw





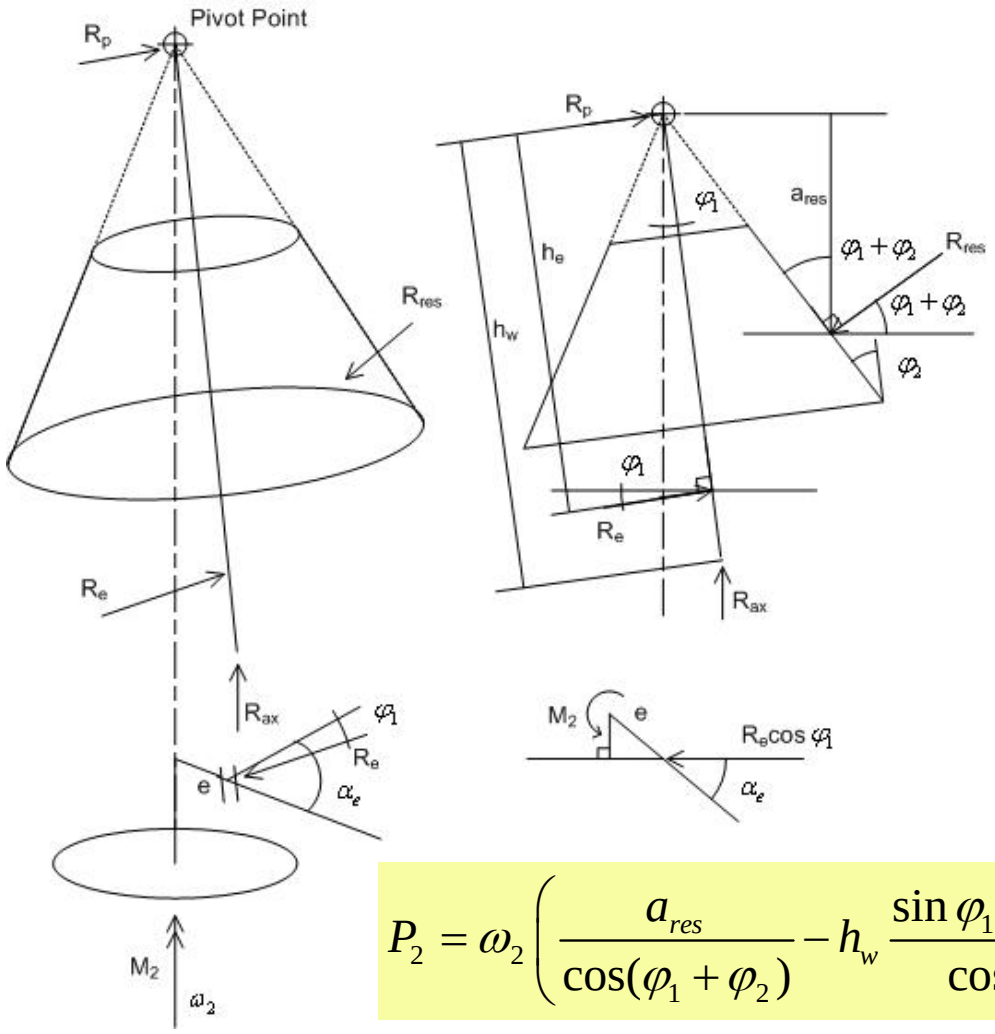


Mechanical model of spiderless cone crusher

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

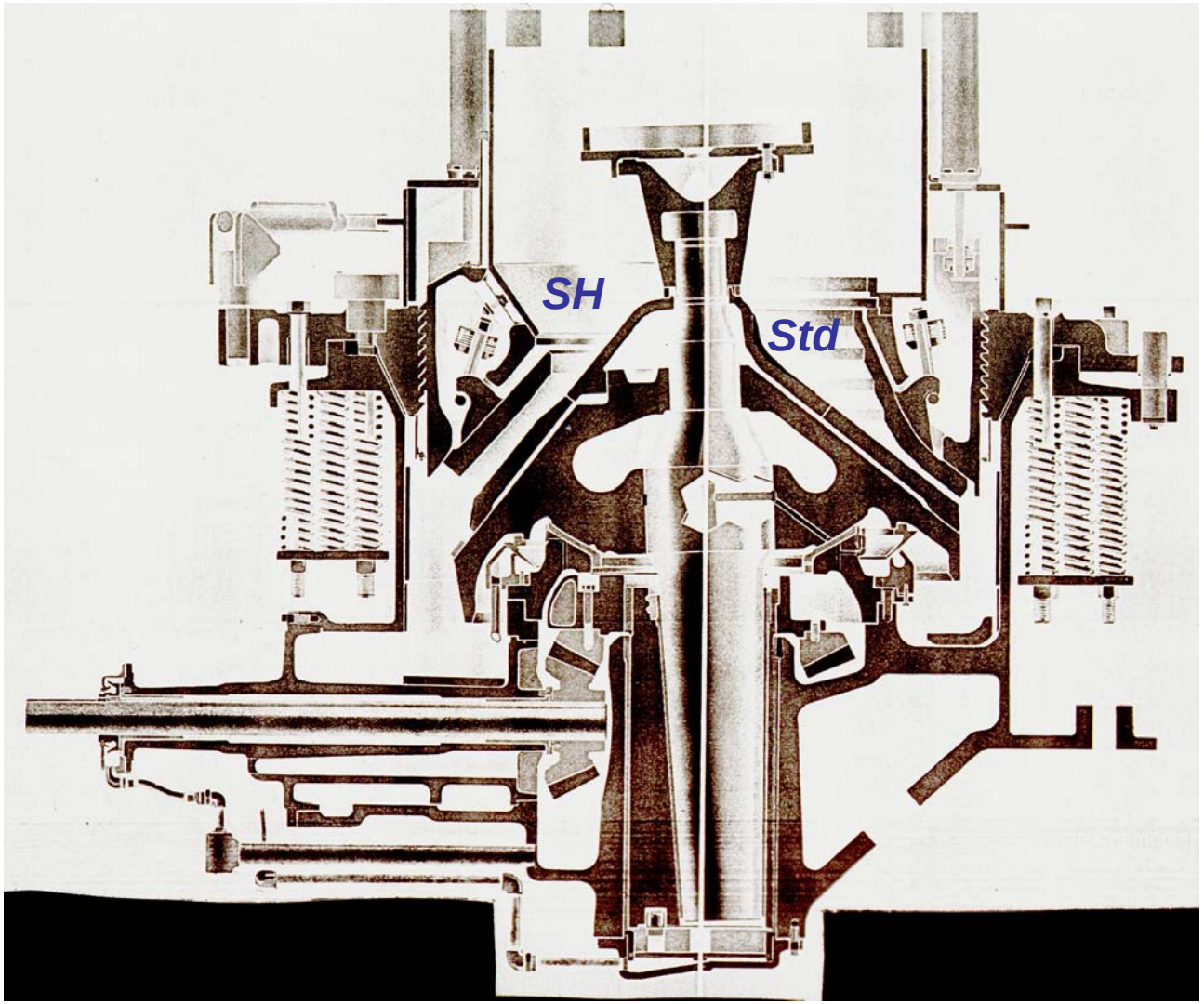


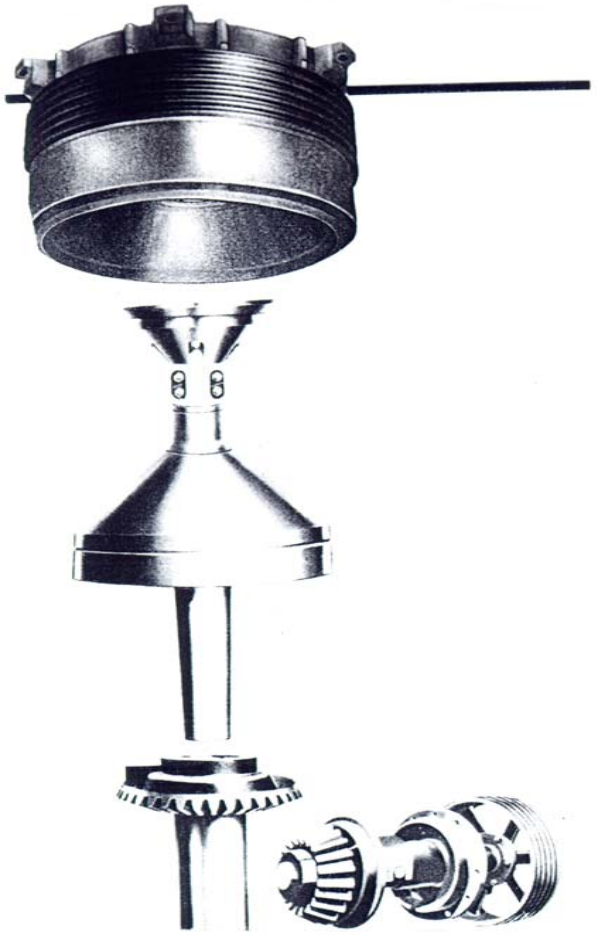
Mechanical model of a top supported cone crusher

HYDROCONE-type

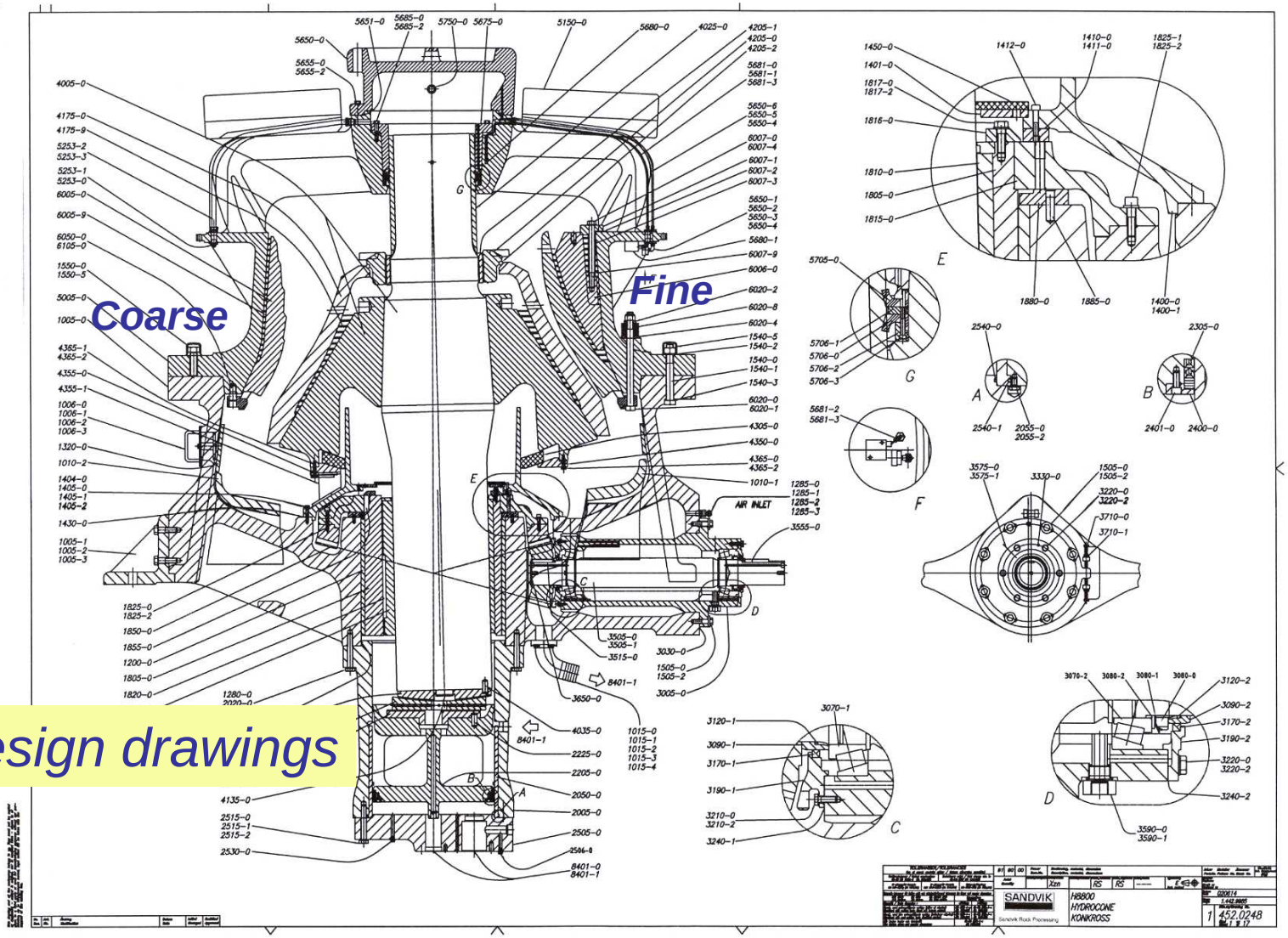
$$P_2 = \omega_2 \left(\frac{a_{res}}{\cos(\varphi_1+\varphi_2)} - h_w \frac{\sin\varphi_1 \sin\varphi_2}{\cos\varphi_1} \right) R_{res} \cos\varphi_1 \frac{e}{h_e} \sin\alpha_e$$

Geometry



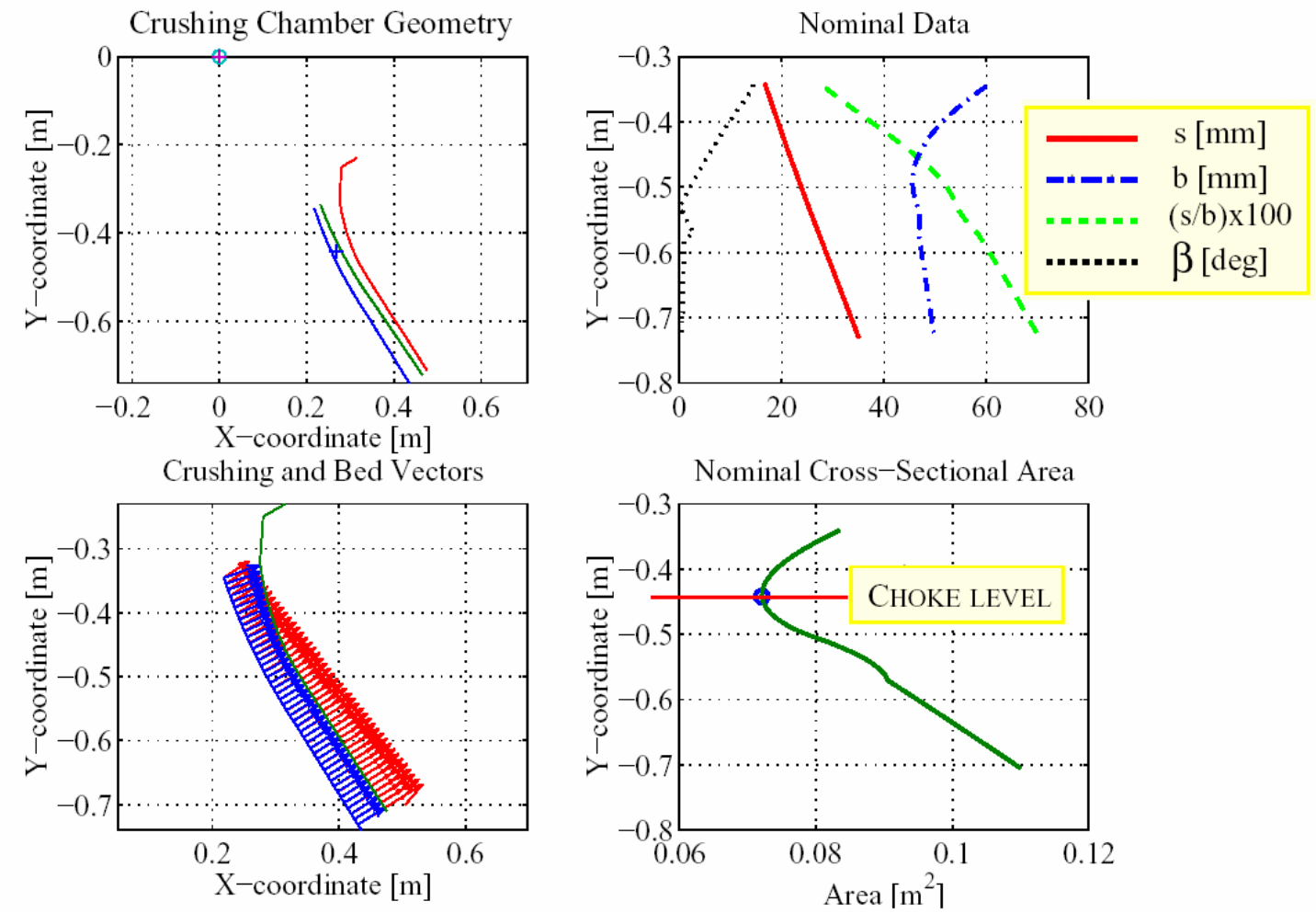


Geometry



Design drawings

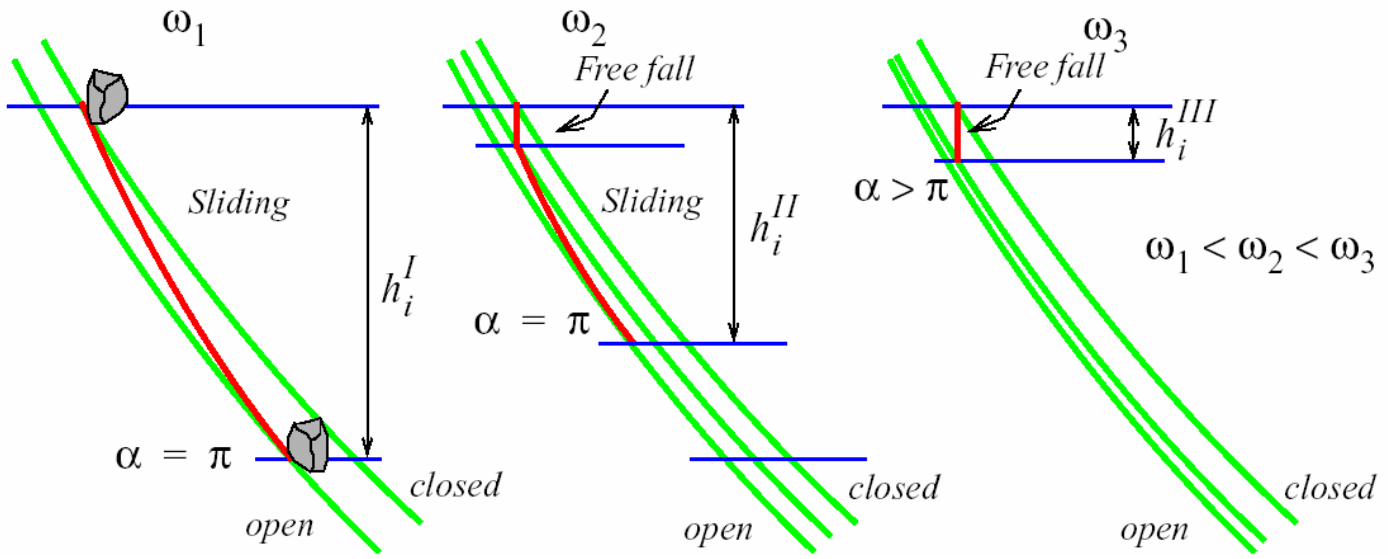
Geometry


Crushing Chamber Geometry
Y−coordinate [m]
X−coordinate [m]
Nominal Data
Y−coordinate [m]
s [mm]
b [mm]
(s/b)x100
β [deg]
Crushing and Bed Vectors
Y−coordinate [m]
X−coordinate [m]
Nominal Cross−Sectional Area
Y−coordinate [m]
CHOKE LEVEL
Area [m²]

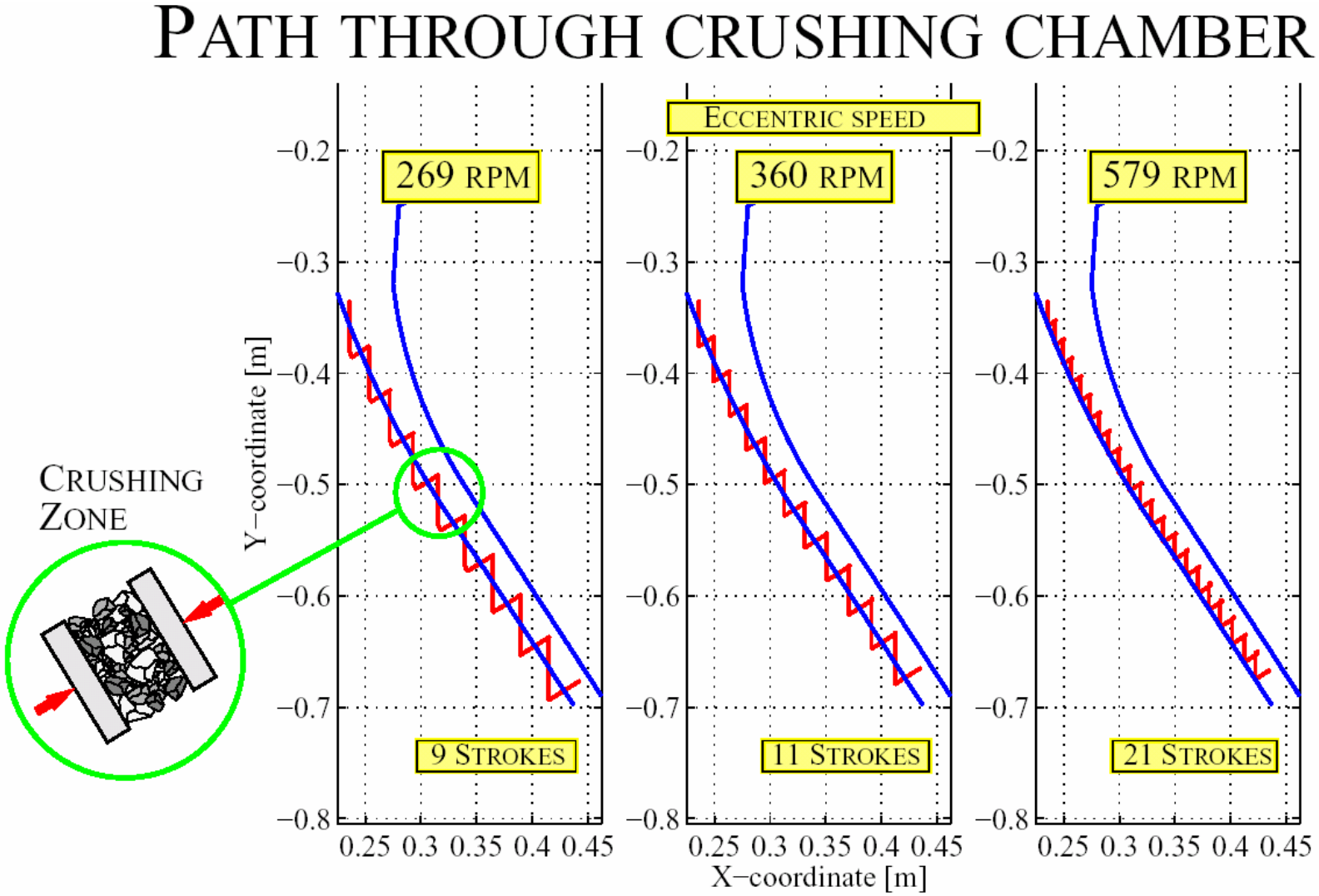
Flow model

Material flow mechanics

- Sliding
- Free fall
- Squeezing

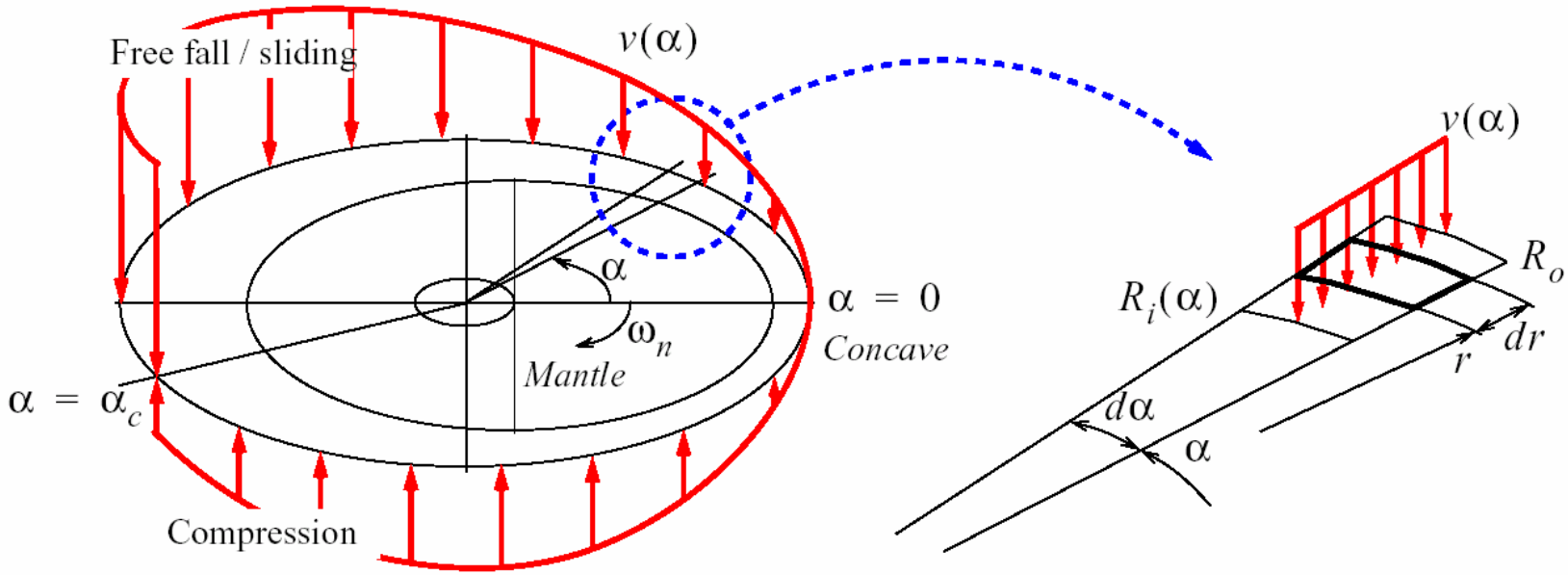


Flow model


PATH THROUGH CRUSHING CHAMBER
ECCENTRIC SPEED
269 RPM
360 RPM
579 RPM
9 STROKES
11 STROKES
21 STROKES
CRUSHING ZONE
Y−coordinate [m]
X−coordinate [m]
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
0.25 0.3 0.35 0.4 0.45

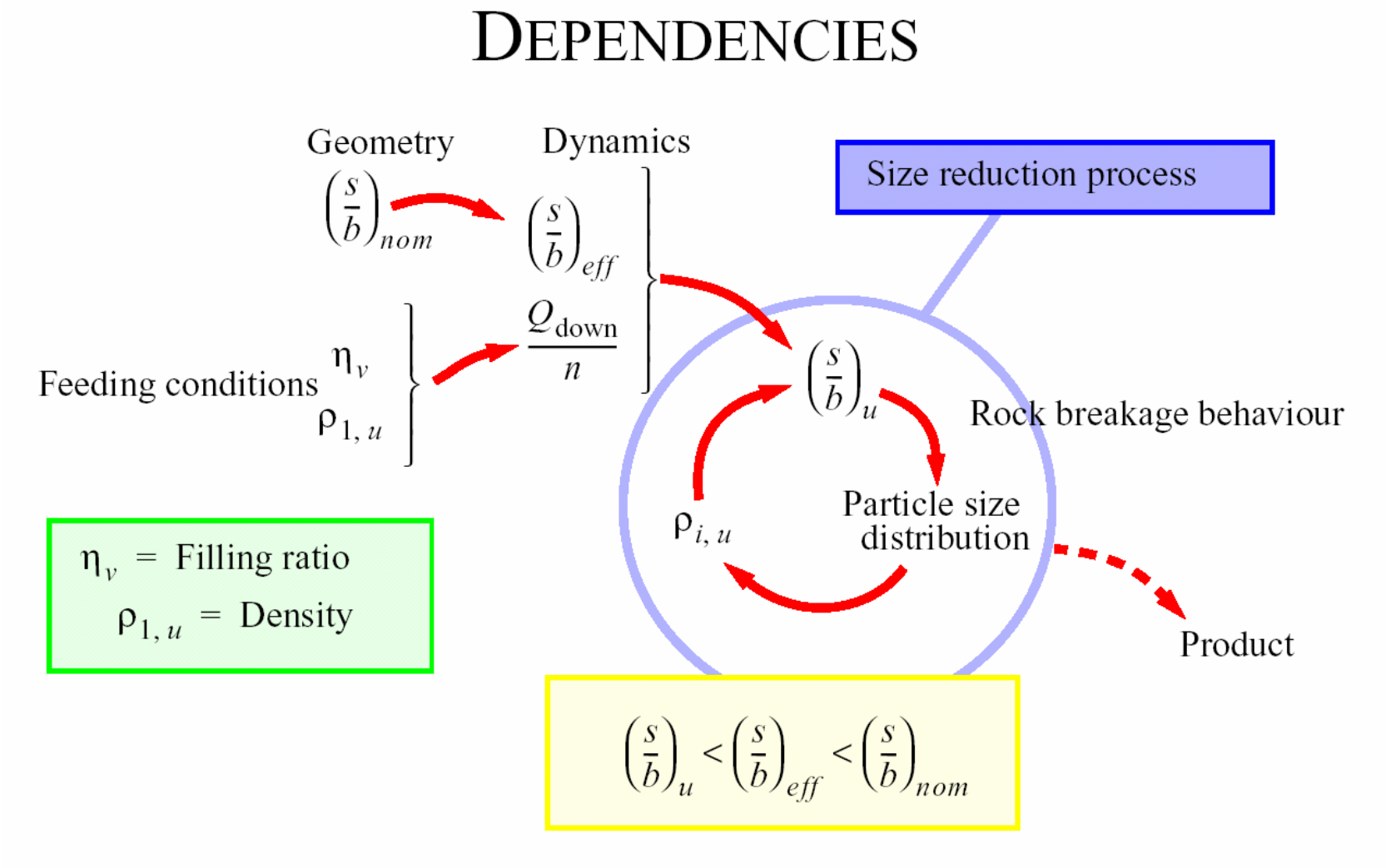
Flow model

CAPACITY



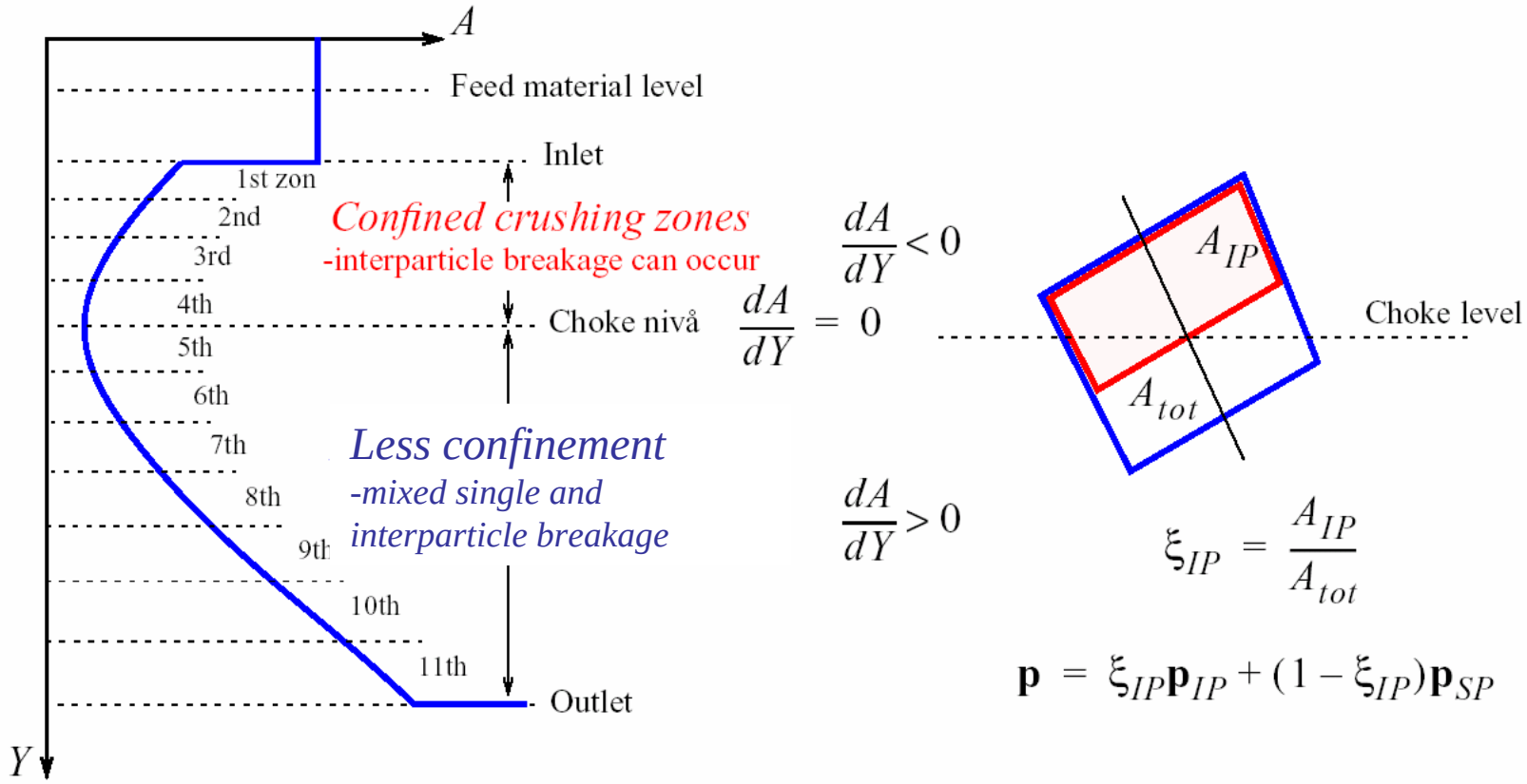
$$Q_{\text{down}} = \int_0^{\alpha_c} \int_{R_i(\alpha)}^{R_o} \rho(\alpha) v(\alpha) r \, dr \, d\alpha = \frac{1}{2} \int_0^{\alpha_c} \rho(\alpha) (R_o^2 - R_i^2(\alpha)) v(\alpha) \, d\alpha$$

Interaction Flow-Size reduction

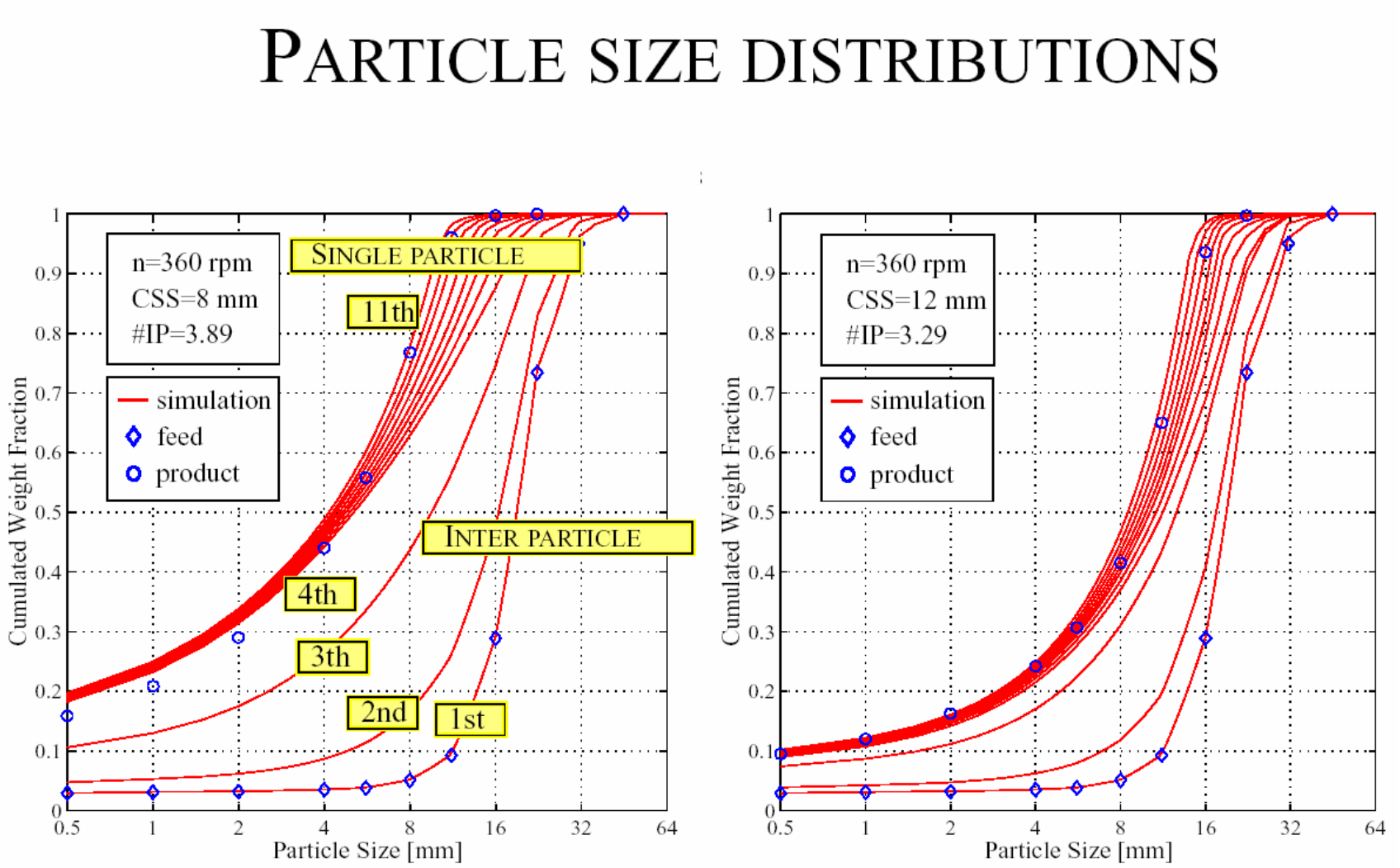


Interaction Flow-Size reduction

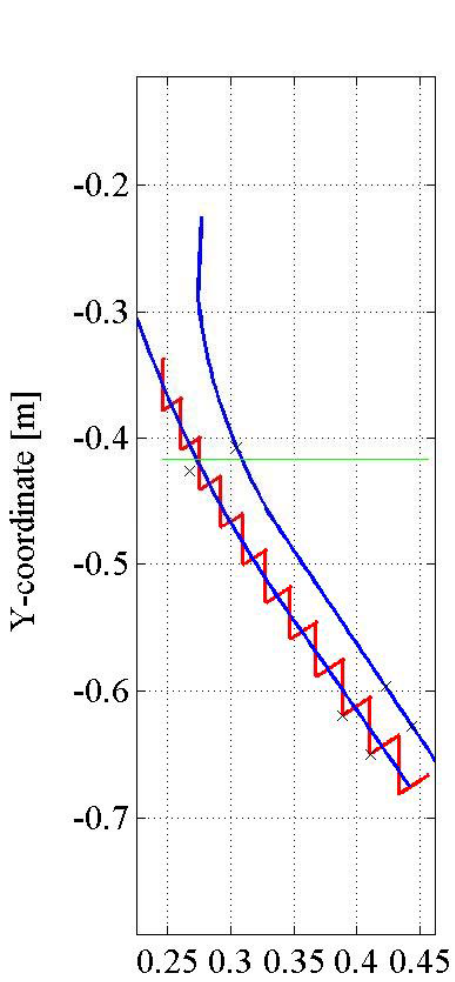
BREAKAGE MODES

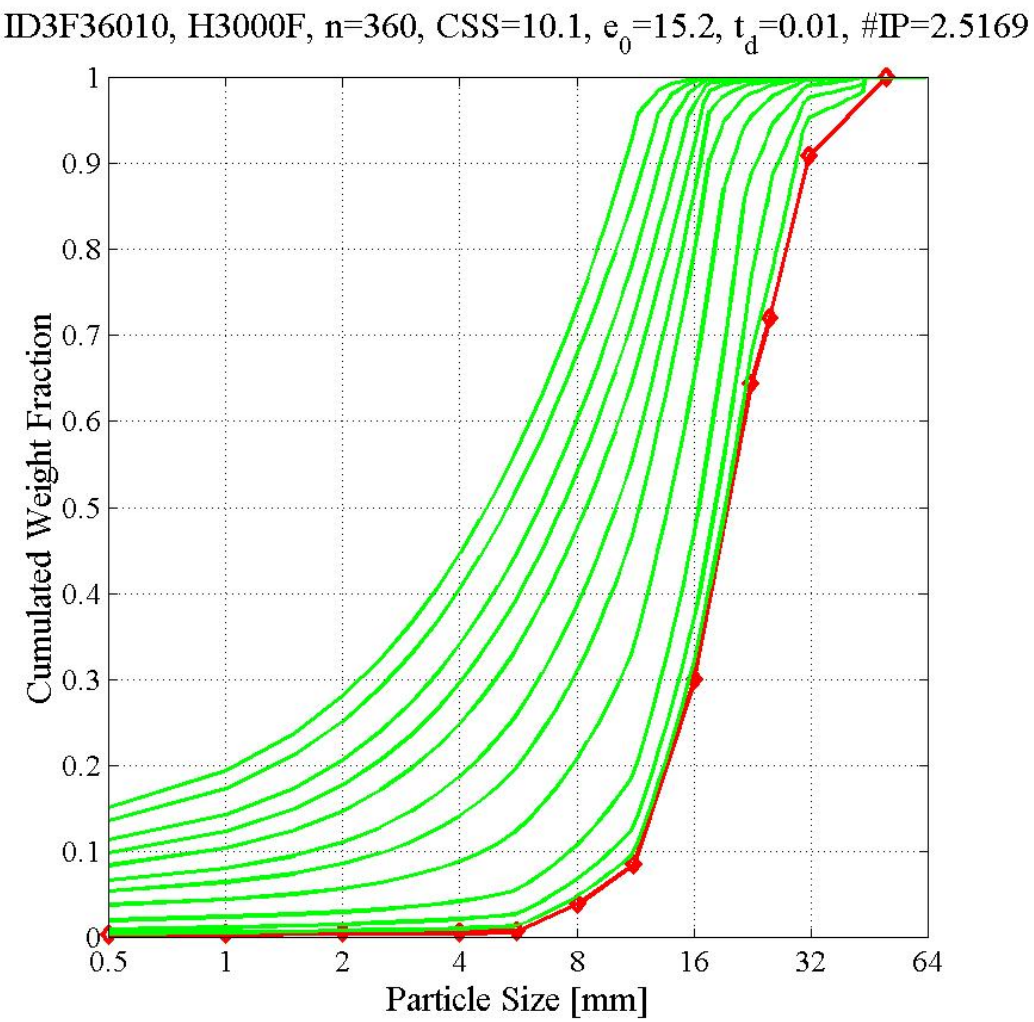


Results

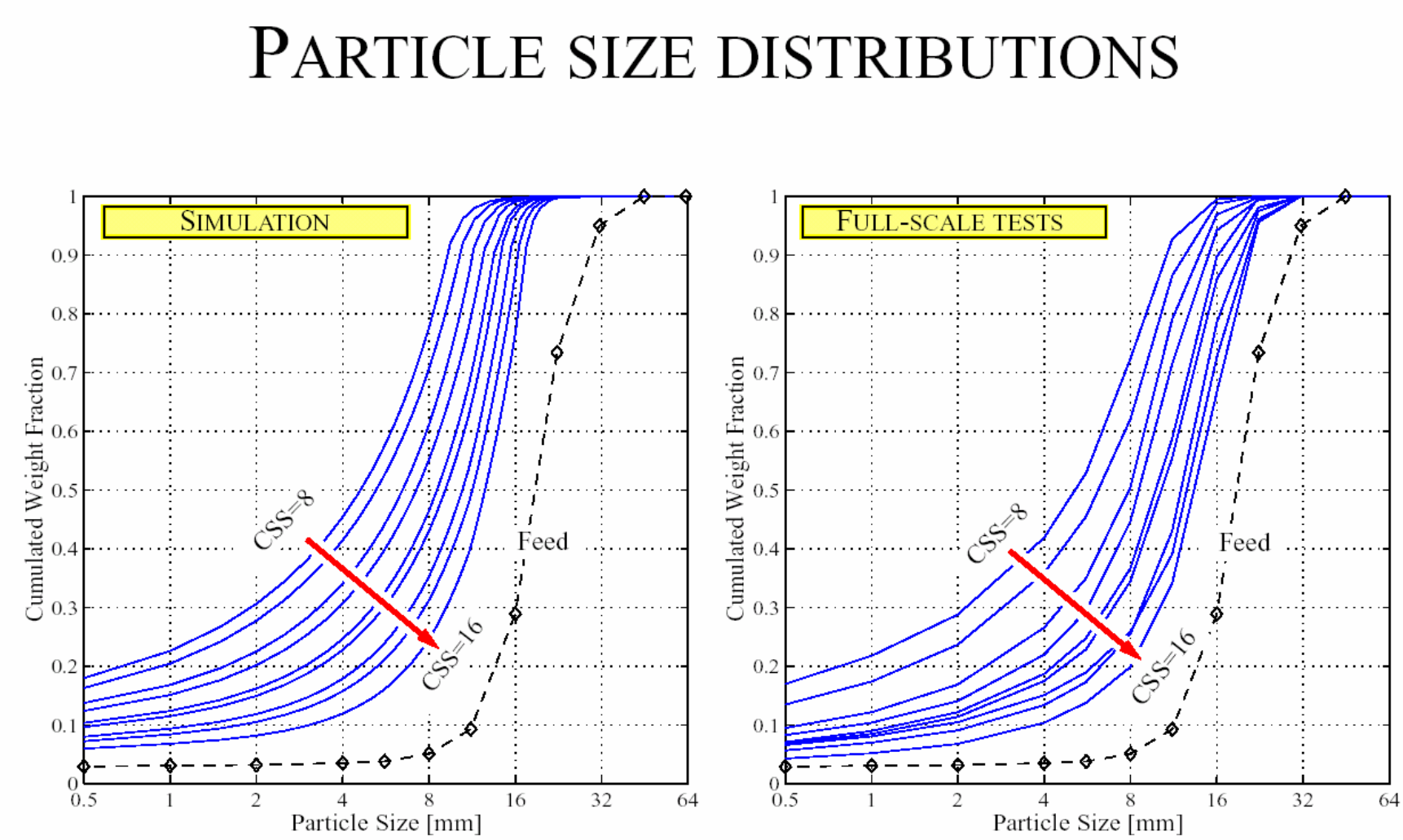

PARTICLE SIZE DISTRIBUTIONS
n=360 rpm
CSS=8 mm
#IP=3.89
simulation
feed
product
SINGLE PARTICLE
11th
INTER PARTICLE
4th
3th
2nd
1st
Cumulated Weight Fraction
Particle Size [mm]
n=360 rpm
CSS=12 mm
#IP=3.29
simulation
feed
product
Cumulated Weight Fraction
Particle Size [mm]

Results - *Particle size distributions*

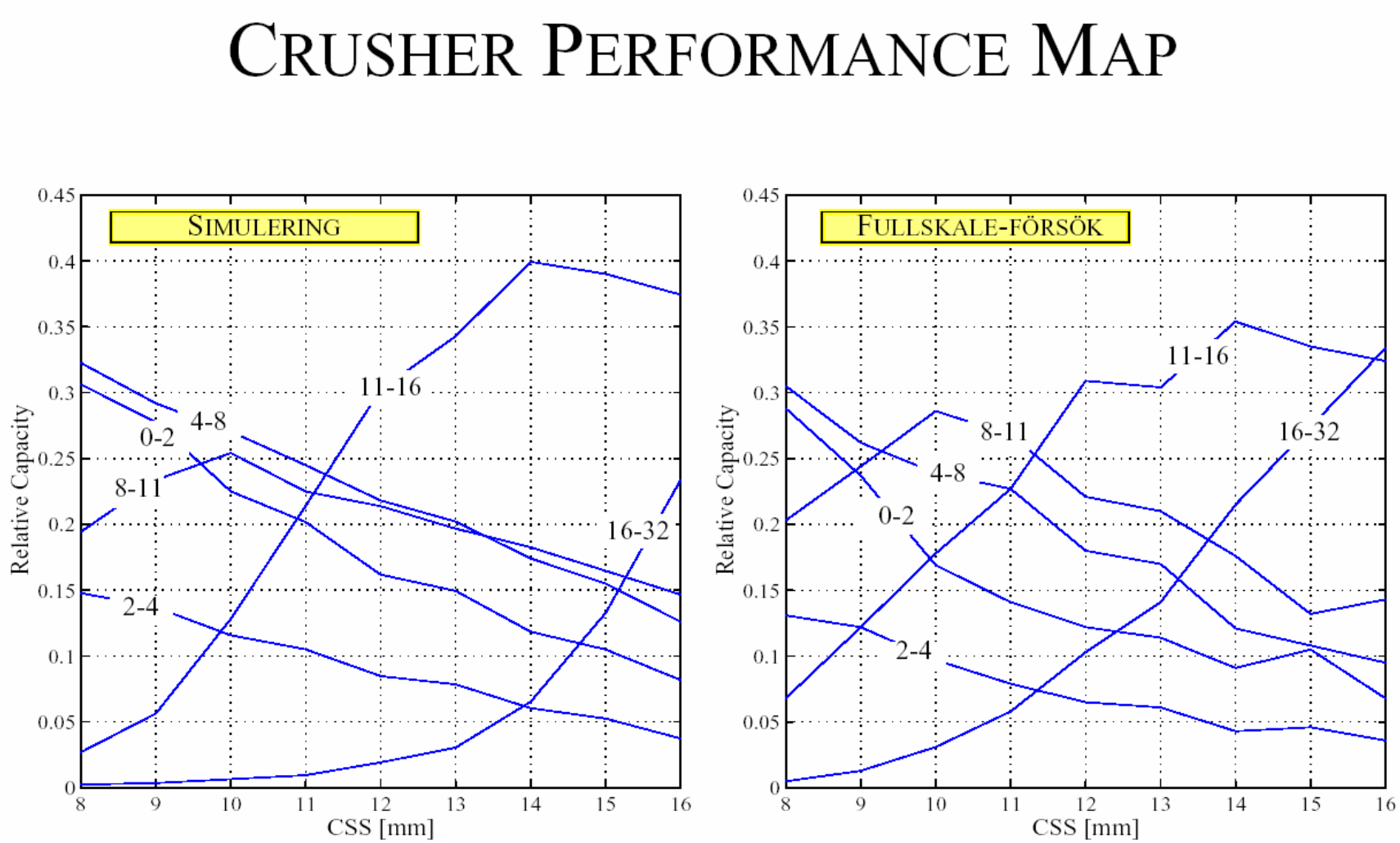




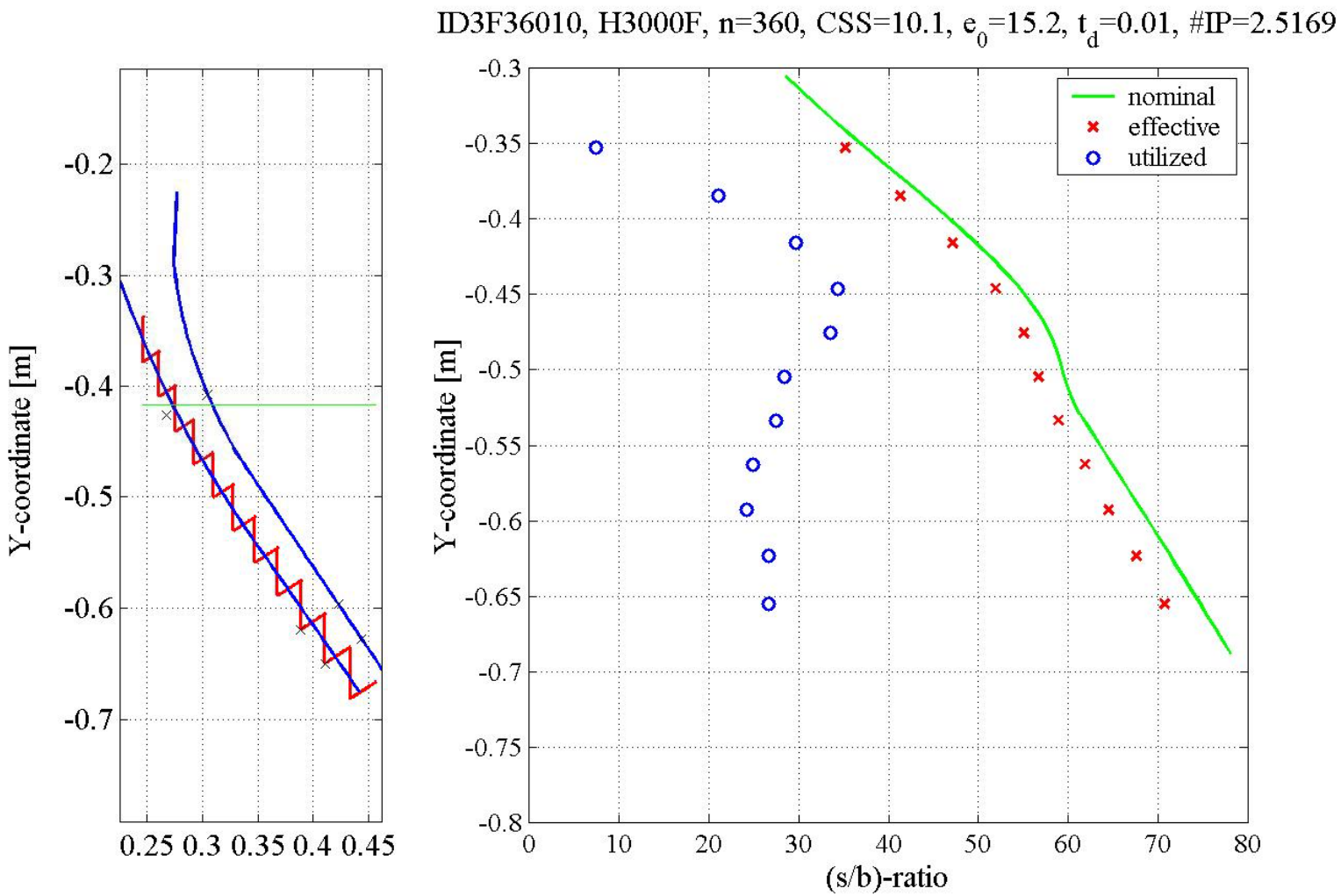
Results - *Particle size distributions*



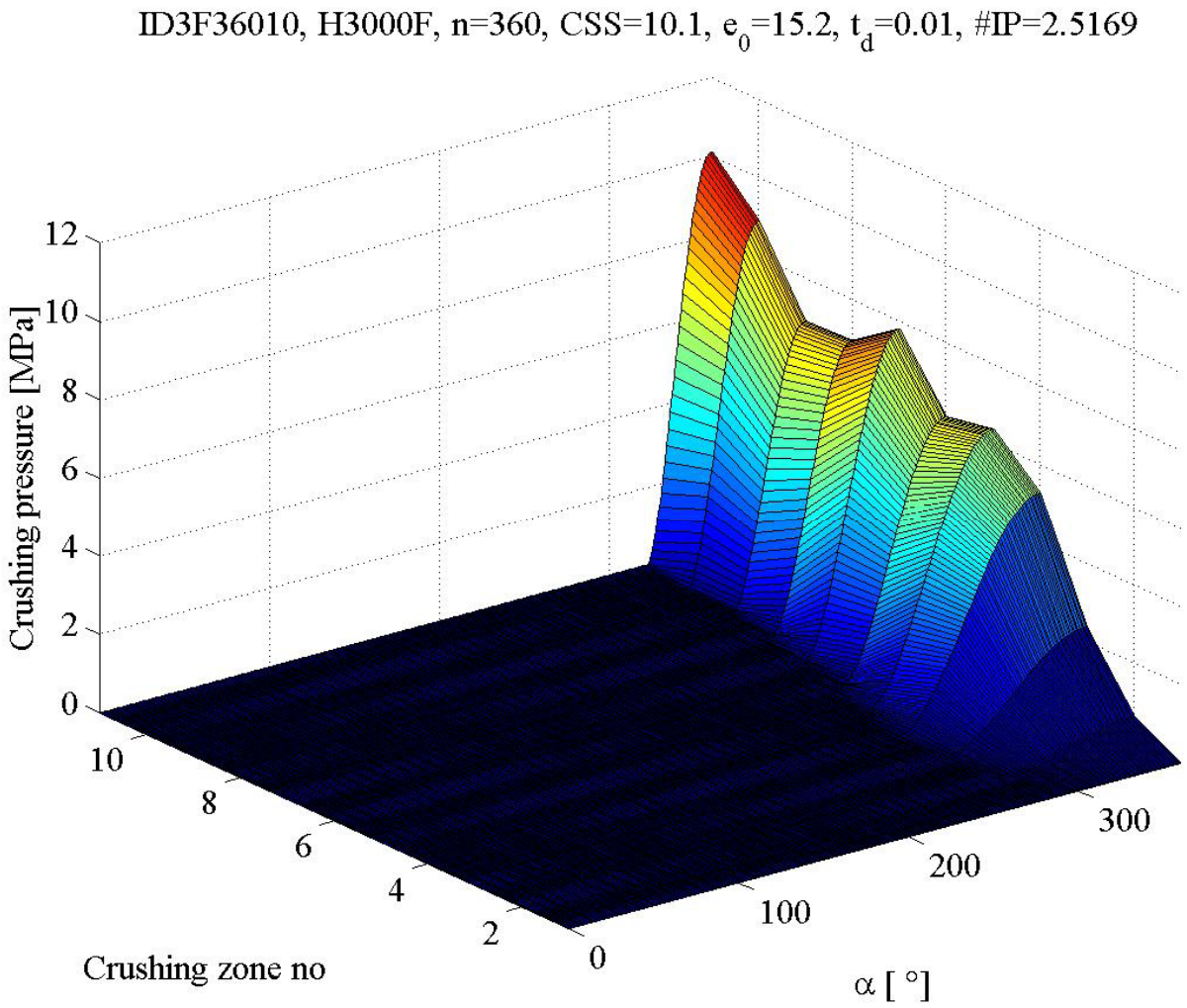
Results - *Particle size distributions*



Results - *Compression ratio*



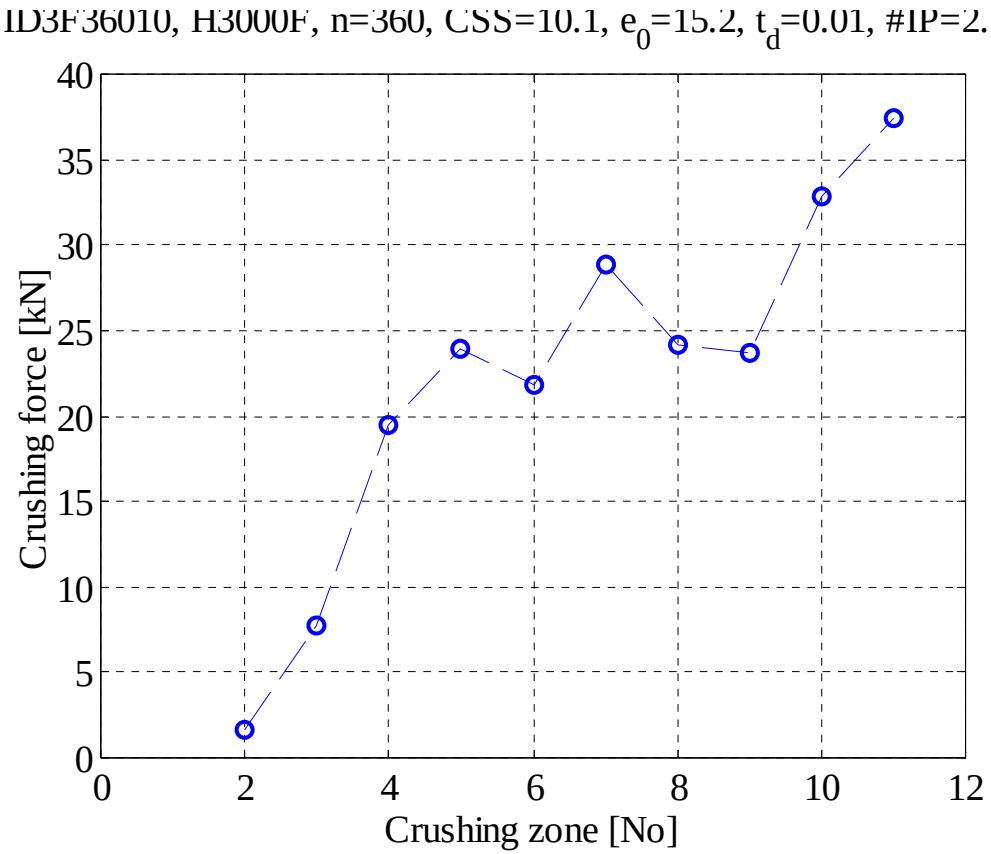
Results - *Pressure*



H3000-F
CSS=10mm
Gneiss
10-30mm

-only a small proportion of the crushing chamber is utilized

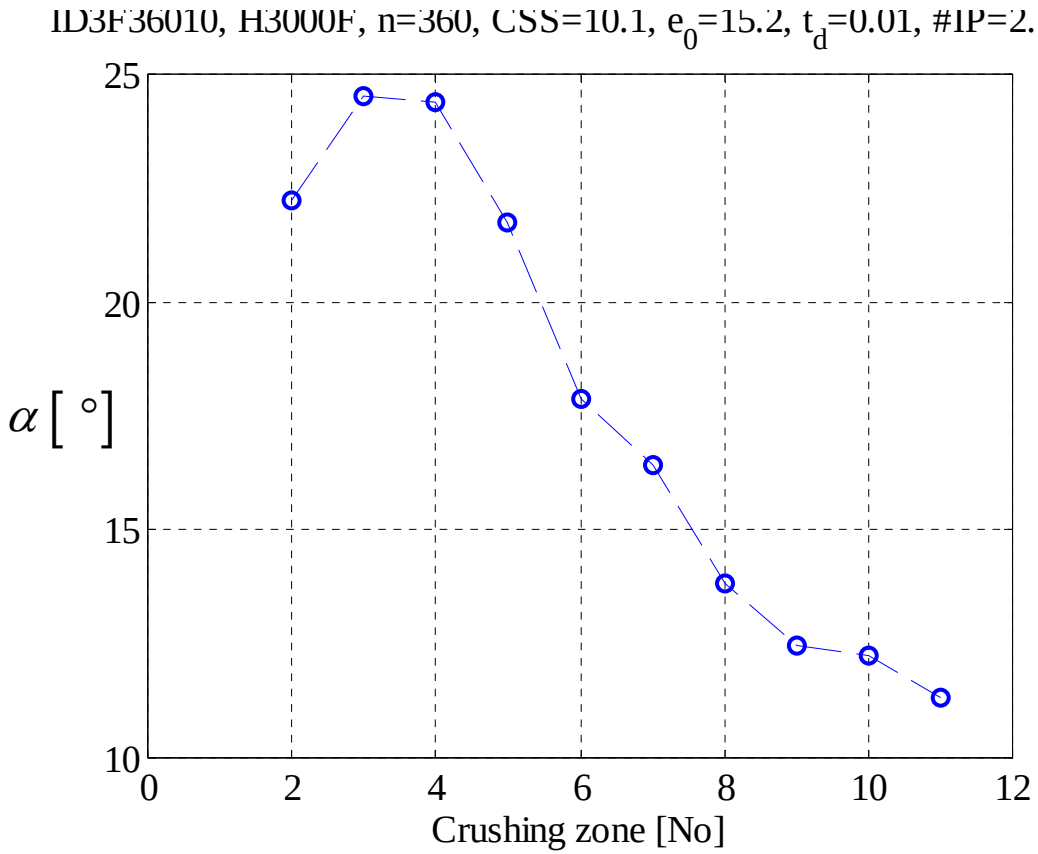
Results - *Crushing force*



Total vertical force

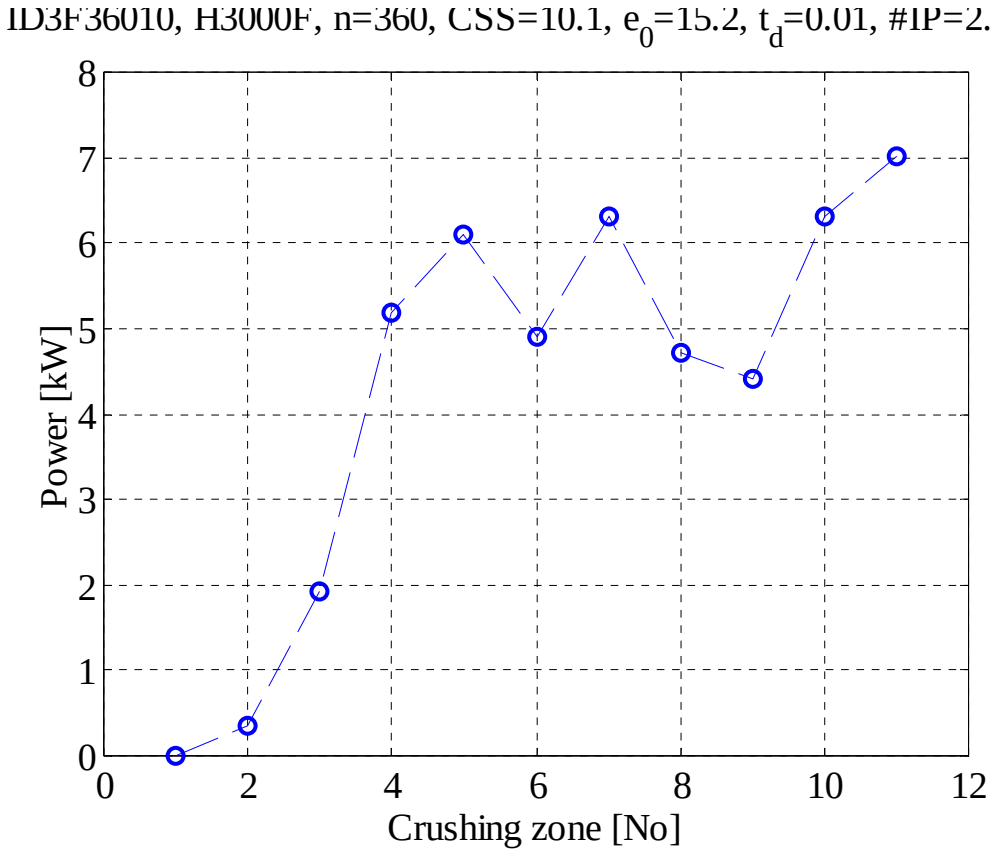
188.3 kN

Results - *Crushing angle*



-very small crushing angles

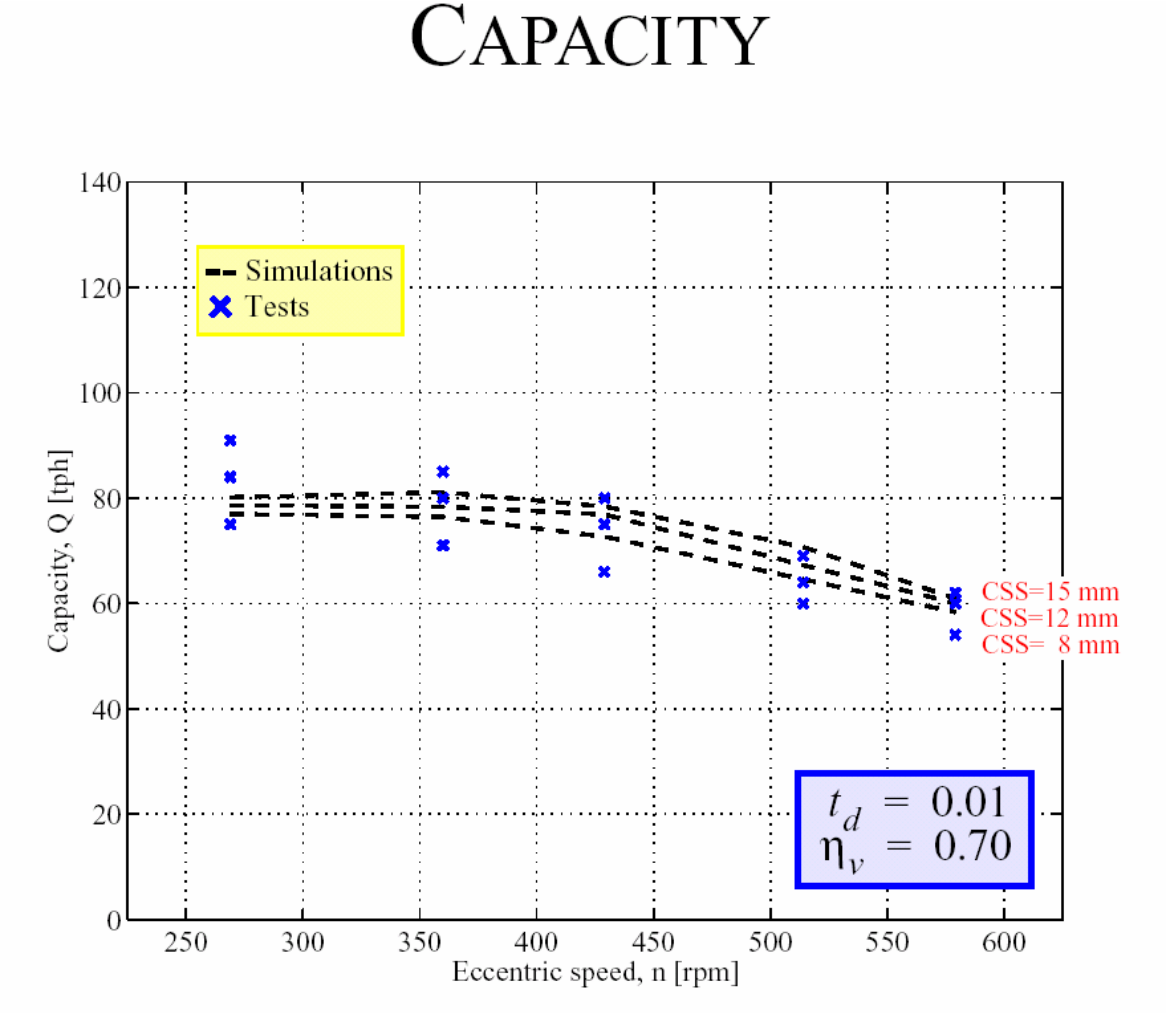
Results - *Crushing power*



Total power

47.5 kW

Results


CAPACITY
Simulations
Tests
CSS=15 mm
CSS=12 mm
CSS= 8 mm
t_d = 0.01
η_v = 0.70
Capacity, Q [tph]
Eccentric speed, n [rpm]
0
20
40
60
80
100
120
140
250
300
350
400
450
500
550
600

Results

Crushing - a complex process

Analytical model for cone crushers

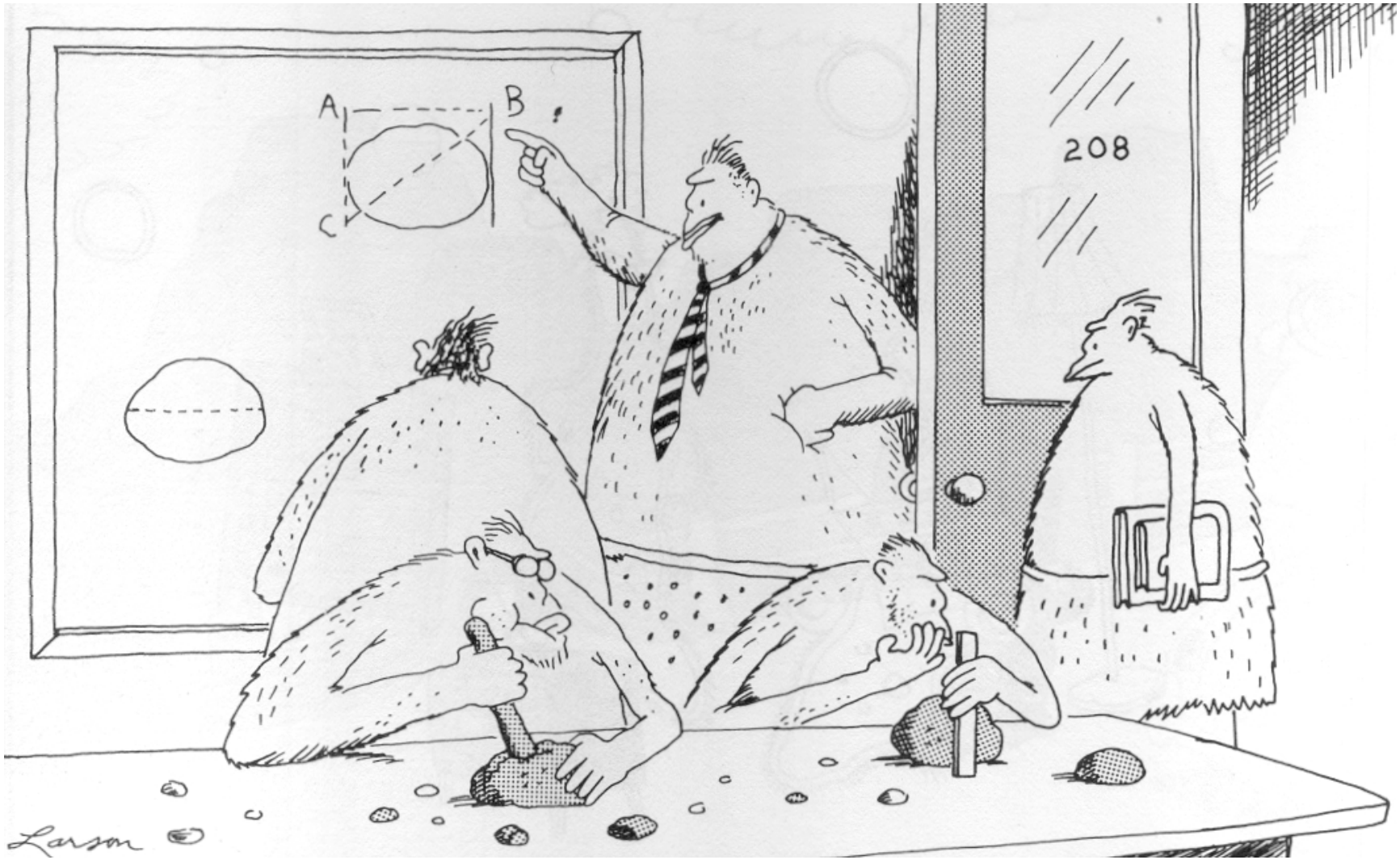
- General
- Simulation
- Optimization
- Design of customized crushing chambers

Results

Three *main factors* identified

- Breakage modes
- Number of crushing zones
- Compression ratio

Detailed understanding of the crushing process on a fundamental level


A
B
C
208
Larson

H7800-Implementation of Results

H7800-Implementation of Results

H7800-Implementation of Results

3C-Implementation of Results

3C-team

- Customized
- Crushing
- Chambers

Fine Tuned Chambers