Metso

Crushing and Screening Handbook

Seventh edition

Preface to the Seventh edition

Rock is the most used natural resource in the world. The two main types of natural aggregates are:

1) crushed rock
2) sand and gravel

As a main ingredient in asphalt and concrete, these aggregates are used in the construction of highways and bridges, as well as in both residential and non-residential buildings. The widespread use of aggregates results not only from its general availability but also from economic considerations.

The cost of aggregate is not a major factor in most applications, but its impact on the use of more expensive components, such as cement in concrete or bitumen in asphalt, is quite essential.

For that reason, it is important to understand those factors in aggregates processing that have the greatest impact on quality and costs. This calls for an understanding of the entire process, from solid rock to its final application.

Metso has published this book to help those involved in the quarrying business. The main target groups are quarry managers, construction site staff, consultants, and technical universities. Of course, the book also contributes to mining, especially in terms of crushing and screening. For those seeking a greater focus on mining, Metso's minerals processing handbook is also available.

This is an updated version of the Metso Crushing and Screening Handbook, the first edition of which was published in 2006.

We at Metso hope that this book contributes to an improved understanding of quarrying operations and thus helps us all to achieve profitable business. Quite a few people have contributed to the book, and I wish to express my warmest thanks to them.

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Metso in brief

To be successful in today's quarry, sand and gravel operations, you need a partner to supply competitiveness, not just equipment. This translates into a comprehensive source of global knowledge, financial resources, innovative technologies and systems, as well as skilled people in worldwide locations.

Over 15,000 Metso employees and our global distributor network operate in sales and manufacturing facilities and service shops covering all continents. They supply you with world-class equipment, complemented by comprehensive service solutions aimed at increasing your operational reliability. In short, we do everything possible to help ensure your success.

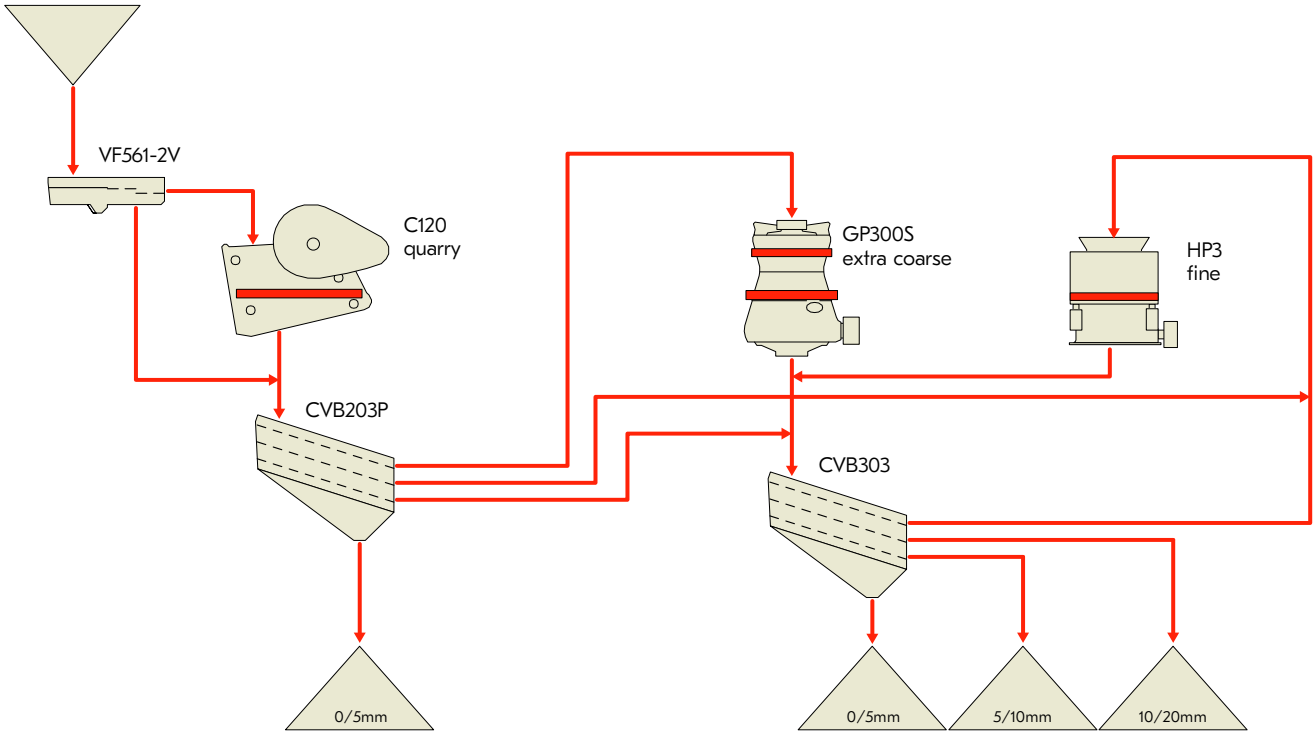
Your trusted partner
Your partner of choice, Metso is the trusted and preferred supplier in the rock processing industry. Our highest priority and personal commitment are to provide lifetime support and service for your aggregates processing operations.

Whether you need a single crusher, a multistage process, or a complete plant, we assist you with the right design for the most cost-effective crushing process. We are the world's leading supplier of both unit machines and complete aggregates processing systems.

Comprehensive process solutions
Your system may involve a whole series of processes, such as crushing and screening, conveying, classifying, stockpiling, storage, loading and unloading, automation, environmental control, and wear protection.

Using sophisticated project tools, our experienced engineers will arrange the appropriate equipment into a balanced system to provide you the high-quality end-products you require, at the lowest cost per ton. We also provide site preparation, structural design, and supply and erection plans.

When designing a new plant, we balance raw material characteristics with the required production rate, size and shape of the finished product. After careful selection of each piece of equipment - from final screening to primary crushing - your process characteristics become optimal quality, productivity and reliability.



Process simulation technology
The computerized "Bruno" process calculation system has already become the proven standard in the crushing industry. Rock quality, feed grading and selected machines are entered to simulate the expected production capacities and product gradings. Contact minerals.bruno@mogroup.com for more information.

Complete stationary or mobile plants
Besides offering complete stationary installations, Metso is the pioneer in fully mobile in-pit crushing operation. Integrating two or three mobile crushers combined with a mobile screen and a mobile conveying system result in improved efficiency and end-product accuracy.

We have the expertise to build a fleet of track mounted crushers and screens for primary, secondary and tertiary stages according to your application. Moving along the quarry face the track-mounted units replace dump truck haulage, thus achieving substantial savings.

The whole mobile plant can be moved from site to site on standard trailers. This is one example of how our worldwide process know-how can serve your crushing, screening and conveying needs.

Broad product range

Feeders – a wide range of heavy-duty feeders designed to absorb impact, meter material to the crusher and scalp out fines.

Primary gyratory crushers – ideally suited to all high-capacity primary hard rock crushing applications.

Jaw crushers – we have more installed jaw crushers than anyone in the world. The leading choice due to their high reduction ratio and heavy-duty design.

Cone crushers – capacities available to suit all secondary, tertiary, or quaternary crushing applications. High performance technology.

Impact crushers – primary and secondary machines for soft and medium-hard materials. High reduction ratios. Can eliminate need for a tertiary crushing stage.

Vertical shaft impactors – helps shape the rock to high-quality aggregates. Rock on rock crushing.

Stationary screens – an extensive range of complete screening solutions for scalping, closed circuit screening, final sizing, and dewatering inclined screens, banana shaped screens or horizontal screens.

Crusher automation – ensures consistent and efficient operation. Improves productivity and product quality while reducing maintenance costs by preventing overload situations.

Stationary conveyors – a complete range of belt conveyors. Wide variety of widths, lengths, accessories, and options. Various models incorporate truss frames that are simple, compact, and fast to dismantle, transport and erect.

Track-mounted crushers – fully mobile jaw, cone, or impact crushers, with or without screens and equipped with open or closed circuit and discharge conveyors. Easily transportable on standard trailers.

Portable crushers – excellent transportability between sites and fast installation, in addition to high crushing capacities. Can be fitted with jaw, cone, or impact crushers, with or without screens, and equipped with open or closed circuit and discharge conveyors.

Mobile screens – track-mounted units for excellent mobility and high performance on-site. Ideal for a wide range of applications. Also, mobile screens on wheels which incorporate on-board conveyors and travel over roadways without special permits.

Mobile conveyors – mobile conveyors link a Lokotrack primary mobile crushing plant to further processing stages. They can follow the primary unit as it moves along the quarry face, replacing costly dump truck haulage.

Plant automation systems – monitor and control all crushing, screening, storing, and conveying with real-time accuracy. Maintain maximum production capacity by adjusting process parameters online.

Original wear and spare parts – using original Metso wear parts is the key to a successful crushing process. The design of our certified wear parts starts with CAD simulations of the crusher cavity, which is the heart of the crushing process. By computer based planning and continuous quality control of the casting, we can guarantee premium material quality, which translates into improved wear life and a higher operational capacity and reliability.

Customer service products – Metso, using its long-term experience of crushing equipment and crushing processes, has developed an expert service offering aimed at improving the reliability and productivity of customer operations.

Our certified customer service organization is available worldwide to add customer value through customer-specific solutions. Customer success and satisfaction are cornerstones of Metso services.

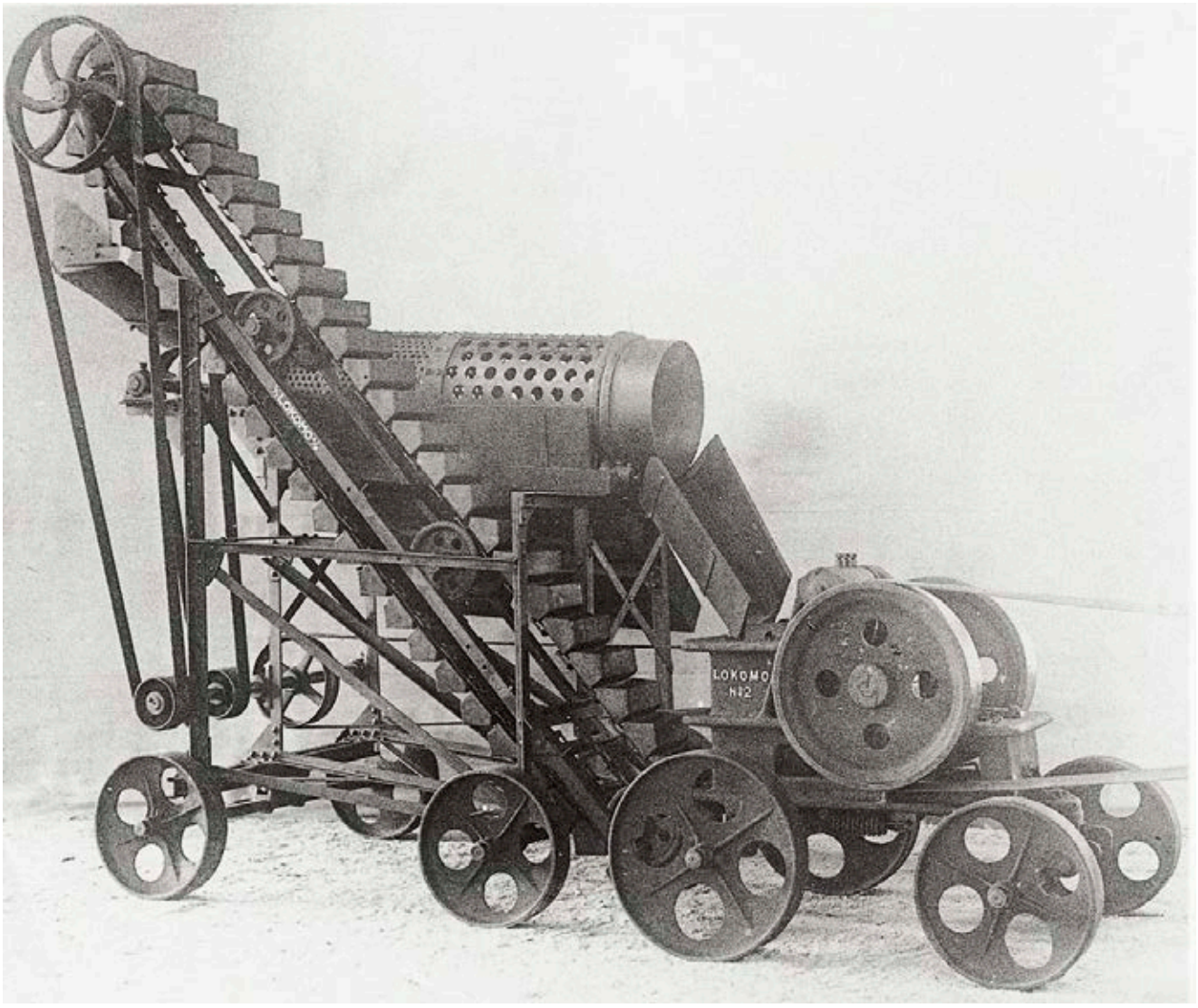
Brands served

The brand and trade names owned by Metso include: A.C. Hoyle, Allis Chalmers, Allis Mineral Systems, Altairac, Ambassador, Armstrong Holland, Babbitless, Barmac, Bergeaud, Big Bite, Boliden Allis, Cable Belt, Citycrusher, Citytrack, Combi-Screen, Conrad Scholtz, Denver, Dominion, Dragon, Dravo Wellman, Ellivar, Faço, Flexowell, G-Cone, GfA, Goodwin Barsby, Grizzly King, Gyradisc, Hewitt-Robins, Hummer, Kennedy Van Saun (KVS), Kue-Ken, Laser, Lennings, Lindemann, Lokolink, Lokomo, Lokotrack, Loro & Parisini, Ludlow Saylor, Marcy, Masterskreen, McCully, McDowell Wellman, McKiernan Terry (MKT), McNally, McNally Wellman, Meade Morrison, Morgårdshammar, Neyrtec, Nordberg, Nordpactor, Nordwheeler, Omnibelt, Omnicone, Omnimatic, Orion, Pyrotherm, Reed, Sala, Scanmec, Screen-All, Seco, Senator, Simplicity (slurry pumps), Skega, Stansteel, Stephens-Adamson, Strachan & Henshaw, Superior, Supersteel, Supralok, Svedala, Symons, Thomas, Tidco, Trellex, Waterflush, W.S. Tyler, Yernaux. The list is only indicative, since the actual number of brand and trade names includes many more widely known and historic names.

Metso in brief

Metso is a frontrunner in sustainable technologies, end-to-end solutions and services for the aggregates, minerals processing and metals refining industries globally. By improving our customers' energy and water efficiency, increasing their productivity, and reducing environmental risks with our product and process expertise, we are the partner for positive change. Metso is committed to limiting global warming to 1.5°C with Science Based Targets.

Headquartered in Helsinki, Finland, Metso employs over 15,000 people in more than 50 countries and its sales for 2021 were about EUR 4.2 billion. The company is listed on the Nasdaq Helsinki. metso.com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Quarry process and development

In quarrying, the main activities are:

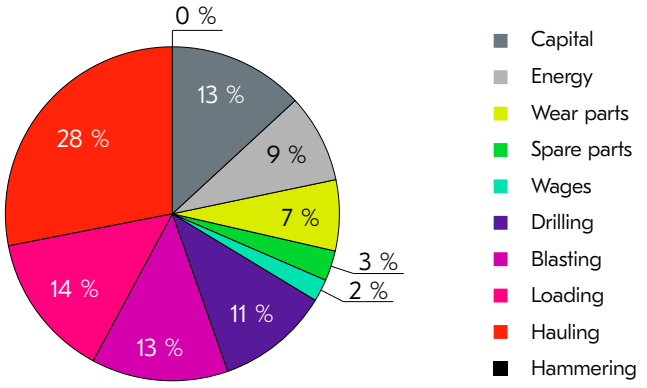
- Drilling
- Blasting
- Boulder handling
- Crushing & screening
- Material loading
- Hauling

These are the main determiners of quarrying costs, and thus understanding these costs, how to influence them directly, and how they impact each other is the key to successful quarry development.

It is important to have a basic understanding of this process because it is the 'world' where those in quarry work, live and do business. To have a good overall picture, it is useful to look at the typical cost structure of quarry operations.

These are shown in Figure 2, which shows two cases: a stationary one and a case where the primary section is mobile = in-pit crushing, which in many cases can yield remarkable benefits because material hauling costs can be reduced considerably. This issue is reviewed later, in the mobile crushing section of this book.

Stationary:



Mobile primary crusher:

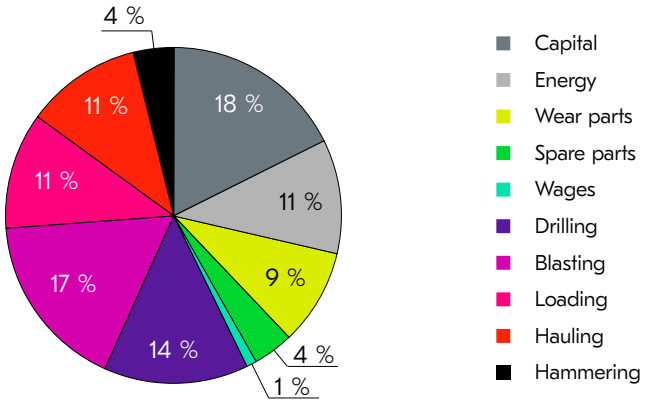


Figure 2: Examples of cost structure in quarrying

In quarrying, it is important to understand that many activities impact each other, so that

Optimized (blasting + crushing + screening) = max. ($$$)
Opt. (blasting) + opt. (crushing) + opt. (screening). This calls for a so-called integrated approach.

The blasting process must be adjusted to different types of rock, because they have different properties, and the result will be different fragmentation. An integrated approach at its best includes the steps shown in Figure 3.

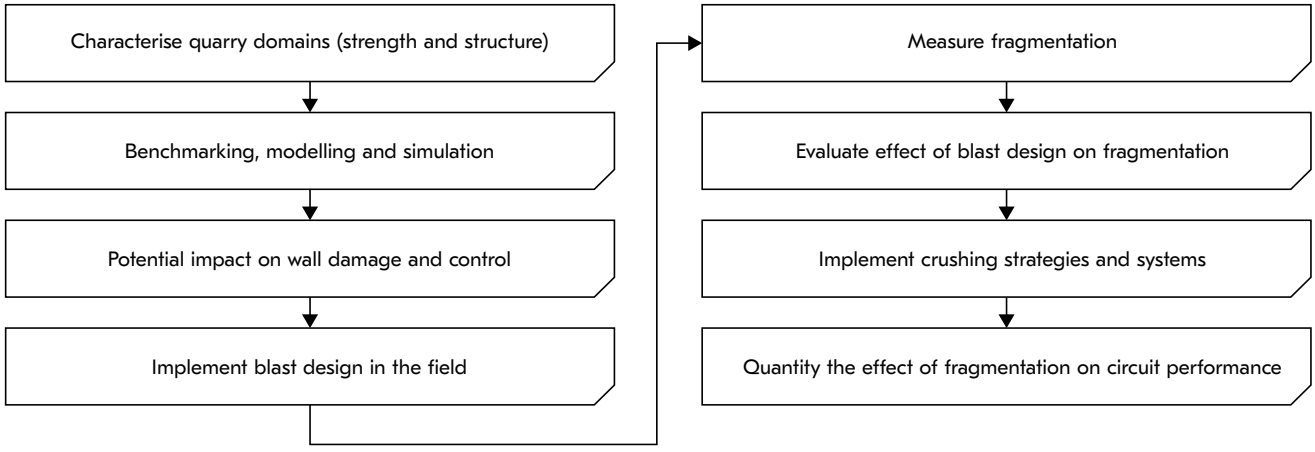


Figure 3: Integrated methodology in quarrying

The target in quarry development is to maximize the yield with respect to production costs according to Figure 4.

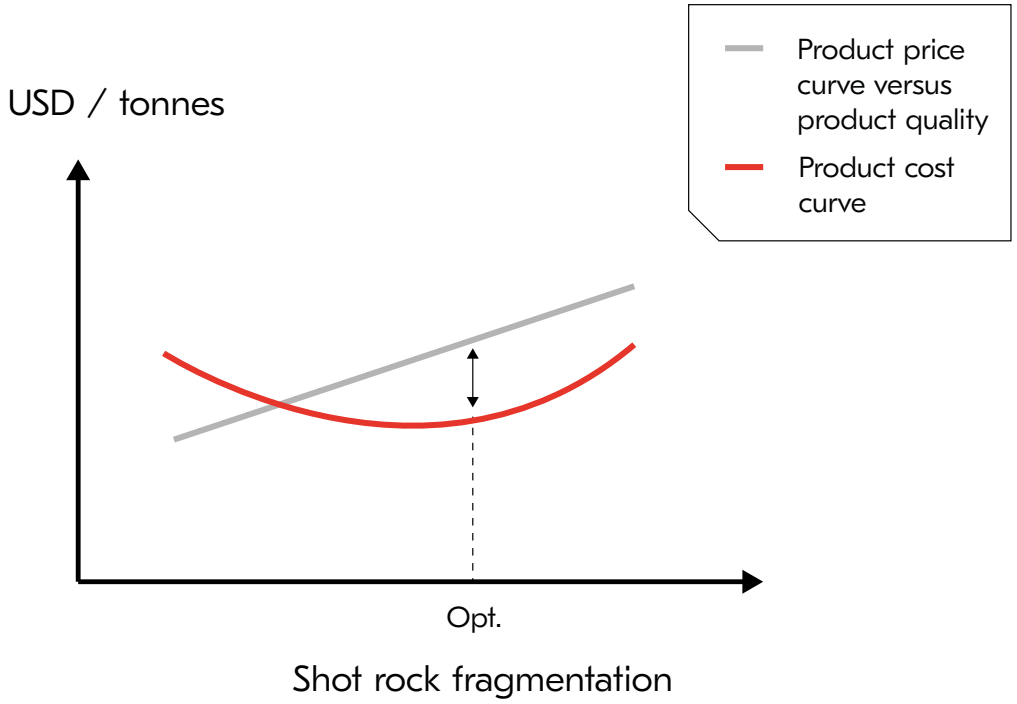


Figure 4. Target in quarry development

Optimizing quarrying from the end product yield and cost point of view can be very complicated, and justified to do in detail in cases where the scope of operation is great enough.

In most cases, it is enough to understand the basic guidelines on how drilling and blasting, crushing, hauling, etc. impact each other. So, let's have a look at some highlights of these key elements in quarrying:

Drilling and blasting

Figures 5 and 6 show the basic impact of drillhole diameter on costs and on some key parameters with importance for the later stages in the process as well as end-product yield and quality.

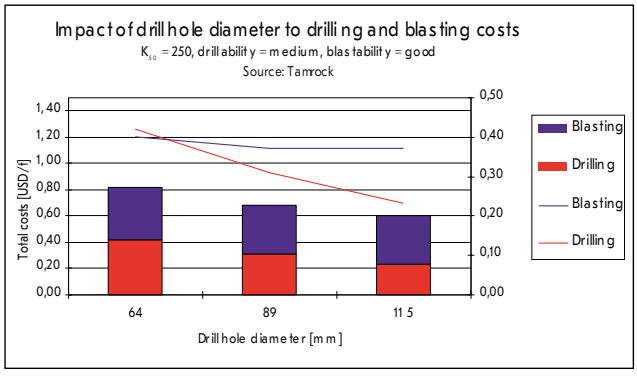
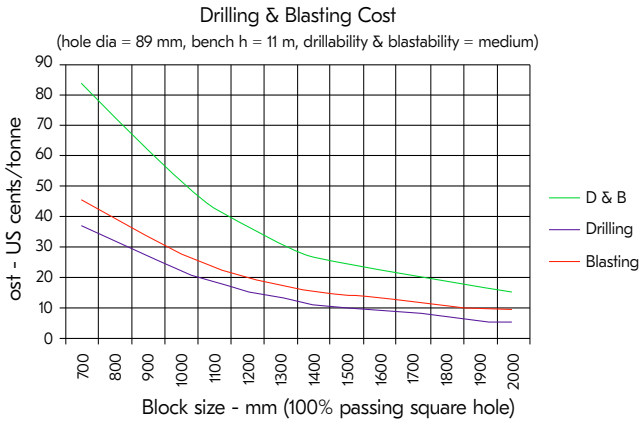


Figure 5: Costs vs. drillhole diameter and boulder size.



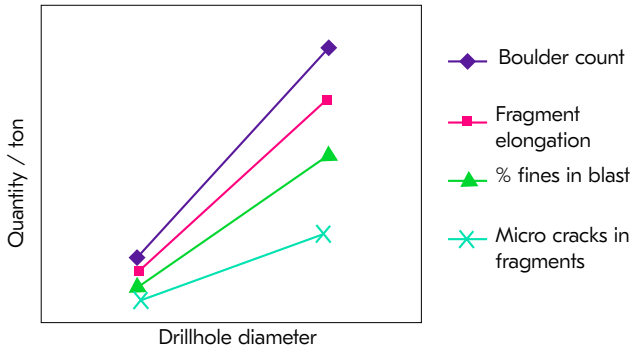


Figure 6. Impact of drillhole diameter on some important process & quality parameters.

Crushing and screening

Crushers and screens will be reviewed in detail later in this book, but the following factors must be stressed:

- Handling of oversize boulders. Try to avoid oversized materials entering to the feeder and crusher cavity as well as possible. If possible, break the oversized blocks or boulders separately before the actual crushing process.
- Role of process planning: By using the same equipment, process capacity can be doubled but at the cost of quality.
- Selection of stationary vs. mobile configuration.
- Selection of the right type of crusher and screen for the application in question.

Figure 7: No oversize breaking in crushing process

Loading and hauling

Loading and hauling are one of the major costs in the quarry process. These could be characterized by figures 8 and 9. In these graphs, the K50 value shows the percentage passing. So K50 = 250 mm means that 50% of blast distribution is passing 250 mm.

Reasons that cost increase greatly with coarse blasts are that:

- Material is more difficult to load due to
  - toe problems being more likely
  - bigger boulders
- The scope of equipment is changed due to more difficult and/or longer cycle times
- In the equipment there is
  - more wear
  - more maintenance

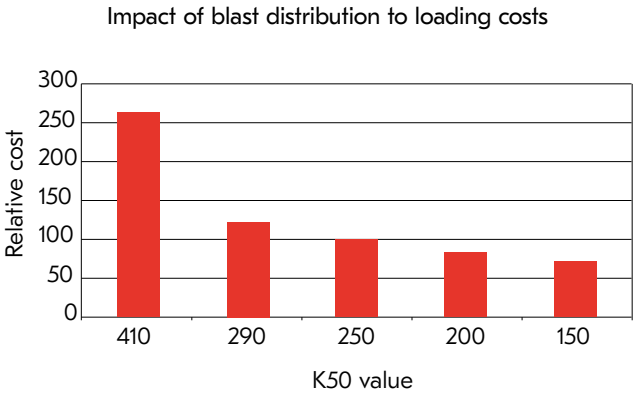


Figure 8: Influence of blasting on loading costs

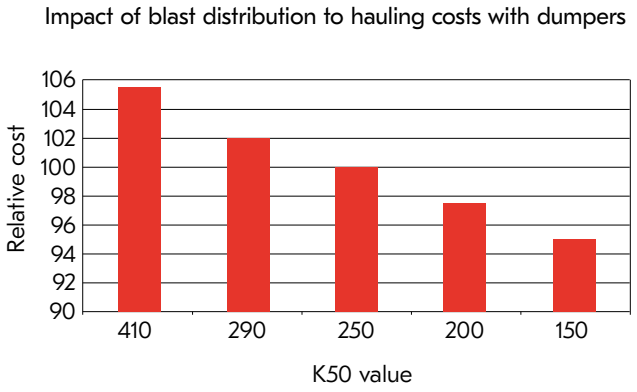


Figure 9: Influence of blasting on loading costs

Summary of quarry development

Quarry development could be summarized as follows:

- There is optimal shot rock fragmentation from the total product cost point of view.
- Oversize boulder frequency has a significant impact on capacity and cost.
- Smaller drillhole diameter produces less fines. In many cases, this is considered to be a waste.
- Crushing cost share is almost unchanged with different K50 values when the crushing method is the same.

Optimum selection depends on:

- Rock type due to abrasion
- Case-specific factors' like life of the quarry, investment possibilities, etc.
- Optimization of the whole quarry process instead of sub-optimization of individual components.
- In-pit crushing can give remarkable benefits.

Finally, as a practical aid to memory, Table 1 (on the next page) can be presented.

Table 1: Impact of dependencies.

+ = increase, - = decrease, 0 = minor impact						
	Increase of					
Impact on	Drillhole diameter	Drill pattern	Drillability index	Shotrock frag. size	Blastability index	Work index
Drilling costs	- -	- - -	- -	- - -	+ +	+
Blasting costs	+ +	- - -	0	- - -	+ + +	+
Total excavation costs	- -	- - -	-	- - -	+ +	+
Hammering costs	+	+ + +	0	+ + +	+ +	+
Loading costs	0	+ + +	0	+ + +	0	0
Hauling costs	0	0	0	0	0	0
Crushing costs	-	+ +	0	+ +	+	+
Amount of fines	+ +	- -	+	- -	+ +	+
Number of boulders	+	+ + +	0	+ + +	+	0
Amount of micro-cracks	+ +	- -	0	- -	+ +	+
Size of primary crusher	+	+ +	0	+ +	+	0
Amount of scalps	+ +	- -	+	- -	+ +	+
Shotrock fragment cubicity	- -	+ +	+	+ +	- -	-
Total costs	-	+	-	+	+ +	+

Process planning and expertise

Process examples and planning basics
Every crushing and screening process has been set up to make some production, which includes desired end products and sufficient capacity. Good process can fulfill the production targets without unrealistic machine performance expectations.

To achieve the performance targets, process machines should be in their good operating range and inherent stability built in the process.

Typically, there is no absolutely correct or absolutely wrong process solution. Instead, there are multiple solutions capable of the same production. Instead of the process performance only, we may evaluate solutions by other criteria such as operating cost or ease of operation or service availability.

Application
The process planning starts from the application: the intended products and the feed properties. The most important properties of feed material that effect on the crushing process planning are feed fraction, moisture content, material solid density, material crushability and material abrasiveness. Feed properties are a key element in selecting suitable crusher types for the process.

The role of a primary crusher is to reduce raw feed size for the following crushing stage. In special applications there might be just one crusher in the process. Both compressive crusher and horizontal shaft impactor can be used as primary crusher.

Impact crushers perform well in high crushability (> 40 %) i.e. soft rock, and low abrasiveness (< 400 g/ton) applications. Compressive crushers don't have specific rock type limitations. Secondary stage typically follows the same rules as the primary.

In fine crushing applications there are more possibilities for crusher selection. For high crushability and low abrasiveness, for example Limestone, there is the rock-on anvil VSI crusher as well as the HSI crusher that would suit the job. For good shape requirement, rock-on-rock VSI crusher is performing well in all kinds of applications regardless of the high abrasiveness. The maximum feed size is limiting the use of rock-on-rock VSI crusher. The fine cone crushers are flexible when it comes to feed maximum size, as there are different size liners available. Cones are performing very well with all kinds of rock types.

Reduction ratio and total reduction
Total reduction i.e. reduction ratio from feed to the coarsest final product gives an indication of the number of required crushing stages. Crushers in the process have to produce together at least the same reduction ratio as is the required total reduction.

The rock crushability has an effect on the expected crusher reduction ratio. The harder the rock, the lower is the reduction ratio in each crushing stage. In the other words, more stages are needed while crushing harder rock compared to softer rock. Typical reduction ratios in the table below.

Crusher	Reduction ratio
Primary gyratory	6-8
Jaw crusher	3-5
Horizontal shaft impactor	5-10
Secondary cone crusher	3-4
Tertiary cone crusher	2-3,5
Vertical shaft impactor rock-on-rock	1-1,5
Vertical shaft impactor rock-on-anvils	1-2,5

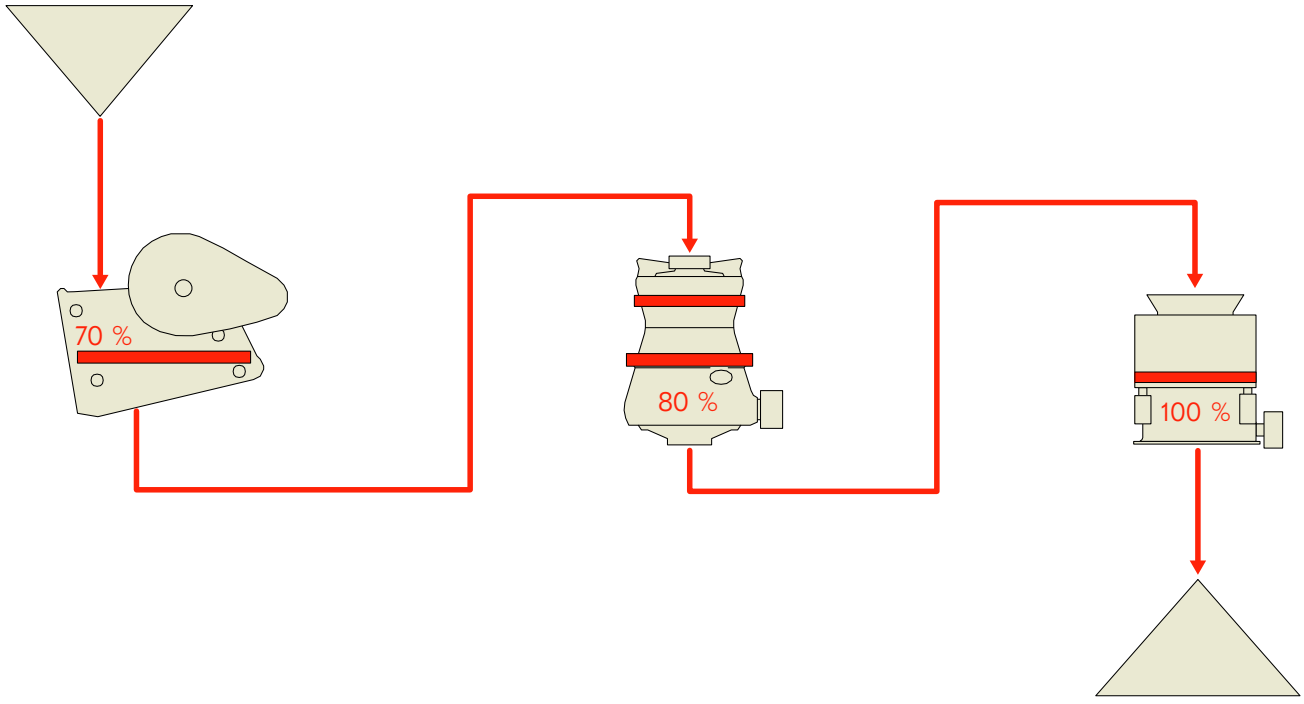
Process balance
There is always some fluctuation in a crushing and screening process. Feeding is a common source of instability.

Therefore, process should be designed to absorb feed variations and to minimize disturbances in production. As a rule of thumb, final crushing stage should be kept under 100% load all the time. Loading on the secondary crushing state should be about 80% and primary stage about 70%.

This gives some extra capacity to the early stages of the crushing circuit to handle the interruptions caused by feed variation.

100% load on final crushing stage, gives control over the products and probability to good product shape.

Process stability can also be achieved by separating crushing stages with silos and stockpiles that act as buffers.



Choke feed
100% load refers to volumetric capacity. When crusher loading is 100%, cavity is full and throughput is at its maximum. Full cavity is often called choke feeding. The following table shows the pros and cons of full cavity filling level (choke feed) and half full cavity filling level (non-choke feed) in cone crusher.

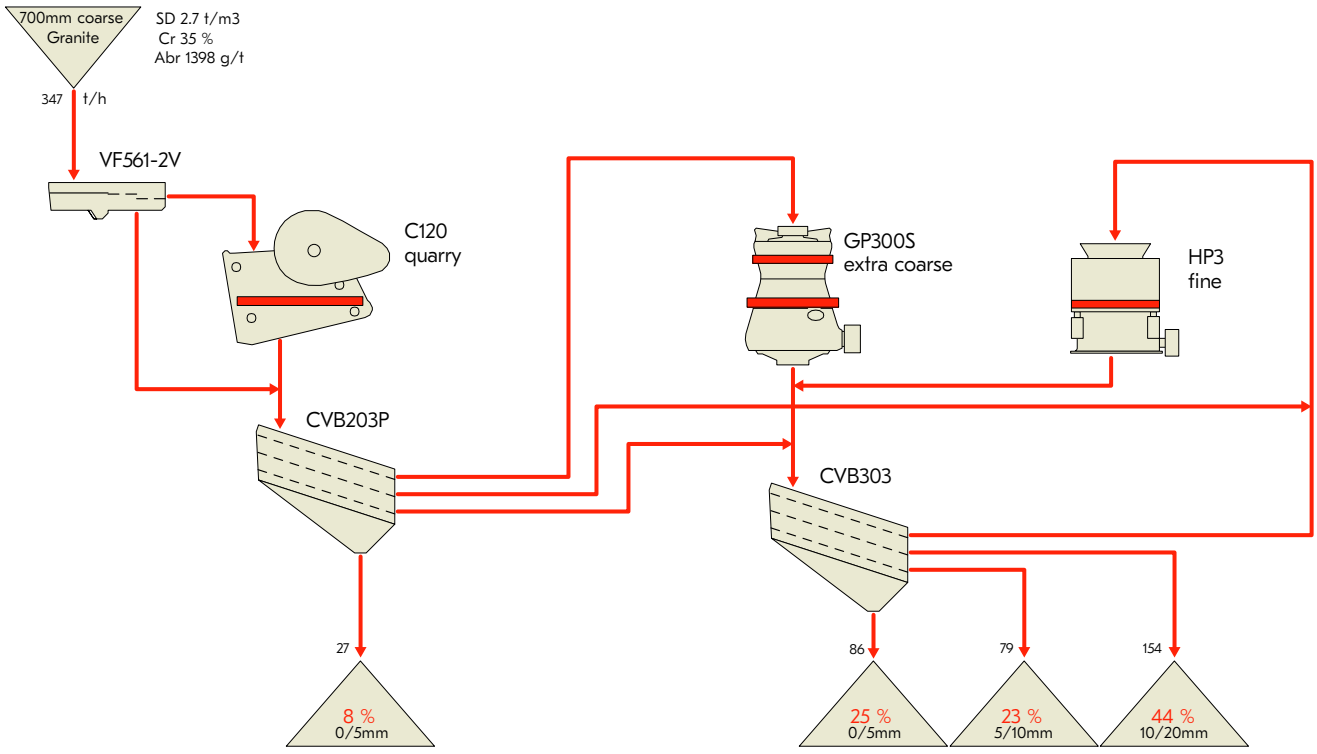
	Cavity filling level	
	Half full	Full
Amount of product bigger than c.s.s	▲	▼
Power need/kW	▼	▲
Capacity/tph	▼	▲
Nominal power need/kWh/ton	▲	▼
Shape of aggregates	▼	▲
Wear part consumption/g/ton	▲	▼
The crusher frame load	▲	▼

▲ Grow/improve ▼ Decrease/worse

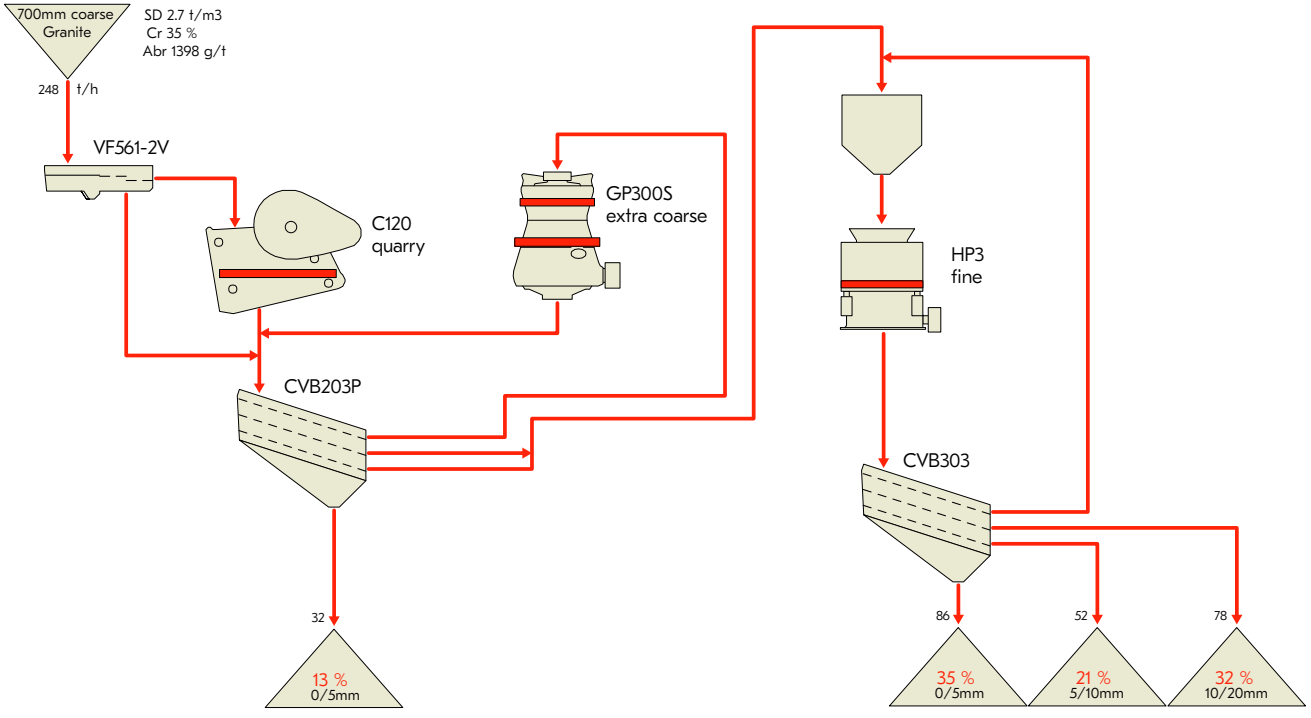
Process examples

Previously mentioned process planning basics are shown in the following crushing circuits. Each of the circuits is an example and the usage of the flowsheet and crushers should be considered separately. Equipment selection is highly influenced by local application requirements.

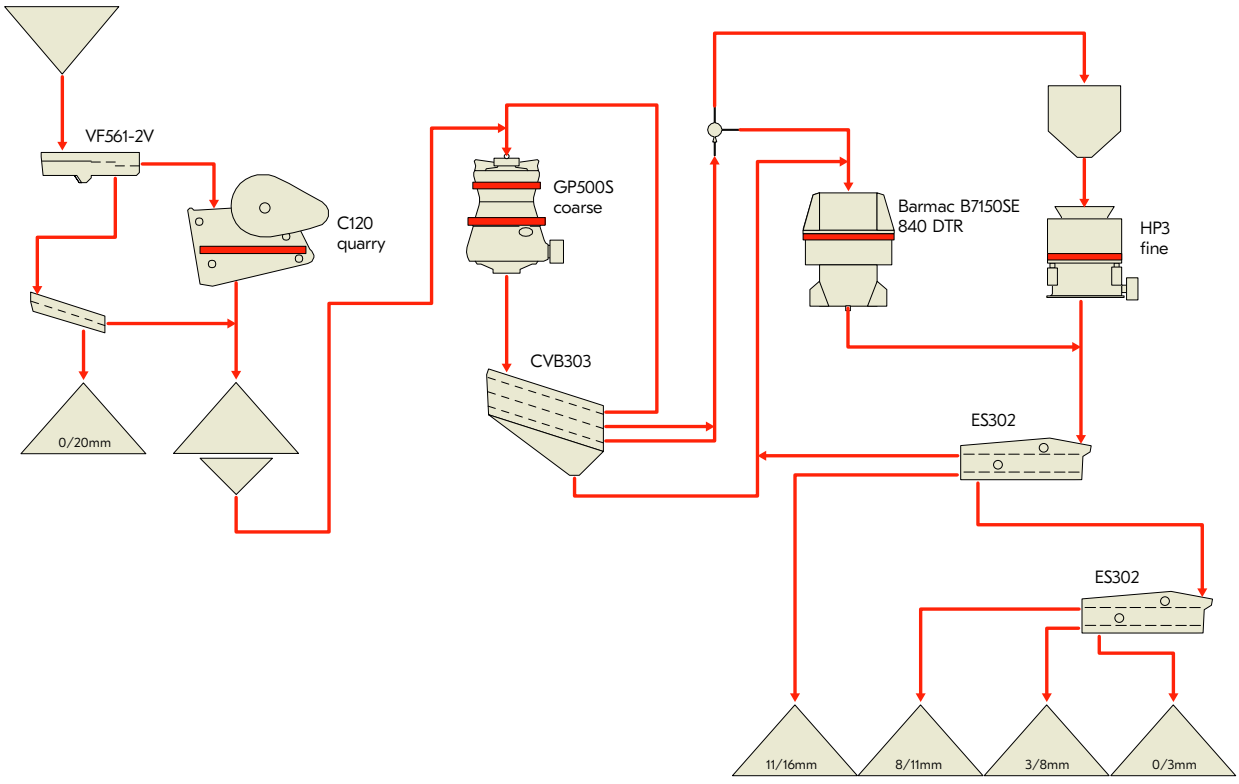
1. Three stage crushing process designed to maximize capacity. 300t/h.



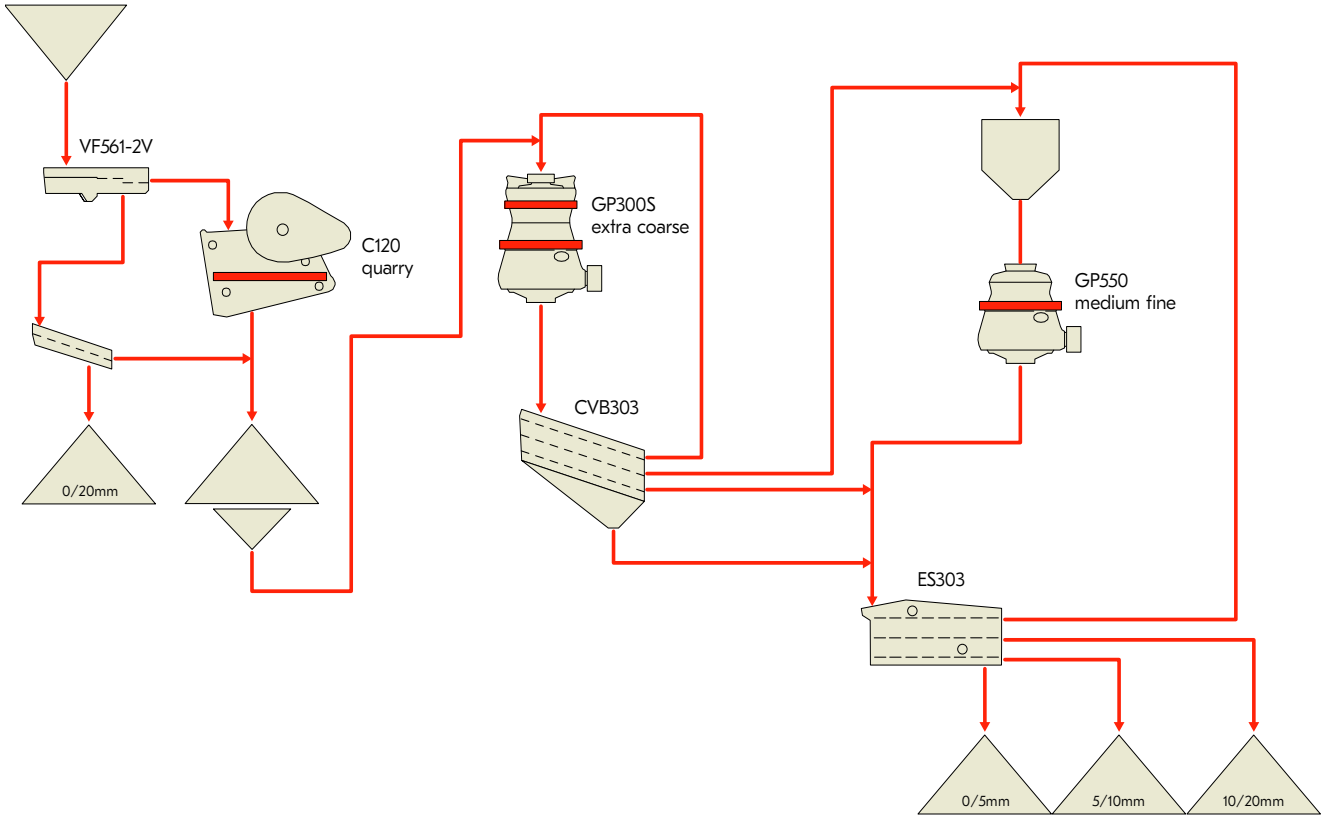
2. Three stage crushing process designed to maximize the quality. 230t/h.



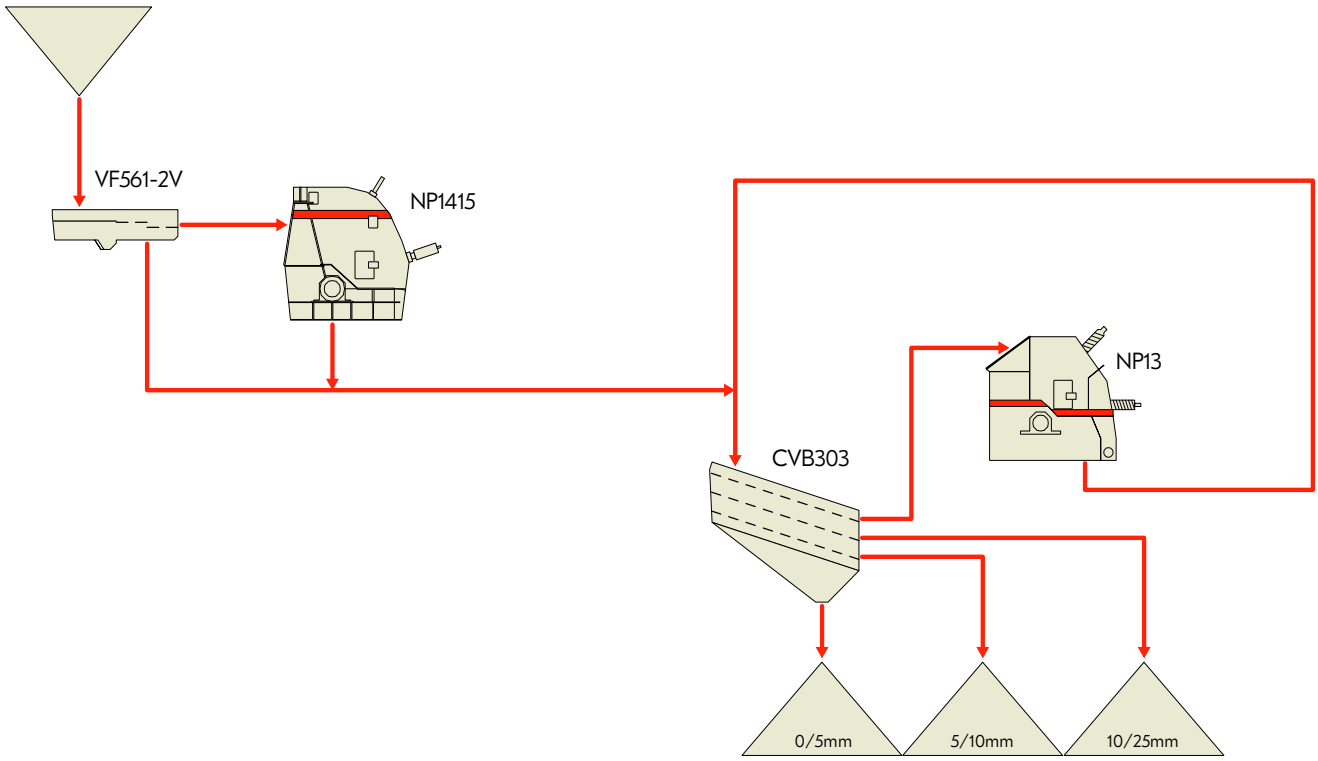
3. Concrete aggregates.



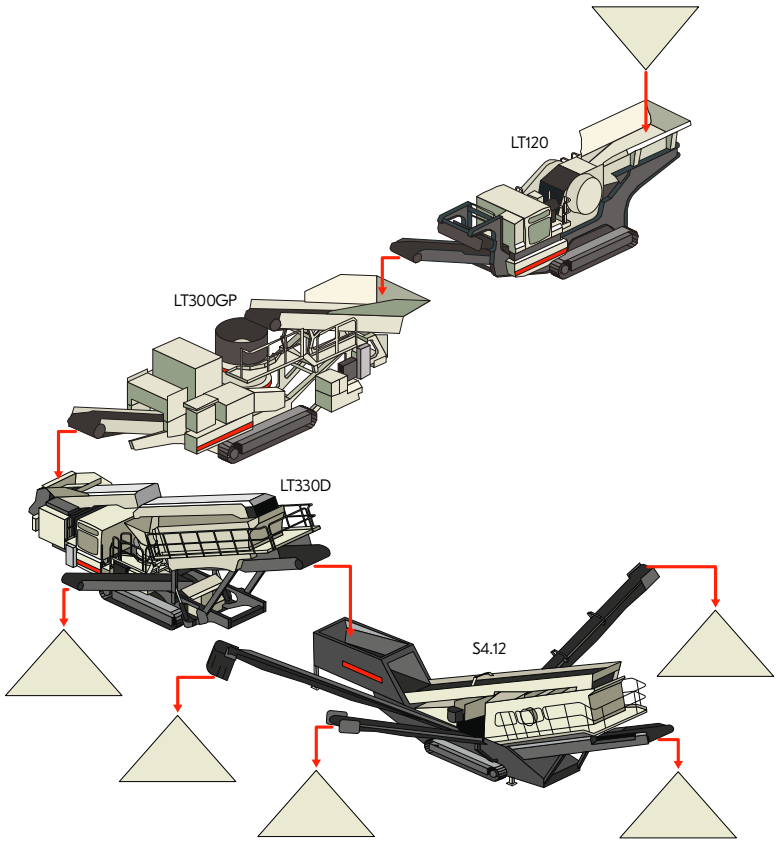
4. Asphalt aggregates.



5. General construction aggregates – limestone application.



6. General construction aggregates – mobile application.



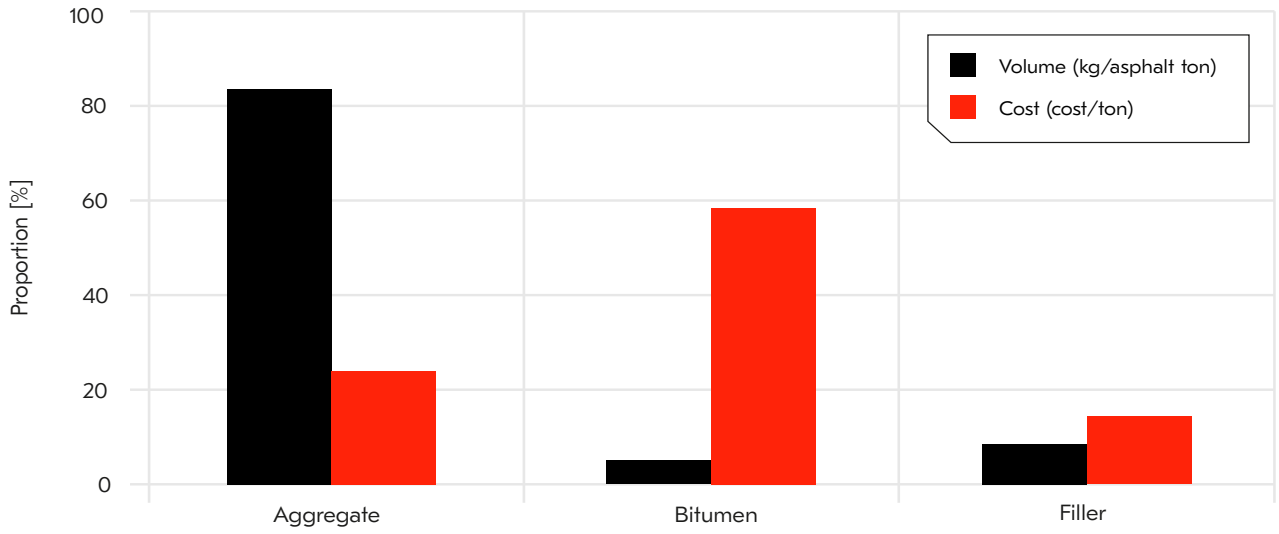
Some application related information
There are issues worth noting with respect to two major applications in which most aggregate is being used: roads and general construction.

These key issues are summarized below.

Road construction
If we combine the costs with aggregate consumption on the surface layer, we get the following graph. This demonstrates that the cost of bitumen determines the cost of the surface layer.

So, if the use of higher quality aggregate can extend the life of a road, it represents an investment which will pay itself back.

Cost and volume proportions of ingredients in asphalt

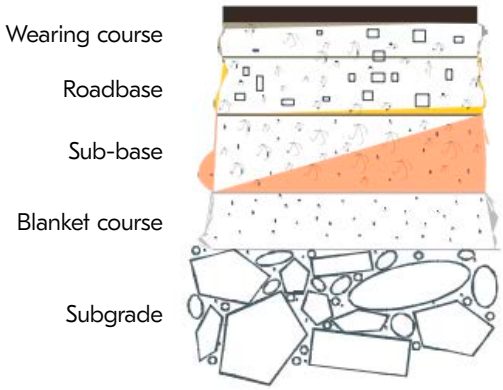


The role of aggregate in asphalt:
- Increases resistance against wear (and saves on maintenance costs)
- Improved workability
- Internal friction for resisting loads on surface

Related aggregate requirements:
- Angular shape, but not flaky or elongated
- Constant gradation

High voids ratio in bulk material
Depending on the geographical area, there can be several layers in a road construction.
Typical aggregate consumption on a high quality 10-meter-wide road is given in the table below.

The layer in question and the rock characteristics have a major influence on the production process. The figure on the right gives an indication of how many crushing stages are needed for different layers. A subgrade can be produced with a single two stage plant, when layers closer to the surface require at least two and, in some cases, even four stages for the production of high-quality fractions.

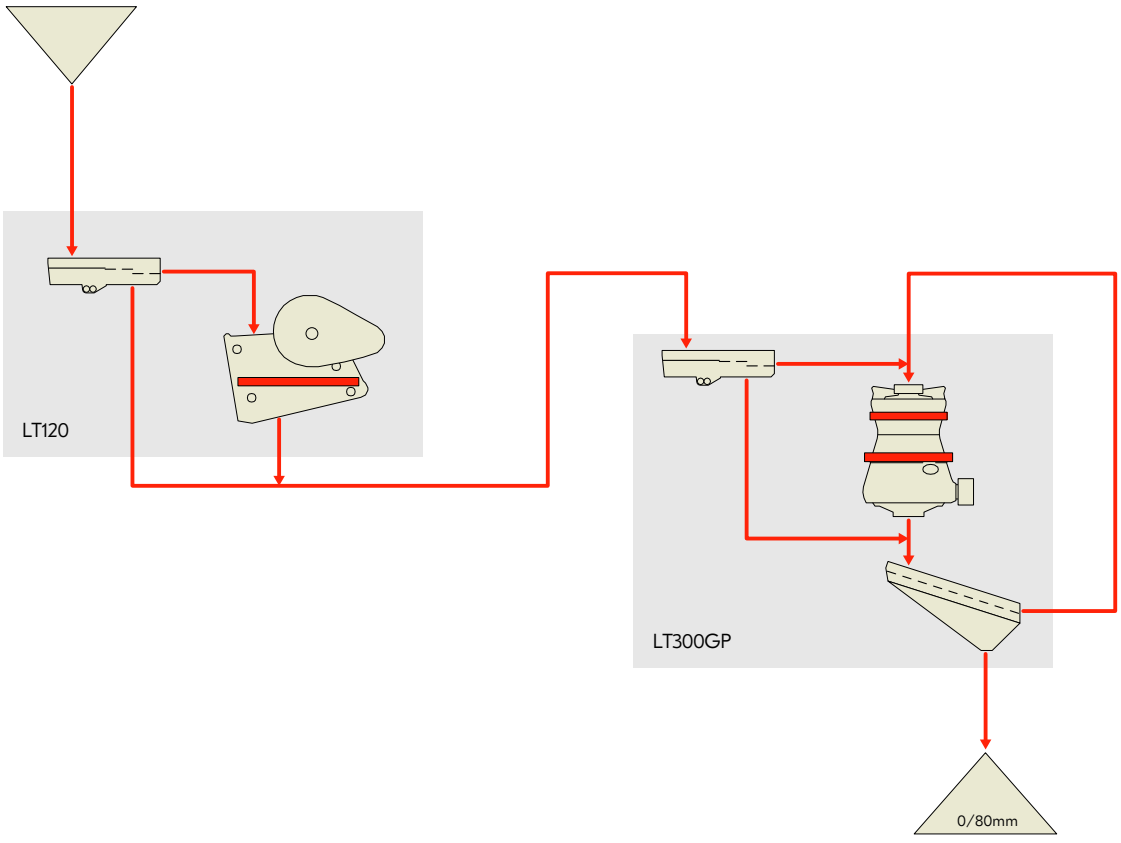


Layer	Thickness [mm]	Weight [tons/km]
Wearing course	20 - 200	320 - 3200
Roadbase	100 - 250	1600 - 4000
Sub-base	300	4800
Blanket course	150 - 300	2400 - 4800
Subgrade	< 1000	16 000

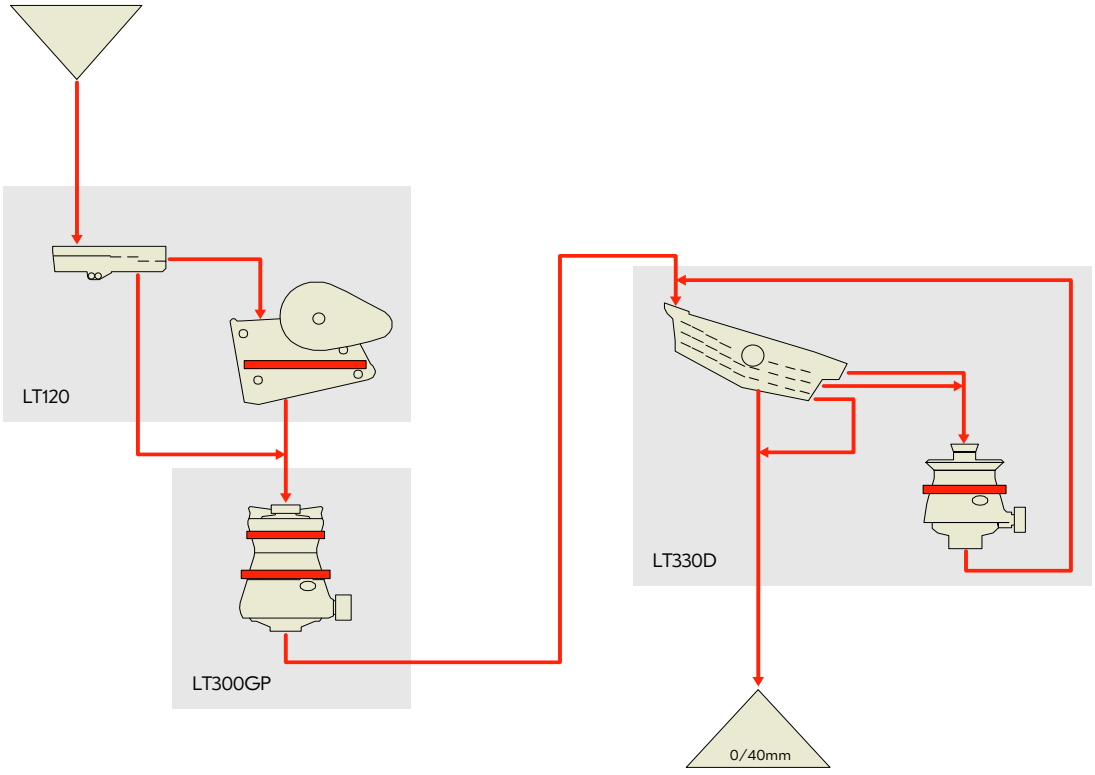
Quarry face
Road pavement
A typical three-stage road pavement application using Lokotrack LT120, LT300GP and LT330D.

As mobile model processes, these layers can be presented as shown in the flow diagrams below.

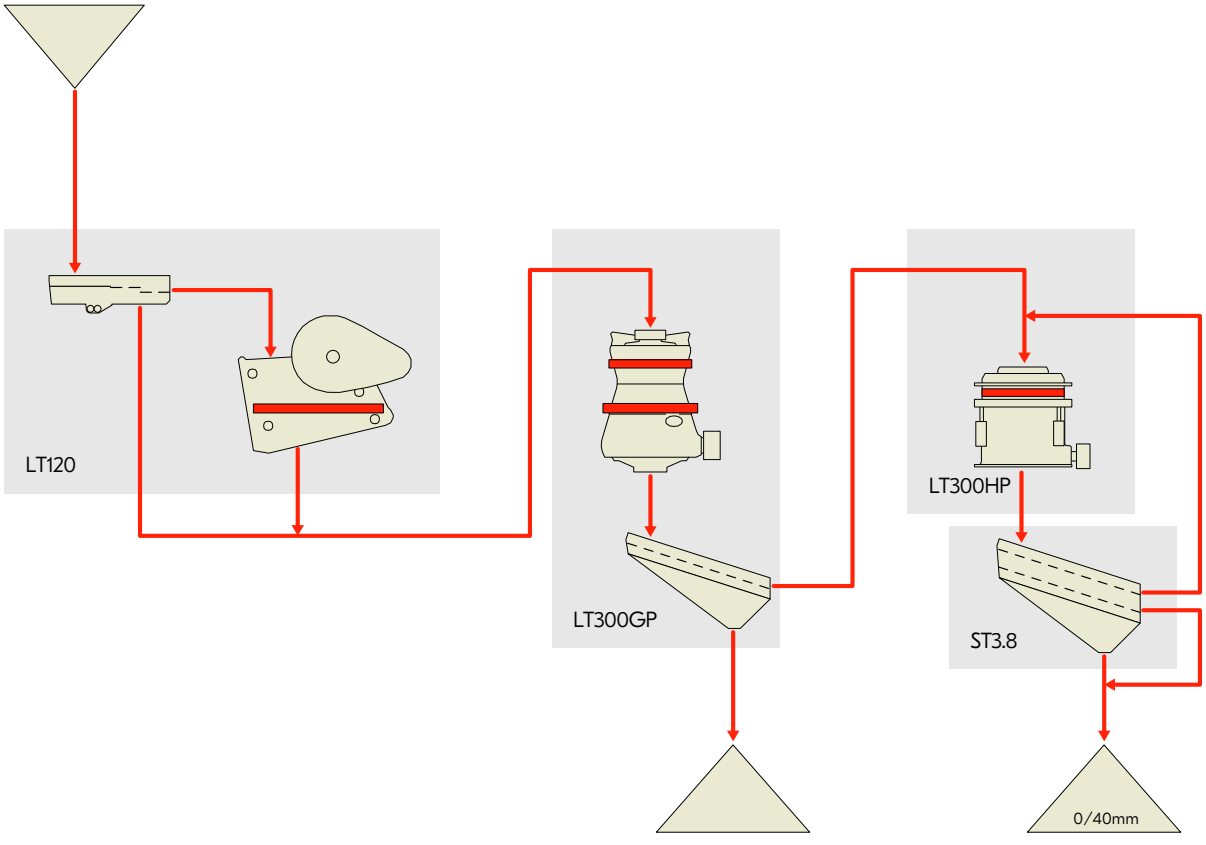
Sub-base layer:



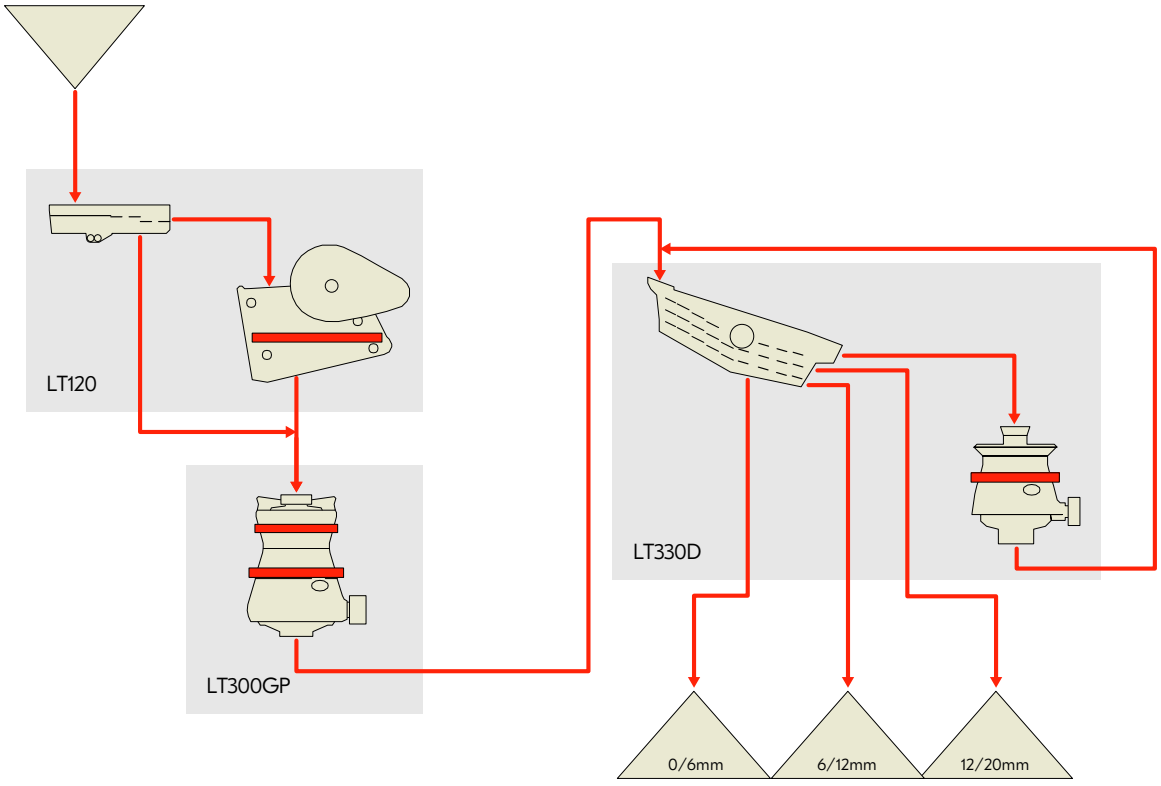
Road base layer (easy material)



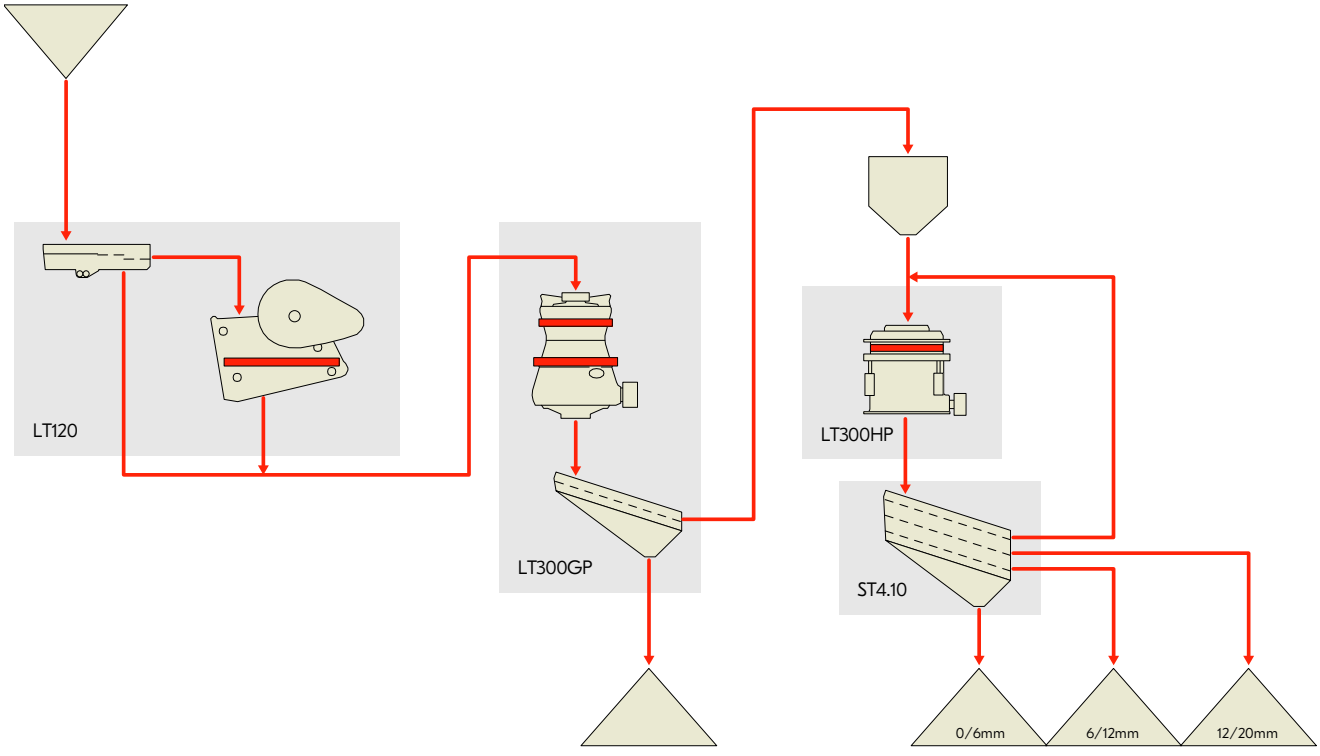
Road base layer (difficult material)



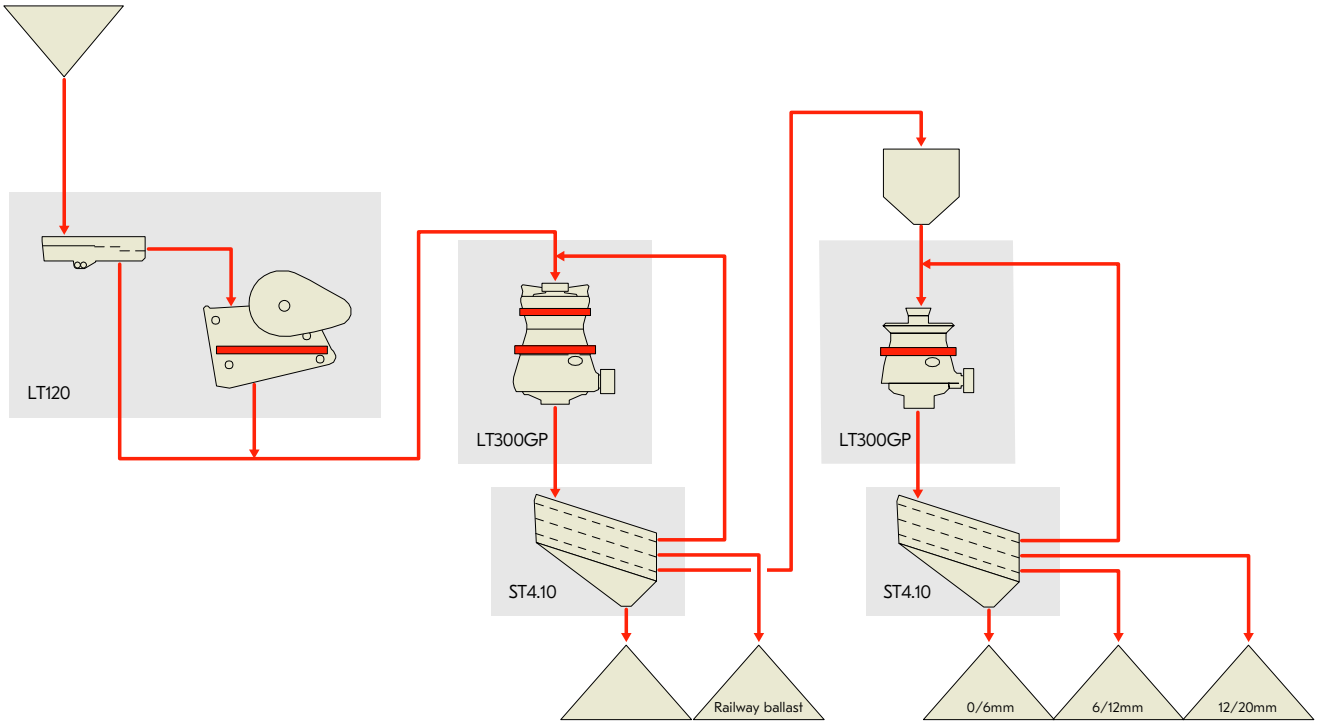
Asphalt layer (easy material)



Asphalt layer (difficult material)



Asphalt layer + railway ballast (difficult material)



Poor concrete flow.

In the most difficult cases, 100% of the final product has passed through all three crushing stages.

General constructions, such as houses
From the same perspective, we can review aggregate in concrete applications. This is shown in the next figure which demonstrates a very similar situation to that of asphalt.

The role of the aggregate:
- Decreases cement content (=> price decreases)
- Improves workability, and thus
- Increases strength of hardened concrete

Related aggregate requirements:
- Spherical, cubical ("smooth face") particle shape (not flaky or elongated)
- Even gradation
- Low specific surface of sand particles and
- Low voids content in 0/4
- Controlled microfines content; clay and other organic microfines are harmful in concrete

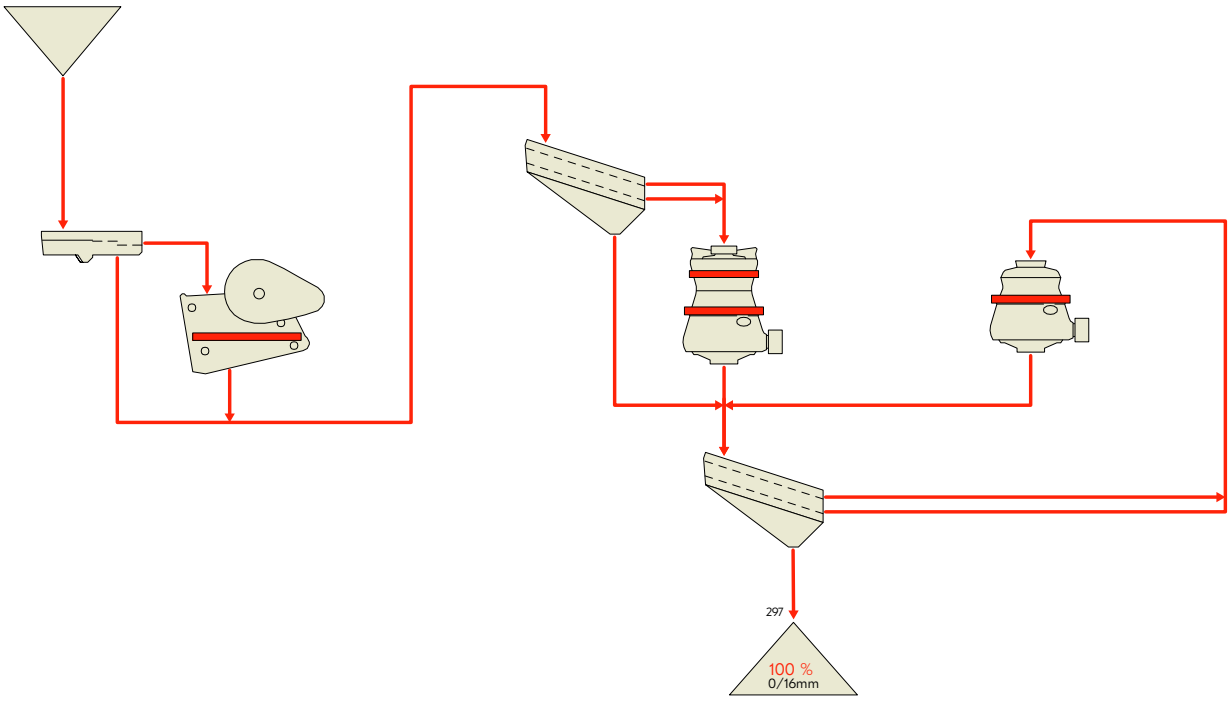
Different strength class concrete has several requirements, summarized in Table 1.

The photo above provides an example of what happens when poor concrete flow ruins a surface. This can be avoided by improving aggregate quality based on the correct water/cement (W/C) ratio.

The role of the aggregate in concrete
Source: Consolis 2005

Example of process influence to end product quality

Let us consider a few examples, reviewing the proportion of the final product, 0-16mm, produced at different stages of the process. Figure below displays these proportions.



Production of 0-16mm at a maximum rate of 300 t/h

By examining the production of 0-16mm more closely, table 2 can be created:

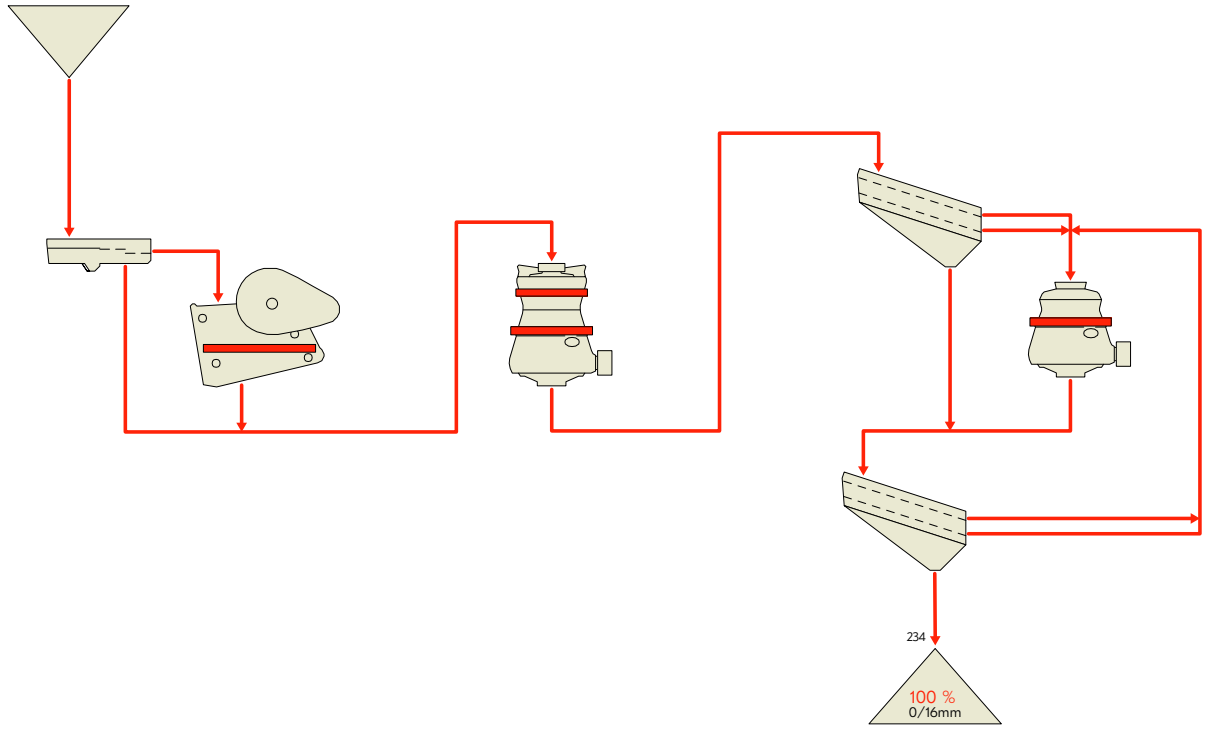
Origin of the 0/16mm end product					
	Feed	**C120**	**GP300S**	**GP550**	**Product**
0-4	14,5 t/h	6,25 t/h	16,5 t/h	68 t/h	105,25 t/h
4-16	18,7 t/h	11,9 t/h	36,9 t/h	127,8 t/h	195,4 t/h
0-4	13,8 %	5,9 %	15,7 %	64,6 %	100 %
4-16	9,6 %	6,1 %	18,9 %	65,4 %	100 %

Origin of end product

About 35% of the final product, 0-16mm, is produced in stages other than the tertiary. 11% of the product comes directly from the feed and 6% from primary crusher. This 17% share of the final product can potentially ruin the quality.

The process making the same end product can be designed differently keeping the quality in mind.

Production of 0-16mm at a maximum rate of 223 t/h.
The tonnage of 0-16mm is 77 tons/h less than in the previous example, but its quality is expected to be considerably better.



As can be seen from table 3, the reason for this lies in the origin of the 4-16 mm product being 100% tertiary cone, while 4-16 mm fraction from the feed and the primary crusher is not allowed to enter the final product and spoil it.

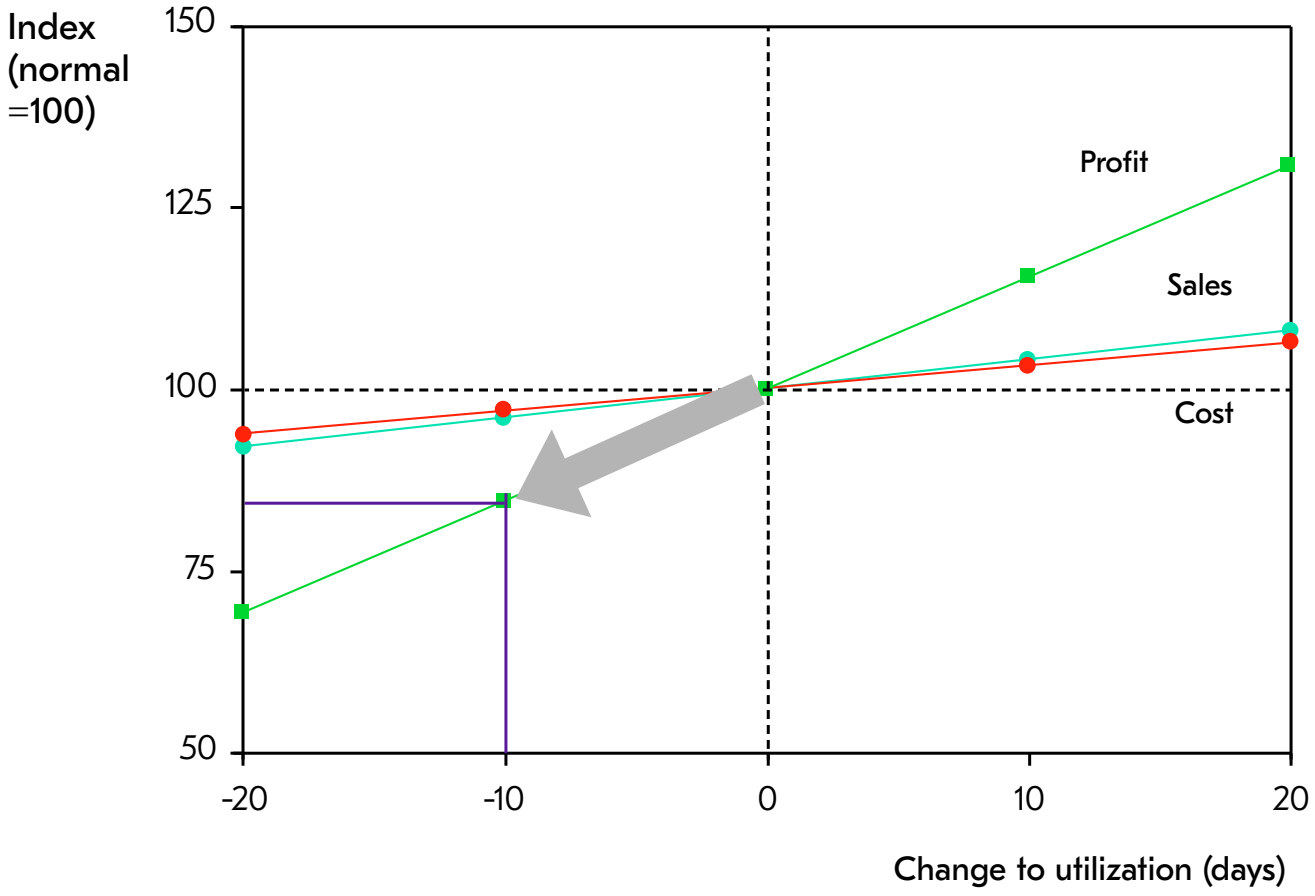
On the contrary, this product is recrushed to achieve a better shape which, since this uses up capacity, makes the total tonnage 77 t/h less.

Origin of the 0/16mm end product					
	Feed	C120	GP300S	GP550	Product
0-4	0 t/h	0 t/h	20 t/h	70 t/h	90 t/h
4-16	0 t/h	0 t/h	0 t/h	133 t/h	133 t/h
0-4	0 %	0 %	22,2 %	77,8 %	100 %
4-16	0 %	0 %	0 %	100 %	100 %

Conclusion regarding process optimization and influencing to end product

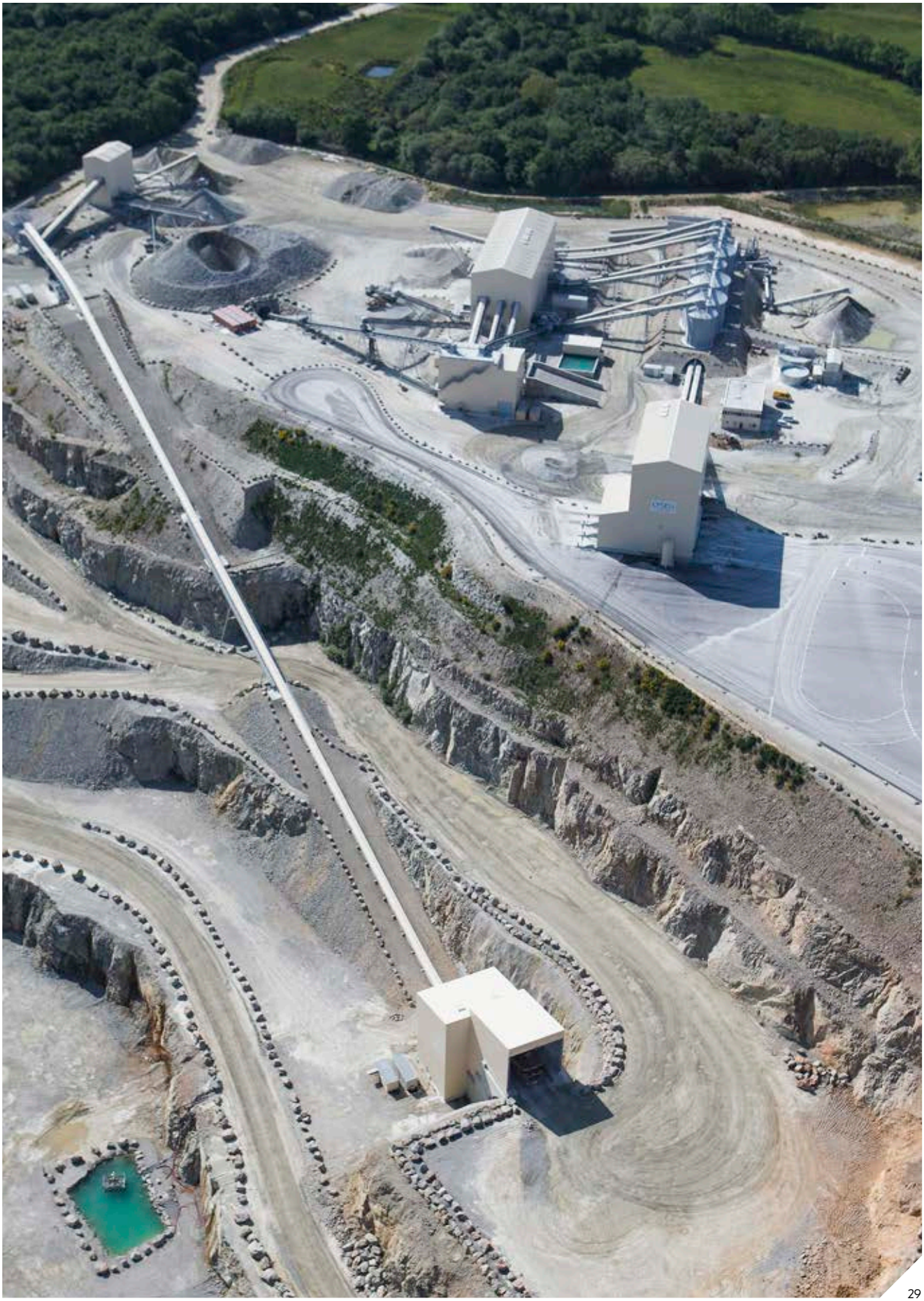
These few, simplified examples clearly indicate two main findings:

- The flowsheet and lay-out must be correct in order to produce the right aggregate amounts and fulfill the specifications. If this is not performed correctly in the first instance, later modifications, albeit possible, will prove expensive.
- Running the process using optimal parameters in the equipment can make a real difference in terms of financial success. Achieving this requires the continuous monitoring and adjustment of the equipment and process. Additionally, high availability and utilization rates are a MUST, otherwise the process will become non-viable with a few days. Figure below presents a simplified illustration of this process, based on a €4.5M plant investment.



Impact of utilization on profit

As seen above, the changes in utilization have a strong impact on profit, entailing that a ten day stoppage can wipe out the entire annual profit.



Manufactured sand and air classifying

Metso sand solution

Why not natural sand?

Sand is the most consumed natural resource on the planet besides water. It is the primary raw material that modern cities, glass, or technology equipment, in one way or another are made from.

The overwhelming bulk of sand we harvest goes to make concrete. The most suitable natural sand can be found in lake and riverbeds, banks, floodplains and seashores and also ridge formations. Despite the apparent availability, desert sand is not included in easily usable construction sands.

So, the enormous demand of this raw material has conveyed the world to an overexploitation of those natural deposits, with massive impacts and negative consequences on the planet.

Why manufactural sand?

Manufactured sand could be a substitute for natural sand, but it requires a manufacturing process designed and controlled for this purpose to meet the product properties and specifications required for the application.

It is more environmentally friendly since manufactured sand can be produced from rock quarry crushed fines or quarry waste materials. If a land fill of unsellable crushed fines or quarry waste materials is turned in to a sellable premium quarry product, a win-win situation for the environment is created.

Nowadays there are several manufactured sand specifications and standards for the different product applications, and with modern technologies, process and the understanding of aggregate behavior, different crushed waste materials can be turned into a high-quality product also for concrete applications. Unlike natural sand the quality of manufactured sand can be controlled, which leads to savings in cement and bitumen. Besides the cost savings, also a direct and indirect impact on the CO^2 footprint reduction for the construction work will be achieved.

The Metso way to manufacturing sand

One of the main reasons customers started to look for alternatives to manufactured sand to replace the natural sand, was the requirement for a steady quality in their product. Natural sand gradation curves are severely affected by natural phenomenon like river floods, heavy rain, weather conditions and so on.

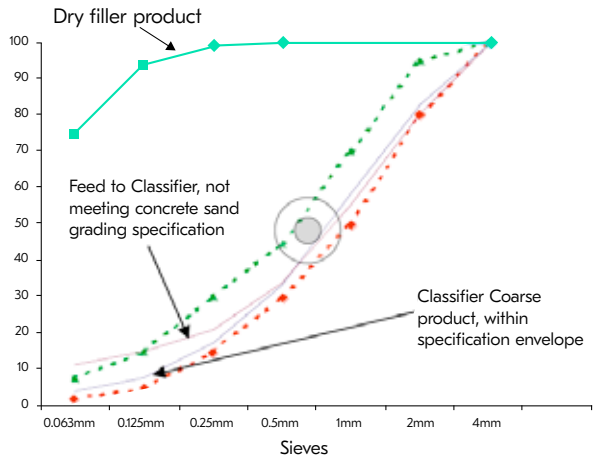
There are fundamentally two ways to replace natural sand with manufactured sand. First, we can try to produce sand similar to natural sand, because it is easy for a customer to start using this sand. However, the natural sand grading is challenging to achieve, which may lead to overly complex process setup. The other alternative is to co-operate with the customer and create a good quality substitute for natural sand. Then, adjusting the customer's processes to use slightly different sand.

Sand manufacturing process includes three main functions

- reduce feed size to sand
- ensure sufficient quality
- produce required product grading

Crushers have a key role in all three functions.

Two AC 27 working in parallel with a joint capacity of 150 tph.



Typical particle size distributions of feed and products using gravitational inertial air classifier.

Application: Concrete / Mortar						
Sand requirement:	Rounded cubical shape					
	Minus 5 mm	Minus 12.5 mm	Minus 25 mm	Pea gravel	12.5 - 5 mm	25 - 5 mm
Soft rock*	Barmac B-series					
Medium rock**						
Hard rock***						
Application: Concrete / Mortar						
Sand requirement:	Angular Cubical Shape					
	Minus 5 mm	Minus 12.5 mm	Minus 25 mm	Pea gravel	12.5 - 5 mm	25 - 5 mm
Soft rock*	Barmac B-series			HP / GP / Barmac VI		
Medium rock**				HP / GP / Barmac VI		
Hard rock***				HP / GP		
Application: Asphalt						
Sand requirement:	Angular shape					
	Minus 5 mm	Minus 12.5 mm	Minus 25 mm	Pea gravel	12.5 - 5 mm	25 - 5 mm
Soft rock*	Barmac B-series	Barmac VI	Barmac VI	HP / GP / Barmac VI		
Medium rock**		Barmac B-series		HP / GP		
Hard rock***				HP / GP		

Crusher selection

Crusher selection is based on the hardness and abrasiveness of the source rock, feed fraction to the circuit and the nature of the sand required.

In an application where there is a coarse feed gradation curve (i.e. 75-10 mm) then HSI and cone crushers is the preferred technology to produce also coarse sand (i.e. 10-0 mm or 0-6mm). This is a high reduction ratio demanding application with other implication for the process, but it is very used by contractors utilizing portable plants to generate several products with the minimum amount of machines. The manufactured sand quality is difficult to control under such high demand for the crushing equipment.

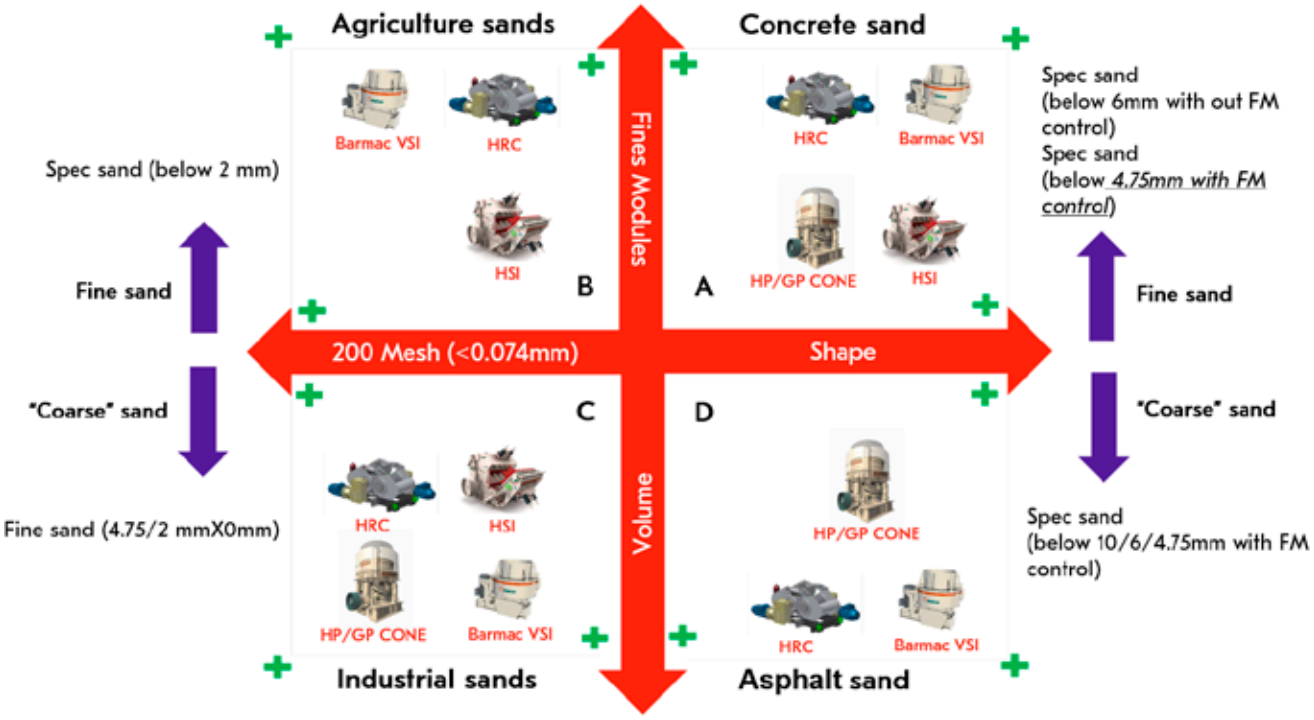
When the feed fraction is finer (i.e. 40-6mm) then high speed or compression crushing can be applied like VSI and/ or cone crusher configured for the application, normally to produce coarse sand but with finer gradation spec (i.e. 6-0 mm). The reduction ratio in those applications is not as high, but the process will have to be configured to achieve the final objective in an efficient way. This is a very common application, but the manufactured sand quality is tricky to control specially if the customer wants the product to meet a low FM value and meet a gradation spec requirement.

In applications where the feed fraction is much finer (i.e. 19–4mm or 12-3mm) then high speed or compression crushing like VSI and HRC crushers can be applied but properly

configured for the application, normally to produce fine sand with fine gradation spec (i.e. 4-0 mm or 2.4-0mm).

The reduction ratio in those applications is much lower and the process will have to be configured to achieve the final objective in an efficient way. This could be the ideal application to produce high quality manufactured sand especially if the customer wants the product to meet a low FM value, good particle shape and meet a gradation spec requirement.

Crusher options in manufacturing sand production



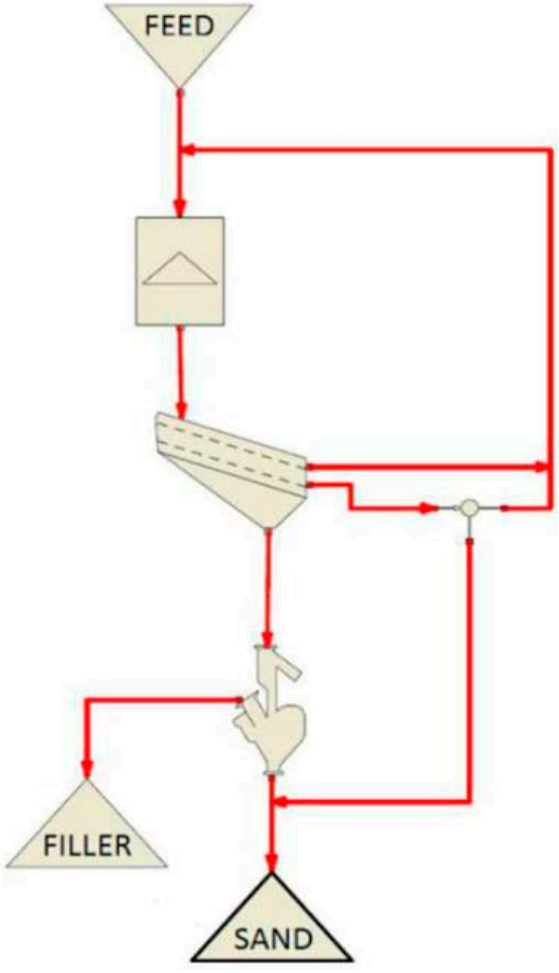
Crusher technology options in manufacturing sand production

Crusher type	Type of manufactured sand			
	Concrete sand	Industrial sand	Asphalt sand	Agriculture sand
Cone crusher	X	X	XX	
HSI NPXX series crusher	X	X		X
VSI Barmac crusher	XX	XXX	X	XX
HRC High pressure roll crusher	XXX	XX	XXX	XXX

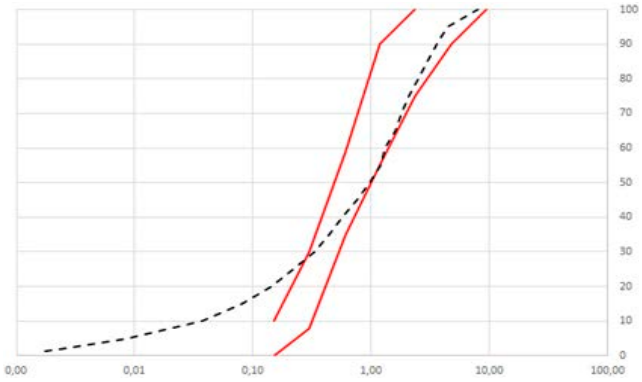
X - Good
XX - Very good
XXX - Best technology

Summarizing, we can also say that the Barmac VSI will produce the best particle shape for concrete sand, but it may lack of some particle sizes in the final product to meet the concrete spec curve depending on the application, and the type of rock. It may also produce excess of fines <0.063mm. In asphalt sand, it will produce very good quality product, the anvil ring configuration could be the best one to use in this type of application if the feed material characteristics allows for a cost-effective operation.

The HRC technology can produce very good particle shape for concrete sand, and a very good product gradation curve to meet the concrete spec curve and the FM required, depending on the application and the type of rock. It may also produce lower amount of fines <0.063mm. In asphalt sand, it will produce excellent quality product.



Fines removal with AC.



Manufactured sand with excess fines.

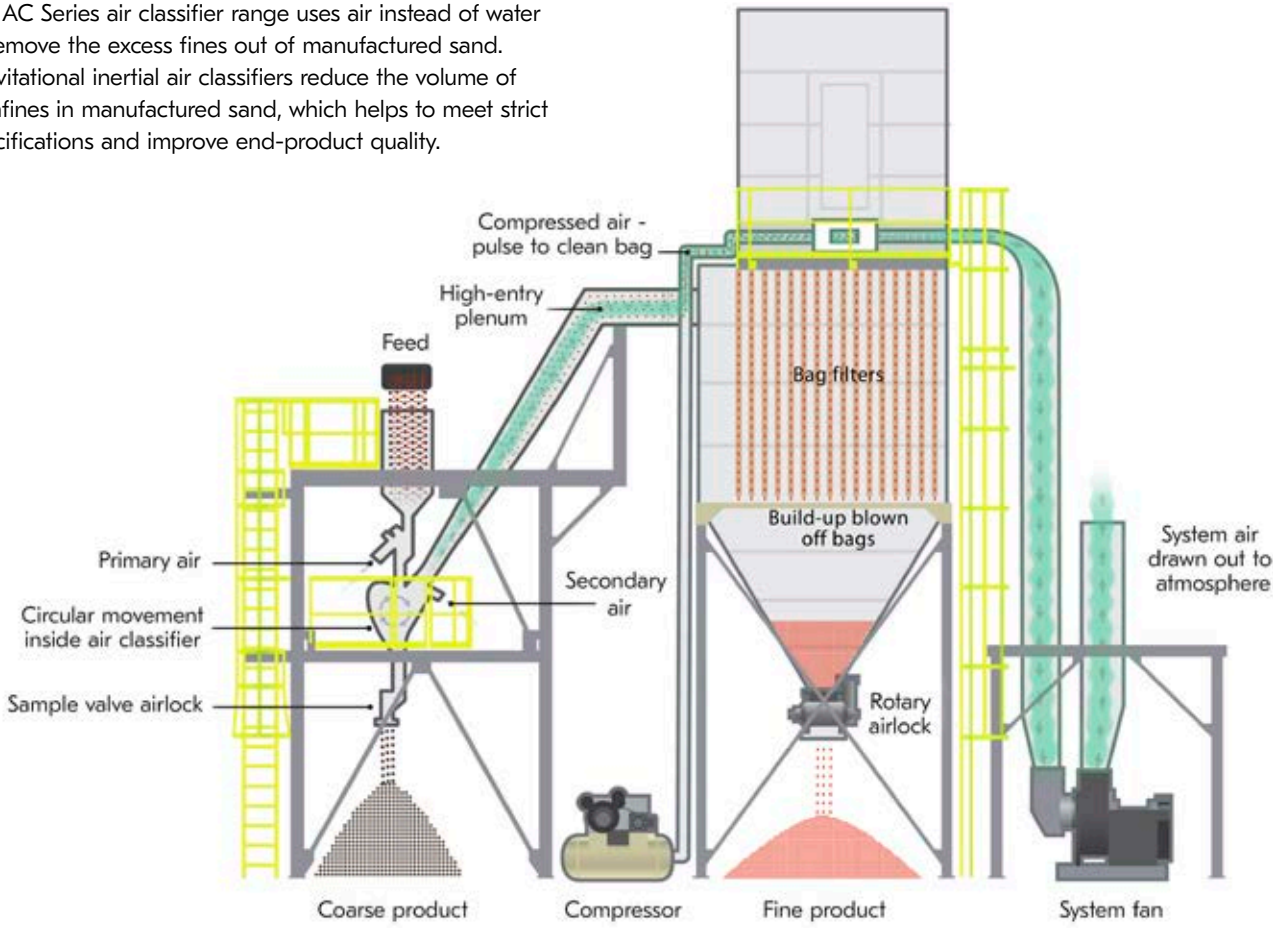
Product grading
Each crushing stage produce 0 -based product. As a result, manufactured sand typically contains too much fines in the region between 0-0,064mm compared to concrete grading specification envelope widely used in the industry.

This is outside the practical operation range for most conventional vibrating screens, so the traditional way to remove these fines has been using wet process equipment such as sand screws, sand wheels, hydro cyclones, compact wet sand recovery systems or air classifiers.

Comprehensive air classifier range
AC Series gravitational inertial air classifiers separate fines from crushed rock in manufactured sand production. The dry solution uses a unique chamber and airflow design to ensure precise separation of ultrafines from sand with an accuracy of microns.

MANUFACTURED SAND AND AIR CLASSIFYING

The AC Series air classifier range uses air instead of water to remove the excess fines out of manufactured sand. Gravitational inertial air classifiers reduce the volume of ultrafines in manufactured sand, which helps to meet strict specifications and improve end-product quality.



The solution uses a unique chamber and airflow design with ceramic liners to ensure precise separation of ultrafines from sand. The result is sand with optimized grading.

Separating different fractions in with accuracy
Gravitational inertial air classifiers use a primary and a recirculating secondary airflow to separate fines from coarse particles.

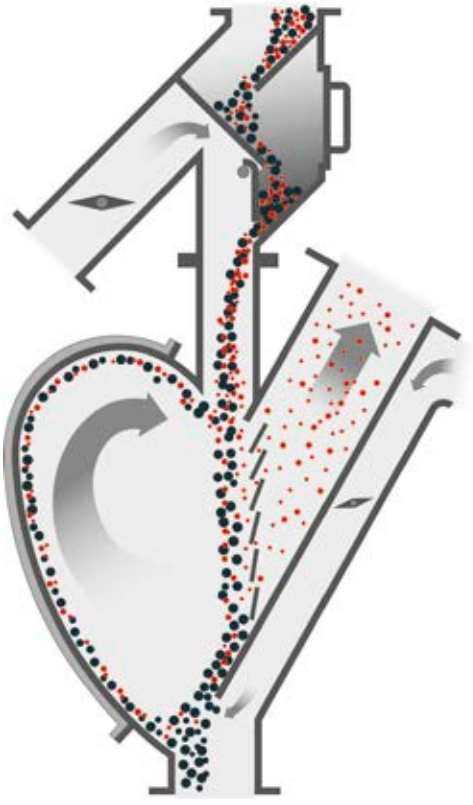
Because the airflows are not affected by wear, the grading remains consistent to an accuracy of microns. At the same time, particle moisture remains at an optimal level (Maximum moisture content in the feed material is 2%).

Different fractions ranging from 300 µm to 63 µm can be separated with an accuracy of microns.

Thanks to the process not using water, it is both economical and environmentally friendly as well as ideal for colder climate.

Easy to adjust
The volume of ultrafines in the end product is adjusted by changing the total airflow, and by changing the ratio of primary and secondary airflows.

With the right combination, both separation size and accuracy can be fine-tuned to meet application requirements.



How does it work?

1. Feed material is evenly introduced from the top of the classifier in a controlled curtain along with primary air
2. Secondary air is drawn in at the bottom, inducing a scrubbing effect on similar-sized particles
3. Recirculation and scrubbing enable high efficiency and precise separation of ultrafines
4. Coarse particles drop out of the bottom of the classifier through an airlock

For further manufactured sand technical information, please visit: www.metso.com/aggregates/solutions/manufacturing-sand

For further air classifier product and technical information, please visit: www.metso.com/portfolio/classifiers/air-classifiers

Cost per ton

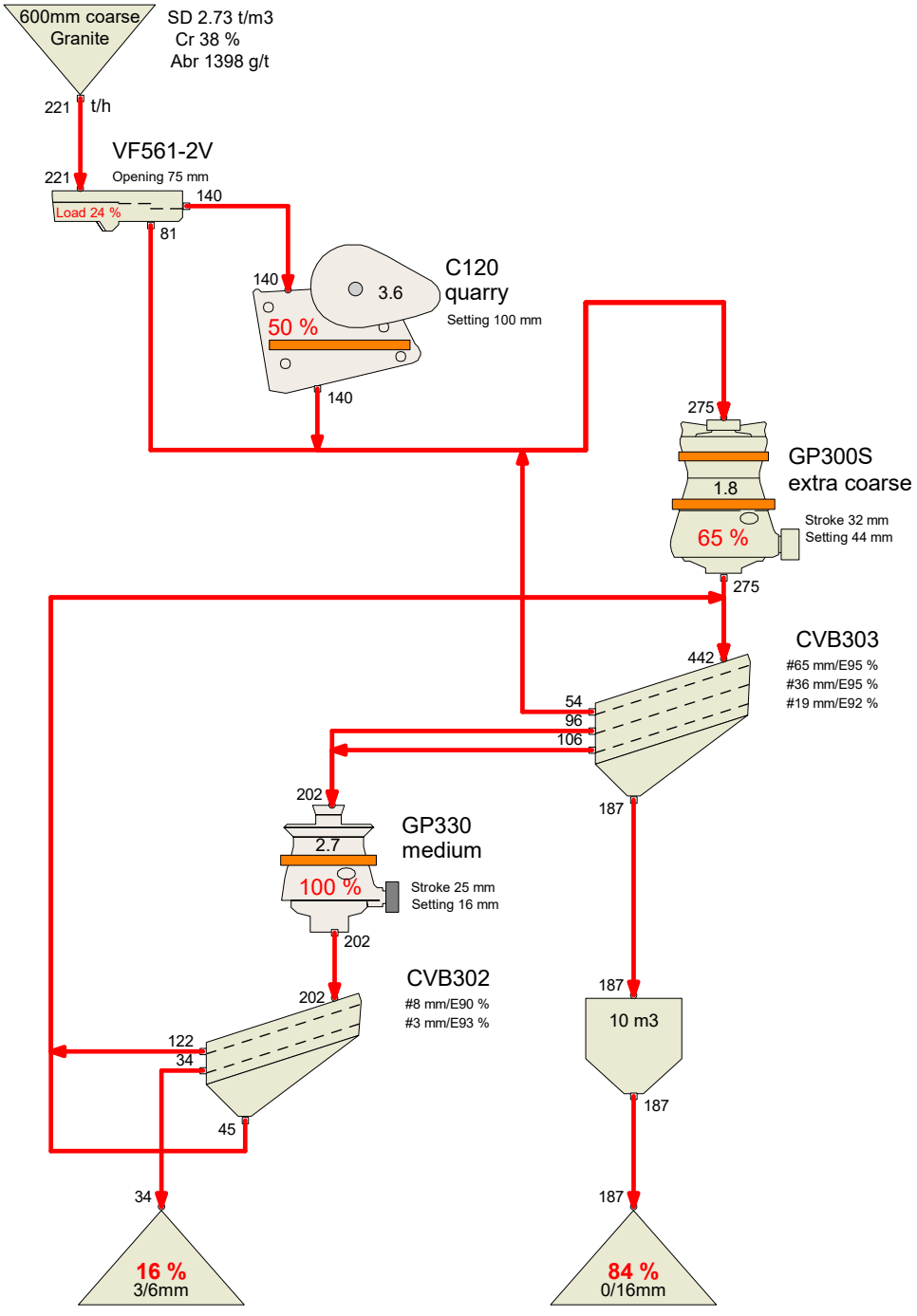
Influencing crushing plant costs & revenues
The flowsheet below depicts a typical mobile plant which can produce different fractions depending on the screen openings.

The fractions produced by this plant are as follows:

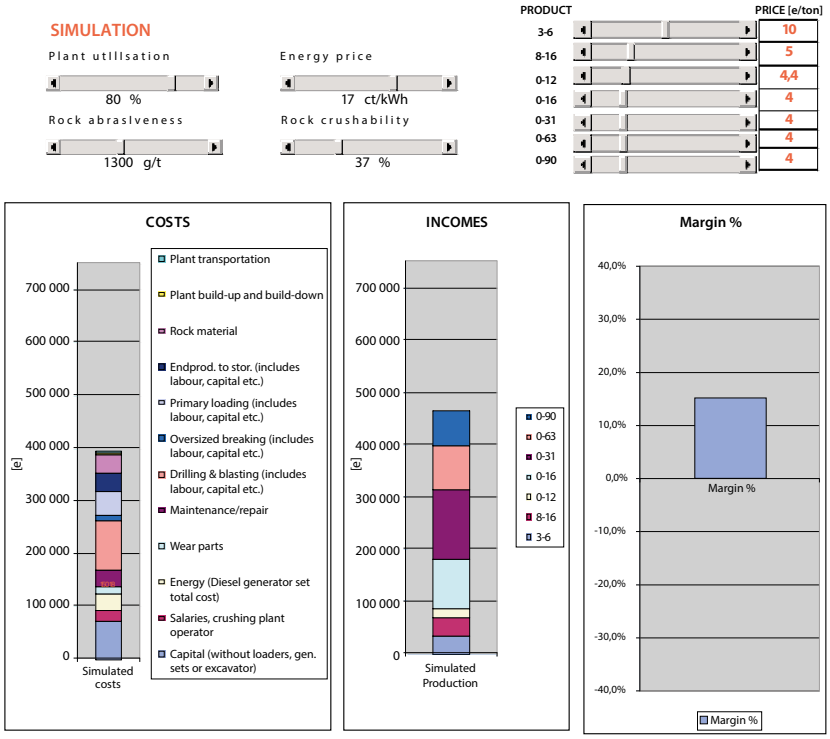
- 0-12 mm and 8-16 mm
- 3-6 mm and 0-16 mm
- 3-6 mm and 0-31 mm
- 8-16 mm and 0-63 mm
- 8-16 mm and 0-90 mm

The variables used in the analysis are as follows:

- plant utilization rate or availability
- energy cost
- abrasiveness of the rock
- hardness of the rock

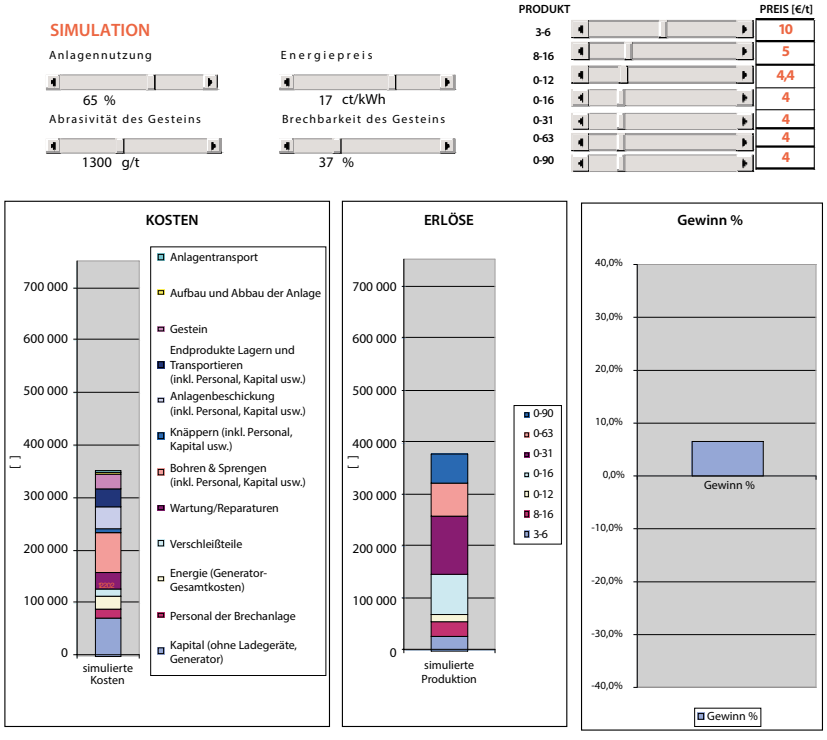


Plant production was 110,000 tons at an 80% utilization rate and the production amounts of different fractions were constant. As a basis for the plant's configuration, the configuration economy was as follows:



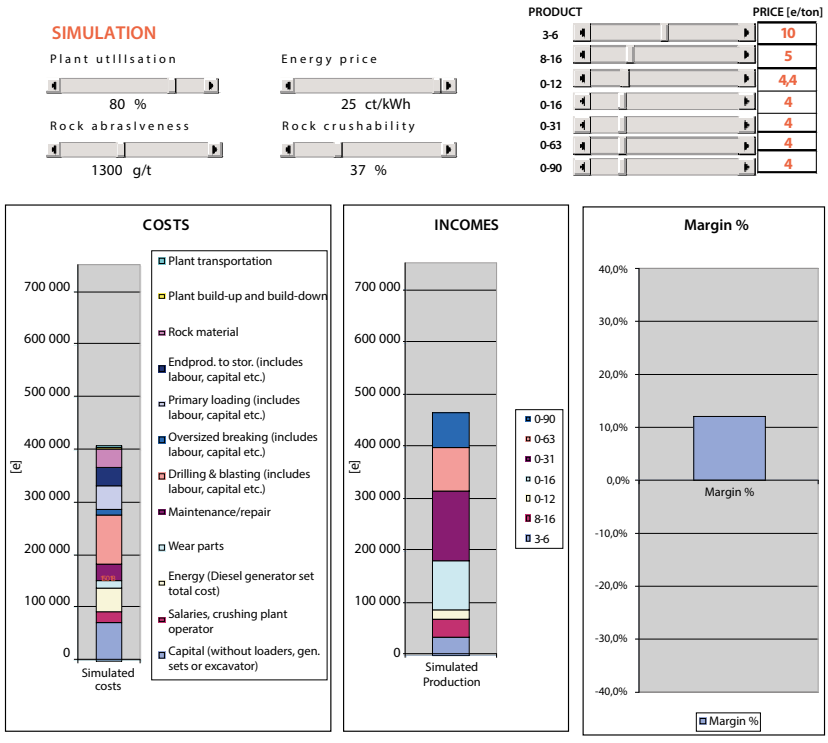
In the following figures, the changes given below were made:

- Utilization rate of 80% -> 65%
- Energy price +50%
- Abrasiveness of rock +50% (from medium to high abrasiveness)
- Hardness of rock from medium to hard

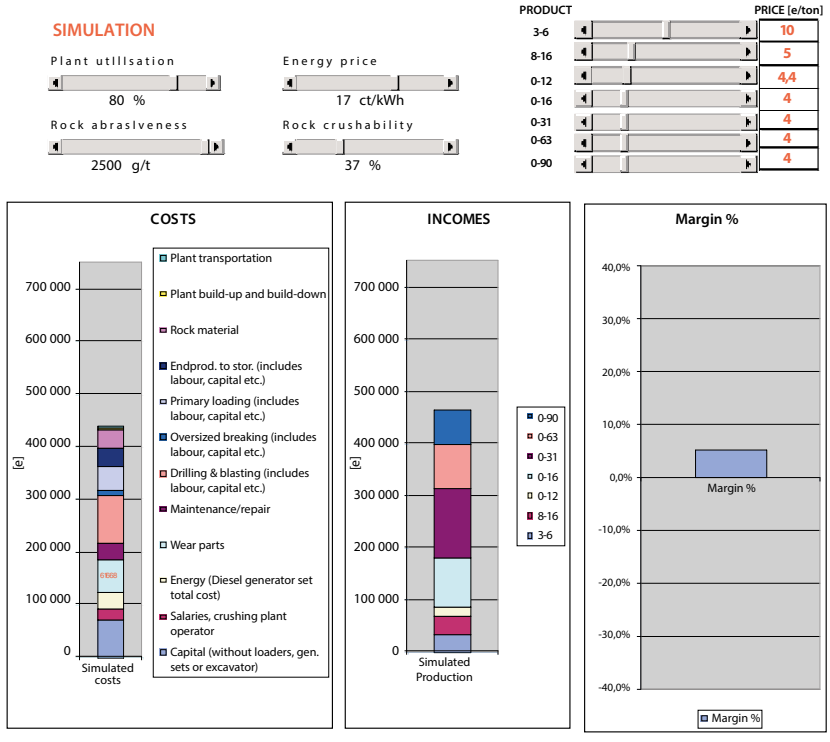


Utilization rate of 80% -> 65%

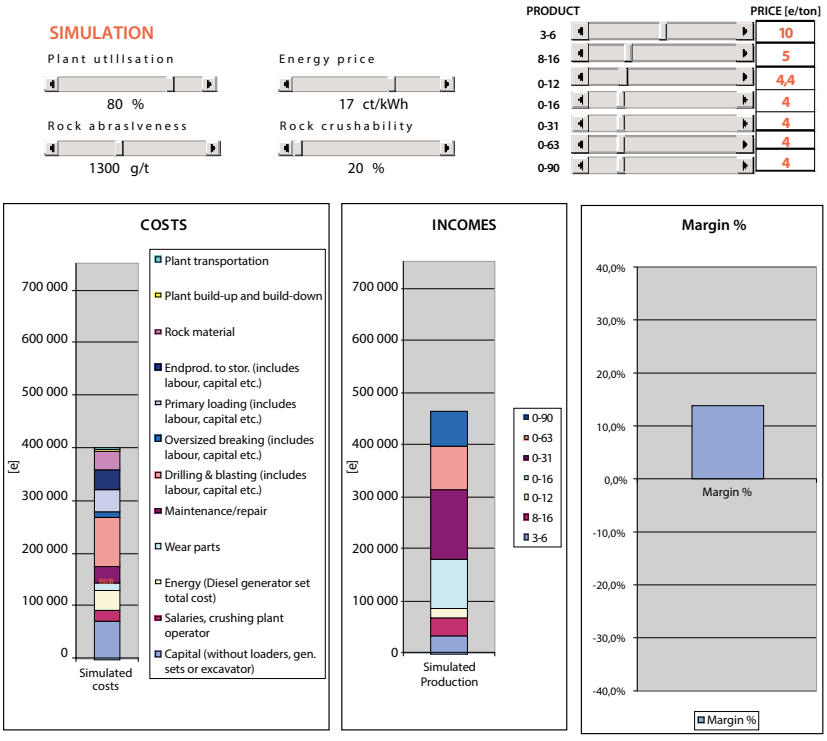
COST PER TON



Energy price +50%



Abrasiveness of rock +50% (from medium to high abrasiveness)



Hardness of the rock from medium to hard.

In conclusion, two major factors determine profitability with a given production split and sales price between different fractions.

These factors are plant utilization rate/availability and wear part costs, both of which place a great deal of pressure on the timing of wear part changes, so that wear parts are used as much as possible and plant downtime is kept to a minimum.

A reduction in the utilization rate can easily prove fatal to annual profitability. Of course, this varies depending on the plant setup and cost structure.

Process simulation

Bruno crushing process simulation
The basic objective of crushing process planning is to be able to define a process that fulfils the end-product quality and quantity requirements reliably and economically. The increasing mobility of crushing equipment sets new requirements.

The machines initially optimized for certain processes are also expected to fit in other applications with exceptional performance.

Bruno is an easy-to-use software tool for planning and simulating the crushing process. With Bruno you can quickly explore various machine combinations for certain applications or find out whether the existing machines are suitable for other applications.

The calculation model
The core knowledge in Bruno is reliable modelling of a unit machine. The basis is extensive amount of field test data of all types of crushers in various applications.

The tests revealed the process of turning the feed into the product. The process outcome is called machine performance.

There are two leading principles in modelling a machine performance in Bruno:

1. The performance depends on the same settings and adjustments as in real life.
2. The performance related variables are all linked together.

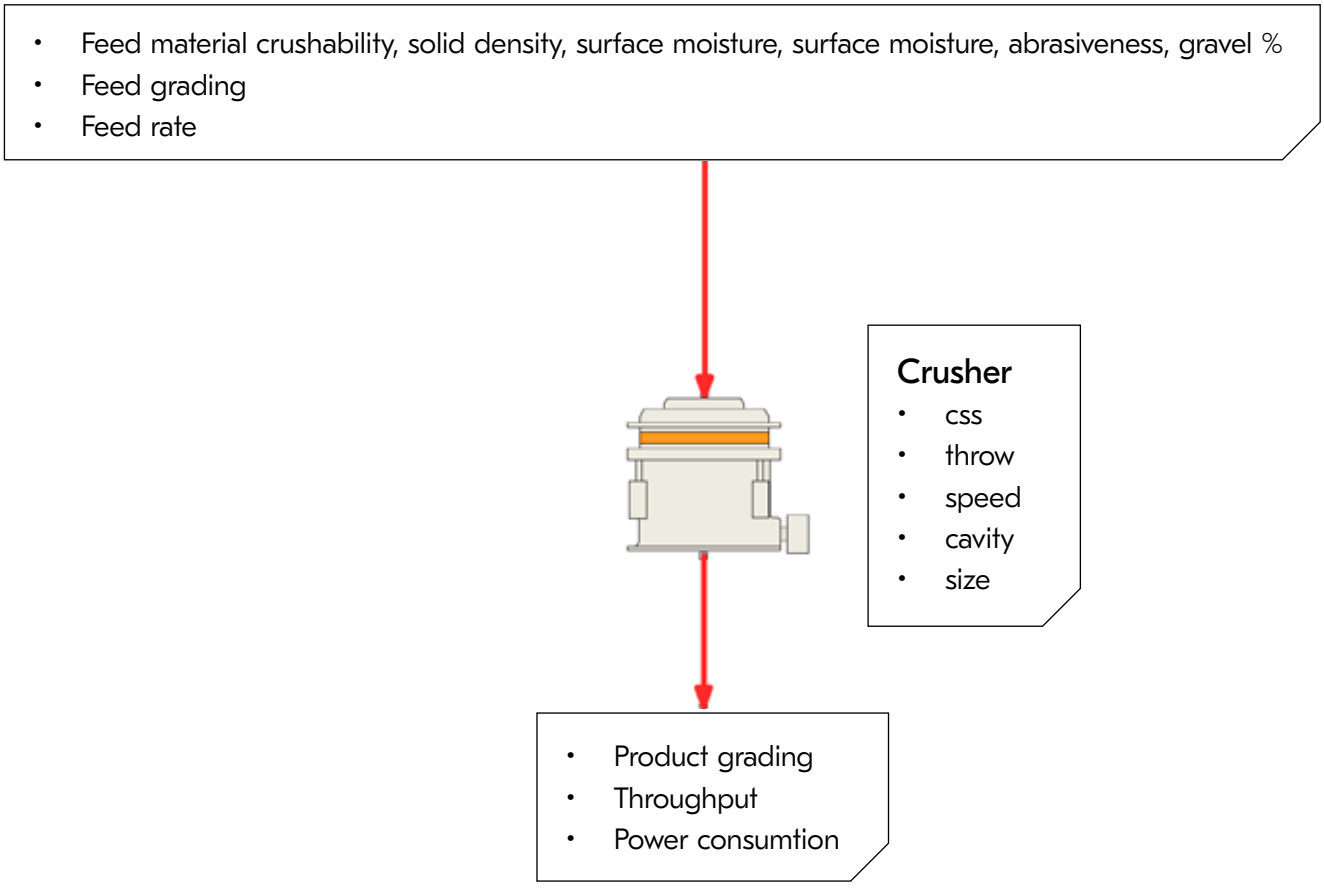


Figure 1. Inputs and outputs of a crusher performance calculation model.

In Bruno there are two sets of input parameters (Figure 1), machine parameters and process parameters. In real life some of them can be controlled and the rest depend on the crushing site, application etc.

Nevertheless, the parameters together determine the crusher performance, which is described by product grading, throughput, and power consumption.

Because all the parameters are linked together, the change in just one of them has effect on all three performance key figures.

Naturally, every input parameter does not have a similar impact on the results, but there is no such parameter that would change only one of the key figures.

In figure 2, the only change is feed material crushability. It increases throughput by 3%, it makes the product finer and power requirement becomes 48% lower.

When unit machines are compiled as a process, the importance of realistic results will be emphasized. The process parameters – the feed related parameters – come from the preceding process. If there is a clear error in some result, it will affect the process performance.

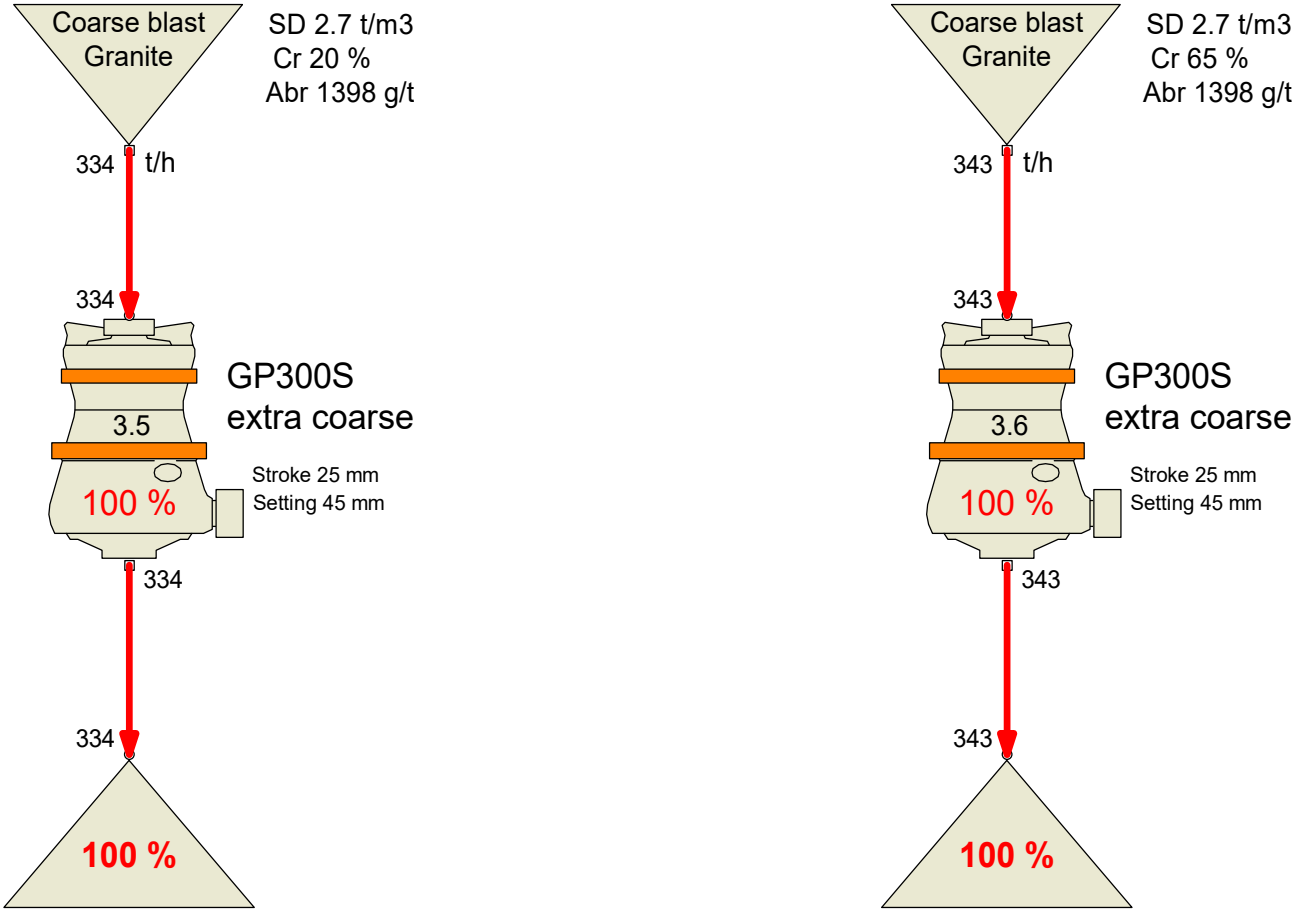


Figure 2. Change in feed material crushability.

Process simulation
Bruno can handle basically any crushing process a user can define. User can also use process library to find applicable process configuration for certain purpose.

Bruno finds a mass balance of the process and calculates the following results:

- Material flow for each connection between process machines
- Load for each screen and crusher in the process
- Particle size distribution for each material flow
- Power consumption for each machine
- Screening efficiency for screens and grizzly feeders

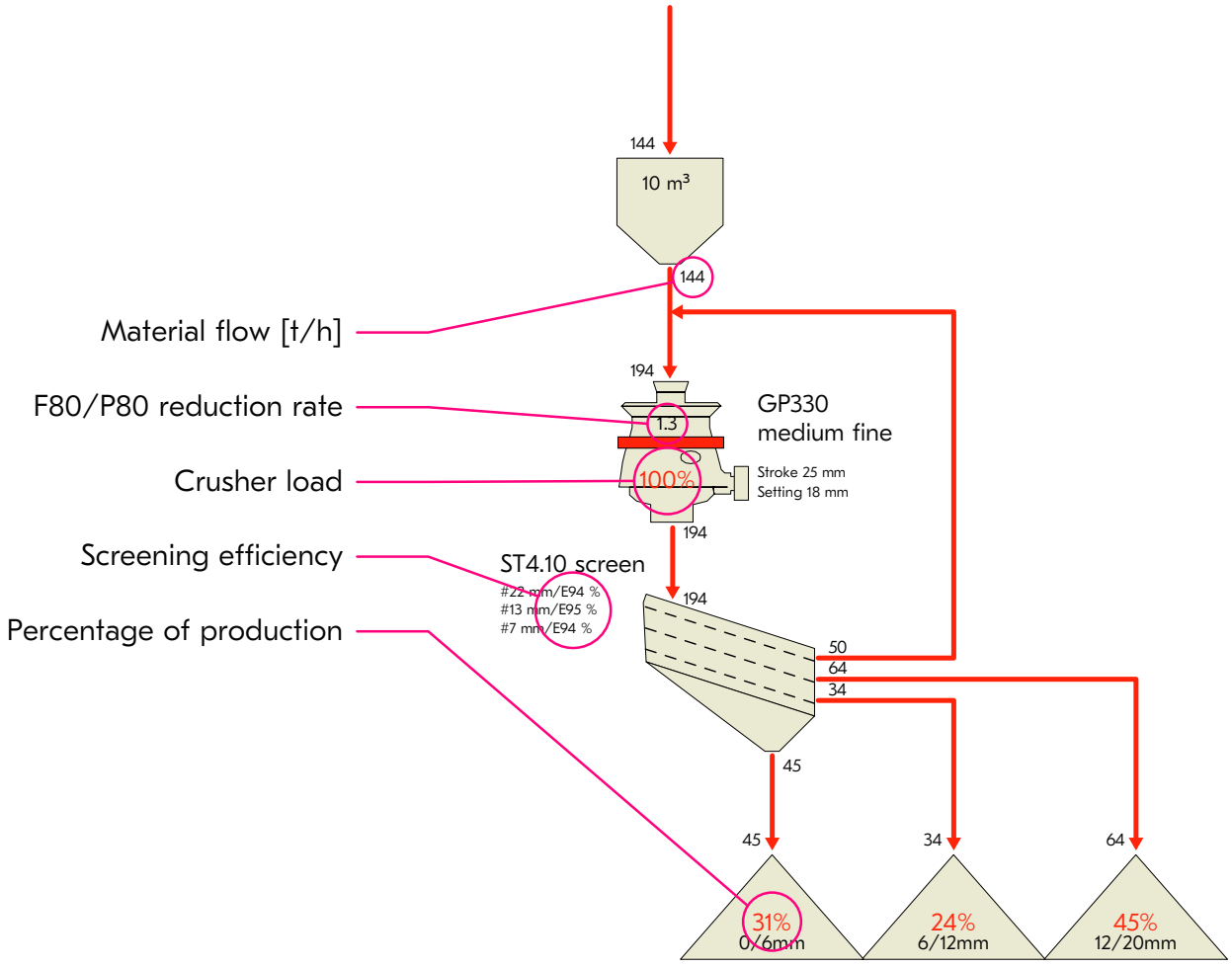
From the results it is easy to see how well the process meets the planned requirements.

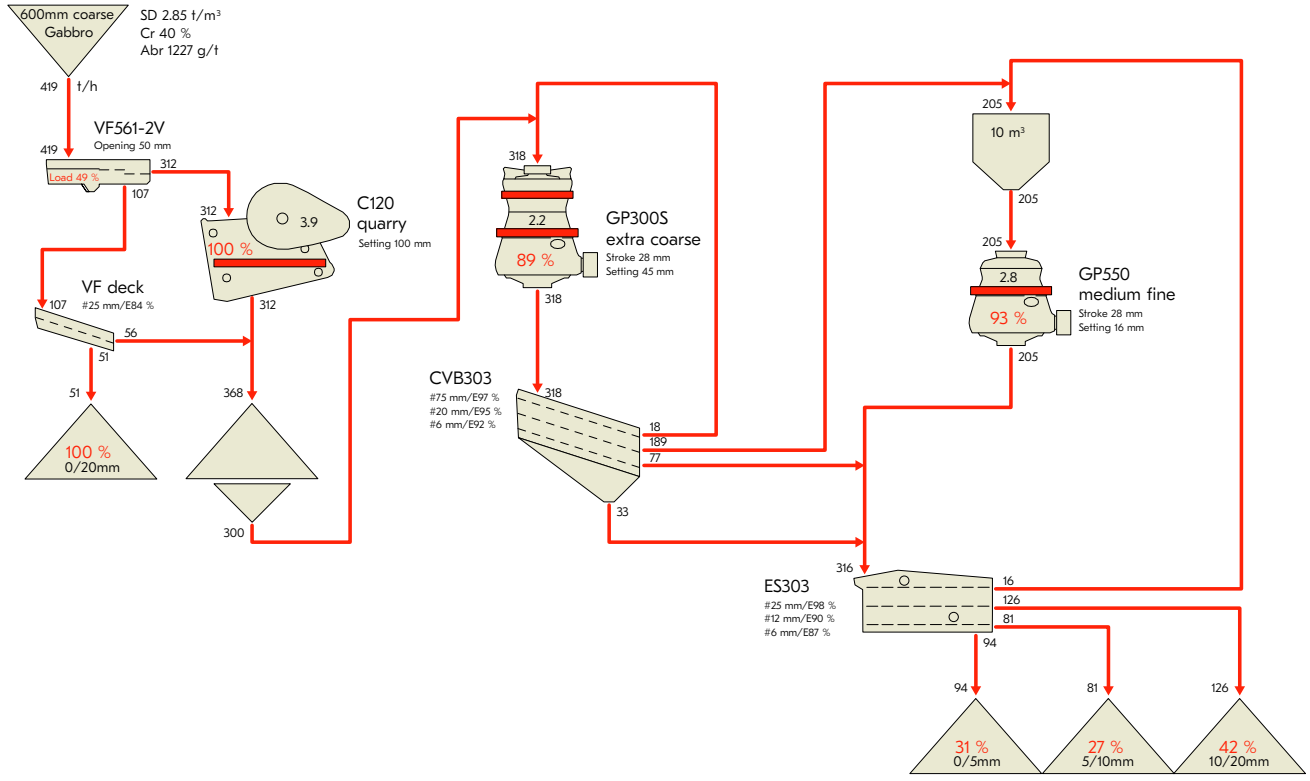
Typically, the most interesting result is the amount of each product. Crusher loads and material flows in the closed circuits reflect the process balancing. Crusher load and reduction ratio together gives an indication of attainable product shape.

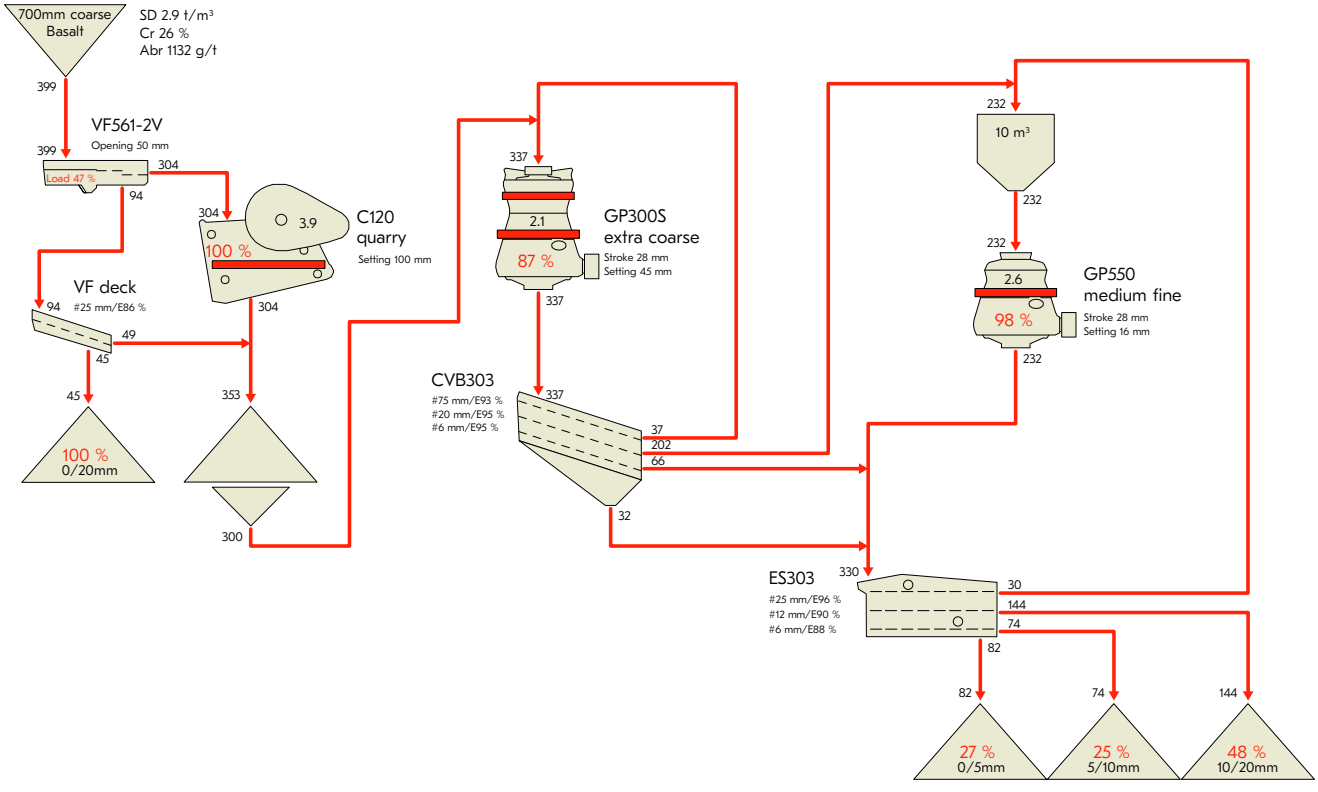
Bruno does not evaluate the process usefulness as such, but it gives warnings about exceeding machines' physical limits such as maximum intake particle size. If the process cannot be balanced, it also causes an error. Other deficiencies must be interpreted from the results.

The example process has originally been designed for 300 t/h capacity producing asphalt aggregates from crushability 40 gabbro and 0 – 600 mm feed. When feed material crushability changes from 40% to 25% and feed grading becomes 0 – 700 mm, secondary and tertiary crusher loads increase. Harder material turns crusher product coarser, which increases the load of the closed circuits.

Also, kW/ton of product raises due to harder material. Without any changes to the machine settings, almost half of the production is the coarsest 10-20mm product.




600mm coarse
Gabbro
SD 2.85 t/m³
Cr 40 %
Abr 1227 g/t
419 t/h
VF561-2V
Opening 50 mm
Load 49 %
C120
quarry
Setting 100 mm
100 %
VF deck
#25 mm/E84 %
100 %
0/20mm
GP300S
extra coarse
Stroke 28 mm
Setting 45 mm
89 %
CVB303
#75 mm/E97 %
#20 mm/E95 %
#6 mm/E92 %
10 m³
GP550
medium fine
Stroke 28 mm
Setting 16 mm
93 %
ES303
#25 mm/E98 %
#12 mm/E90 %
#6 mm/E87 %
31 %
0/5mm
27 %
5/10mm
42 %
10/20mm


700mm coarse
Basalt
SD 2.9 t/m³
Cr 26 %
Abr 1132 g/t
399
VF561-2V
Opening 50 mm
Load 47 %
C120
quarry
Setting 100 mm
100 %
VF deck
#25 mm/E86 %
100 %
0/20mm
GP300S
extra coarse
Stroke 28 mm
Setting 45 mm
87 %
CVB303
#75 mm/E93 %
#20 mm/E95 %
#6 mm/E95 %
10 m³
GP550
medium fine
Stroke 28 mm
Setting 16 mm
98 %
ES303
#25 mm/E96 %
#12 mm/E90 %
#6 mm/E88 %
27 %
0/5mm
25 %
5/10mm
48 %
10/20mm

All crushers can be classified as falling into two main groups:

- Compressive crushers, which compress the material until it breaks.
- Impact crushers, which use the principle of quick impacts to crush the material.

Jaw, cone, gyratory, and roller crushers operate according to the compression principle, and impactors and hammer mills use the impact principle.

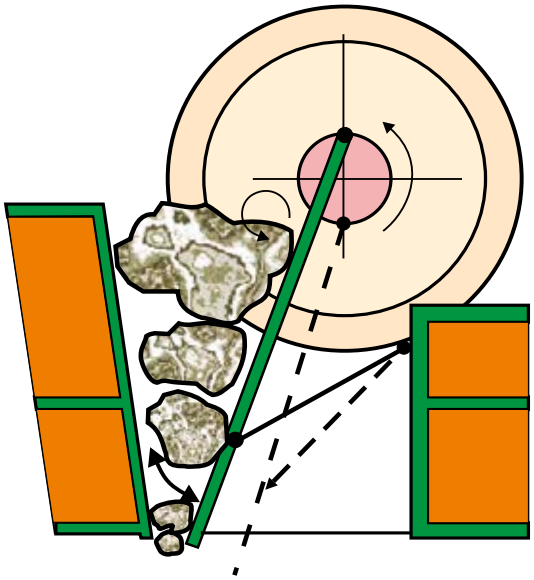
Compressive crushers

Jaw crushers
Jaw crushers are mainly used as primary crushers. Their main purpose is to produce material that can be transported by belt conveyors to the next crushing stages.

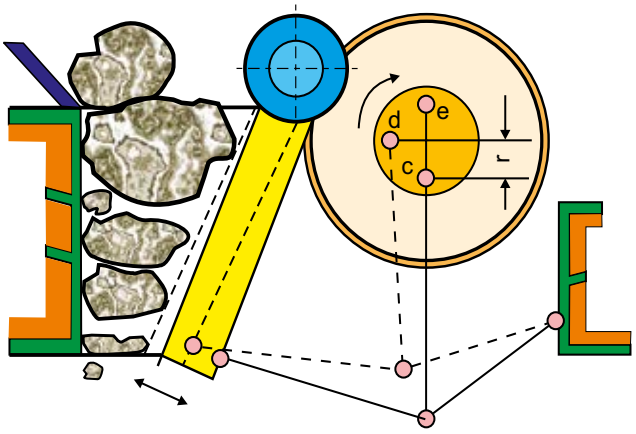
The crushing process takes place between a fixed and a moving jaw. The moving jaw dies are mounted on a pitman that has a reciprocating motion. The jaw dies must be replaced regularly due to wear.

There are two basic types of jaw crushers: single toggle and double toggle. In the single toggle jaw crusher, an eccentric shaft is on the top of the crusher. Shaft rotation causes, along with the toggle plate, a compressive action.

A double toggle crusher has two shafts and two toggle plates. The first shaft is a pivoting shaft on the top of the crusher, while the other is an eccentric shaft that drives both toggle plates. The moving jaw has a pure reciprocating motion toward the fixed jaw.



Single toggle crusher.



Double toggle crusher.

The chewing movement, which causes compression at both material intake and discharge, gives the single toggle jaw better capacity, compared to a double toggle jaw of similar size.

The jaw crusher is reliable and robust equipment, and therefore, quite popular in primary crushing plants.

Cone and gyratory crushers

Both cone and gyratory crushers have an oscillating head which supports the inner wear part, the mantle. The material is crushed in a crushing cavity, between an external fixed element (bowl liner) and an internal moving element (mantle) mounted on the oscillating head.

An eccentric shaft rotated by a gear and pinion produces the oscillating movement of the head and mantle mounted onto it. The eccentricity causes the cone head to oscillate between o.s.s. (= open side setting) and c.s.s. (= closed side setting) discharge opening. In addition to c.s.s., eccentricity is one of the major factors that determine the capacity of gyratory and cone crushers.

The fragmentation of the material results from the continuous compression that takes place between the liners around the chamber. An additional crushing effect occurs between the compressed particles, resulting in less wear of the liners. This is called interparticular crushing also.

Modern cone crushers are equipped with hydraulic setting adjustment and wear compensation system, which adjusts the crusher c.s.s. and thus affects onto the product gradation.

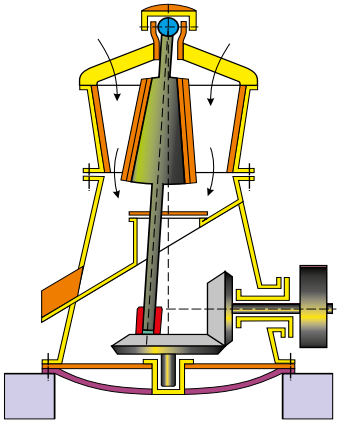
Depending on cone type, setting can be adjusted in two ways. The first way is for setting adjustment to be done by rotating the bowl against the threads on the adjustment ring assembly attached to the crusher main frame so that the vertical position of the outer wear part (concave) is changed. One advantage of this adjustment type is that liners wear more evenly.

Another principle is that of setting adjustment by lifting/lowering the main shaft. An advantage of this is that adjustment can be done continuously under load.

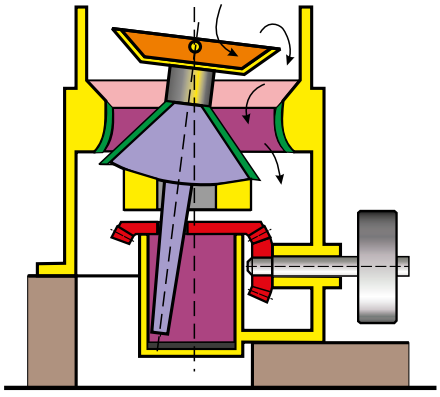
To optimize performance, process stability and operating costs and improve the product shape, as a rule of thumb it is recommended that cones always be choke-fed, meaning that the cavity should be as full of rock material as possible.

This can be easily achieved by using a stockpile or a silo to regulate the inevitable fluctuation of feed material flow. Level monitoring devices detect the maximum and minimum levels of the material, starting and stopping and optimally actively regulating the feed of material to the crusher, as needed.

Gyratory crushers
Primary gyratory crushers are used in the primary crushing stage. Secondary gyratory crushers are normally used in the second crushing stage, but, in some cases, they can be used in the primary stage if the material has a size that fits the feed opening.



Gyratory crusher



Cone crusher

Compared to the cone type secondary crusher, a gyratory crusher has a crushing chamber designed to accept feed material of a relatively large size in relation to the mantle diameter. Therefore, the cone head angle is smaller than that of a gyratory type of cone crusher.

Secondary, tertiary, and quaternary cone crushers
These cone crushers are used for secondary, intermediate or fine crushing, and/or to obtain a product with good cubical shape. The feed material is typically received from the previous crushing stage. In the case of gravel, mother nature has done the primary crushing, and therefore the cone-type secondary crusher can, sometimes, carry out the complete crushing process.

One of the key factors for the performance of a cone type secondary crusher is the profile of the crushing chamber or cavity. Therefore, there is normally a range of standard cavities available for each crusher, to allow selection of the appropriate cavity for the feed in question.

Impact crushers

There are two main types of impact crushing: HSI, Horizontal shaft impactor and VSI, Vertical Shaft Impactor. Both of these are characterized by a good cube-shaped product. HSI crushers have a high reduction ratio.

The impactors can also be used for selective crushing, a method that liberates hard minerals from the waste material.

The impactor consists of a steel plate body containing a shaft and rotor assembly. The number of moving parts is quite small.

Horizontal-shaft impactors (HSI)
The feed material is crushed by highly intensive impacts originating in the fast rotational movement of hammers/bars fixed to the rotor.

The particles produced are then further crushed inside the crusher as they collide against crusher parts and against each other, producing a finer, better-shaped product.

Vertical-shaft impactors (VSI)
The vertical-shaft impactor can be considered a 'stone pump' that operates like a centrifugal pump. The material is fed through the center of the rotor, where it is accelerated to high speed before being discharged through openings in the rotor periphery.

The VSI can be either autogenous VSI crushers, with an external ring made of a stone bed that use Rock-on-rock crushing principle, or with metal liners.

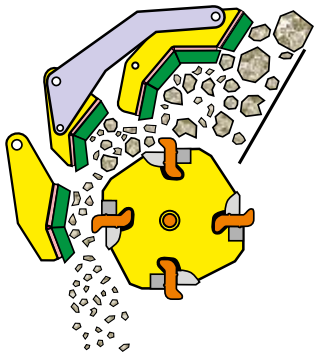
This last family offers a higher reduction ratio and a lower energy consumption than autogenous models but is more sensitive to wear and therefore is used for low abrasion material application. Rock on rock principle reduces the number of wear parts exposed to material and thus minimizes wear costs.

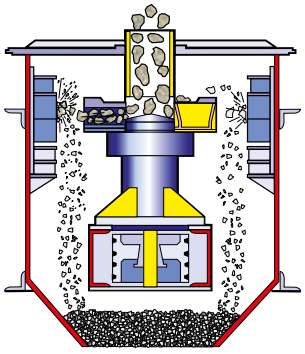
The material is crushed as it hits the outer body at high speed and due to the rock-on-rock action.

The VSI crushers are mainly used in the production of fine materials, including sand, with a good cubical shape.

Hammer mills
Hammer mills are quite like impactors. The difference is that the hammer mill rotor has many pivoted hammers attached to it and the discharge openings consist of a grate through which the material must pass, thus contributing to the reduction process. Hammer mills are used to grind and pulverize materials that are not too hard or abrasive.

The rotor speed and the grate spacing can be optimized to suit different applications.





Impactor (VSI) rock-on-rock action

Impactor (HSI)

Crushing equipment selection

Some who are familiar with the technique for selecting crushing equipment are of the opinion that it is possible to select merely based on calculations.

However, theoretical conclusions must always be counterbalanced by practical experience with the different materials as well as the operational, maintenance and – finally – economic aspects of the various solutions.

Primary crushing

The main purpose of a primary crusher is to reduce the material to a size that allows its transportation on a conveyor belt. In most crushing installations producing aggregates, a jaw crusher carries out the primary crushing. Plants with very high capacities normally use a primary gyratory crusher.

When the material is easy to crush and not very abrasive, an impact crusher may be the best choice for primary crushing. One of the most important characteristics of a primary crusher is its capacity for accepting feed material without bridging. A large primary crusher is, naturally, more expensive than a smaller one.

Therefore, the investment cost calculations for primary crushers are compared together against the total costs of primary stages, including quarry face clearing, blasting, and drilling costs. In many cases, dump trucks transport the rock to a stationary primary crusher.

This may be an expensive solution. Amortization, fuel, tires, and maintenance costs can be included when the vehicles are in high demand. In modern operations, the use of mobile primary crushers that can move alongside the rock face is, in many cases, the most economical solution.

A stationary primary crusher can be transformed into mobile equipment with the help of a track system (with crawlers). A track-mounted primary crusher may be an interesting solution economically in cases where the equipment needs to be constantly repositioned in the quarry.

However, it can be a slightly more expensive solution in terms of investment and maintenance. There may be potential for cost savings in material loading and transportation.

If these savings are realized, the potential savings over traditional methods could be up to 25%. All this means that these matters must be analyzed case by case, and there are effective tools available for this.

Jaw crushers
In terms of the size of the feed opening, the client gets a better return on investment when the primary crusher is a jaw crusher. That means less drilling and blasting because the crusher accepts larger boulders.

The disadvantage of this type of crusher, when high capacity is required, is the relatively small discharge width, limiting the capacity as compared with the discharge circuit of a gyratory crusher. Jaw crushers are mainly used in plants producing up to approximately 1600 t/h.

Primary gyratory crushers
The primary gyratory crusher offers high capacity thanks to its generously dimensioned circular discharge opening (which provides a much larger area than that of the jaw crusher) and the continuous operation principle (while the reciprocating motion of the jaw crusher produces a batch crushing action).

The gyratory crusher has no rival in large plants with capacities starting from 1200 t/h and above. To have a feed opening corresponding to that of a jaw crusher, the primary gyratory crusher must be much taller and heavier. Also, primary gyratories require quite a massive foundation.

Impactors
The primary impact crusher offers high capacity and is designed to accept large feed sizes. The primary impact crushers are used to process from 200 t/h up to 1900 t/h and feed sizes of up to 1500 mm (60″) in the largest model.

Primary impact crushers are generally used in nonabrasive applications and where the production of fines is not a problem. Of all primary crushers, the impactor is the crusher that gives the best cubical product.

Secondary crushing

The purpose of secondary, also called intermediate, crushing is to produce several coarse-grade products – for example, road base aggregates – or to prepare material for final recrushing. If the intermediate crushing is done with the purpose of producing railway ballast, the quality of the product is important.

In other cases, normally there are no quality requirements, except that the product be suitable for fine crushing.

In most cases, the goal is to obtain the best possible size reduction at the lowest cost. Cone crushers are often used for secondary crushing, due to their high capacity and low operating costs.

Fine crushing and cubicising

These crushing stages determine the quality of the final products. Quality specifications are precise for the final products, especially in the aggregates industry.

Common demands from clients in aggregate production as well as in mining operations are capacity and quality (gradation). The aggregates industry has additional quality demands also, such as for the cubical shape of the particles.

In most cases, fine crushing and cubiclizing are combined in a single crushing stage. The selection of a crusher for this job requires practical experience and theoretical knowledge. This is where Metso can help.

Two main types of crushers for fine crushing and cubicizing
The user will have to choose between the two main types of crushers for fine crushing and cubicizing – i.e., cone and impact crushers. The decisive factors for selection of the most appropriate equipment are the abrasiveness and crushability of the material, as well as the desired gradation curve.

Cone crushers
Due to their design, cone crushers are generally a more expensive investment than impactors are. However, when correctly used, a cone crusher offers lower operating costs than a conventional impact crusher.

Therefore, clients crushing hard or abrasive materials are advised to install cone crushers for the final crushing and cubicizing stage. Cone crushers can in most cases also give a good cubic shape to fine grades. Cone crushers can be adapted to different applications.

This is an important factor, as client-specific needs often change during a crusher's lifetime.

For cone crushers there are few rules to be followed of optimum cubical shape. These 'Ten Golden Rules' are:

1. Full crushing chamber. This means that cone head must be covered by rock.
2. Stable and continuous feed.
3. Material below setting in the feed 10-30% (but no filler and fines 0-4 mm normally).
4. Maximum feed size. Reduction ratio must be limited to 3 (-4). Recommended max feed size is 50 mm.
5. Correct feed distribution. Feed distribution should be non-segregated and evenly distributed around crushing cavity.
6. Setting closer to required product.
7. Correct choke point. This means the right selection of cavities for feed in question.
8. Crusher itself. New generation cones will produce considerably better shape than so called old generation. This is due to improved crusher kinematics and shape of cavity.
9. Closed circuit. This improves shape by attrition, gives constant feed curve and recrushing of flaky product. In secondary stages closed circuit calibrates feed to tertiaries.
10. Flow sheet in general. Important, especially in production of very high quality (shape) aggregate is that selective circuits are used, meaning that secondary and tertiary products are not mixed.

Impactors
The impactor family consists of two main types of impact crushers.

The conventional type has horizontal shaft configuration, known as HSI. The other type consists of a centrifugal crusher with vertical shaft, generally known as VSI. Impactor operation is based on the principle of rapid transfer of impact energy to the rock material.

Impactors produce cubic products, and they can offer high reduction ratios as long as the feed material is not too fine. This means that in certain cases it is possible to use a single impact crusher to carry out a task normally done in several crushing stages using compressing crushers (i.e., jaw, gyratory, and/or cone crushers).

Impactors are mostly used for nonabrasive materials. The two main types of impactors can be further subdivided, into various groups.

Conventional horizontal-shaft impact crushers are available in various sizes and models, from high-capacity primary crushers for large limestone quarries to specially designed machines for the crushing of materials such as slag.

There are two main categories of VSI crushers – machines with impact wear parts around the body, typically anvils, and machines that use a layer of accumulated material. With a stone bed, the material undergoes an intense rock-on-rock crushing process.

With anvils, most of the reduction is done by the impact of stone against metal. The rock-on-rock solution has lower operating costs than anvil solution, but its reduction ratio is also lower.

Customers operating old, rebuilt, or expanded plants often have problems with the shape of the product. In these cases, the addition of a Barmac VSI in the final crushing stage offers a solution to product shape problems.

The same applies to many mobile crushers. As the number of crushing stages is normally small with this type of plant, it is almost impossible to obtain a good product shape unless the rock is relatively soft and thus more suited to produce cubic product. A centrifugal crusher in the final stage can help to solve the problem.

Feed size and plant capacity the main factors
The plant's capacity and the size of the feed material are the main factors in selection of a primary crusher. To ensure good performance of the primary plant and prevent production losses, it is necessary to have an adequate correlation between the size of the feed material and the dimensions of the crusher feed opening.

This means that the maximum size of feed material should be in the range of 60 to 80% of the crusher intake opening's size. Factors that may influence the choice include the type of feeder used, material flow to the crusher, and the availability of the necessary means (like breakers) to remove large-sized boulders in the event of bridging at the material intake opening.

In cases where capacity requirements are very high, the natural choice is a primary gyratory crusher.

Naturally, a large intake opening is always an advantage. However, in practice, the limit is set by the capacity of the plant and the budgeted investment.

Crushing – calculation of reduction ratio

All crushers have a limited reduction ratio meaning that size reduction will take place in stages. The number of stages is guided by the size of the feed and the requested product, example see below.

Feed material size: F80 = 400 mm

Blasted rock, 80% smaller than 400 mm

Product size: P80 = 16 mm

Road aggregates or rod mill feed 80% smaller than 16 mm

Total reduction ratio (R) F80/P80 400/16 = **25**

Reduction ratio in the primary crushing stage
R1 = **3**

Reduction ratio in the secondary crushing stage
R2 = **4**

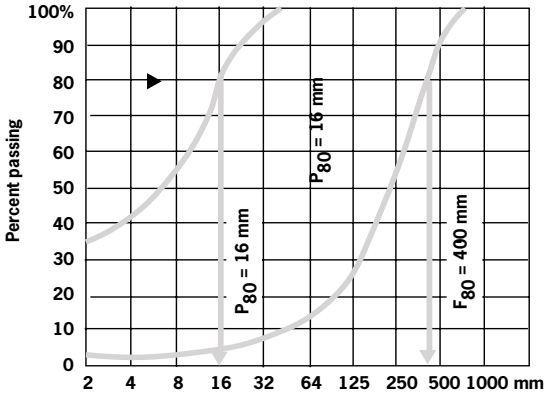
Total in 2 crushing stages gives
R1xR2 = 3x4 = **12**

This is not sufficient. We need a third crushing stage.*

For example:

Reduction first stage	R1 = 3
Reduction second stage	R2 = 3
Reduction third stage	R3 = 3

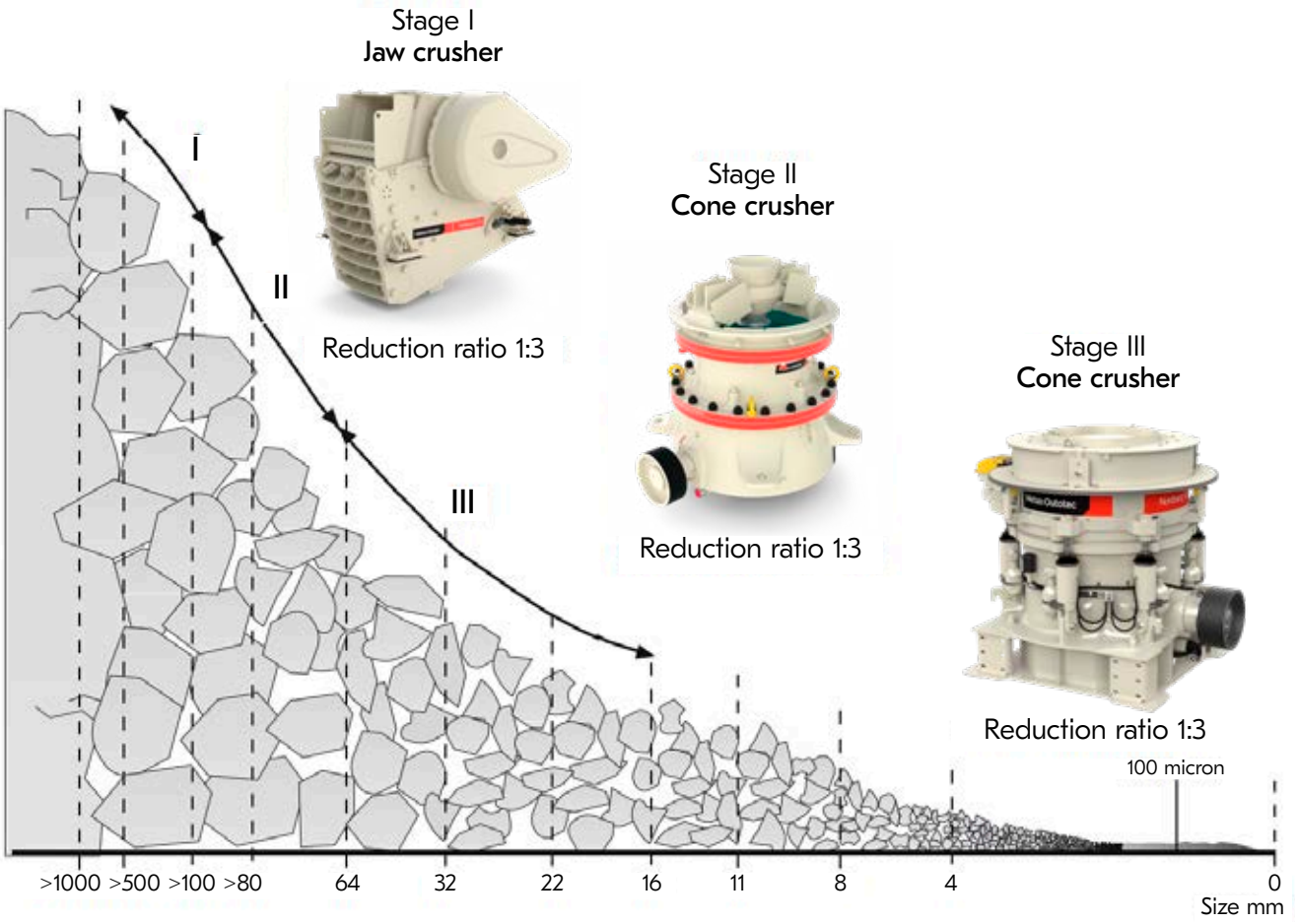
Together these three stages give
R1xR2xR3 = 3x3x3 = **27** = sufficient reduction



**As we must use three stages, we can reduce the reduction ratio a bit in every stage, giving more flexibility to the circuit!*

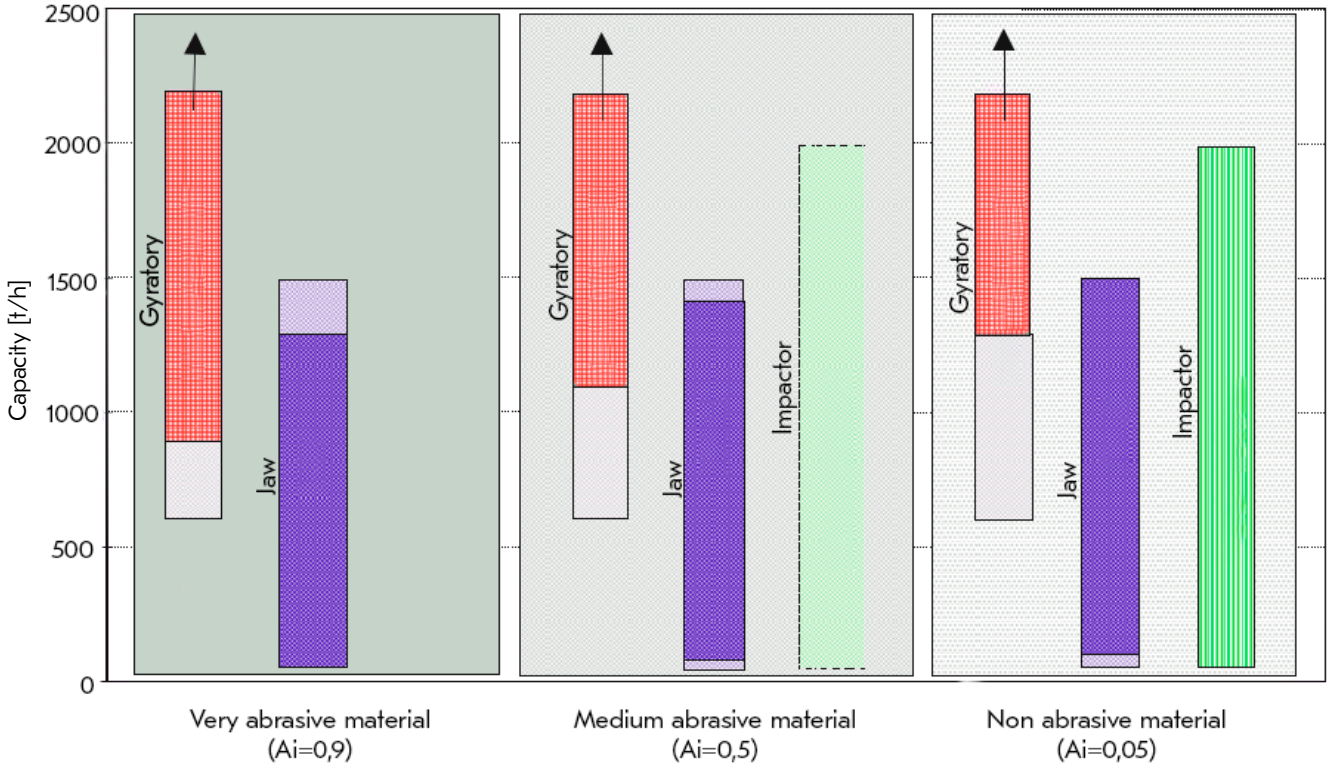
The same size reduction with soft feed (below mohs 5) is done with two stages of HSI (horizontal shaft impactors) as they can easily reduce 1:10 in each stage giving max reduction possibility of 1:100.

For inches divide by 25.4



Crusher selection

In the table below there are some very basic guidelines for crusher applications. The information in the table below is only indicative and not a rigid rule. Primary crusher selection can also be summarized as shown in the diagram below.



Major crusher type	Typical process stage	Feed size up to (mm)	Typical max. end product size (mm)	Typical capacities (t/h)	Abrasiveness		Amount of fines produced	Product shaping
					low	high		
Gyratory crusher (large)	primary	1500	200-300	over 1200		x	low	
Jaw crusher	primary	1400	200-300	up to 1600		x	low	
Horizontal impact crusher	primary/ secondary/ tertiary	1500	0-50	up to 1800	x		medium/ high	yes
Cone gyratory crusher	secondary	450	60-80	up to 1200	x	x	low	
Cone gyratory crusher	tertiary	300	0-30	up to 1000	x	x	low/ medium	yes
VSI Barmac, B series	tertiary/ quaternary	40	0-30	up to 600	x	(x)	high	yes
VSI Barmac, VI series	tertiary/ secondary	150	0-30	up to 500	x		high	yes

For inch divide by 25.4 *For STPH multiply by 1.1*

Indicative Impact of different parameters
The impact of rock characteristics and the operational parameters of crushers on the final product is complicated. In many cases, the impact of single factors depends on the combined effect of several others.

The table below presents a simplified summary of the effects of some variables on the end product and crusher performance. As implied above, in many cases the impact of a parameter can be the opposite of that expected, depending on another parameter.

A practical example is the influence of the cone crusher stroke on the shape. If feed contains smaller fractions than the crusher setting, a larger stroke is good for the product shape.

But if the feed fraction is narrow, without factions smaller than the setting, then, from perspective of the end product shape, a smaller stroke is the better choice. At any rate, with this kind of configuration such an end product quality can never be achieved with a wider feed with fractions < setting.

For this reason, the aforementioned simultaneous effects occur and should be taken into account.

Increase		Effection							
		Product					Crusher		
	+ = value increases - = value decreases	Share of 0/4	80 % point	Curve steepness	Capacity	Flakiness index	Power	Crushing force	
	Feed 80 % point	-	+		-	+			Feed material
	Sare of below setting in feed				+			+	
	Crushability	+	-	-	-	-	-		
	Moisture	+	-		-				
	Flakiness in feed	+	-	-	+	+			
	Jaws								Crushers
	Setting		+	+	+		-	-	
	Speed		-	-		+	+		
	Nip angle				-				
	Cones								
	Setting	-	+	+	+		-	-	
	Stroke			-	+		+	+	
	Speed	+	-	-			+		
	Nip angle				-				
	Horizontal shaft impactors								
	Speed	+	-	-		-	+		
	Setting		+		+	+	-		
	Number of breaker plates	+	-		-	-			
	Feed rate	-	+		+		+		
	Vertical shaft impactors								
	Speed	+	-	-	-	-	+		
	Cascade	-	+		+	+	-		
	Feed rate	-			+		+		

Crushing – general concepts Capacity

Crushers' capacities
The production capacities given in the performance tables on the pages that follow was prepared as a tool to aid in the correct use of the crushers. The capacities (t/h) indicated are based on materials with a bulk density of 1,600 kg/m^3.

The crusher is only one component of the crushing circuit. Therefore, its performance will also depend on the right choice and correct operation of feeders, conveyors, screens, frames, electric motors, drives, and silos.

For good performance, all the factors below should be considered:

1 — Selection of an appropriate crushing chamber for the material.
2 — Feed curve with adequate size distribution.
3 — Feed rate control.
4 — Adequate material distribution over the 360° of the crushing chamber in the case of cone crushers.
5 — Appropriate dimensioning of the discharge conveyor as regards crushers' maximum capacity.
6 — Correct dimensioning of scalping and classifying screens in closed circuits.
7 — Automation.
8 — Adequate crusher discharge area.

The factors listed below, when not taken into consideration, may affect the capacity and the performance of the crusher.

1 — Presence of sticky material in the crushers' feed.
2 — Presence of fines in the feed (0-5 mm) exceeding 10% of the crusher capacity.
3 — Excessive humidity.
4 — Segregation of feed in the crushing chamber.
5 — Uneven distribution of feed around the crushing chamber, in the case of cone crushers.
6 — Lack of feed control.
7 — Wrong motor size.
8 — Insufficient capacity of the crusher's discharge conveyor.
9 — Insufficient capacity of scalping and/or circuit closing screens.
10 — Insufficient crusher discharge area.
11 — Material for crushing being extremely difficult to crush or hard.
12 — Crusher operating at a rotation speed below specifications.

To determine the effect of one characteristic alone, please consult Metso.

Crusher performance simulation
Rock crusher performance consists of size reduction, throughput capacity, energy consumption and quality (grading and particle shape).

Crusher performance has several parameters
- Processed rock material characteristics
- Feed material size distribution
- Material characteristics
- Moisture etc.
- Crusher parameters
- Crusher kinematics
- Crushing chamber geometry

Reliable crusher performance simulation
- Enables crushing chamber and kinematics optimization
- Serves as a problem-solving tool

Simulation model background
The first prediction models for jaw and gyratory crusher performance were published in the 1950s. These models calculated the flow of material into the crushing chamber, the result being an estimation of crusher capacity. Models developed later were based on equations of motion and took account of selection and breakage functions derived from laboratory tests.

The model developed by Metso research is also based on the laws of mechanics and predicts size reduction using selection and breakage functions.

Empirical selection and breakage functions are obtained through extensive laboratory test series, including both single particle and particle layer compression tests for different materials.

Simulation is fine-tuned to high accuracy through hundreds of full-scale crushing tests conducted by Metso technology research.

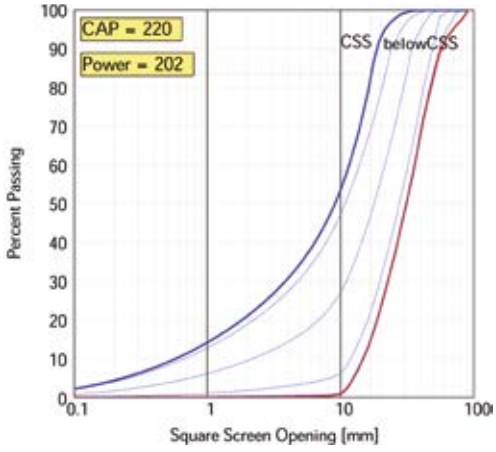
Simulation program input and output parameters
Simulation program input parameters are divided into two categories, crusher, and feed material parameters. Crusher parameters are:
- Crushing chamber geometry
- Crushing equipment
- Crusher
- Setting
- Stroke
- Eccentric speed

A size reduction model needs input data from the flow model and material characteristics:

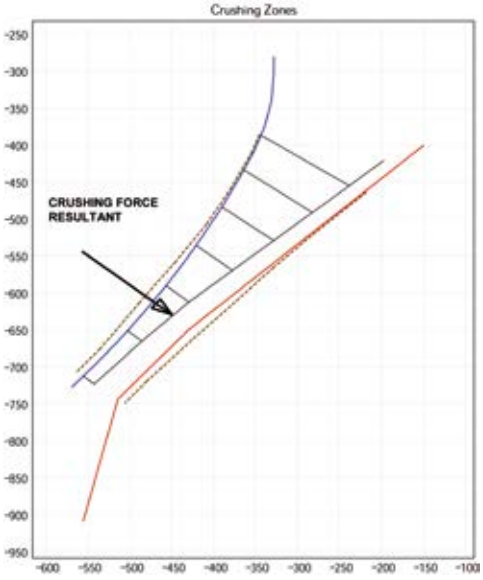
- Feed size distribution
- Feed material crushability
- Feed specific gravity

Simulation program output:

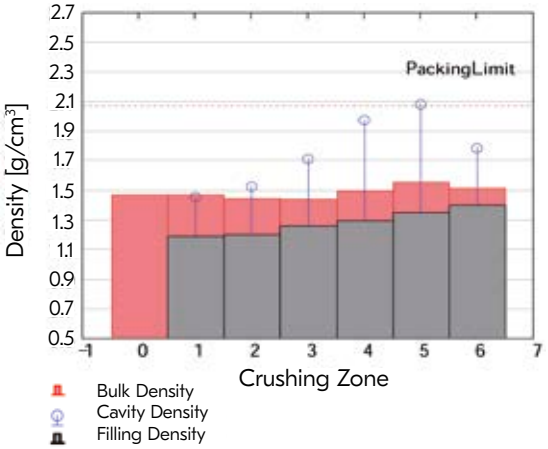
- Product grading
- Throughput capacity
- Power draw
- Material density in crushing chamber
- Estimation of wear profile in cavity
- Crushing pressure/force
- Key values for estimating product quality

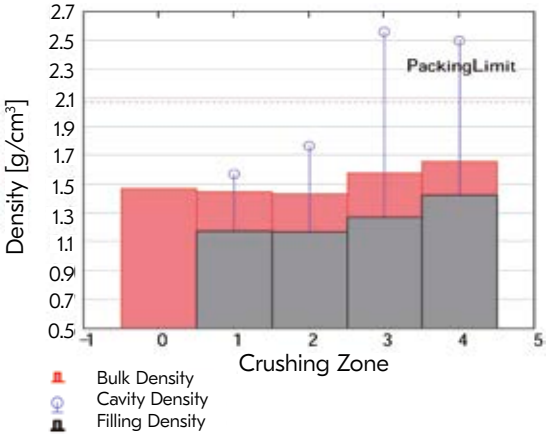


Examples of calculation results. Product grading, capacity, and power draw.

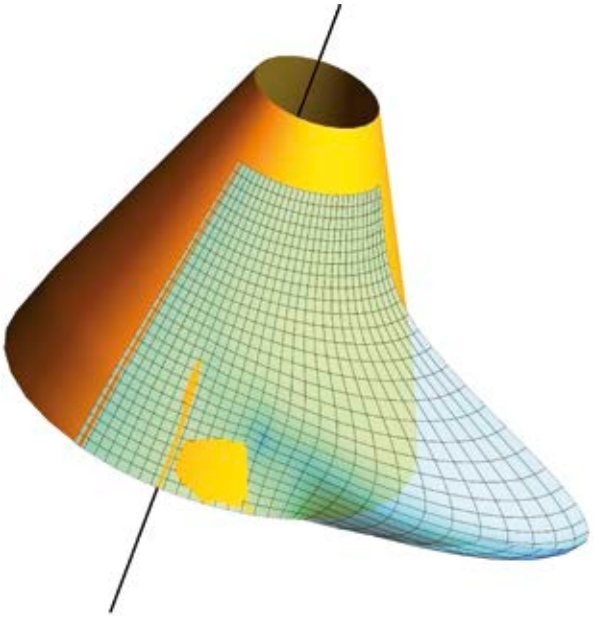


Examples of calculation results using a cone crusher. Crushing zones, crushing force and estimation of wear profile after 10% of liner life used.





Examples of calculation results, material density in crushing zones. Depicts a normal situation where cavity density remains below the packing limit and an undesirable case where the crusher is packing, leading to a high crushing force and, usually, fluctuations in crusher production.



Example of calculation results, cone crusher. Crushing pressure distribution on mantle.

C Series jaw crushers

C Series jaw crusher - the world's favorite jaw crusher
Metso, the world's leading rock and mineral processing group, has installed the biggest population of jaw crushers since the 1920's. Today the Nordberg® C Series™ is indisputably the world's favorite jaw crusher.

All C Series™ jaw crushers are based on a revolutionary modular, non-welded frame construction. This design offers owners the highest possible fatigue strength, excellent reliability, and numerous mounting possibilities.

This, combined with high-quality cast steel components and premium spherical roller bearings, means exceptionally high crusher availability, cost efficient crushing and low cost per ton.

World-class craftsmanship and materials
C Series™ crushers are premium class crushers due to their design as well as to the materials that are used to produce them. Good examples are the oversized high-quality bearings and eccentric shaft.

Attention has been paid to even the smallest details, to ensure the highest possible functionality and reliability, without any compromises.

Modular, non-welded construction
A uniquely modular, non-welded frame construction is a state-of-the-art design with two hot-rolled steel side plates joined to high quality cast steel frames through robust, precision-machined bosses secured with bolts. The absence of stress inducers such as weld seams ensures excellent durability against shock loads.

The right cavity designs
C Series™ jaw crushers are literally designed "from the inside out" because the cavity is the heart and only purpose of the jaw crusher. That is why over the years great attention has been paid to the feed opening dimensions as well as to the cavity height. The right feed opening width to depth ratio ensures minimum blockage and eliminates unnecessary height from the crusher.

Many types of jaw dies have been developed over the years to optimize the performance of Nordberg® C Series™ crushers in a very wide range of applications, including conventional quarries, mines, gravel pits, and recycling of demolition material and asphalt. The tooth profiles as well as the thickness of the jaws are optimized and combined with the right manganese steel alloys to maximize throughput and minimize operating costs.

To optimize the durability and performance of the crusher wear parts, several different jaw die profiles, manganese steel alloys and thickness are available. The optional intermediate plate and the spacer maximize the utilization of the manganese jaws.

Aggressive kinematics and high power
In addition to the right cavity dimensions, the right kinematics must be applied. That is why C Series™ jaw crushers have a large eccentric throw coupled with a steep toggle plate angle that magnifies the effective stroke at the crusher discharge.

The large stroke, combined with the right speed, aggressive nip angle, flywheel inertia and high available crusher power result in truly high crusher performance.

Smaller closed side settings can be often used depending on application and production requirements. For a performance estimation for your specific application, please contact Metso.

Measurement of the crusher's closed side setting varies depending on the jaw profile that is being used and has an impact on the crusher's capacity and product gradation.

The following factors will enhance crusher capacity and performance:

1. Proper selection of the jaws.
2. Proper feed gradation.
3. Controlled feed rate.
4. Sufficient feeder capacity and width.
5. Adequate crusher discharge area.
6. Discharge conveyor sized to convey maximum crusher capacity.

Fast and safe setting adjustment systems
All C Series™ jaw crushers are equipped with a proven, rugged, and fast two wedge setting adjustment system. The crusher's setting can be manually adjusted in a matter of minutes.

Alternatively, the crusher's setting can be changed in seconds, with the optional hydraulic setting adjustment.

Low installaton height
Lower foundation loads rubber dampers and stoppers effectively decrease crushing loads to the foundation by absorbing peak shock loads and allowing the crusher to move vertically and longitudinally.

This unique and innovative system eliminates the need for anchor bolts. The C Series™ jaw crusher is well balanced, this combined with the rubber dampers and stoppers decreases the dynamic loads on the foundation.

The most durable bearings available
All C Series™ jaw crushers incorporate four (4) equally sized larger and sturdier eccentric shaft spherical roller bearings than other crushers of comparable size. Their higher load bearing capacity and effective labyrinth seals result in considerably longer bearing lifetimes.

Versatile integral motor base
An optional integral motor base is mounted on the main frame of the crusher, thereby reducing the need for space, additional motor foundation and excessively long v-belts. V-belt lifetime is prolonged because there is no differential movement between the crusher and the integral motor base.

The integral motor base allows the use of standard flywheel guards, thereby eliminating the need for local engineering and fitting.

Other excellent cost saving features
There are several additional features that will assist you in reaching lower operating and installation costs. Amongst these features are an automatic grease lubrication system, different mounting brackets to accommodate different feeding heights, temperature and speed sensors and casting protection plates.

The C jaws product engineering follows the latest EN safety standards. Safety equipment include lifting tools and safety service platforms.

Contrary to popular belief, not all jaw crushers are the same. This is certainly the case for Nordberg® C Series™ jaw crushers, and there is no secret to this success.

For further Nordberg® C Series™ jaw crushers product and technical information, please visit:
www.metso.com/portfolio/nordberg-c-series

Superior MK-III gyratory crushers

Primary gyratory crushers are the initial driving force for the entire mineral processing circuit. Metso's third generation Superior™ MKIII primary gyratory crushers provide high throughput and less downtime to bring maximum efficiency to your operation.

Mainshaft position control provides peak crushing efficiency
The Mainshaft Position System (MPS) – successfully used for decades, is a hydraulic method of vertical adjustment to compensate for wear and maintain product size. It consists of a pump, operated by a push-button and a heavy-duty hydraulic cylinder that supports and adjusts the mainshaft assembly.

The high capacity and low operating cost of the Superior™ MK-III primary gyratory crushers meet the demand for improved efficiency. Mine managers, maintenance and operators know what they want for today...and tomorrow.

We have listened and provide the Superior™ gyratory crusher with features required by demanding applications. The Superior™ MK-III design is based on a century's worth of experience in crushing technology.

Low installation costs
Worldwide, Metso has the largest installed base of gyratory crushers in mines and quarries. The features include high capacities due to increased speed and efficiency, the SUPER SPIDER concept and better balancing, thus allowing lower installation costs.

The SUPER SPIDER concept consists of the use of an additional topshell using the same base to obtain a larger feed opening and higher capacity.

The improved spider arm design with increased extra coarse material passing space reduces bridging and increases productivity.

The spider, topshells and bottomshell are constructed of shock-resistant, high strength cast steel, allowing the use of more powerful drive motors, and therefore, higher production than similar models.

Mainshaft position control provides peak crushing efficiency
The Mainshaft Position System (MPS) – which has been successfully used for decades – is a hydraulic method of vertical adjustment to compensate for wear and maintain product size. It consists of a pump, operated by a push-button and a heavy-duty hydraulic cylinder that supports and adjusts the mainshaft assembly.

This MPS is also used to clear the crushing chamber. If a sudden power failure stalls the crusher under load, the mantle can be lowered to release the load – which means no more digging out! The Superior™ MK-III primary crusher is equipped with a balance cylinder that protects the step bearing and piston by keeping them in contact with the mainshaft assembly when any upward movement of the mainshaft occurs.

Superior™ MK-III primary gyratory crushers are fitted with a mainshaft position sensor probe. This gives a direct indication of the mainshaft position, enabling the operator to maintain the crusher setting, provide a consistent product and monitor liner wear.

Features for better crushing economy

— Exceptionally high capacity and maximum liner life provided by the steep crushing chamber and long crushing surfaces.

— Long life and reliable operation provided by an extra heavy-duty frame, large diameter integral mainshaft assembly and high-performance bearing alignment.

— Optimized production for your application provided by a computer-designed crushing chamber.

— Versatility of changing the eccentric throw – crusher capacity can be matched to plant requirements simply by changing the eccentric bushing.

— Easy maintenance and service:

- Automatic spider lubrication
- Modular lubrication system
- Mainshaft position indicator system
- Easy adjustment of backlash
- Optional hydraulic spider separation

Crushing chamber provides even wear
Many years of design experience and accumulated operating data have led to the Superior™ MK-III crusher design. Thousands of crushing chambers have been evaluated to optimize crushing performance.

We have developed a unique crushing chamber concept providing:

- Greater product uniformity
- Better distribution of wear throughout the entire chamber (fewer service problems and lower operating cost)
- Reduced liner change intervals (less wear costs per ton of product)
- Improved energy efficiency

Heavy-duty mainshaft design
The mainshaft is forged in one piece. There is no risk of loosening head centers, thereby reducing downtime. The headnut threads are on the patented, replaceable alloy steel mainshaft sleeve – no threads to damage on the shaft. Threads cannot act as stress risers on the shaft, increasing reliability.

The large, highly polished radius between the shaft upper journal diameter and the taper strengthens the mainshaft, providing long life. The self-tightening headnut tightens the mantle automatically during crushing.

The large upper journal diameter provides extra strength for severe crushing applications.

Superior™ MK-III primary gyratory crusher features:

1. **Crushing chambers** are matched to each individual application, optimizing crushing performance.
2. **Manganese wearing parts** are standard – chrome alloy steel liners are optional.
3. **Efficient dust seal** – Equipped with an overpressure air blower to keep dust out of the eccentric and drive, increasing crusher bearing life.
4. **Counterbalanced design** is ideal for all applications, mobile or stationary, and minimizes the forces transmitted to the supporting structure.
5. **The spider bushing and seal** can be replaced without removing the spider – reducing manpower, time, equipment, and lost production due to downtime.
6. **Heavy-duty integral mainshaft** with a patented alloy steel threaded sleeve reduces stresses on the mainshaft.
7. **High-strength shell design**, proven in the toughest applications, provides trouble-free operation and long life.
8. **Mainshaft and head center** are forged in one integral piece, eliminating the possibility of the head center separating during operation.
9. **External gear and pinion adjustment** simplifies and speeds up the backlash adjustment.
10. **The Mainshaft position system (MPS)** provides easy adjustment of the mainshaft to compensate for liner wear and maintains the product size.
11. **Internally mounted mainshaft position sensor** provides a direct indication of the mainshaft position, allowing the operator to maintain the crusher setting and monitor liner wear.

For further Superior™ MK-III primary gyratory crusher product and technical information, please visit: www.metso.com/portfolio/superior-mkiii-series

GP Series cone crushers

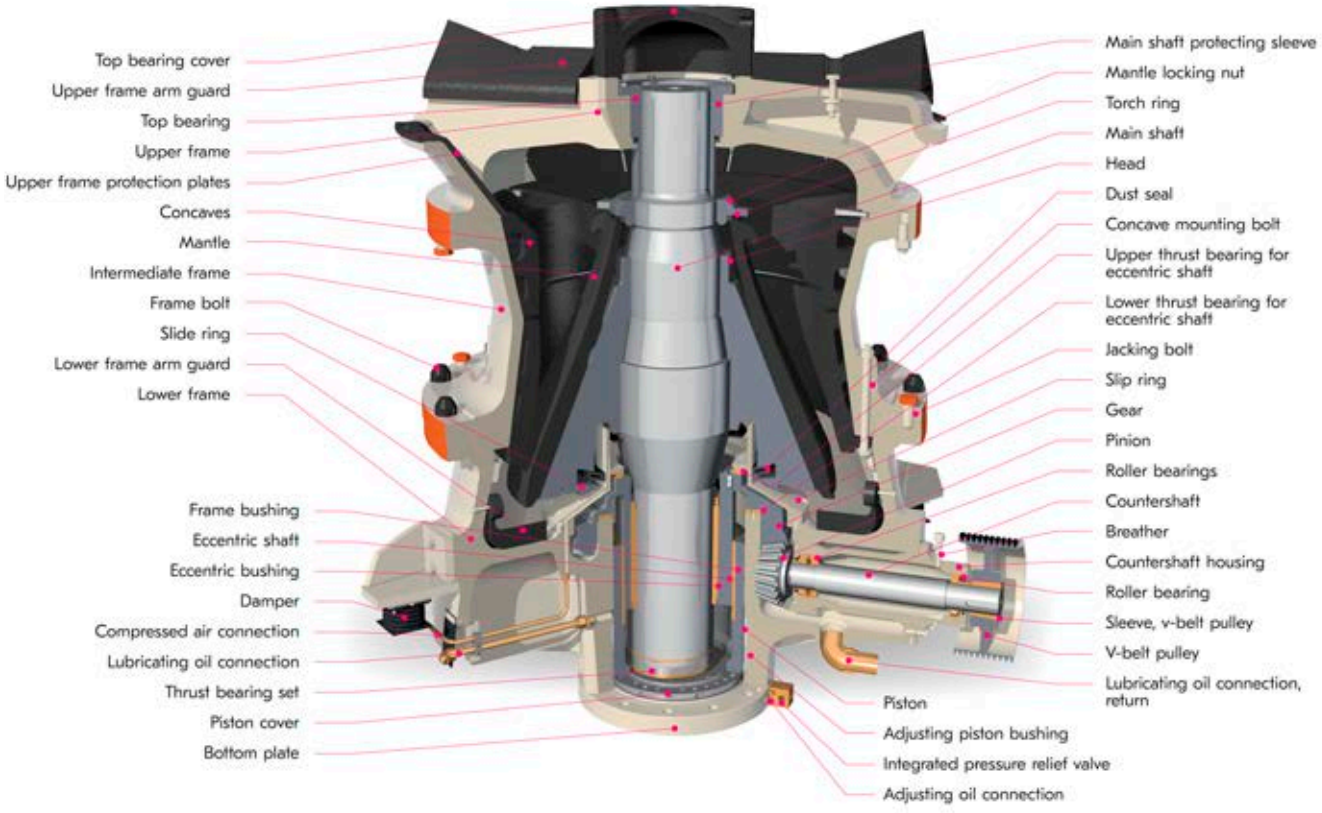
The cone crusher to meet the production requirements
Nordberg® GP Series™ cone crushers have been developed to crush feed materials into desired end products efficiently, reliably, and economically. Engineered for all rock types, these machines can be utilized as secondary, tertiary, and quaternary crushers in aggregates production plants and in mining operations.

Metso has installed thousands of GP cone crushers since the 1970s. GP cone crusher with its' innovative features and state of the art performance is the number one choice for many aggregates producers all around the world.

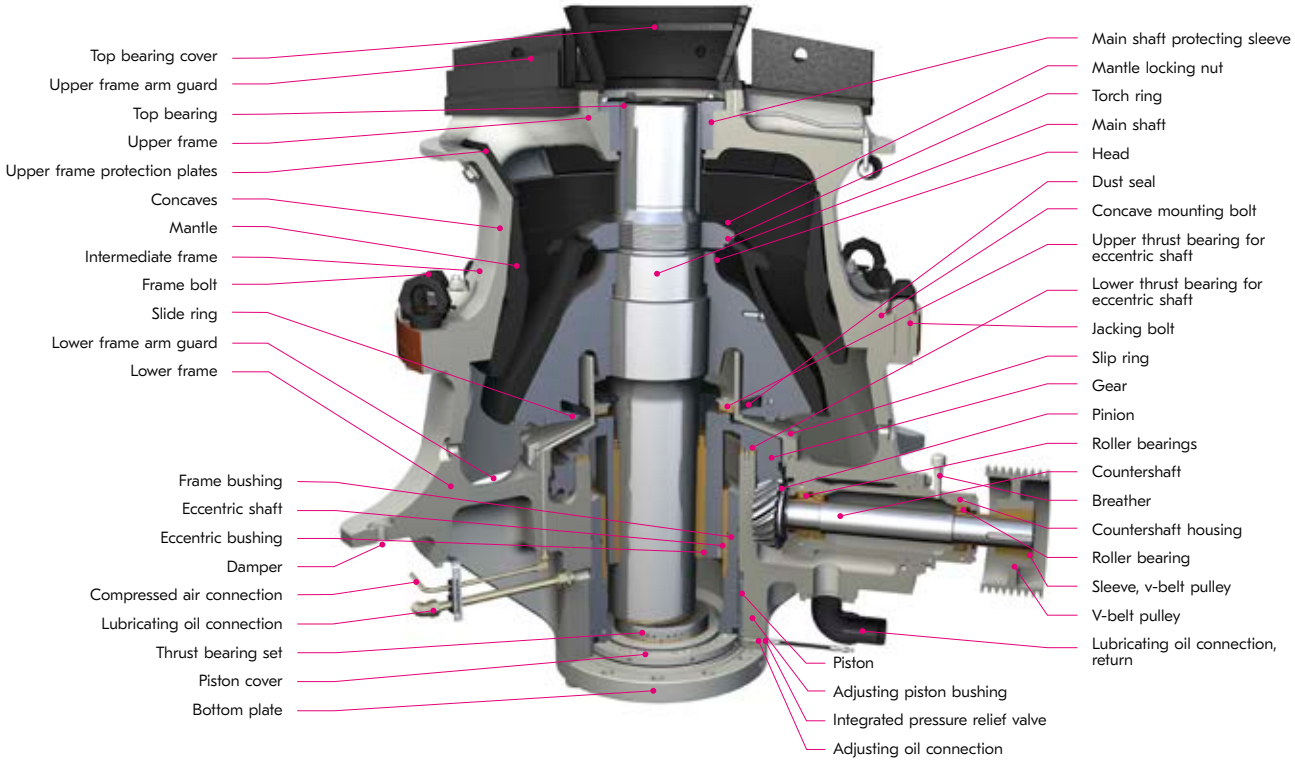
The GP cone crusher heavy-duty design is based on a two-point supported main shaft that allows high performance steep cavity designs.

Main shaft is vertically supported with a hydraulic cylinder that is used for holding or moving the main shaft vertically to adjust crushing process automatically and continuously under load. This strong design allows high crushing performance due to high power and crushing force levels utilized.

GP-series™ include also S-models that are designed particularly for low cost efficient secondary or primary (gravel) crushing applications. GP-S cone crushers provide maximum feed opening for undisturbed operation with big feed calibrating material. This turns it into a much easier-to-process size for the rest of the plant.



GP Secondary cone crusher



GP Versatile cone crusher

High production and reliability: Superior know-how in compressive crushing

Metso is using significant resources to research compressive crushing in our own test crushing plant and studying customer operations in different kinds of application all around the world.

The conclusions of this research work are found in solutions utilized with GP cone crushers. GP cone crushers can be easily adjusted to different types of production requirements with change of cavities, eccentric strokes, counter shaft speeds and different control methods.

Value adding features and innovation
Stable performance through liner life
Due to cavity design, feed opening is maintained and wear part profile change is minimized through liner life. This ensures stable crusher throughput capacity and plant operation through wear part life.

Low installation height due to innovative piston design (valid for GP220, GP330, GP300S, GP550, GP500S)
GP and GP-S cone crushers have unique piston design. The main benefit of this design is lower installation height. Lower height reducers installation costs with smaller support structures and shorter conveyors needed and makes GP and GP-S cones excellent solution for mobile applications.

Can be operated with on/off feed
For GP-models same machine can be used as secondary, tertiary, or quaternary machine with a liner change.

Due to crusher kinematics, low head spin when machine running empty and long cavities GP and GP-S cone can be used with partial feed.

Because of this feature, GP and GP-S cones are an excellent choice for application where choke feed condition can't be ensured – e.g., mobile two stage crushing plants without surge pile between primary and secondary crushers.

Metso IC™ automation system as standard part of delivery
IC™ Series complete easy to use crusher automation system that maximizes production and ensures trouble free operation.

Metso IC™ Series controls all the cone crusher related functions e.g., crusher setting – load, feed capacity, lubrication, oil heating and cooling, correct start and stop sequences.

Crusher setting can be continuously adjusted under load

based on power draw or crushing force measurement. With automation, system mode can be selected between two options: setting mode or load mode.

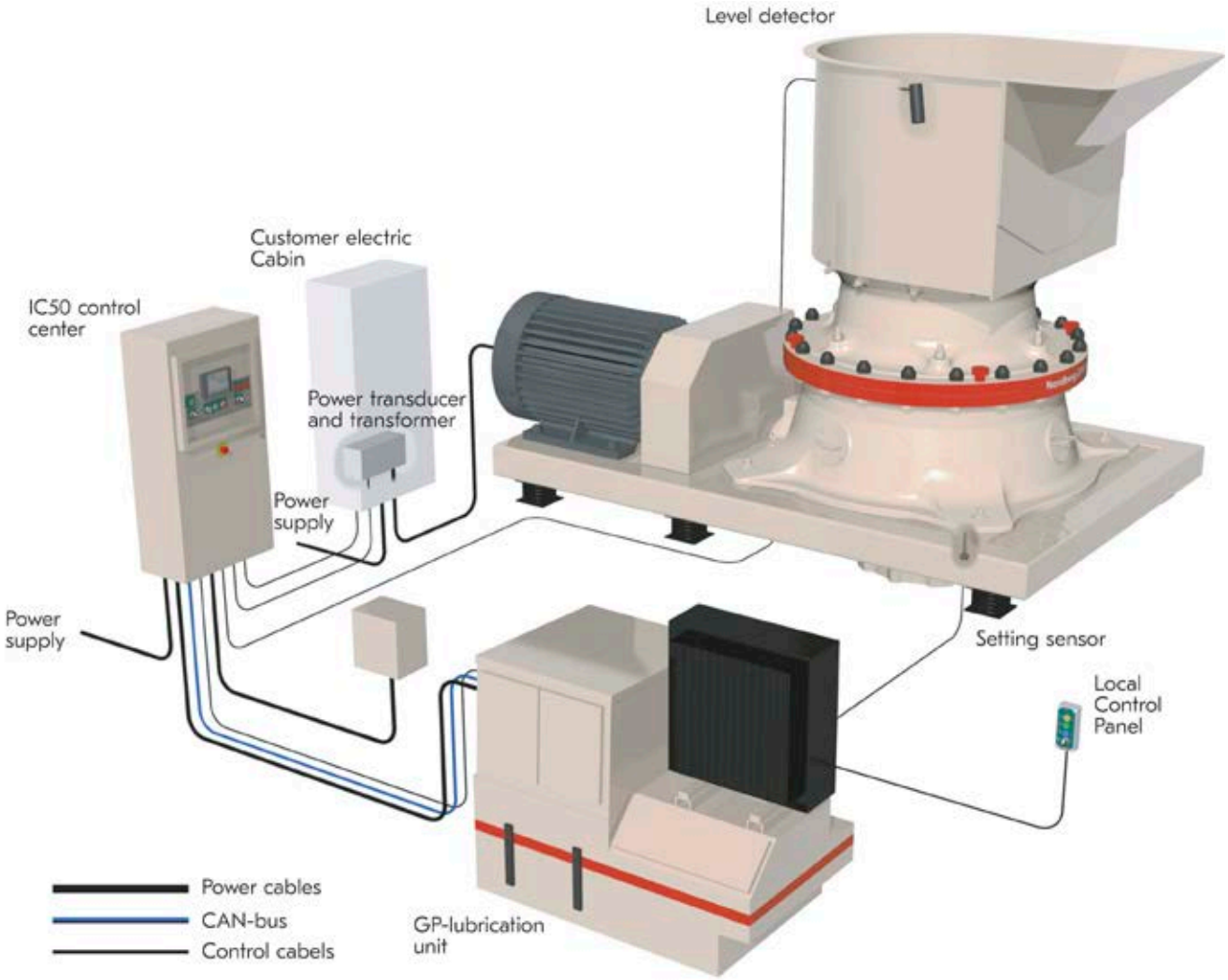
When setting mode is selected, the crusher keeps a constant setting. When load mode is selected, Metso IC™ automation system adjusts the setting, trying to maintain high power draw and crushing force maximizing crushing work.

For GP-models same machine can be used as secondary, tertiary, or quaternary machine with a liner change
GP cone crusher can be used in several different applications with a liner change. Every model has a good selection of optimized liner design to ensure ideal operation in different types of applications.

No packing material needed for liner fixing
GP and GP-S cones do not require use of packing material for liner fixing. This makes liner changes quicker.
Also, costs are saved because there is no need for handling packing material.

Easy maintenance - all service from above
GP and GP-S cones can be disassembled from above.
All heavy components can be lifted up which makes disassembling easy and safe. Safety equipment include lifting tools and safety service platform.

For further Nordberg® GP Series™ cone crushers product and technical information, please visit:
www.metso.com/portfolio/nordberg-gp-series



*GP secondary cone general installation**

HP Series cone crushers

For dependable operation
For high productivity, low operating and wear costs, long service life and high efficiency, providing high quality product, there is no better choice than a Nordberg® HP Series™ cone crusher. Metso is the market leader with its "High Performance" crushers for aggregates and mining operations.

HP Series™ cone crushers are characterized by the optimized combination of crusher speed, eccentricity, and cavity profile. This mix has proved revolutionary, providing higher capacity, better product quality and suitability to a wider range of applications.

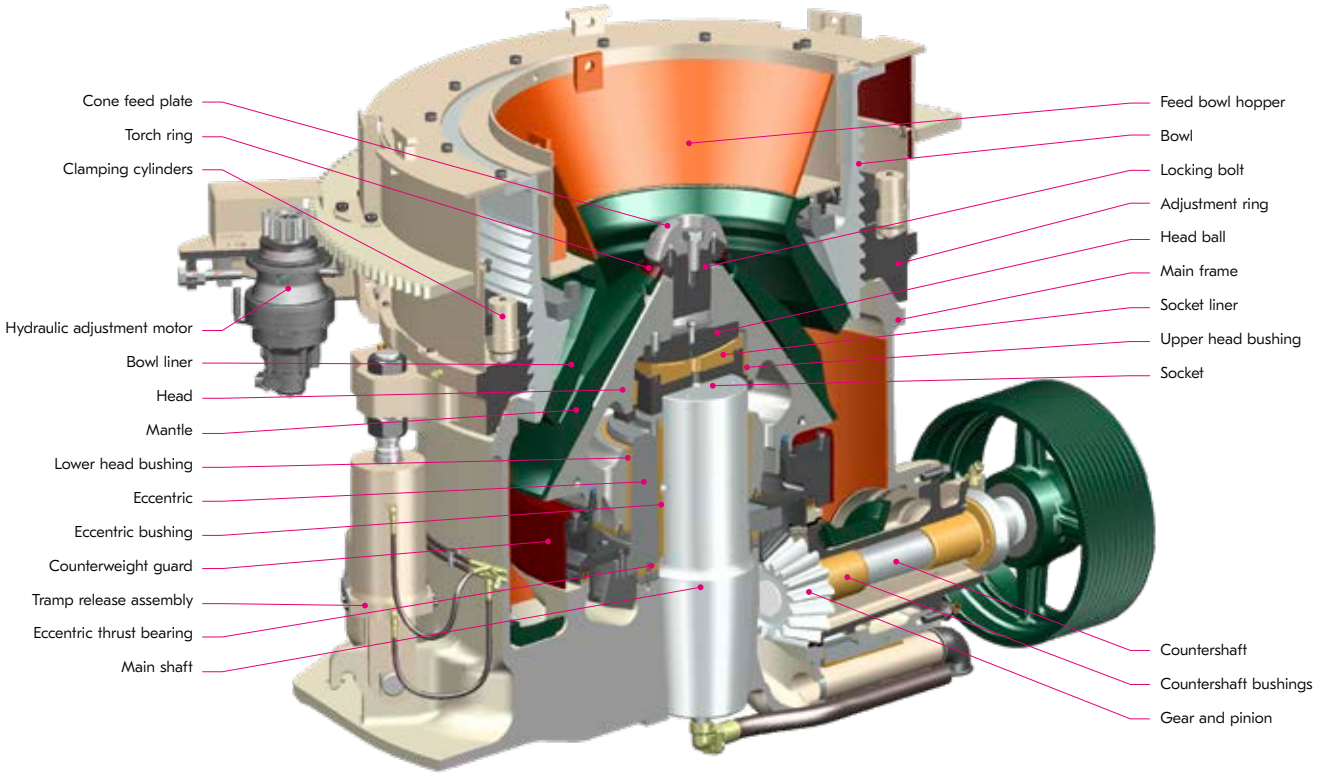
From limestone to compact hematite, from ballast to manufactured sand production, and from small aggregate plants to large mining operations, Nordberg® HP™ crushers are unbeatable in secondary, tertiary, and quaternary applications.

All Nordberg® HP Series™ crushers are available as stationary, and many models also as mobile or portable versions.

Optimized performance
Nordberg® HP series™ crushers feature a unique combination of crusher speed, throw, crushing forces and cavity design. This combination is renowned for providing higher capacity and superior end-product quality in all secondary, tertiary and quaternary applications.

Long stroke and high power with the retaining force in perfect balance with it are the key parameters defining and ensuring the great performance of the HP cone crushers.

A higher density in the crushing chamber improves the inter-particle crushing action, resulting in superior product shape, high reduction ratio and high capacity.


Cone feed plate
Torch ring
Clamping cylinders
Hydraulic adjustment motor
Bowl liner
Head
Mantle
Lower head bushing
Eccentric
Eccentric bushing
Counterweight guard
Tramp release assembly
Eccentric thrust bearing
Main shaft
Feed bowl hopper
Bowl
Locking bolt
Adjustment ring
Head ball
Main frame
Socket liner
Upper head bushing
Socket
Countershaft
Countershaft bushings
Gear and pinion

Cost efficient and ecological
In a size-class comparison, Nordberg® HP™ crushers have a higher output capacity, higher density in the crushing chamber, better reduction ratio, and they produce higher on-spec yield end products with the same energy consumption.

They are equipped with the latest high-efficiency motors, making them efficient and ecological crushing machines.

Nordberg® HP™ crushers produce finer products by limiting crushing stages, which lowers your investment cost and saves energy. This is achieved through a combination of optimized speed, large throw, crushing chamber design and increased crushing force.

Safe and user-friendly
Designed for your needs, Nordberg® HP™ crushers are safe and easy to maintain. Fast and easy access to all the main components from the top, and dual-acting hydraulic cylinders significantly reduce downtime and ensure quick, easy and safe cavity clearing in case the crusher stops under load due to, for example, power grid failure.

HP™ crushers are engineered to ensure maximum operator safety and easy maintenance. The crushers have an access from the top of the crusher to the principal components, an easy access for liner maintenance, and mechanical rotation of the bowl for removal with a simple press of a button. Maintenance tools are also available.

Another way Nordberg® HP™ crushers deliver is through less downtime and increased operator confidence.

Dual-acting hydraulic tramp-release cylinders are used to let the crusher pass tramp iron and to provide a large clearing stroke if needed.

The accumulator arrangement provides better reactivity of the hydraulic system.

Crusher automation
Metso IC70C™ is a crusher automation system that further improves the operation of your Nordberg® HP™ crusher. Using it can increase your production by more than 10%.

With Metso IC70C™ you can control maintenance, setting modifications, production follow-up and data extraction. All parameters can be adapted to your plant characteristics, and you can easily do all this close to the crusher or remotely from the control room.

You set the goals and IC70C™ helps you reach them. It allows you to monitor the feeding, change the settings automatically depending on the load or liners wear, and select the product size distribution according to your preference of coarse or fine aggregate production.

Excellent for manufactured sand
Nordberg® HP Series™ cone crushers are also excellent crushers to produce manufactured sand. The combination of high speed and large eccentricity, together with the crushing chamber which promotes intense interparticular crushing, produces manufactured sand with high cubicity particles and excellent gradation for concrete.

Due to its good properties, manufactured sand produced in HP cone crushers has replaced partly or totally natural sands, with many advantages. In manufactured sand production, HP cone crushers can offer advantages over other crushing methods.

HP cones offer higher production with the same installed power and less micro-fines. The high quality of manufactured sand produced by HP cone crushers can be witnessed in many plants around the world.

Less downtime
Dual-acting hydraulic tramp release cylinders let the HP Series cone crushers pass tramp iron that would stall, or damage, many other crushers. And if the crusher does stop under load, those dual-acting cylinders provide a large clearing stroke, independent of liner wear, to quickly clear the crushing cavity.

An advanced fastening system for mantle and bowl liner makes backing material unnecessary and makes liner changes faster. Thicker liners mean longer liner life.

When liners are changed or the crusher is reconfigured, the same hydraulic motor that rotate the bowl for setting adjustment will rotate the bowl completely out of the adjustment ring threads, greatly simplifying liner replacement. A new fixed counterweight guard protects the counterweight and seals out dust.

Versatility
Due to its strength, speed range and ease of converting from coarse to extra fine applications, the HP Series provide application flexibility that was unheard of until now.

- Save stockpile space by recrushing excess or slow-moving products without an intermediate crushing stage.
- Converting from coarse to extra fine application and back again just by changing liners and rpm.
- Liner and rpm combinations go from secondary applications to sand manufacturing.

For further Nordberg® HP Series™ cone crushers product and technical information, please visit: www.metso.com/portfolio/nordberg-hp-series

MP Series cone crushers

Nordberg® MP Series™ cone crushers are known for having the highest crushing force of any cone crushers similar in size. Suitable for reducing and shaping both hard rock and soft rock, these crushers are designed especially for mining applications.

Productivity
The MP series unique design incorporates the best in process technology to produce the highest crushing force in the industry. With field-proven technology in demanding mining operations, the MP2500, MP1250, MP1000 and MP800 can process more ore at the same reduction, or the same quantity of ore to a finer reduction, than any competitive unit.

Cost-efficiency and crushing force
Nordberg® MP Series™ crushers have a long history of performing well in a wide variety of mining operations.

The product family consists of models of various sizes and features that have been field-tested in the most demanding mineral processing circuits.

Good availability
Nordberg® MP™ crushers provide more availability for your crushing needs. A fully automated tramp release that passes uncrushables instantaneously allows the high crushing force to be maintained. After the uncrushable material passes through the tramp, the production setting is automatically returned to where the cone crusher was set.

The MP™ crushers' availability is further enhanced by the hydraulic clearing system. With a large vertical stroke, material can fall easily, and this provides consistent stroke capabilities throughout the entire liner's life.

High performance
Nordberg® MP™ crushers bring cone crusher performance to a new level. They provide the highest crushing power for any cone crusher of similar size. Advanced crushing dynamics leads to more work per cycle.

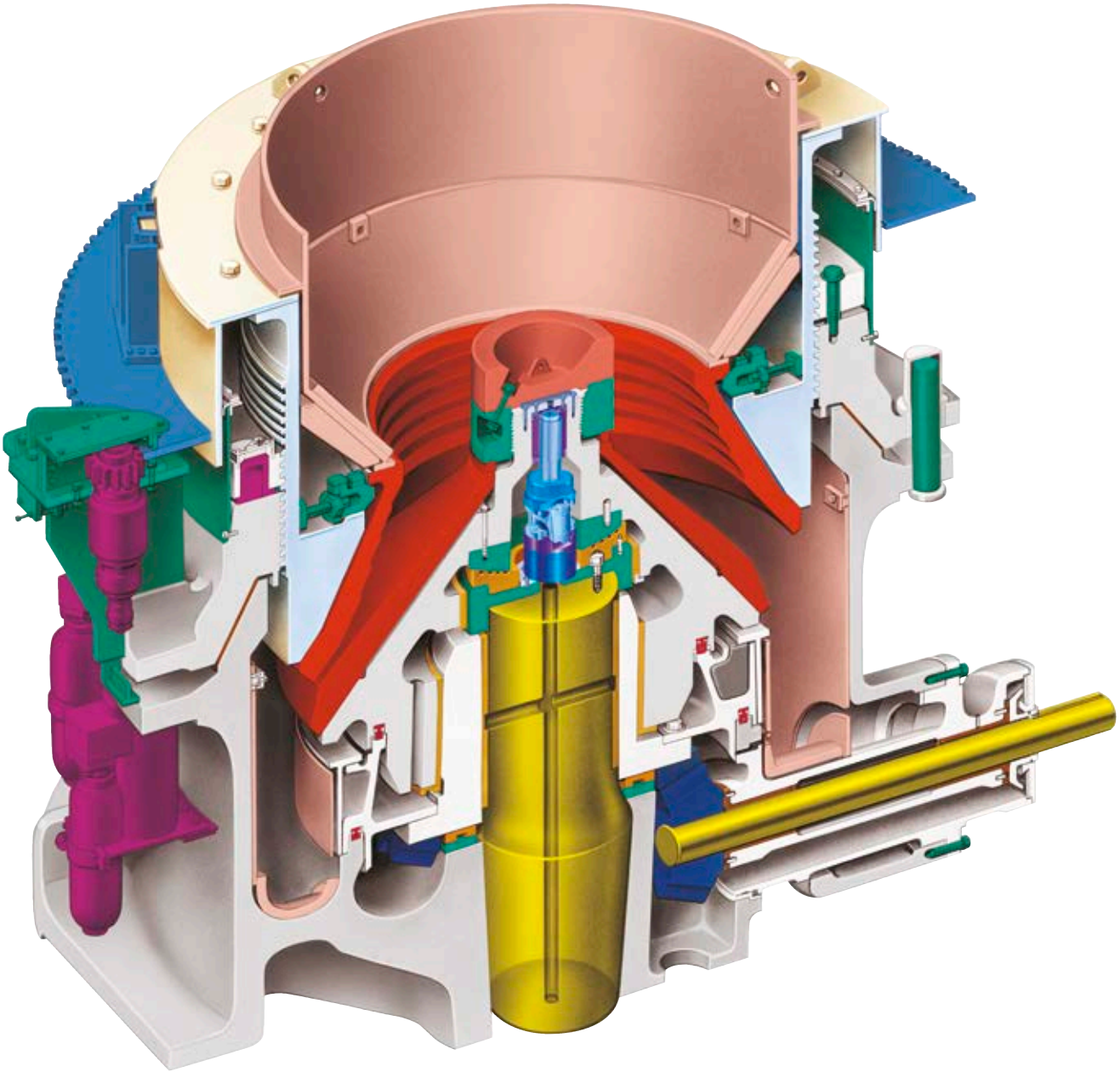
The MP™ crushers increase the power draw resulting in an increase in capacity, and a higher power-to-production ratio and energy efficiency.

Downtime means more than just lost time in operation. Nordberg® MP™ crushers incorporates hydraulic cavity clearing and easy setting adjustment for minimizing downtime.

The ruggedness in design has been proven to be reliable in operations. The crusher's rotating bowl compensates for feed segregation and uneven feed rates. Even wear in the crushing cavity avoids localized restriction of the feed opening and achieves consistent size reduction results.

Ease of maintenance
Maintaining Nordberg® MP™ crushers is made safe and simple by paying attention to every detail in every component. The crushers feature a push button disassembly for routine maintenance. Modular design, on the other hand, makes the components easier to replace when needed.

For further Nordberg® MP Series™ cone crushers cone crushers product and technical information, please visit: www.metso.com/portfolio/nordberg-mp-series



NP Series impact crushers

Nordberg® NP Series™ impact crushers
Metso is focused on customer's success and the development of the NP impact crushers strictly follow this rule.

Metso has built impact crushers for over 60 years. We know that customers are looking for high performance to have higher profitability. That's why we combine the best technical solutions to offer a reliable crusher, so that the customer can forget it and focus on his plant operation.

NP Series™ impact crushers feature a unique combination of heavy rotor design, wear material and crushing chamber design. This combination has proved revolutionary in improving capacity, product quality and in reducing operating and wear costs.

Plant profitability
NP Series™ impact crushers are characterized by a unique blow bar fixing system providing a higher degree of reliability. NP Series™ impact crushers have been designed to minimize maintenance and improve adjustment operations. NP Series™ impact crushers deliver unbeatable performances in primary, secondary, tertiary and recycling applications.

NP Series™ impact crushers are the solution for operating conditions where output and productivity demands are increasingly stringent, from quarry to industrial applications and from mining to recycling.

You can easily build your own crusher configuration by adding the suitable options for your application:

- Fully hydraulic breaker plate adjustment setting to reduce downtime.
- Third breaker plate to control the top product size in open circuit.
- Different grades of steel and cast iron, and possibility for ceramic inserts for the blow bars to decrease the wear cost.
- Multiple options to facilitate the maintenance.

The Self Rotor Rotation system (SRR) is available over the NP range and is part of Metso's constant efforts to innovate and find ways to enhance the quality, ease of use, and safety of its products.

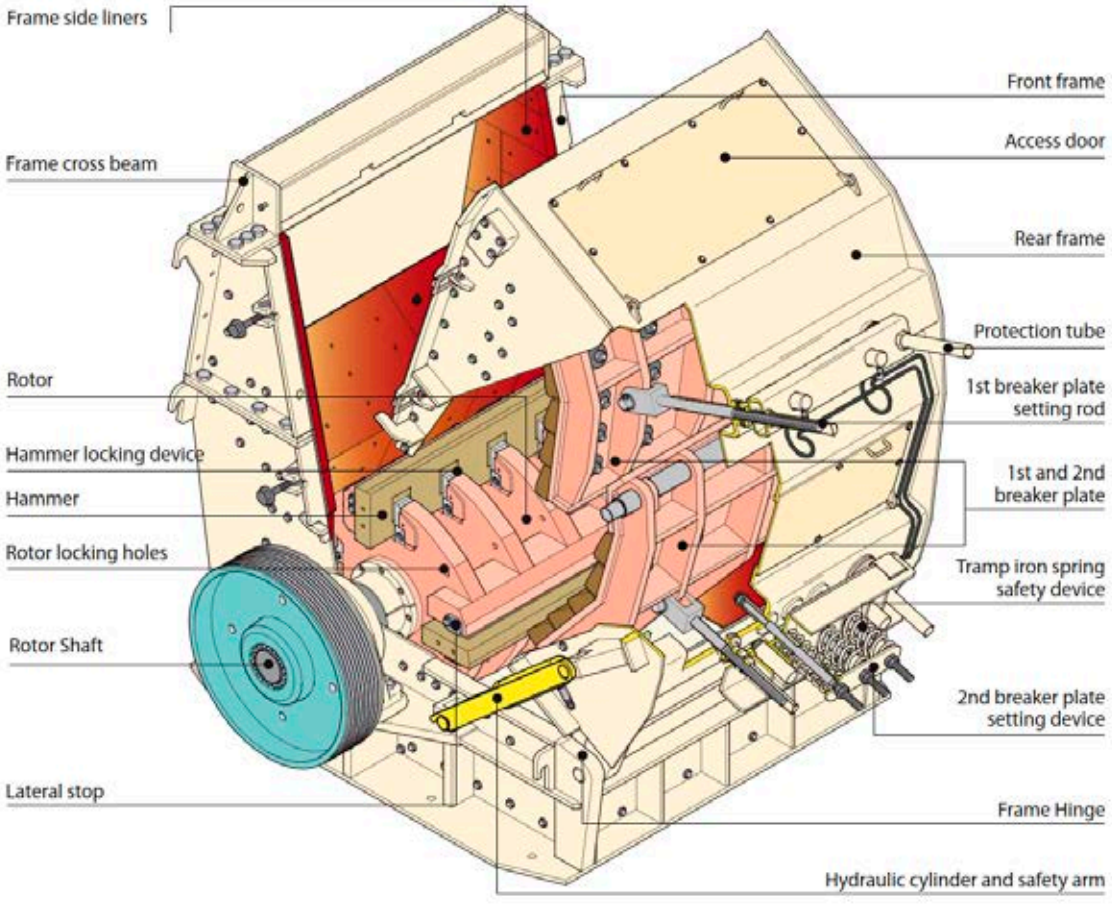
The principle consists in positioning the rotor during the maintenance period when changing the blow bars or adjusting the breaker plates, without human intervention inside the crusher.

The NP Series™ automation (IC Series) controls the crusher operation and gives a perfect and complete overview of the performance. From a basic crusher control to complete plant automation, the automation gives you more from your process.

Reduce your plant operating costs
Continuous collaboration with research laboratories brings you state of the art technical innovations in terms of durability of wear parts and reliability of mechanical components. Higher reduction with fewer crushing stages lowers your capital costs and saves energy.

Mechanical reliability and simplified process, easy machine operation, easy and safe maintenance increase the global availability of the plant and makes the operation more profitable.

Easy to install, easy to drive and easy to maintain, NP Series™ impact crushers are an easy choice. High performance and high-quality product for low investment, NP impact crusher is an efficient choice. Metso support and assistance lasts along the whole crusher life.



For further Nordberg® NP Series™ HSI crushers product and technical information, please visit: www.metso.com/portfolio/nordberg-np-series

Barmac B Series VSI crushers

Barmac® Vertical Shaft Impactors
Metso markets the original, proven Barmac® Vertical Shaft Impactor (VSI) crusher lines.

The world famous Barmac® B Series™ rock-on-rock VSI, previously known as the Barmac Duopactor, offers a complete VSI range for secondary, tertiary, and quaternary applications.

With thousands of units operating in aggregate and mineral processing installations around the world, Barmac® VSI crushers have established a track record of cost savings, durability, and unmatched performance in a variety of tasks to which they been applied.

These include the production of high-quality aggregates for a range of applications, manufactured sand to all specifications and a range of mineral and recycling operations.

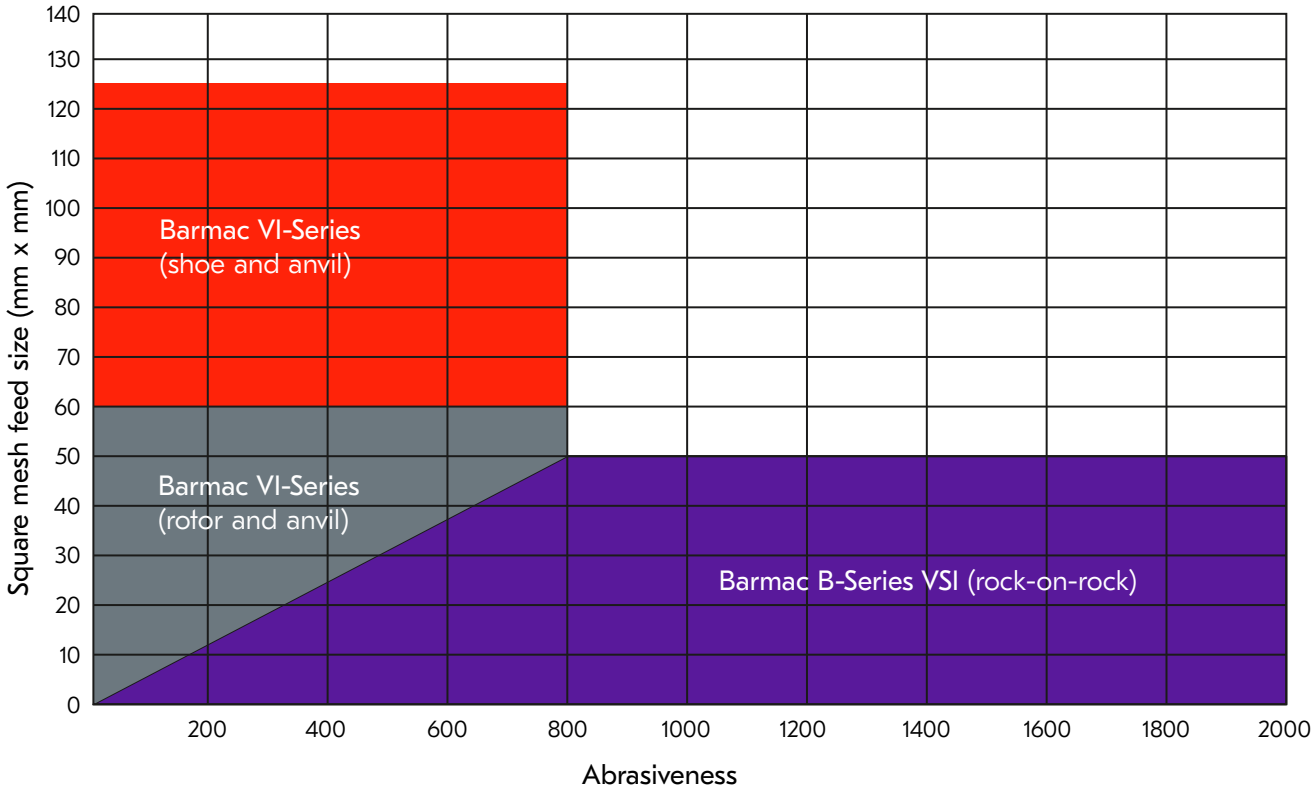
Barmac® B Series VSI
The Barmac® B Series™ VSI is an excellent third and fourth stage reduction unit and has demonstrated a unique ability to operate in many demanding and diverse crushing operations within the construction industry.

This is possible because of the unique free impact crushing and grinding action and the ability to fine-tune this process by simply changing rotor speed or cascade ratio.

Coupled with low wear costs, the result has seen the Barmac® B Series™ VSI finds applications not only in traditional quarrying operations but also a large range of specialist crushing plants.

The Barmac® VSI has a competitive capital cost, especially when compared with conventional crushing equipment. Barmac® VSIs require minimum support structure and are also utilized in a mobile configuration, ensuring installation is quick and easy.

Bamac application guidelines



Mobile crushing
The popularity of mobile crushing amongst our customers has seen the world's Number 1 VSI range go mobile. Barmac® VSI crushers have been installed on both chassis and Lokotrack® configurations to improve their versatility.

The Barmac® VSI is offered as a final phase crusher to provide either high reduction ratios or to provide shaping to improve aggregate quality.

The choice of which Barmac® VSI to recommend is dependent on feed top size and the abrasiveness of the source rock.

In medium to high abrasive rocks, the B Series will offer the lowest cost per ton and offer excellent shaping over the range of product produced. The B Series take a smaller feed size. The figure above shows the recommended configuration given the feed top size and the abrasiveness of the feed material.

Aggregate production
The aggregate market has been the traditional home of the Barmac® VSI crushers. The impact crushing action of the Barmac® VSI produces a product that is cubical in nature and performs well in concrete, asphalt, block, and mortar applications.

When applied, these aggregates provide superior quality of product, maximum strength concrete with no added cement, bitumen savings in asphalt and high-quality blocks.

Manufactured sand
The Barmac® VSI product range produces excellent manufactured sand for concrete, asphalt, block, and mortar applications. The impact crushing action produces sand where all the particle sizes are well represented, which ensures it performs well in a range of applications.

Just as important is the cubical shape of sand, which limits the water required in concrete mixtures improving strength and other hardened concrete properties. In asphalt, good quality manufactured sand reduces the bitumen demand while providing higher stability and resistance to rutting.

Cascade feed system

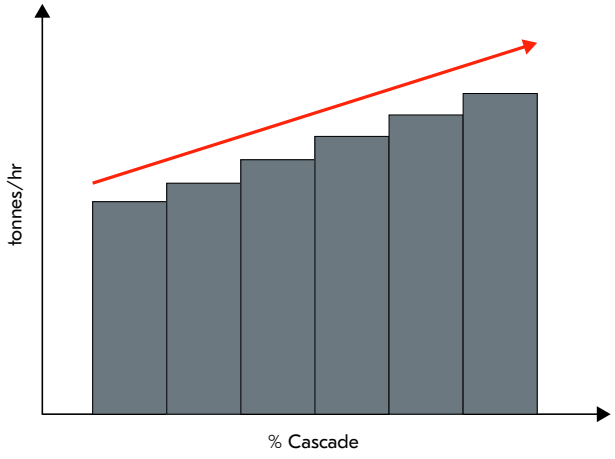
The Barmac® B Series™ VSI uses a unique feed system with the ability to introduce a second stream of material directly into the crushing chamber turbulence. This results in a supercharging of the particle population within the chamber, increasing the chance of rock-on-rock collision.

This feature enables the operator to make optimal use of the power available and to manipulate the product grading and shape to best suit their requirements. The primary path for feed material is through the rotor. Material is accelerated to up to 90m/s (295ft/s) before being discharged into the crushing chamber.

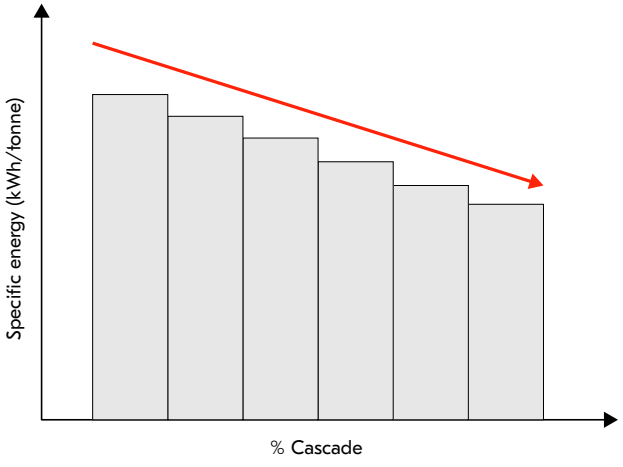
Additionally, material may be introduced into the crushing chamber via cascade, thus bypassing the rotor. Cascading material combines with material from the rotor, forming a denser particle population, which optimizes reduction.

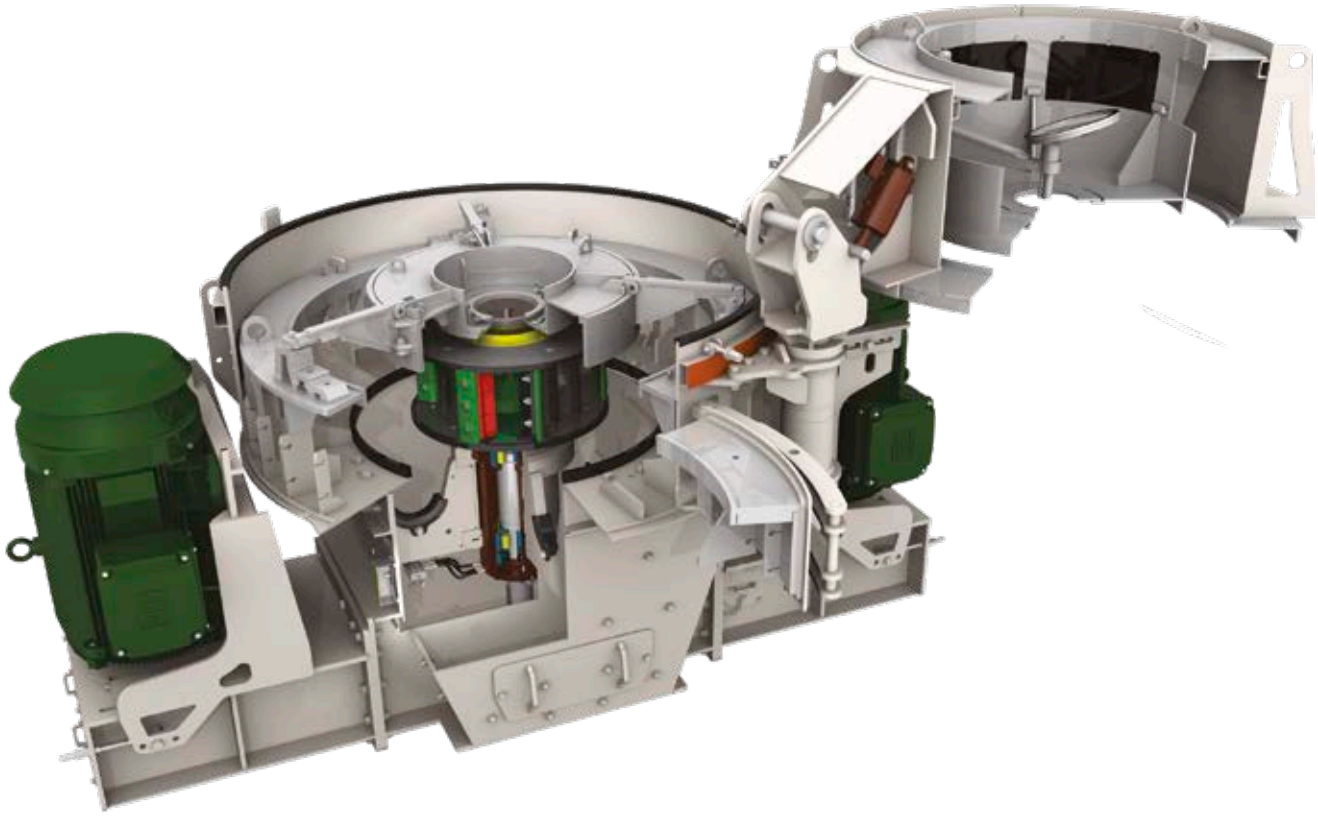
This most efficient use of the rock-on-rock crushing action leads to improved crusher efficiency and increased throughput. These graphs are indicative examples of the effect cascade has on productivity and power consumption. Increasing material through cascade is like slowing the rotor.

Final product (at constant power draw)



Cascade % vs. specific energy





Rotor - the heart of the Barmac® VSI

The heart of the Barmac VSI is the rotor. The development of deep rotor technology, combined with long wear life parts and segmented tip assemblies, dramatically reduces time associated with wear parts replacement. The deep rotor is designed with serviceability and optimal rotor and wear part life in mind.

Power consumption and rotor wear are both reduced by creating more room for material to enter and pass through the rotor. Since running an AC motor at less than full load current is inefficient, power savings can be made in three ways:

- Increase rotor throughput – leads to gains in product quantity.
- Increase rotor speed – leads to increased product quality.
- Install a smaller motor – provides gains in power saving.

This will give the customer:

- Lower wear costs per ton. In some cases, average wear part lives have increased by 50%. This means less maintenance time and higher crusher availability.
- Lower power consumption/draw per ton.
- Higher throughput for a given power consumption.
- Lower power consumption for a given throughput.
- Higher capacity. A denser particle population in the chamber will cause more effective reduction and improved shape.
- Improved flowability due to the higher clearance height within the rotor, especially with coarser feeds.

Deep rotor technology has increased crusher throughput, in some cases by up to 30% over standard rotors. It has also led to a reduction in downtime, service labor costs and wear costs. These lead to very real monetary advantages.

For further Barmac® B Series™ crushers product and technical information, please visit: www.metso.com/portfolio/barmac-b-series

HRC Series grinding rolls

The HRC™e high pressure grinding rolls (HPGR) are evolving the industry standard for grinding efficiency. Using innovative technology of flanges and an anti-skew assembly, the HRC™e HPGR brings an energy efficient and high throughput solution while reducing operational costs.

Superior grinding and energy efficiency
Challenges for grinding are arising. Installation and energy costs are increasing, declining ore grades, stricter regulations and more. As grinding plays an essential role in minerals processing, the need for innovation in grinding is critical to circuit optimization.

The Metso HRC™e high pressure grinding rolls (HPGR) is combining proven technology with a customer-focused evolution for superior grinding and energy efficiency to help optimize your operations.

Since cone compression crushers can perform very well in manufacturing sand applications, especially in hard and abrasive rock materials, engineers evaluated for years how to design a crusher that will not be so sensitive to packing. This is due to the presence of high % of fines in the feed, the moisture content in the feed, and the fact that it's automated, all with a low cost in producing high quality fine spec sand.

The solution they were seeking was to apply very high crushing forces to a well grain distributed feed material, easy to control and to get high interparticular crushing effect. They tried to avoid high speed as wear increases relative to the square of speed, and it should be a robust machine without a damageable mechanism.

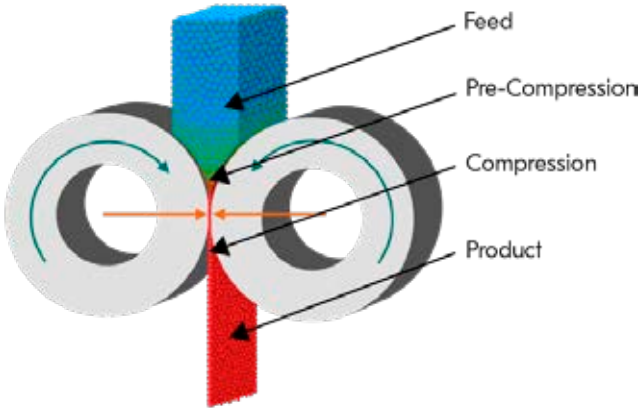
The high-pressure roll crusher was the solution found. The slow-moving rolls with almost no material friction or gliding promised to have a very long life, hydraulic cylinder with modern oil control valves gave the possibility to apply very high crushing forces with very sensitive control capabilities to change the product gradation in a very easy way and providing a very quick reaction to relieve the overload from non-crushable materials.

From the process point of view, the HRC™e works like a compressive crusher. Material is squeezed between the two rollers which circular arc come closer to each other until they reach the smallest point between the rollers. There is the point with highest crushing force in the bulk bed between the roller surfaces and creates a high interarticular crushing.

Furthermore, there is a possibility to adjust the crushing force by changing the hydraulic pressure in the system. Thus, the crushing performance can be adjusted to the process and material needs. With the possibility to adjust the rollers speed the whole HRC™e performance can be adjusted very exact to the client material needs and an optimized production applies.

A huge benefit is that crushing process and capacity is not linked and can be adjusted individually.

As HRC™e is a slow continuous moving machine. The noise, dust and vibration emission are very low and plant layout very simple.



HRC™ Crushing principle

As the machine implements the crushing force in a controlled way, it is not sensitive to fines in the feed at all, the crushing cavity high density is achieved on a constant basis. If there is less void in the bulk between the rollers, the resulting operation gap stays bigger, but the crushing force remain the same. Therefore, crushing of very fine material and near size sand particles becomes possible.

On the same design feature, it can handle also sticky material with high moisture and some impurities in the feed like organics, clay, or other deleterious materials.

While such abrasive, wet, contaminated and fines containing feed combinations create a hell of wear in other comminution equipment, the HRC™e has shown long lifetimes on its rollers in long term operations.

This makes it the perfect crusher for sand and gravel application or in wet manufactured sand processes.

It is reported that the product even down to fine fractions has an excellent angular shape.

The operation with low voids in the feed and high pressure showed the best cubical shape for the use in asphalt and concrete applications.

The adjustable high crushing force makes the HRC™e the machine with the best reduction ratio for sand fractions. In the comparing test, it showed more sand production in open crushing circuit than other crushers.

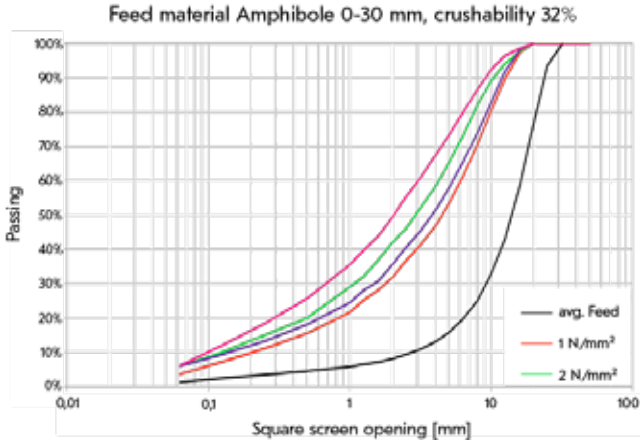
This allows to design the manufactured sand production in a closed process with less recirculation and less load on the product screen.

Less circulation due to higher crushing work also means less power needed for sand production. This is what makes the HRC™e one of the most power efficient crushing equipment. In combination with the long lifetime of the rollers it seems to be the most cost-efficient manufactured sand producing machine.

Another positive effect is that less dust is created in relation to the comparable sand production of other size reduction processes. As the HRC™e goes quicker to the desired sand fractions in the product, less fines are created compared to the VSI and a compressive crusher.

Here is also the adjustaility of the crushing force. This is a great benefit, as the discharge curve of the HRC product can be optimized to the manufactured sand production needs. Test with different forces showed a direct relation to the product PSD.

The test showed that the coarse end and the fines end of product PSD don´t change a lot with the different pressure. However, the middle fraction in range of the desired sand envelope is influenced heavily. So changes the production of 0/2 from 30% (1N/mm²) to 50% (2.5N/mm²) in the test result diagram below.



HRC™e conclusion:

- HRC™e can turn waste into value, HRC™e can treat feed where other crushers are not efficient!
- Produces more sand with less dust
- Less power consumption in sand production (up to 50% less)
- Compact design, no vibrations, minimum noise and dust, no scalping or prescreening, easy to use
- Can process high abrasive material
- Crushes material with low crushability shows high reduction ratio
- Not sensitive to moisture in the feed
- Not sensitive to fines in the feed, crushes even sand fractions
- Product curve can be optimized by pressure adjustment.
- Steady production in open and closed process
- Capacity can be adjusted by roller speed
- Minimizes energy and wear cost
- Limited capacity ~100t/h for the HRC™e TM8 size

Maximum productivity

The HRC™e HPGR takes proven technology and enhances it. The high throughput comes from the elimination of the edge effect with the flange design, which will ultimately maximize the amount of crushed material. With the skew control system, you will find faster restarts and minimize downtime from skewing events.

The HRC™e also comes with a large feed size acceptance and improved energy efficiency compared to similar HPGRs. Boosting the efficiency and cost savings.

Ease of maintenance
The HRC™e HPGR creates a safe and simple maintenance operation. The edge segments replacement process is simple due to the bolted design and flange integration. The dust enclosure separates the crushing zone from critical mechanical components within the machine.

The unique feed chute also comes with control gates for quick maintenance and reliable start up. These features and reduced tire wear life leads to low downtime.

Skew control system
The skew control system is a field-proven mechanical solution that balances the loads by the distributor device ensuring the tires remain parallel for maximum efficiency. The system is also self-monitoring and evaluates skewing, segregation, and mechanical condition of the parts.

The skew control system increases availability and reliability of the machine by controlling skewing events and allows for flange rolls assembly.

Tire assembly flange rolls
Metso is the only OEM to successfully operate reliable flanges. The flange rolls eliminate the edge effect by evenly distributing the material, which also maximizes the amount of crushed material during the process.

The HRC™e HPGR flange rolls bring improved energy efficiency, reduces the circulating load and increased tire life.

HRC™e grinding roll benefits:
- Improved energy efficiency by up to 15%
- Reduced circulating loads by up to 24%
- Increased throughput by up to 19%
- Ease of maintenance
- Reduced downtime from restarts

For further HRC™e HPGR grinding rolls product and technical information, please visit:
www.metso.com/portfolio/hrc-series

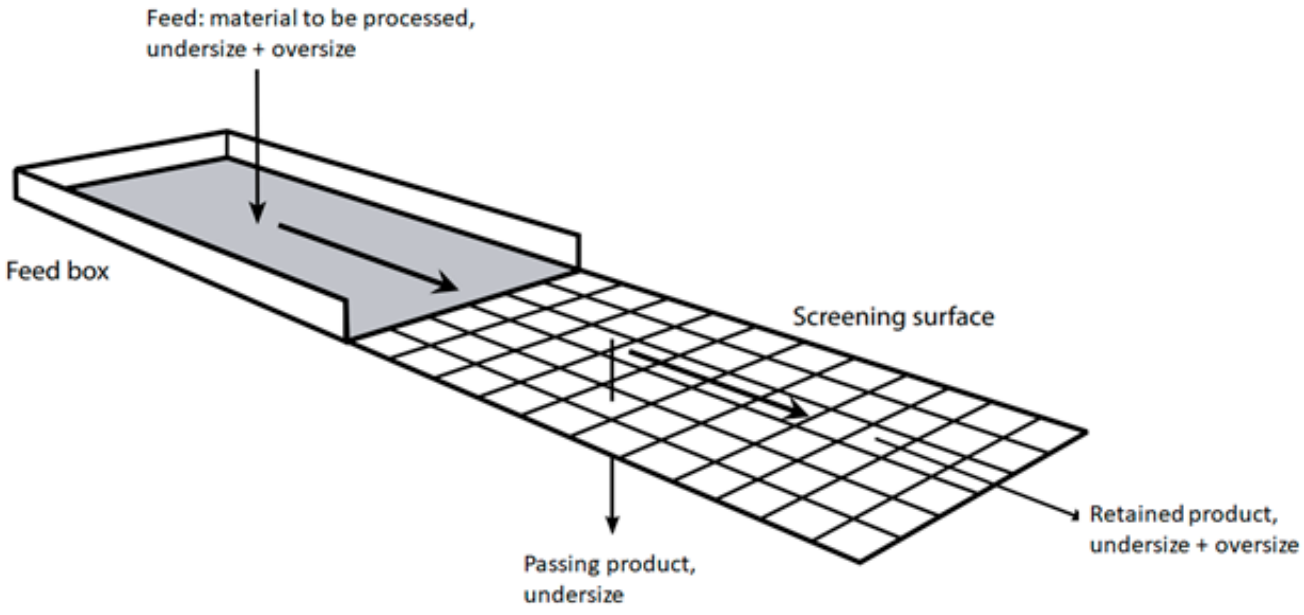
Screening

Screening is a process to mechanically separate particles by size. Screening surface with openings is doing the separation when feed travels over the surface.

Feed particles smaller than screening surface openings (=mesh size) is called undersize and particles bigger than mesh size is called oversize.

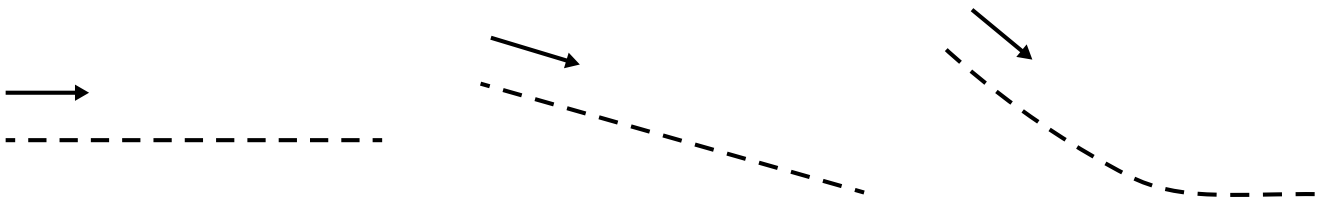
Passing product is the share of undersize particles that managed to fall through the openings. Retained product consists of oversize particles and the undersize particles that didn't fall through.

In this chapter we focus on vibrating screens and processes enabling the separation.



Vibrating screens

Basic types of vibrating screens based on the design of the screening surface.



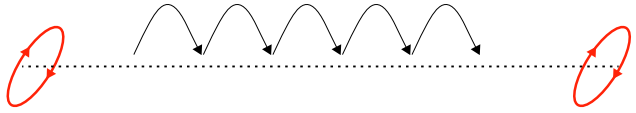
Horizontal screen

Inclined screen

Multislope or banana screen

Since there is a continuous material flow in a crushing and screening process, ability to convey material over the screen deck is vital.

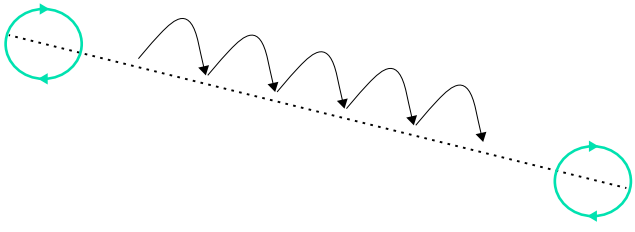
In horizontal screens material conveying is based entirely on the vibrating motion.



To enable material forward movement, vibration must be directional. Options are linear and elliptical motion.

Linear Elliptical

In inclined screen conveying is based on material movement and gravity. Inclined screens typically use circular motion.



Directed stroke in combination with inclined screen decks can increase transport speed and carrying capacity.

Screen type and motion have a strong influences on screening performance. The final selection depends on the application (see selection guide at the end of the screening chapter).

Passing probability

When feed is introduced to the screening surface, we expect undersize particles to fall through the openings. Since individual particles can not be mechanically forced through, we have to make sure the probability of a particle to pass through is as high as possible. There is a number of identified features that improve passage probability:

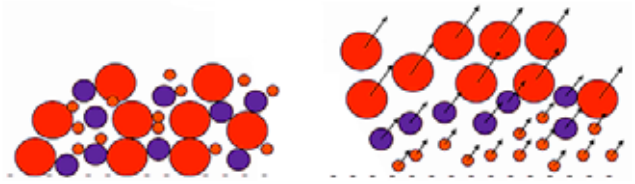
- particle has to be in contact with screening surface
- particle has to have as many passing attempts as possible
- the smaller the particle is in relation to the opening, the higher is the probability
- the less flaky/elongated particle the higher is the probability

The theoretical approach to passing probability is based on the behavior of an individual particle on screening surface. Particle interaction in the material layer on a screening surface is not handled in this text.

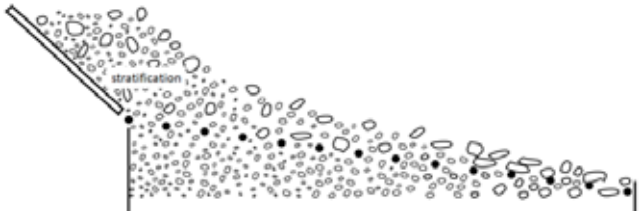
The following chapters go more detailed into the elements of passage probability.

Stratification

When a layer of loose particles is introduced to a vibrating surface, smaller particles shift through the gaps and fill the voids between large particles in the bottom of the material bed. The phenomenon is called stratification and it enables small particles come in contact with the surface.



A screen feed box is a practical application to get material layer stratified already before it meets the actual screening surface.



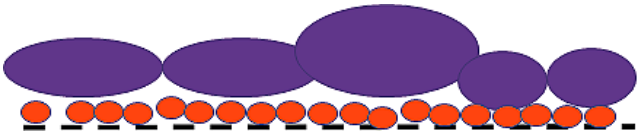
Stratification is often mixed up with segregation. Instead of organizing the material bed into layers of different sizes, stratification is a continuous process. When the smallest

particles fall through the openings from the bottom of the material layer, new voids are opened allowing stratification to continue.

There are interrelated factors that affect stratification:

1. Particle size difference. The bigger the size difference the more effective stratification. Stratification is most visible at the feed end of a screen, where there are still all feed particle sizes present. Multi slope screens are designed to exploit effective stratification to pass through fines as quickly as possible.
2. Bed depth. The higher material bed depth, the longer it takes to shift fines through the layer. Excessively high bed depth also dampens particle movement, which slows down stratification.
3. Fine particles can stick together or stick to bigger particles due to excess moisture and prevent free flow through material layer.

Stratification is not only the process to bring small particles into contact with the screening surface. It is also the process to keep them in contact with surface.



A layer of larger rocks prevents smaller rocks bouncing randomly on the screening surface.

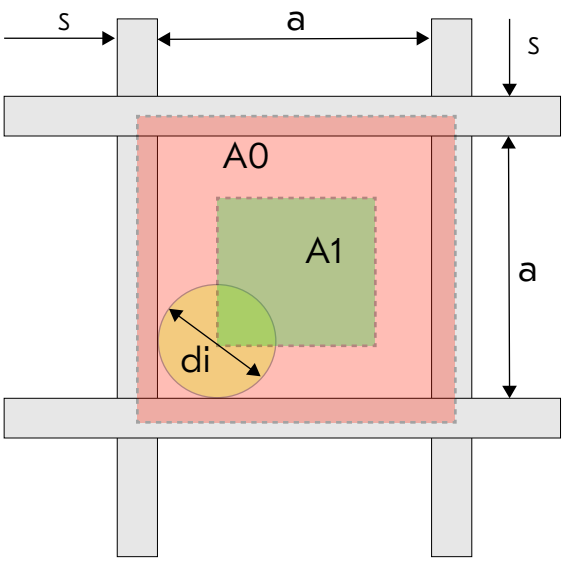
Particle size

The passing probability of a particle depends very much on its size in relation to the size of the screen opening. The larger the difference in size, the easier it is for them to pass through.

In the next picture

a is the length of the side of a square opening
di is the diameter of a particle, assumed ball
A1 is the area the center of the ball must hit to cleanly fall through the opening.

The larger A1 the higher passing probability.



Particles measuring di > a (=oversize) have zero passing probability. These particles retain on the surface and increase carry over loading.

Particles with di < 0.5a are assumed to pass through in any case, because their passing probability is so high.

Particles of 0.5a < di < 1.5a are called 'critical class'. They affect screening performance significantly. Particles of a < di < 1.5a are oversize with zero passing probability, but these particles tend to block openings preventing smaller particles from passing.

Particles of 0.5 a < di < a belong to undersize. The passing probability of all undersize particles is over zero. The closer the particle size is to square opening size, the lower the single attempt passing probability. As a result, the number of required passing attempts increase.

Example:
There are 150 rows of 35mm x 35mm openings on a screen deck.

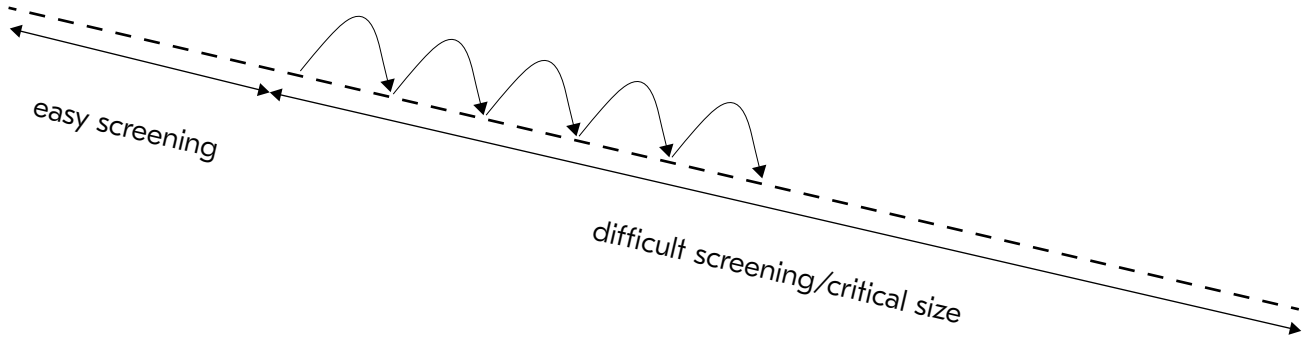
Theoretically a single rock travelling in a straight line has 150 passing attempts.

We assume the openings are clear and rocks are assumed balls to estimate the best possible situation. We also assume that theoretically 85% passing probability guarantees the passing in real application.

Rock size di [mm]	Attempts to 85 % probability	Probability after 150 attempts
17,5	9	99,99 %
20	13	99,99 %
25	31	99,9 %
30	138	87 %
32	429	48 %
34	9320	3 %

In optimal conditions, particles up to 25mm (0,7a) will pass through easily.
Particles up to 30mm (0,86a) use almost all 150 attempts, but eventually pass though.
Particles 0,9a < d < a need significantly larger number of attempts. Majority of di 34mm particles retain with oversize.

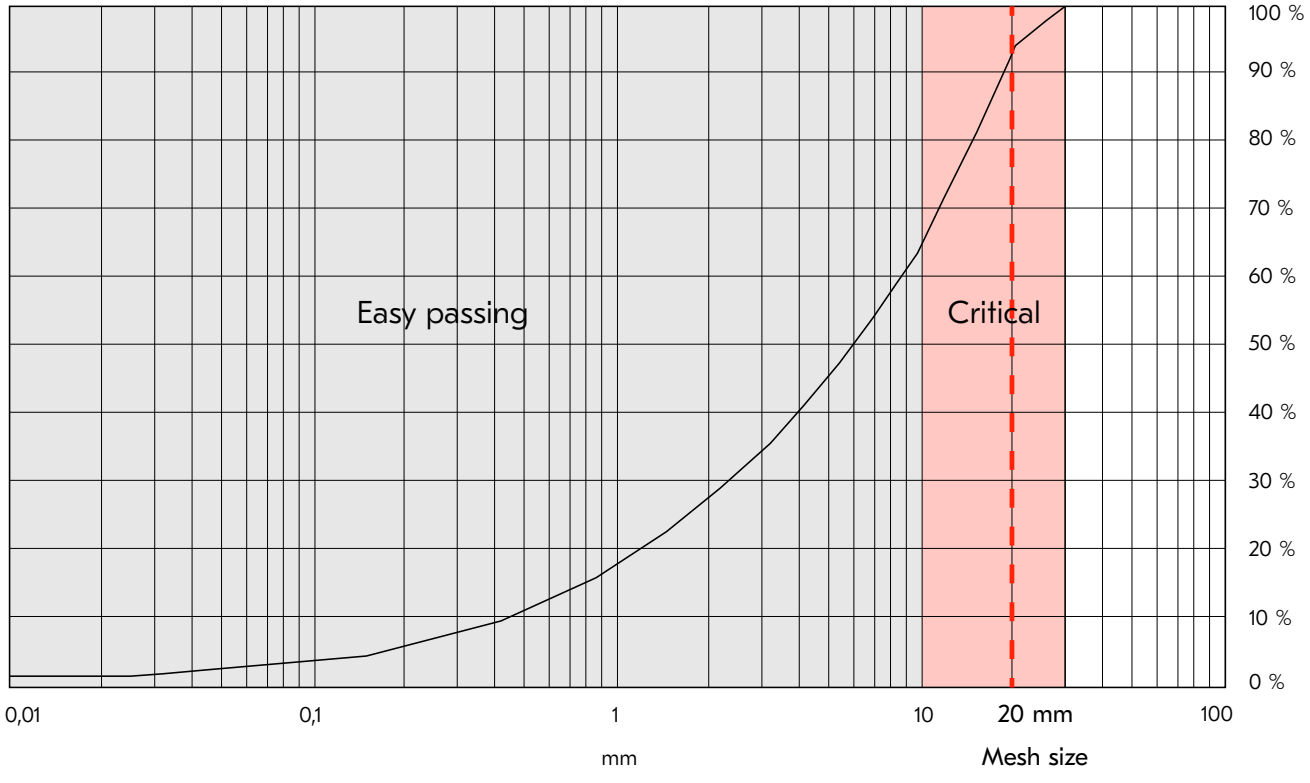
About 15% of the screen length is needed to pass through easy passing particles. The rest of the length is required to ensure enough passing attempts for bigger undersize particles.



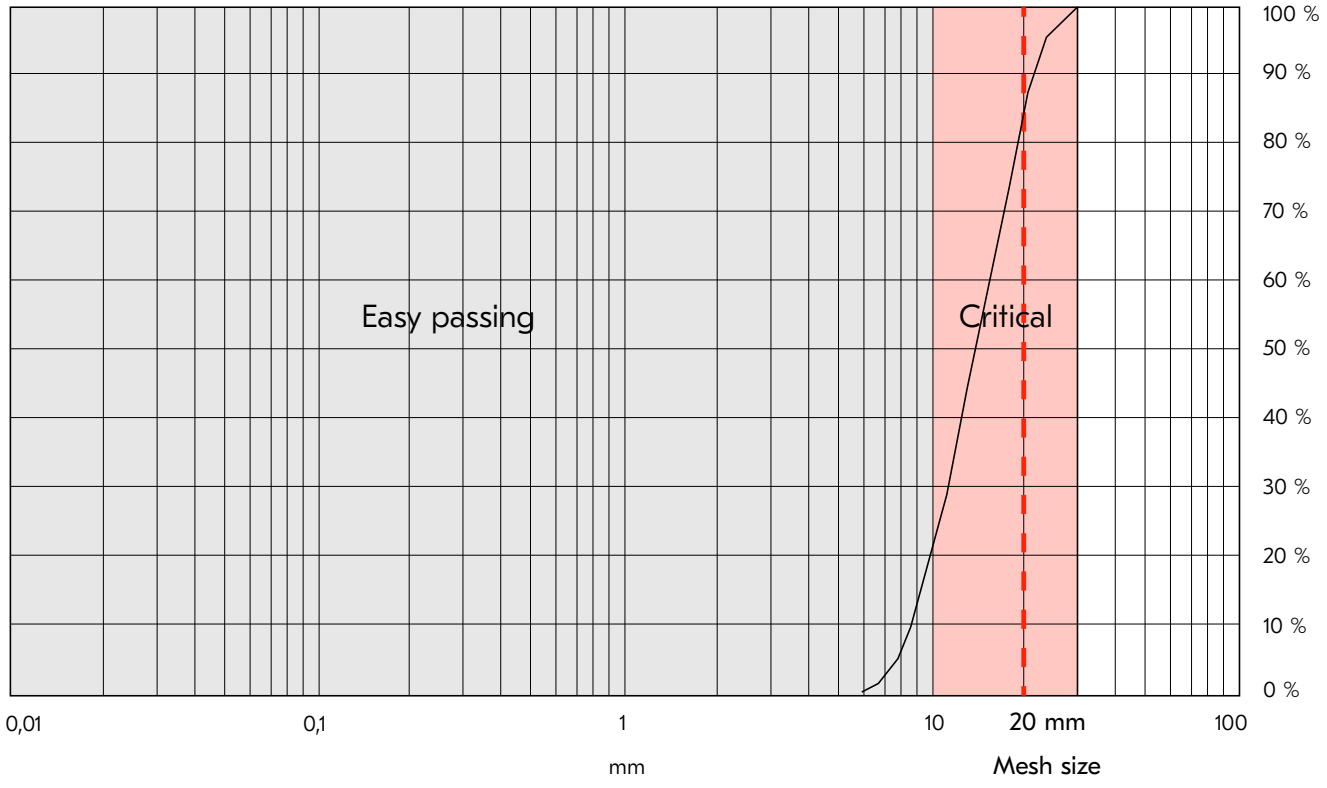
Feed PSD

In real life applications we observe overall screening performance instead of individual particles. Feed particle size distribution (PSD) or feed curve gives an indication on expected screening performance. The key factor is the share of easy passing and critical particle sizes in the feed.

In the graph below 65% of the feed belongs to easy passing size class and 35% is critical. Since the overall target of screening is to get undersize particles through the openings, we very often concentrate on the undersize section of the feed curve. The key figure in estimating performance or difficulty of the screening is the share of critical particles in undersize, 10 – 20mm fraction in the graph. The less undersize in critical size class, the easier is the screening task and the better is expected performance.



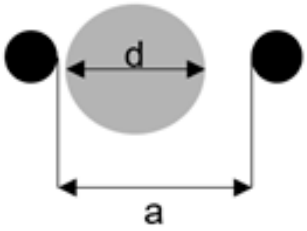
In the graph below majority of the feed undersize belong to critical size class, which makes screening task significantly more difficult.

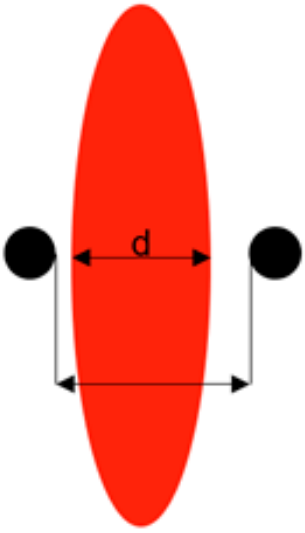


Particle shape

The shape of particles that belong to the same size class can be anything from spherical to flaky or elongated. As spherical particle has the same passing probability regardless of the orientation, an elongated particle has to be in specific orientation to pass.

An attempt in non-favorable orientation effectively reduces passing probability.

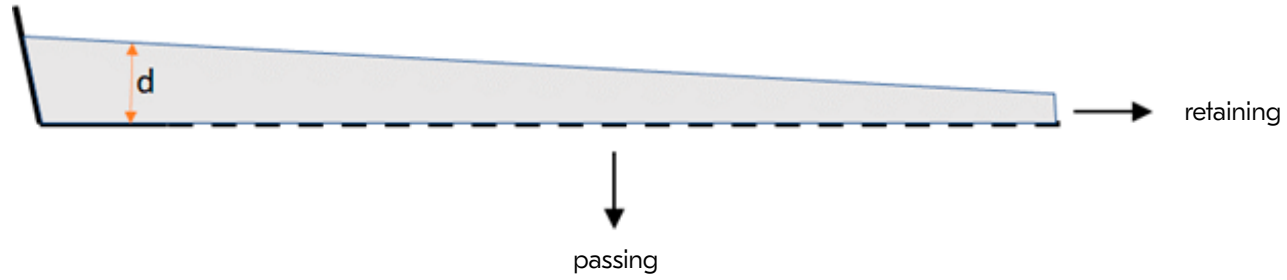




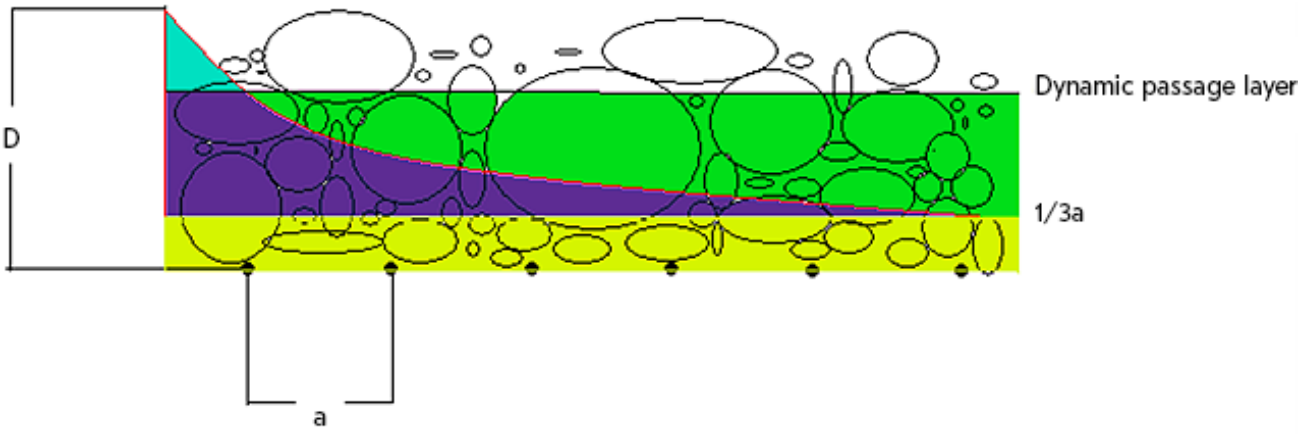
Bed depth

Material bed depth on the screening surface is closely linked to both getting undersize particles to contact with the surface and assuring as many passing attempts as possible.

In an optimal situation, bed depth (d) at feed end of a screen is about 5 – 7x opening size allowing acceptable feeding capacity and quick stratification. At discharge end there is a layer of oversize on remaining undersize particles still attempting to pass though.

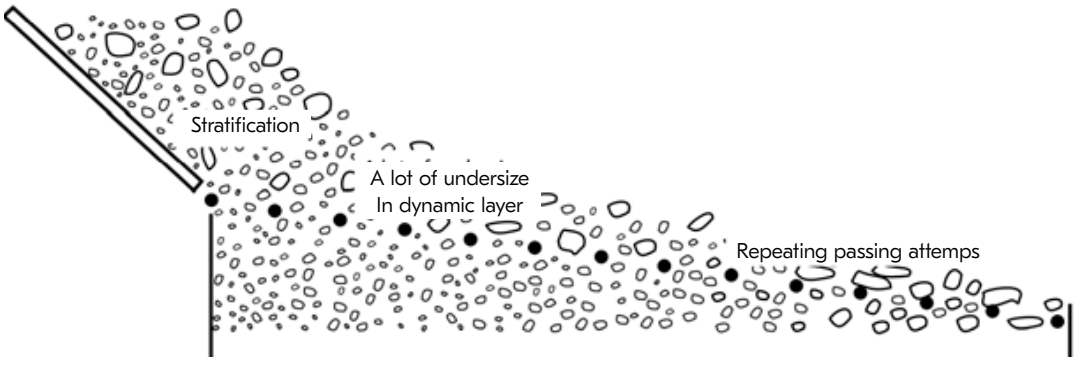


Material bed is constantly moving on the vibrating screening surface. In any given moment particles are roughly in two layers. There is a so-called dynamic passage layer in the bottom and the layer above it.



Undersize particles in the dynamic passage layer can become in contact with the surface and pass though. Particles move into the dynamic layer by stratification. The higher the total bed depth, the longer it takes to shift particles to dynamic layer and passing attempts are lost. Undersize particle has a theoretical >0% passing probability based on its size. If a particle remains above dynamic layer in material bed, its passing probability is effectively 0%.

In an optimal situation, all the remaining undersize particles should be in dynamic layer at the discharge end of the screen. The layer of oversize particles should be thick enough to prevent rocks bouncing uncontrollably on the surface maximizing the number of passing attempts.



Screen feeding [t/h] has a direct effect on bed depth and screening performance. Higher bed depth slows down movement to the dynamic layer resulting less passage attempts.

Lower bed depth may cause material layer to become too thin to keep particle movement in control.

Vibrating motion

Vibrating motion was already mentioned in Vibrating screen chapter. Here we consider the role of the vibration on passing probability and screening performance.

The vibrating motion moves material over the screen deck and provides consecutive passage attempts. For maximum number of attempts, a good ratio between amplitude and frequency is necessary. When the material travels on a screen it is desirable that a particle neither falls on the same opening nor jump over many openings.

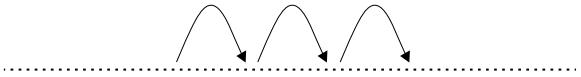
Therefore, as a rule of thumb:

- Larger openings: higher amplitude – lower speed
- Smaller openings: lower amplitude – higher speed

Theoretically the maximum number of attempts is achieved, when a particle tries every opening on its way over the screen deck. This thinking involves the assumption that openings are not blocked. A blinded opening results 0% passing probability.

Therefore, another crucial function of the vibration is to keep the openings clear. In real life applications, speed and amplitude are often set high enough to keep screening surface clear even if it means losing some passing attempts.

Maximum number of passage attempts

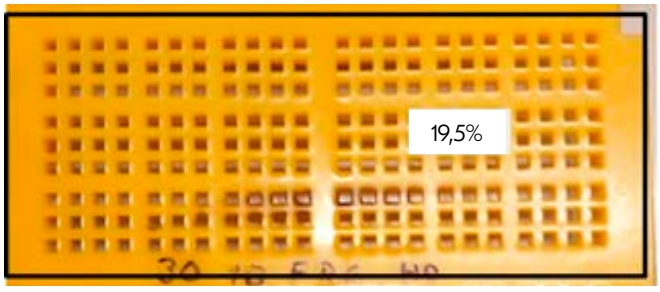


Less attempts, clear screening surface

Screening surface opening, media opening

The length of the screen, the material travel speed and the stroke of the vibration together dictate how long a particle stays on a screen and how many times it is in contact with the surface to attempt passing. To pass through, the particle has to land on an opening or very close.

The number of openings in the particle's path is also the maximum number of passage attempts. Screen media selection affects this number.

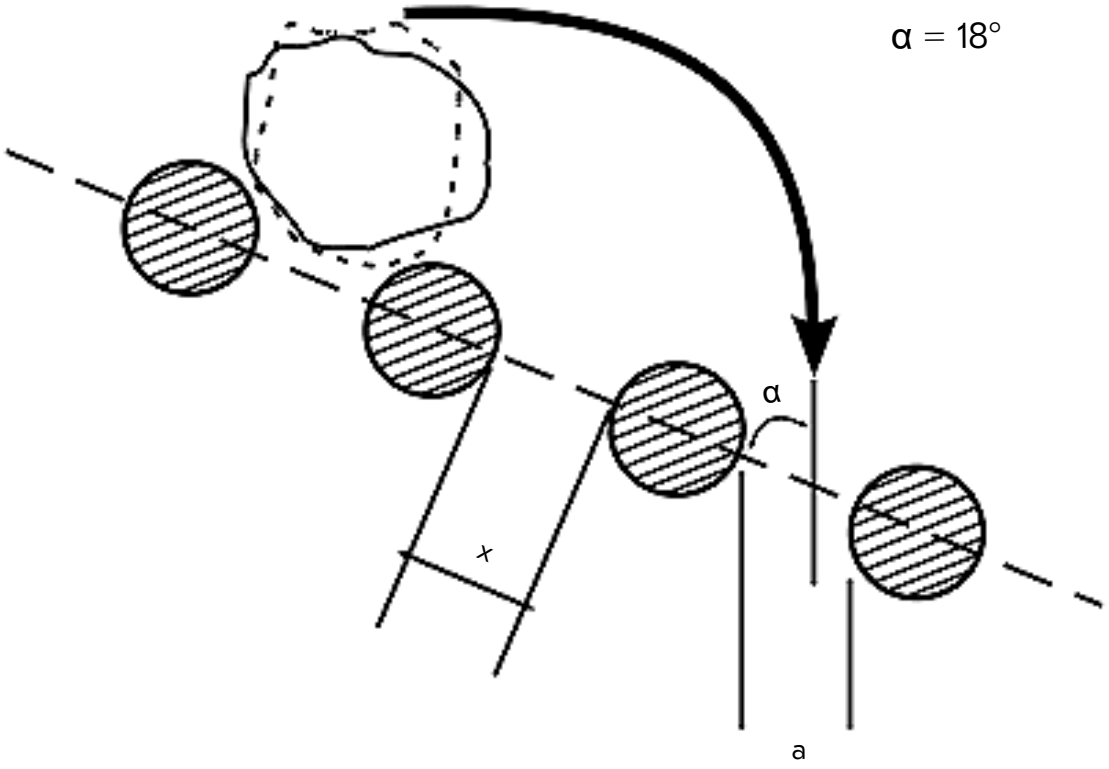


Open area % indicates the share of openings of the screening media. Effective open area % is the most commonly used. It is the share of openings of the total area.

The higher the effective open area %, the more probable a particle lands on an opening and potentially pass through.

Nominal screen media opening is the absolute measured size of the opening. In optimal conditions it is possible to get through particles that just barely fit the opening. In actual screening process the screen inclination, screening media thickness and the shape of the opening reduce the particle size that can cleanly fall through the opening. This size is called effective opening.

In the picture below effective opening X is smaller than nominal opening a, because of the inclination and media thickness. Effective opening is the vertical projection of nominal opening.



Estimating the passing probability by size, the reference is now the effective opening.

According to the example in the Particle size chapter, the particles that are about 10% smaller than the opening can be expected to pass through in quantities.

The largest particle that has reasonably high passing probability is called separation size, which is always smaller than nominal opening. In absolute ideal conditions the separation size can be very close to nominal opening.

Screening efficiency

The target of the screen operation is to make undersize rocks fall through the surface openings resulting the separation by size. Screening efficiency is a key figure that indicates how well the target is achieved.

Passing probability is linked to screening efficiency, which can be considered as an outcome of variables having an effect on passing probability.

The definition of screening efficiency involves one screen deck. In case of a multi deck screen, the efficiency is calculated on each deck separately.

There are two slightly different definitions for screening efficiency depending on which material outflow - passing or retaining - is considered the product.

1. Efficiency of undersize removal

If the retaining material is the product, it is desirable to have a minimum of undersize in it. The efficiency of undersize removal is given by the following formula:

$$\text{Efficiency [\%]} = \frac{\text{Oversize [t/h] in the feed}}{\text{Retaining material [t/h]}} \times 100\ \%$$

2. Efficiency of undersize recovery

If the passing is the product of the screen, it is desirable to recover the maximum undersize material existing in the feeding.

This efficiency is given by the following formula:

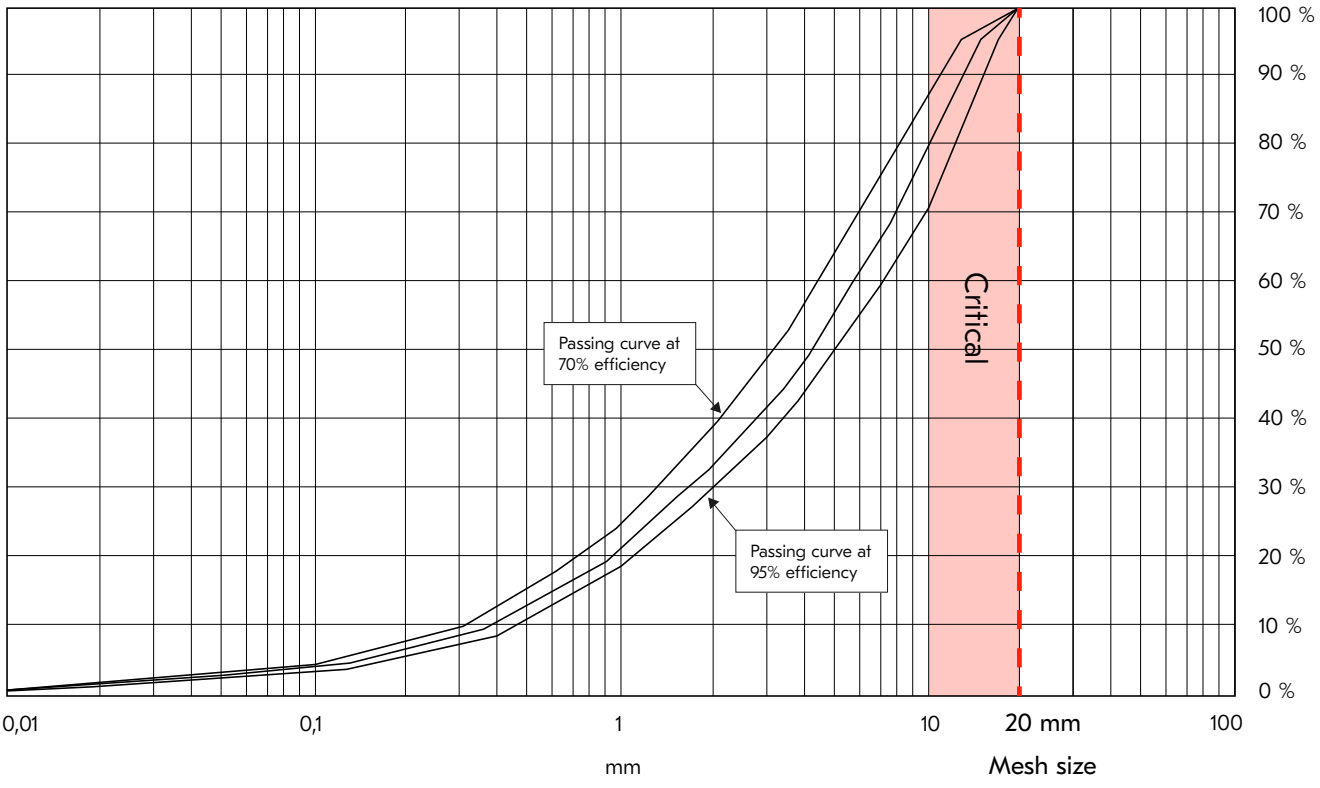
$$\text{Efficiency [\%]} = \frac{\text{Undersize passing [t/h]}}{\text{Undersize [t/h] in the feed}} \times 100\ \%$$

The efficiency of undersize recovery is most commonly referred as screening efficiency.

Product PSD vs. screening efficiency

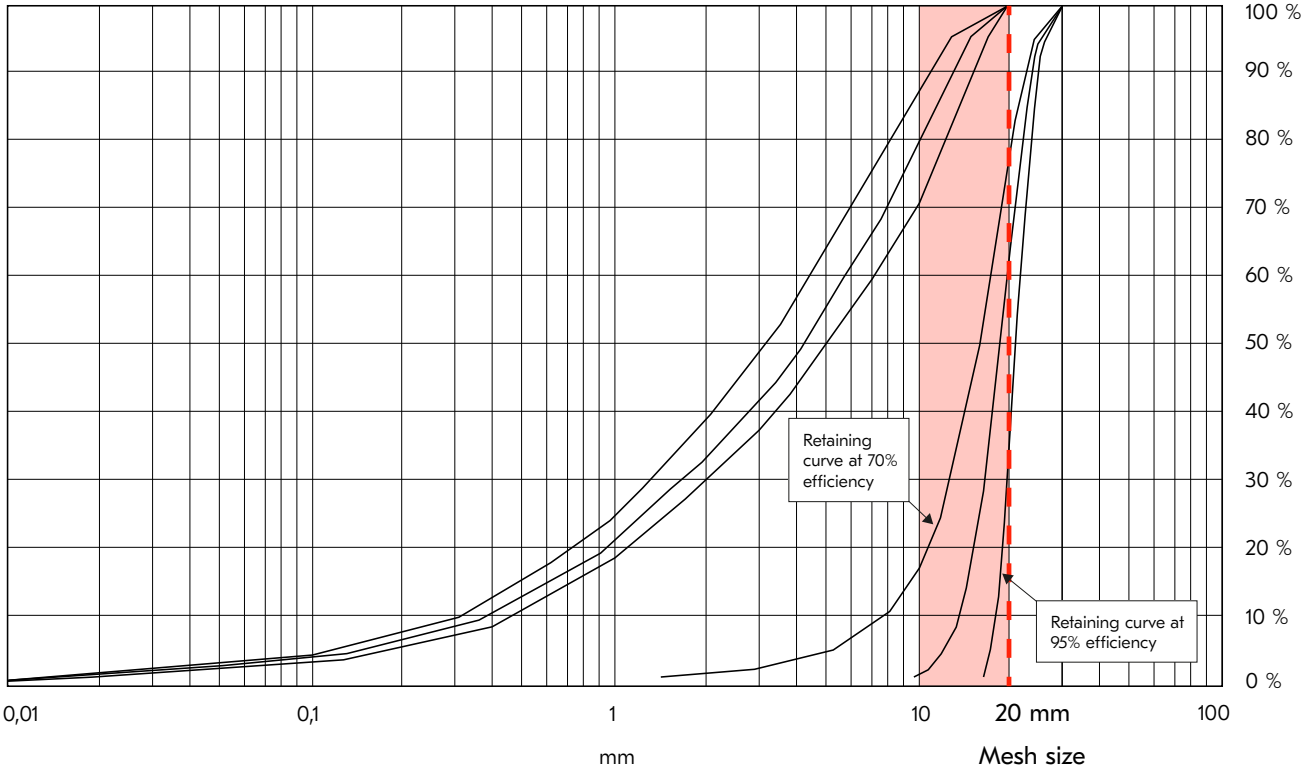
In real life aggregate applications screening efficiency alone is hardly ever used as an indicator of desirable screen performance. Especially in product screening, product curves are vitally interesting because quality product must meet curve requirement.

Product particle size distributions are linked to screening efficiency. The graph below shows how passing PSD changes with efficiency.



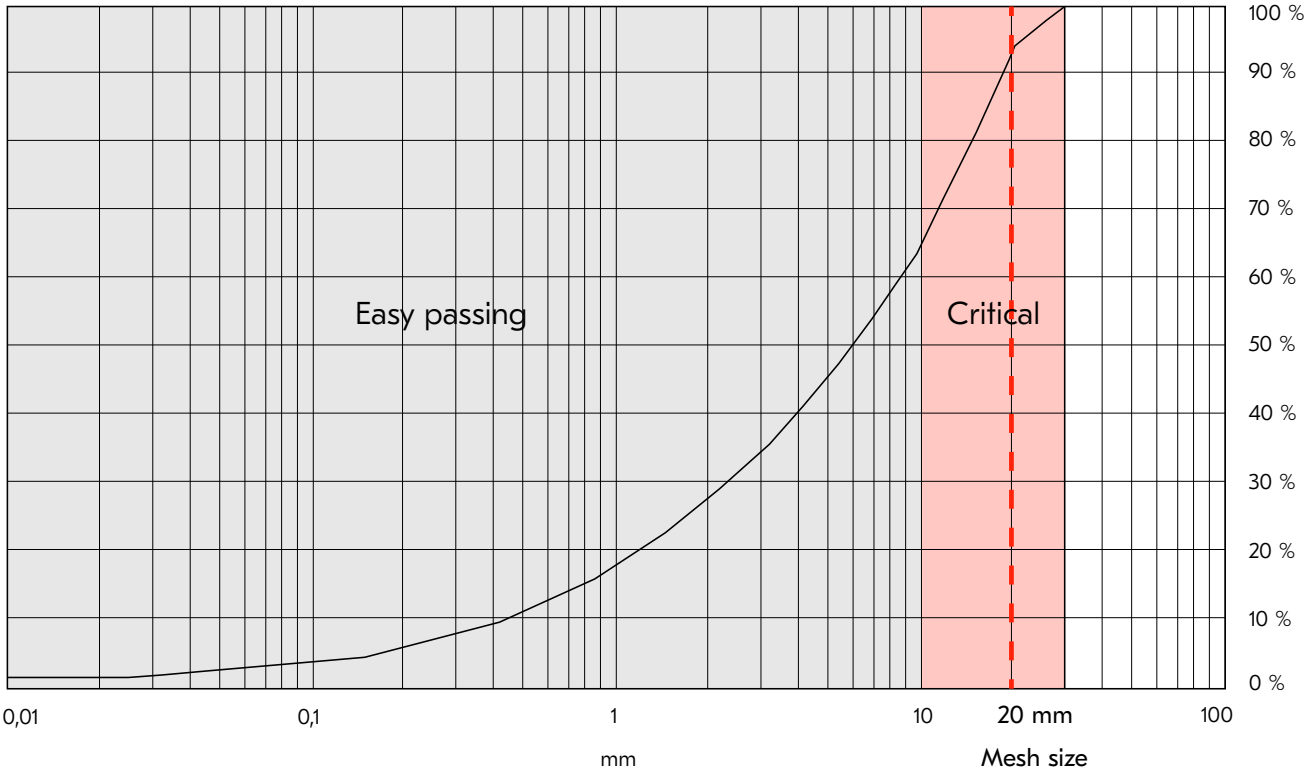
When efficiency decreases, the share of critical size class in passing curve becomes smaller. When screening becomes less optimal, the effect shows in the particle sizes that have the lowest passing probability.

The undersize particles that didn't pass through, retain with the oversize.



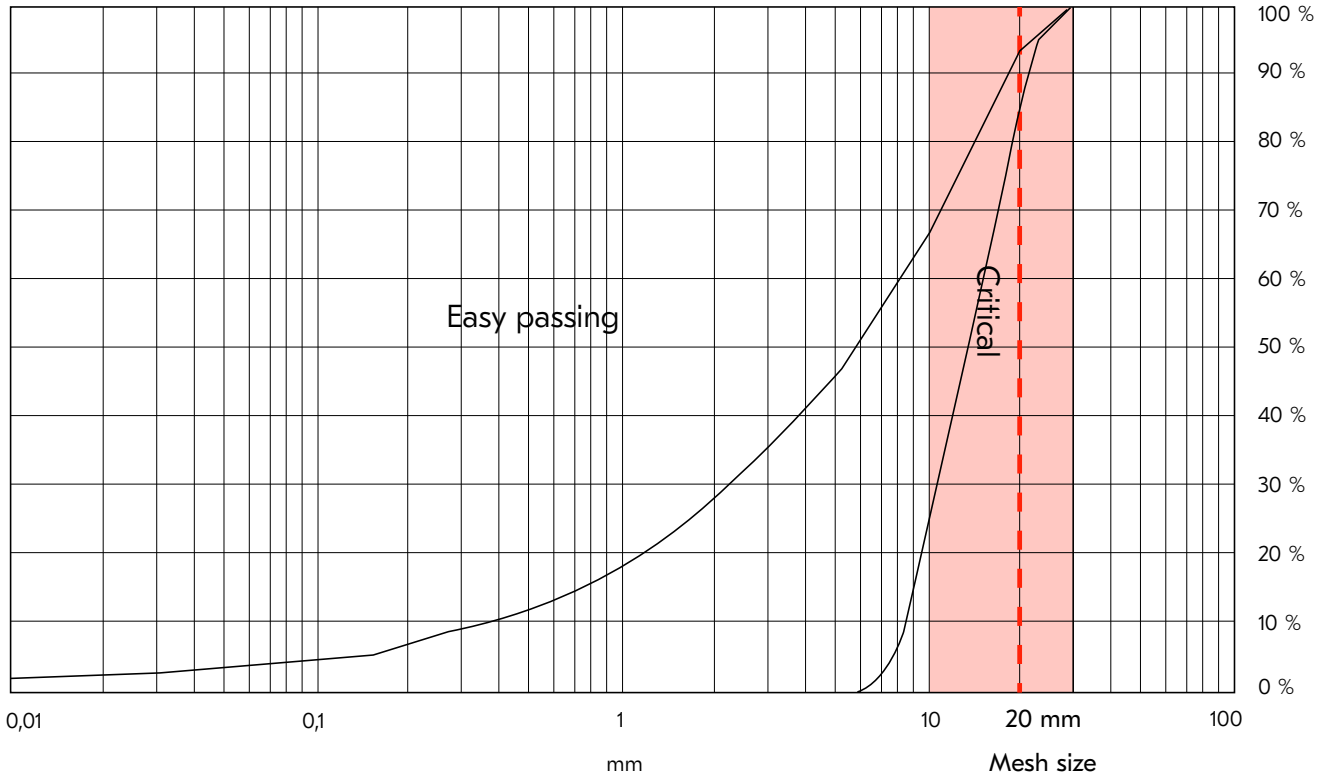
The share of critical size in the passing curve (graph above) decreases from 30% to 14%. At the same time, the share of critical size in retained curve increases from 40% to 80%.

The share of oversize in the feed is 7% (see graphic below). Only a small amount of undersize added to oversize flow causes a big change to the retaining curve.



Feed PSD vs. screening efficiency

Two similar screens, similar screening media, same 20mm mesh size and the feeding [t/h] is the same. The feed curve with more critical size was earlier described as difficult feed curve.



Difficult feed curve results 77% screening efficiency and easy feed curve 91%. Majority of the difficult feed curve consists of critical size particles that have low passing probability. To achieve efficient screening, low probability particles should end up to the screening surface as close to the feed end of the screen as possible to have as many passing attempts as possible. The most obvious way to do this is reduce feeding to find the optimal conditions for this feed curve.

Screen loading vs. efficiency

Feeding [t/h] i.e. screen loading is a major factor effecting screening efficiency. (Efficiency here is referred to as the efficiency of undersize recovery).

Screen loading vs. efficiency graph (see the picture on the next page) shows that the loading "a" results optimal screening performance i.e. the highest efficiency.

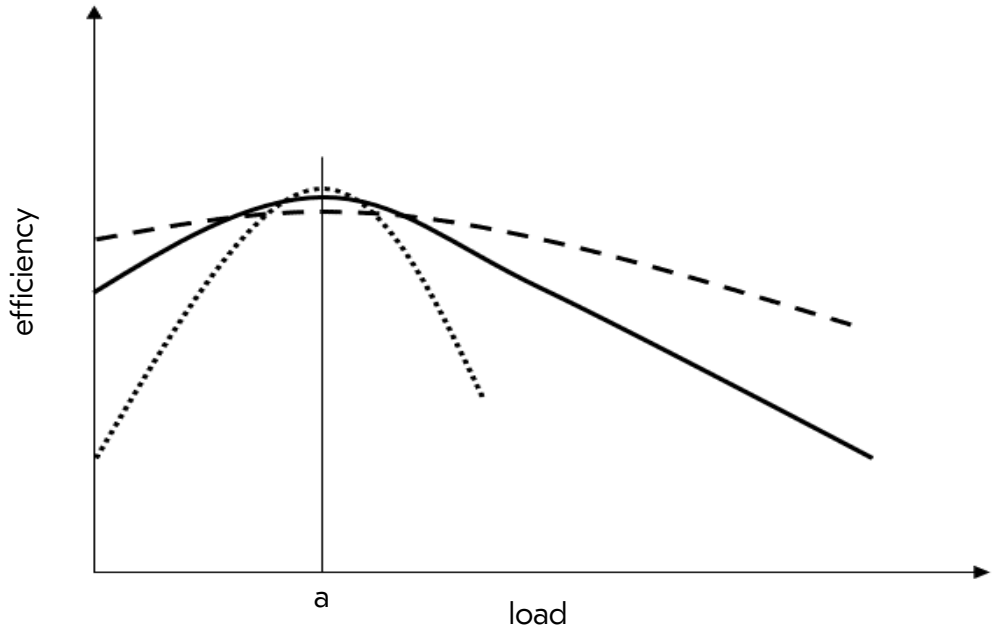
For low feed rates, to the left of point "a", the actual efficiency increases with increased feeding. In this area bed depth tends to be too low and passing probability is low because of particles bouncing on the screen deck. Passing attempts are lost.

Beyond point a, the efficiency starts to decreace with increased feed rate, as the bed depth becomes higher than optimal.

As we learned in the previous chapter, optimal feeding "a" depends very much on the feed curve. Easy feed curve allows significantly higher feeding. The behavior of screening performance is the same in relation to feeding, but absolute feeding tonnage is not constant.

Screen characteristics determine how sensitive screening performance is to changes in loading. There are "high performance" screens (dotted curve).

The best performance can be superior to any other screen, but at the same time it is very sensitive to loading. At the other end of the scale (dashed curve), the best performance may be a bit lower, but screen is relatively insensitive to loading.



Screening efficiency in practise

By the definition screening efficiency is a ratio of actual passing [t/h] and the amount of undersize [t/h]. Since a practical vibrating screen can't be infinitely long, it is almost impossible to pass all critical size particles. Therefore, efficiencies in the 90% to 95% range can be considered perfect.

There is an optimal operating point for each screening application. Earlier feeding tonnage "a" referred to this optimal point. The higher the efficiency, the closer the screening is to its optimum.

In real life, high efficiency is commonly linked to correct screen size for the application. Other variables – screening media, feed curve, particles shape, feeding – are usually considered as characteristics of the application.

In practice, screening efficiency is only an indicative value. From commercial perspective the quality of the production is the decisive factor. High screening efficiency and acceptable product curve are not always linked. In real applications screening performance may be deliberately decreased to manipulate the product curve to meet the requirement.

There are means to influence or troubleshoot inadequate screening performance.

Feeding [t/h] is below optimal:

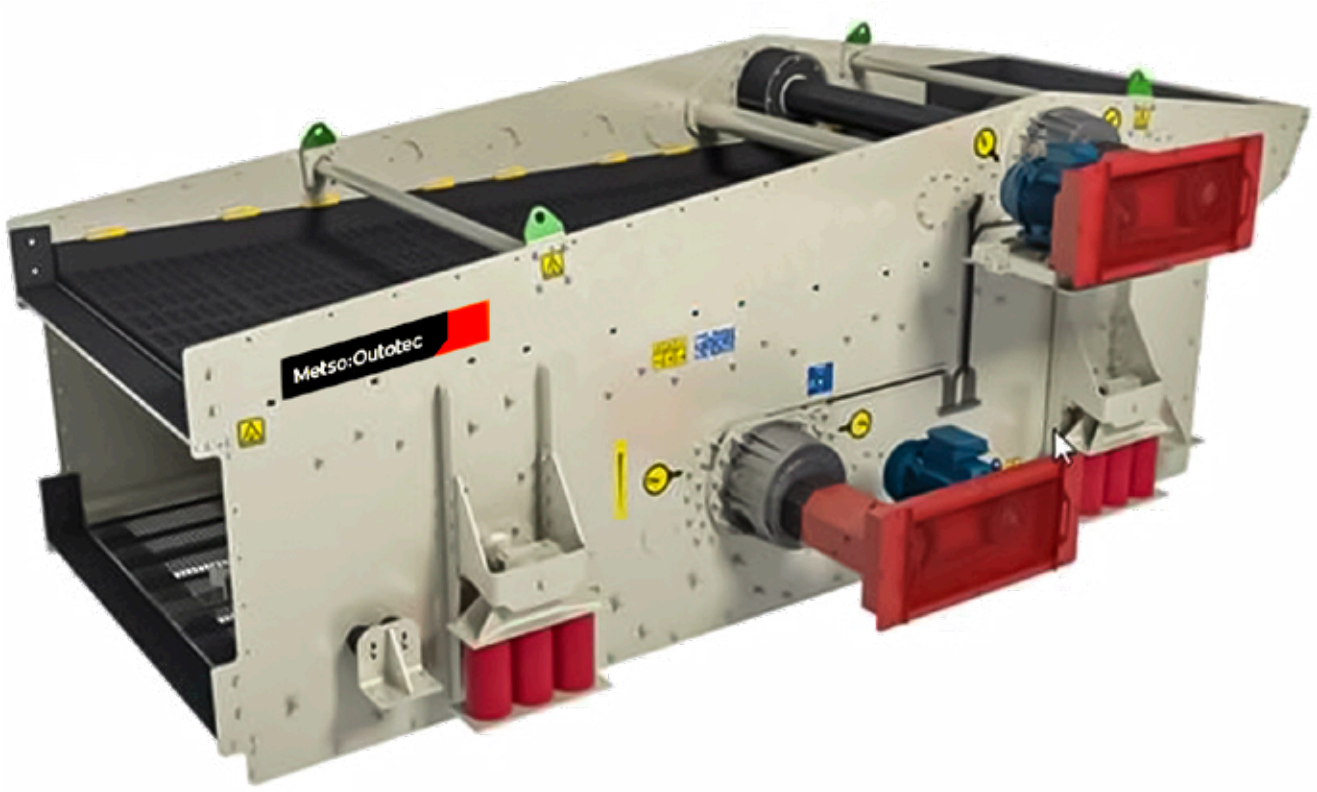
- Slow down vibration frequency.
- Circular counter flow vibration.
- Decrease screen inclination.
- Apply dam bars on the screen deck.

The aim is to make feed stay longer on the screen, which increases the number of passing attempts and creates higher bed depth to keep particles in contact with the surface. Decreased inclination also makes effective opening slightly bigger, which improves passage probability.

Feeding is above optimal:

- increase media open area %
- increase media opening
- increase travel speed

By improving passage probability, the optimal feeding becomes higher and the actual application is closer to optimal operating point. Product curve may move out of spec if the opening becomes too large.



Metso screen range selection

Wide range of reliable screening solutions
The performance of the screen is crucial and has a great impact on productivity. The choice of screen, screening media and associated components is therefore important. Our experience, combined with the market's widest range of screens, screening media, spare parts and services mean we can select exactly the right solution and support the rest of the process perform at the expected level.

All screens as well as all screening media systems and materials have their benefits and limitations. It is important to match the screening media to the screen type and the material being processed, e.g, from large stroke, low frequency screens for coarse high impact materials to short stroke, high frequency fine wet abrasive materials and everything in between that includes circular and elliptical motion screening. The final choice is always determined by type of process/ application and objectives.

Metso offers screening solutions for all types of aggregate and mining customer cases, based on the specific customer need for a defined application and process.

Our wide product range, knowledge and experience makes it possible for us to offer a solution tailored to meet your challenges and targets. We focus on screening performance, uptime, sustainability, safety and importantly – during the entire process.

- Screens – standard offering and classic vibrating equipment for mining and aggregate
    - Scalping screens
    - Horizontal screens
    - Inclined screens
    - Banana screens
    - Ultrafine screens
- Screening media for all applications
- Spare parts supporting all standard and classic screens
- Service and support to ensure a trouble-free operation

For further information, please visit:
www.metso.com/portfolio/screens

Screen/feeder application

Possible Metso screen/feeder solution*

Application	Machine Description	Suitable series	Industry segment
Vibrating pan feeder (extracting feeder)	Vibrating motor feeder	TKP / VMO	AGG and MNG applications
Apron Feeder (primary feeder, extracting feeder)	HD Apron feeder	AF	AGG and MNG applications
Push feeder (reciprocating table feeder, for primary crushing station)	Mechanical table feeder Hydraulic table feeder	DET HRBM	AGG applications AGG and MNG applications
Vibrating pan feeder (for primary crushing station)	Pan feeders, linear motion	PF	AGG and lighter duty Mining applications
Vibrating Grizzly feeder (for primary crushing station)	Grizzly feeders, linear motion	VF / TKF	AGG and lighter duty Mining applications
Vibrating Grizzly scalper (for primary crushing station)	Grizzly scalpers, linear motion HD-Grizzly scalpers, linear motion	VG / TKG LH-1G	AGG and lighter duty Mining applications MNG applications
Secondary crushing applications (if top size is < 350 mm)	Free-Fall screens, linear motion Inclined screens, circular motion Inclined screens, circular motion Multi-slope screens, linear motion	DF-P CVB-P RF MF	AGG applications AGG and lighter duty Mining applications MNG applications MNG applications
Secondary crushing applications (if top size is < 500 mm)	Inclined screens, circular motion Inclined screens, circular motion	CVB-P RF	AGG and lighter duty Mining applications MNG applications
Tertiary crushing applications (small circuits)	Free-Fall screens, linear motion Inclined screens, circular motion Inclined screens, circular motion	DF-S CVB RF	AGG applications AGG and lighter duty Mining applications MNG applications
Tertiary crushing applications (higher capacities)	Inclined screens, circular motion Inclined screens, circular motion Triple-slope, variable elliptical motion Multi-slope screens, linear motion	CVB RF TS MF	AGG and lighter duty Mining applications MNG applications AGG and lighter duty Mining applications MNG applications
Difficult to screen applications (sticky material)	Inclined screens, circular motion Inclined screens, circular motion Horizontal screens, elliptical motion Multi-slope screens, elliptical motion	CVB RF ES EF	AGG and lighter duty Mining applications MNG applications AGG and lighter duty Mining applications MNG applications
Sizing <80 mm with height restrictions	Horizontal screens, elliptical motion Multi-slope screens, elliptical motion	ES EF	AGG and lighter duty Mining applications MNG applications
Sizing <50 mm with height restrictions	Horizontal screens, elliptical motion Horizontal screens, linear motion	ES LH	AGG and lighter duty Mining applications MNG applications
HRC dry circuits	Multi-slope screens, linear motion	MF	AGG and MNG applications
HRC wet circuits	Multi-slope screens, linear motion	MF	AGG and MNG applications
Trash screening (wet)	Horizontal screens, linear motion	LH	MNG applications
Desliming	Multi-slope screens, linear motion	MF	MNG applications

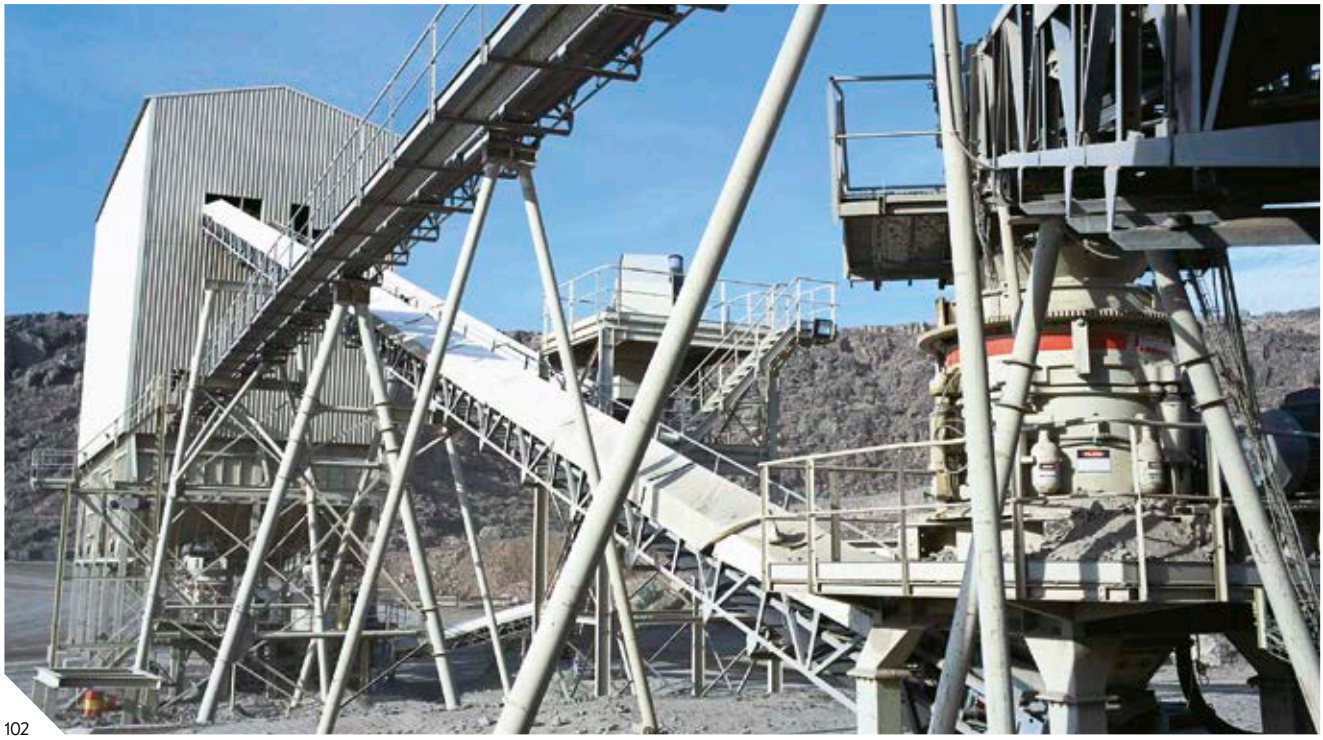
Application	Machine Description	Suitable series	Industry segment
Dry coal screening	Inclined screens, circular motion Inclined screens, circular motion Multi-slope screens, linear motion	CVB RF MF	Lighter duty Mining applications MNG applications MNG applications
Dry coal screening (sticky)	Inclined screens, circular motion Horizontal screens, elliptical motion Inclined screens, circular motion Multi-slope screens, elliptical motion	CVB ES RF EF	Lighter duty Mining applications Lighter duty Mining applications MNG applications MNG applications
DMS (Dense Media Applications), Coal applications, Magnetite media	Multi-slope screens, linear motion	MF	MNG applications
DMS (Dense Media Applications) All other than coal - Ferrosilicium media	Horizontal screens, linear motion	LH	MNG applications
Dewatering applications	Upwards inclined sceens with dewatering back wall, linear motion	LH-DW	AGG and MNG applications
SAG mill discharge screens	Horizontal screens, linear motion Horizontal screens, linear motion	LH LH-SAG	Lighter duty Mining applications MNG applications
Fine wet screening << 1 mm	Ultra-Fine-Screens	UFS	MNG + Industrial Minerals Applications

** final selection depends on customer segment, preferences on machine concepts and feed conditions*
AGG = Aggregate industries
MNG = Mining industries

Complete systems

Complete systems engineered to different applications
For over 100 years, Metso has provided crushing solutions to an immensely broad range of customers. As a result, we've certainly learned a few things along the way when it comes to identifying what works best and what doesn't.

Our systems have been engineered to suit a diverse spectrum of applications in the mining and aggregates industries. And because our engineers have designed systems for customers for more than a century, it's more than likely that Metso has the system that's just right for your application in question.

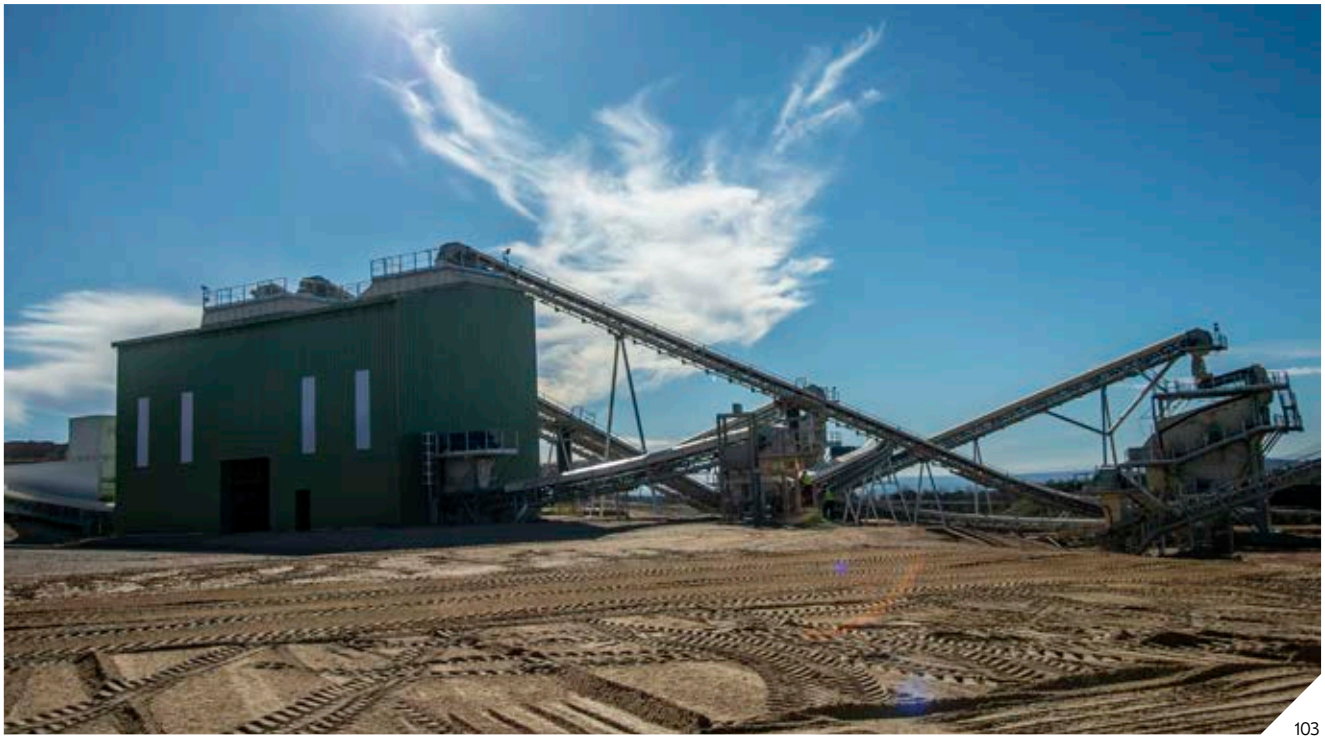


Customer can benefit off our engineering expertise
A big benefit of engineering expertise is that our equipment has been developed to match to different regional standards. Customers get machines and parts that have been built to precise engineering specifications that are tried, tested and proven, thus reducing investment risk factor.

Erection and commissioning lead times are significantly reduced, leading to a faster return on investment and lower operating costs because of these reduced operating costs per ton. Prior to start at any job site, a safety discussion is organized with all stakeholders to work in safe conditions and to avoid all injury risks.

Technology and quality to give the lowest cost per ton
Customers are invited to participate in the creation of their crushing plant throughout the entire project. They will participate in the initial system application development, engineering design, project planning, plant commissioning, operations and maintenance training and the final handover and acceptance of the project.

New, complete systems always require considerable investment. Customers need total commitment from their supplier to support the whole project application requirements, capacity plans and payback time.



Metso fully commits to a plant design that will optimize the investment and will ensure an economical payback period. Efficient cost control of a complete installation is a vital issue after the commissioning of a plant.

Based on large volumes of data gathered from complete systems through many decades, Metso can reach the operating costs discussed during the initial plant design stage.

Automation systems for remote controlling
Crushing plants in most cases are remote from the management's view. Metso has created automation systems that allow management to follow the process from remote places using the latest communication technology.

In joining the cost reduction race, customers are demanding more sophisticated technology to perform real time plant diagnosis that will allow them to optimize their plant maintenance and reduce down time.

Metso automation systems provide plants with the right tools to monitor the whole process accurately. To assist in maintenance planning, our plant automation systems can provide real time plant process data and monitor machine parameters, all of which are necessary input for the proper planning and control of plant maintenance.

Production reporting is also available as part of this automation package.

For more information, refer to CAMEOS chapter, page 146.

Proven design expertise
Metso has the experience of several decades in planning of complete crushing and screening systems. This makes us the most proven provider of plant design.

As Health and Safety are the first Metso concern, a risk assessment according to ISO standard is managed during engineering to guarantee the users safety from the assembly step to the maintenance step, for the machineries and the surrounds chutes and hoppers.

With each plant being different, we use state of the art digital design to lay out and adapt each customer's plant design to his unique site. Our systems engineering department use 3D software which guarantees an accurate plant design.

Being ISO9001-V2000 certified and working to these standards, Metso ensures the same quality and professionalism to the systems projects as seen in our production facilities.

Thorough rock fragmentation knowledge
Input from our extended sales network and our global expertise provides Metso with a thorough knowledge base of plant feed materials and their characteristics. This information enables us to predict how the customers feed material will react to the communication process and is considered and incorporated in all design aspects of a plant system.

The use of latest technology in the crushing and screening process continues to push plant design boundaries. Metso can provide flowsheet design that combines creativity and cost effectiveness.

More and more markets around the world are demanding that their end products meet stringent shape and calibration standards. We can achieve these standards using our high-quality crushing equipment.

SiteBooster™ for plant optimization

SiteBooster™ is a complete optimization solution for stationary crushing and screening plants. In a clearly laid-out project carried out by seasoned professionals, we audit the crushing and screening process and equipment of your quarry, and set the goals based on your specifications and budget.

Then the upgrade is implemented with minimal interference to the plant production. As a result, your trusty old operation will charge to a new level of productivity – from day one.

3 steps to power up

SiteBooster™ enables quarries to upgrade the safety, environmental and financial performance of their existing stationary aggregates plants for today and for the future, without compromising the productivity targets.

Metso makes certain all this is done with minimal disturbance to the current crushing and screening operations. Our SiteBooster™ process consists of 3 steps:

Step 1: audit
- Complete audit of the existing site, it's layout and assets
- Identifying bottlenecks
- Definition of what needs to be done

Step 2: redesign
- 3D scan prior to start project engineering
- Concrete solution and processes for achieving set goals with minimal downtime

Step 3: implement
- Metso expertise and experience at its best - implementation of the new design with minimal disruption of operations
- Equipment
- Process
- A supervisor manages all the installation of the equipment(s)
- The start-up is ensured also by achieving the performance promises given by the process

During the project
- One point of contact with continuous and transparent communications

For further technical information, please visit:
www.metso.com/aggregates/solutions/quarries

Mobile crushers

Mobile crushers are track-mounted rock crushing machines which are easily movable on and between production sites. They are widely used in aggregates production, recycling applications, and in mining operations. Mobile crushers can replace stationary crushing systems, thus reducing the need for dump truck haulage.

The current trend in quarrying is targeting broadly towards mobile systems and solutions. Track-mounted crushers, thanks to their mobility, can maximize productivity and reduce operating costs – while increasing safety and reducing environmental impact.

The concept of mobile and semi-mobile crushers has been around for a long time, but for years the machines were heavy and moving them required thoughtful planning. As result, the crushers that were supposed to be mobile were seldom relocated and tended to stay put in permanent facilities.

Less weight, better mobility

Today the mobile crushers are highly transportable, while their performance as well as their mobility are improved notably. Mobility is not a substitute for effective crushing, and the mobile crushers meet the same performance criteria as stationary plants.

The ability to also crush the largest lumps to the desired shape at the desired rate are all 'must-have' rather than 'nice-to-have' attributes.

The crushers used for mobile crushers are the same as for stationary plants, but with the added advantage of full mobility – even up slopes as steep as 1:20 incline.

From stationary to mobile process

Stationary primary crushers, as their name suggests, are permanently located in one site, often some distance from the quarry or mine work face and are serviced with rock/ore by a system of attendant off highway haulers.

Although effective, one issue with this approach is the cost of the haulage – which can represent more than half of all costs (drilling, blasting, loading, crushing etc.). With a continual need to increase efficiency and reduce costs, mine and quarry owners have, rightly, seen haulage as an area where cost reductions can be made.

These savings have been achieved by moving the stationary primary crusher into the quarry/pit – thereby reducing the haul distance – and replacing smaller older haulers with larger, newer ones.

But this is, at best, only a halfway measure – why not eliminate the haul (and the haulers) altogether? Mobile crushers allow this to happen.

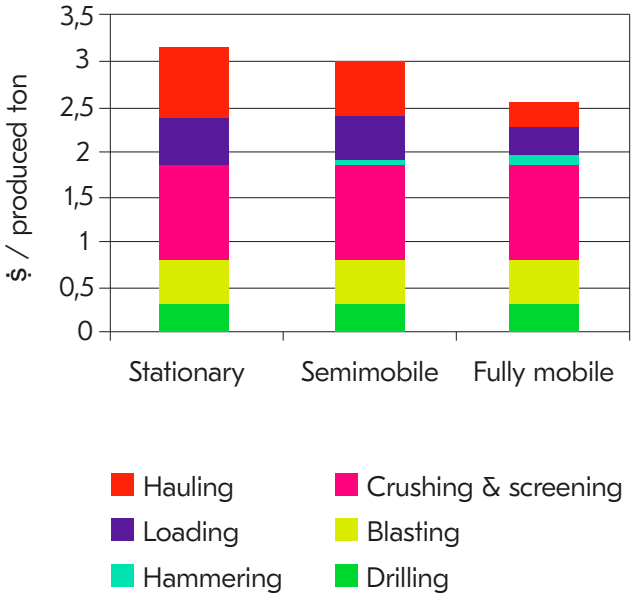
On the move

The main advantages of mobile, track-mounted primary crushers are their ability to maximize productivity and reduce operating costs – while at the same time increasing safety and reducing environmental impact.

While the concept of mobile and semi mobile primary crushers has been around for a long time, many of these were so heavy (up to 1,500 t) and needed so much planning to move them that they were seldom relocated – making them once again effectively permanent facilities.

Mobility is no substitute for effective crushing and tracked mobile crushers should meet the same basic criteria as stationary plants.

Total costs / produced ton
(K50 = 250 mm, Feed rate 1600 t/h)

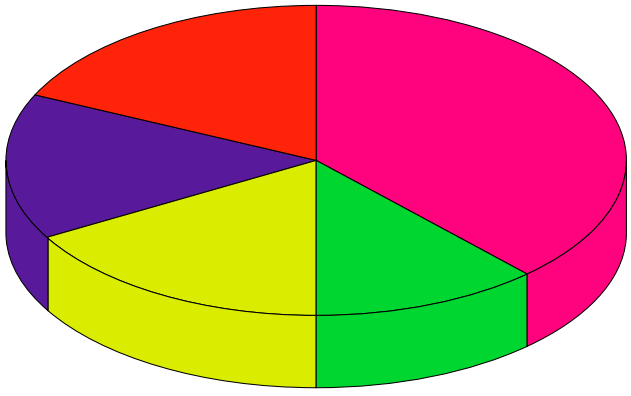


The plants should also be easy to use and maintain - and enjoy high availability and a long-life cycle. The basic components of a mobile tracked crusher are almost the same as for a stationary one (jaw or impactor crusher, power unit, vibrating grizzly feeder, feed hopper etc.) but with the added advantage of complete mobility – even up slopes as steep as 1:10 incline.

But it doesn't have to be just the primary crusher that is mobile – Metso's mobile crushers can be built with two, three or even four different crushing and screening stages.

While it is true that in terms of spares and maintenance there are more hydraulics, engine, and electronic components with mobile crushers, these are generally well supported by the OEM engine manufacturer or the crusher manufacturers themselves.

Example of quarry cost distribution



Quick and easy positioning

But where track-mounted crushing systems really come into their own is their ability to be positioned right at the work face; and then be relocated (when blasting, for example) – under their own power - in as little as 20 minutes.

It is intuitively a good solution, in terms of optimized productivity and lowest operating costs, for the crushing equipment to be sited at the rock face.

Using haulers can be very inefficient, especially when the largest haulers can expend up to 60% of their energy just propelling the vehicle's own weight – with only 40% used for moving the blasted rock.

When you also consider that by default the hauler is empty for half its operational cycle their inherent inefficiencies become apparent.

Example of quarry cost distribution

- Crushing
- Drilling
- Blasting
- Loading
- Hauling

Conveyors are much more economical than using haulers (at 80% efficiency) and there is no limit on their length (30 km+ is not uncommon in open cast mines).

Over 30% cost savings available

The potential cost savings from using a mobile crushing and conveying system based at the rock face are significant. A study conducted by Tampere University in Finland found a 31% cost saving over semi-mobile installations in similar applications.

The savings over using haulers is greater, as the excavators or wheel loaders used for feeding the haulers can be downsized (to ones more suited to the crusher rather than the hauler). Labor costs are reduced too as there are no longer hauler operators to employ. In terms of manpower, the excavator or wheel loader operator can control the complete crushing operation.

Fuel usage is also drastically reduced and there is also no longer a need to build elaborate and well-maintained haul roads – a significant additional (and ongoing) expense.

Safety too is enhanced, as fast-moving vehicles play a significant role in site accident statistics. Mobile systems will not totally replace the stationary variety. In quarries where supply is large (>500,000 tpa) and constant in a small radius the stationary plant is justified.

But where supply is not large, then mobile plants have the advantage of being able to circulate between locations and build up stockpiles. In mining, the advantages of having a primary crusher feeding a conveyor system are becoming more recognized as an effective solution.

The premium quality Metso components together with Caterpillar® and Volvo diesel engines guarantee that your Lokotrack® runs smoothly, efficiently, and safely.

With their lower capital and operating costs, flexibility of siting and elimination of the need for haulers and haul roads, mobile crushing plants offer an attractive alternative to the traditional stationary crusher & hauler system.

The reduction in manpower, fuel usage and pollution are mirrored by an increase in health and safety. Offering higher productivity and low cost per ton production, truly mobile tracked crushing plants are destined to become a more common sight in quarries and mines worldwide.

Intelligent controlling provides optimum results
Metso is a pioneer in incorporating the revolutionary IC™ process control system technology into its track-mounted crushers and mobile screens.

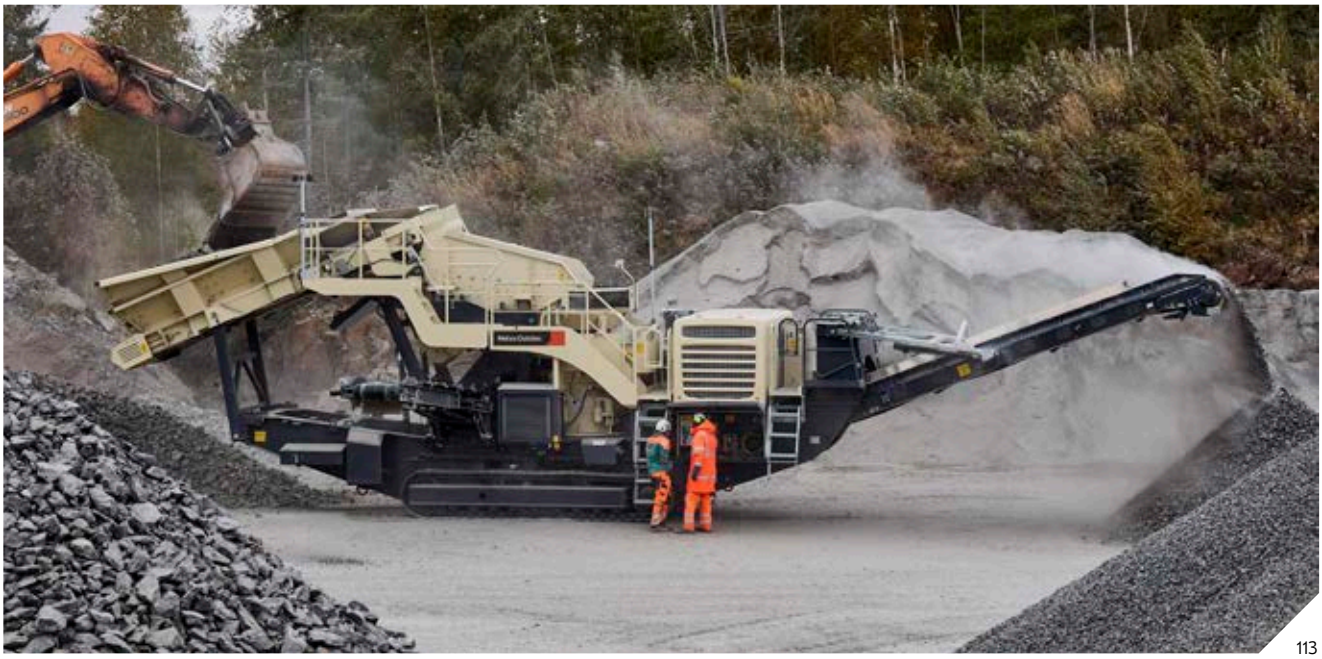
With Metso IC™ process control system you can automate, monitor, control, and optimize the entire crushing process for better productivity, less downtime, and consistent end product quality.

IC technology also means it is possible to link the whole mobile crushing and screening process together.

Our wireless information and control system transfers information from excavator cabin
We also offer the wireless system to enable remote monitoring and control of the crushing process from the excavator cabin.

Wireless monitoring system makes the work of operator easier and safer. All main crusher setting changes can be made easily without the need to leave the excavator. The commands are transmitted using a Bluetooth connection.

The use of the wireless information transfer system adds working safety when minimizing unnecessary walking between the machines.



Lokotrack® and Nordtrack™ product families
Metso's mobile crushing equipment consists of two different product families, Lokotrack® and Nordtrack™ mobile crushers. Both families can be utilized in aggregates production in quarries and construction sites, recycling applications, as well as in mining operations.

Lokotrack® offers a wide range of track mounted jaws, impactors, cones and screens – as well as optional equipment to meet the specific application requirements.

On the other hand, Nordtrack™ products offer more purpose-designed and simple solutions suitable for stand-alone applications.

The family consists of mobile jaw crushers and horizontal shaft impact crushers ideal for short-term contracting, rental offerings, and entry level entrepreneurs.

Metso Metrics maximizes the uptime of your machines
Metso Metrics is a cloud-based remote condition monitoring platform. It connects your crushers and screens giving you data-visibility to improve:

- Availability
- Performance
- Reliability
- Profitability

For more information of Metso Metrics please visit page 162.

For further technical information, please visit:
www.metso.com/aggregates/products/crushers/mobile-crushers

Lokotrack® jaw crushers

Popular Lokotrack® jaw crushers are utilized as primary crushers for reducing the material to smaller sized for further processing.

Lokotrack® mobile jaw crushers suit well for aggregates production and recycling demolition and other waste. They are designed to be easy to transport between sites and quick to set up.

For further Lokotrack® jaw crushers product and technical information, please visit:
www.metso.com/portfolio/lokotrack-lt-series

Lokotrack® cone crushers

Track-mounted Lokotrack® cone plants are ideal for producing aggregates for road construction and railroad ballast, as well as for asphalt and concrete fractions.

Lokotrack cone crushers are used mainly as secondary, tertiary, and quaternary crushers. In case the grain size of the processed material is small enough by nature, they can also operate at the first stage of the crushing process.

For further Lokotrack® cone crushers product and technical information, please visit:
www.metso.com/portfolio/lokotrack-lt-series

Lokotrack® impact crushers

Lokotrack® HSI impact crushers are equipped with a horizontal impact crusher and they are used as primary, secondary, or tertiary crushers.

Lokotrack® VSI impact crushers are equipped with vertical shaft impact crusher, and they are efficient in the final stage of the crushing process, producing precisely shaped cubical end products.

For further Lokotrack® cone crushers product and technical information, please visit:
www.metso.com/portfolio/lokotrack-lt-series

Lokotrack® Urban™ series mobile jaw crushers

Lokotrack® Urban™ Series mobile jaw crushers are noise and dust encapsulated crushing machines that comply with stricter regulations and allow crushing and screening in cities, urban environments, and other populated areas.

The unique noise encapsulation features cut the crushing noise protection distance up to 60% compared to conventional crushing.

Track-mounted Lokotrack® Urban™ Series crushing plants are available in a wide range of configurations and capacities, including models with an integrated screen.

For further Lokotrack® Urban™ Series mobile jaw crushers product and technical information, please visit: www.metso.com/portfolio/lokotrack-urban-series

Lokotrack® e-Power solutions

Electric power has the advantage of being quiet, emission free, and economical whenever the grid is available, like on construction sites in the city. Metso Lokotrack® e-Power solutions provide the highest environment-friendliness in crushing.

Wherever your job takes you, the e-Power solutions make sure you have the advantage of always using the cleanest, most economical power option. There is no beating the flexibility of a modern low-emission, low-noise diesel engine – with a full tank you can work for days anywhere. When available, using electric power from the external power grid provides the most economical and environmentally friendly option for operating the mobile crusher.

So why not have both options built in your machine? The Lokotrack® e-Power solutions gives you twice the choice – with new job opportunities, cost savings and ease of maintenance.

For further Lokotrack® e-Power mobile crushers product and technical information, please visit: www.metso.com/aggregates/products/lokotrack/lokotrack-e-power-solutions

Nordtrack™ mobile crushers

Nordtrack™ mobile crushers
Nordtrack™ mobile crushers are designed for crushing construction and concrete demolition waste, asphalt recycling and small-scale production of medium and soft rock aggregates.

They are most suitable for short-term contracting, rental fleet offering and for entry level entrepreneurs. The mobile jaw crushers with wide cavity and impact crushers range include compact and agile models for crushing recycled aggregates in building construction sites, as well as bigger models for multi-stage aggregate production process.

For further Nordtrack™ mobile crushers product and technical information, please visit:
www.metso.com/portfolio/nordtrack-crushers

Mobile screens

Mobile screens are a cost-effective and flexible way to screen material at your production site. Our wide range of mobile screening equipment provide excellent productivity in smaller aggregates production sites, larger quarries and in mining applications.

Mobile screens, or mobile screening plants as they are also called, are utilized in top soil and recycling applications in the construction sites, in aggregates production, quarries, and in mining operations whenever movable but high-capacity screening is required.

Mobile screens are typically divided in two different types of screening applications; primary screening (scalping) and fine screening (aggregates). Scalping screens are increasingly used nowadays also for fine screening applications (multi-purpose screening).

Excellent mobility and reliability
As the name suggests, mobile screens have outstanding mobility. They can easily be adjusted to perfectly fit your changing process or location needs.

High-quality components and engineering without compromises ensure trouble-free production. When service is required, it can be done simply and easily through easy-to-access maintenance points.

Improved production capacity
Metso mobile screens are based on extensive testing and quality control for increased operational efficiency and reduced downtime.

Having a mobile screen in combination with a mobile crusher can greatly improve your process capacity and flexibility to produce different kinds of end products.

Spare parts and wear parts, as well as services for mobile screens are available through Metso's worldwide network.

Two families for different screening needs
Metso's mobile screens offering consists of two different product families, Lokotrack® ST mobile screens and Nordtrack™ mobile screens.

Lokotrack® ST mobile screens range is known for high-quality and is targeted more to aggregate producers and quarry customers whereas Nordtrack™ mobile screens are more focused to general contractor applications.

ST scalping screens are ideal for screening and scalping blasted rock, sand and gravel, recycled concrete and topsoil to produce a variety of construction and landscaping materials such as road base, and railway ballast.

ST aggregate screens are ideal for screening crushed rock as well as sand and gravel to produce aggregates for concrete and asphalt, road base, building foundations and railway ballast.

Nordtrack™ mobile screens include scalping and product screens. They are simply designed units which perform best in generality of applications and thanks to high mobility are very suitable for project contracts. Nordtrack™ screens are suitable for various applications from topsoil and agricultural materials to aggregate screening and can be used in mobile trains or stand-alone applications.

For further technical information, please visit:
www.metso.com/portfolio/screens/mobile-screens

Lokotrack® mobile screens

Lokotrack® ST track-mounted screening plants provide you flexibility and multiple options, depending on produced material, production volume, site characteristics, and location.

Robust, high-quality Lokotrack® ST mobile screens operate in various standalone and multistage recycling and aggregates applications.

For further Lokotrack® mobile screens product and technical information, please visit:
www.metso.com/portfolio/screens/mobile-screens

Nordtrack™ mobile screens

Nordtrack™ mobile screens are track-mounted units that come in standard configurations, making them ideal for short-term contracting, rental offering, and entry level entrepreneurs.

Nordtrack™ mobile screen range includes scalping screens and product screens that can be used both in stand-alone applications and mobile trains. They are suitable for various applications from topsoil to aggregate screening and are available in several size-classes and deck configurations.

Nordtrack™ screens can also be equipped with Dual Power-system which allows the units to be powered with external electric source for more sustainable operations.

For further Nordtrack™ mobile screens product and technical information, please visit: www.metso.com/portfolio/nordtrack-screens

Nordtrack™ mobile conveyors

Nordtrack mobile conveyors
Nordtrack™ mobile conveyors are track- or wheel-mounted independent units used for material transfer around the worksite. Conveyors can be used for example to create closed loops with existing machinery, creating larger stockpiles, or moving material to further stages of the process.

The use of mobile conveyors can improve plant efficiency and safety by reducing the need for wheel loaders. Also, operating costs can be reduced by lowering fuel consumption and need for designated operators.

Nordtrack™ conveyors are made for convenient transport and are available in different lengths. Several optional features are available to customize the unit for desired application.

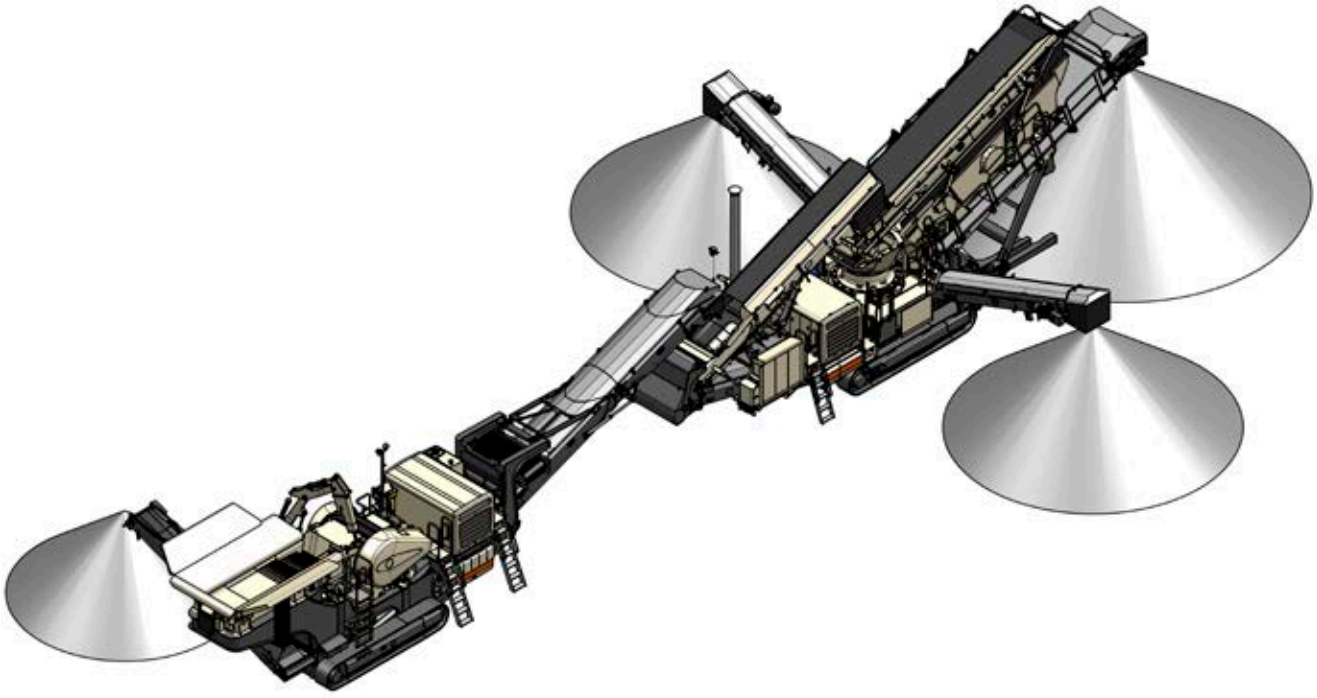
Track-mounted units are always operated with diesel power unit, but wheeled units can be chosen to be powered by external electricity or hydraulic PTO.

For further Nordtrack™ mobile conveyors product and technical information, please visit:
www.metso.com/portfolio/conveyors/mobile-conveyors

Mobile process examples

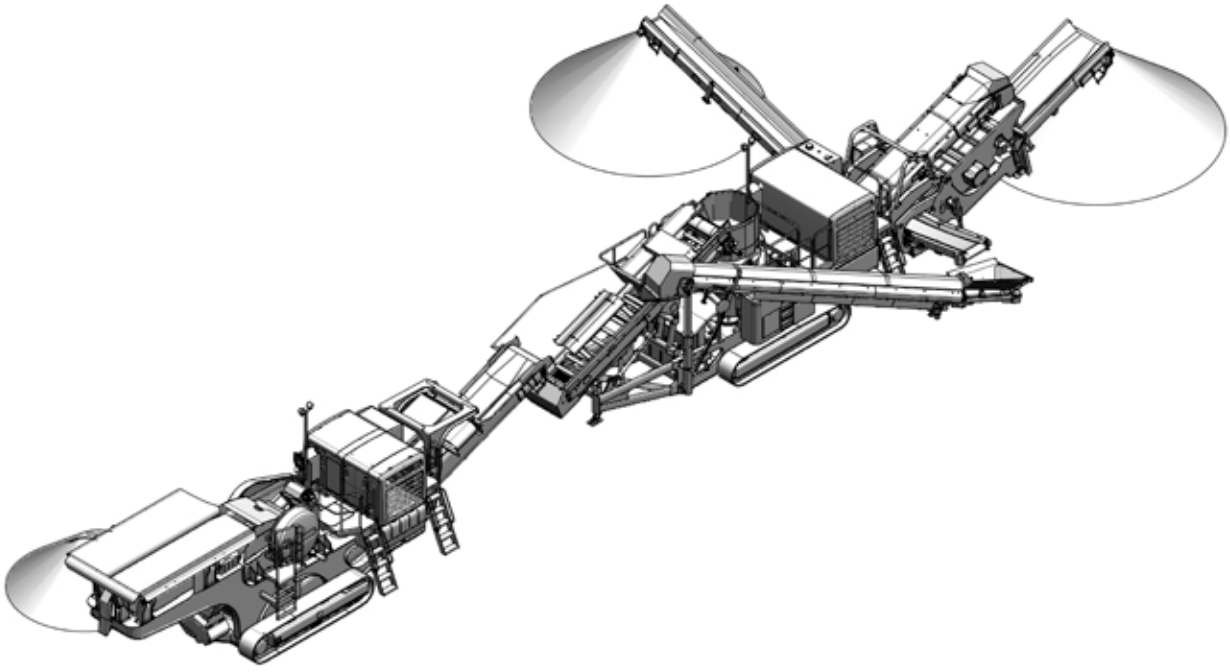
Mobile jaw and cone crushers

LT120 + LT330D

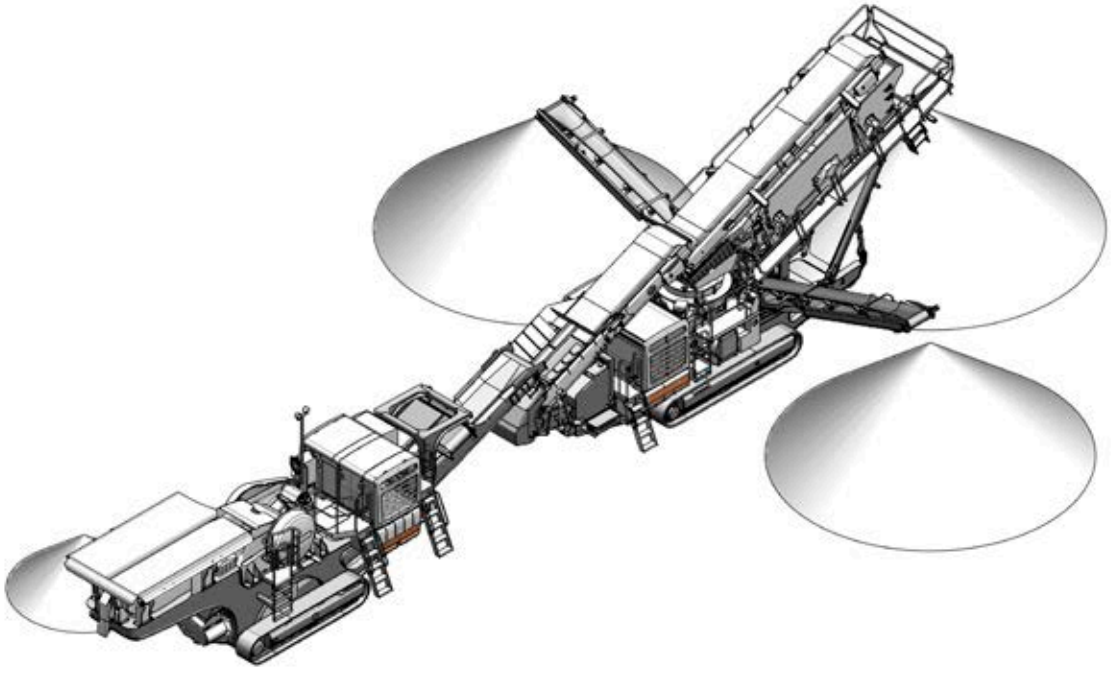


Mobile jaw and cone crushers

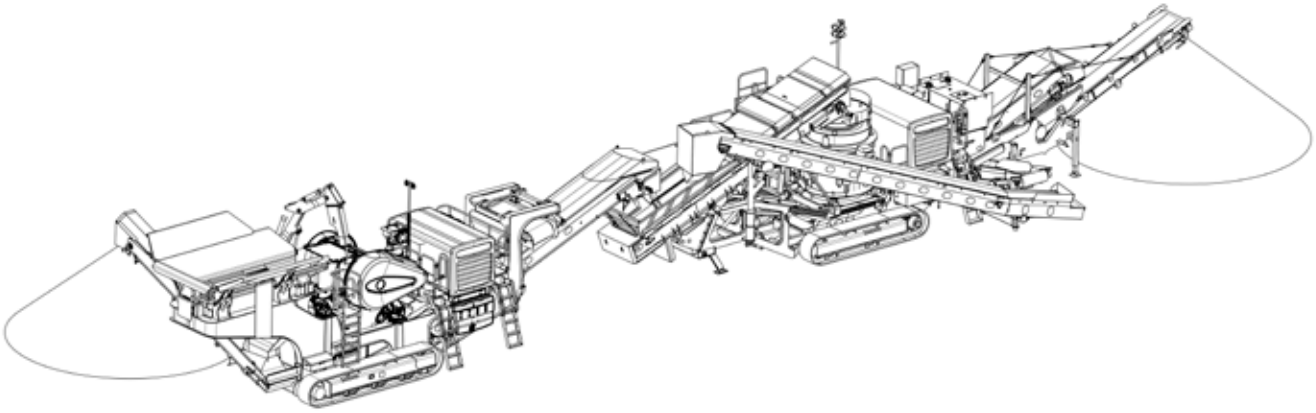
LT106 + LT200HPS



LT106 + LT220D

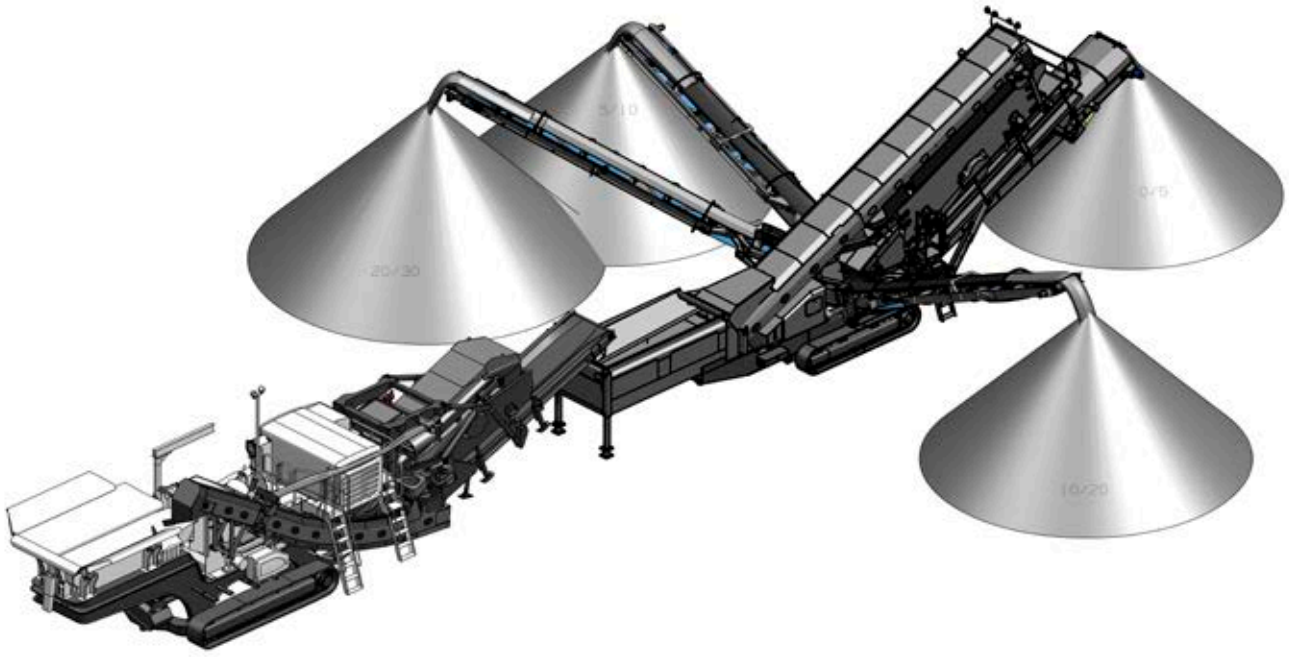


LT20 + LT300HPS



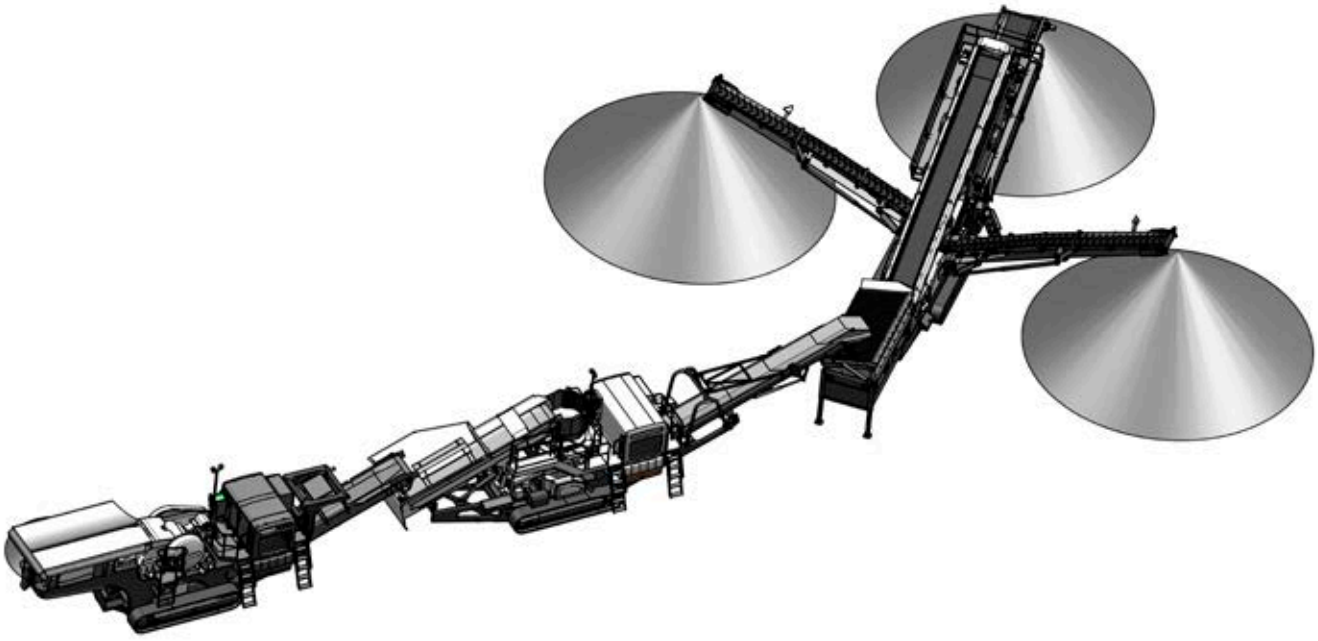
Mobile impact crushers and mobile screens

LT1213S + ST4.8

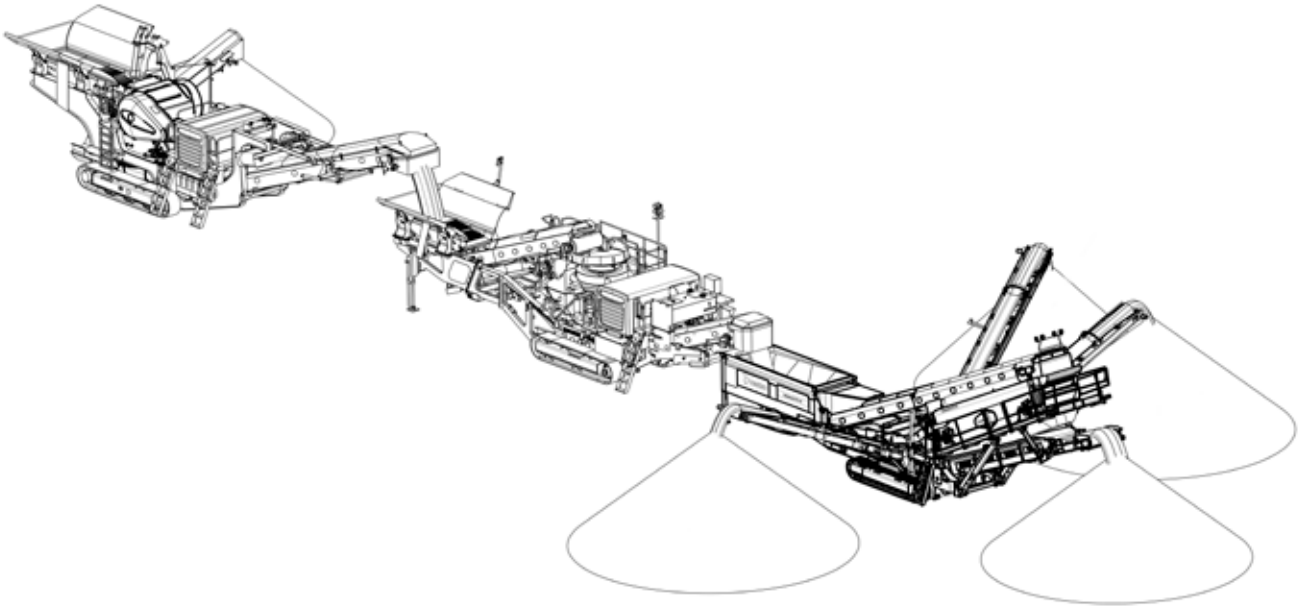


Mobile jaw and cone crushers and mobile screens

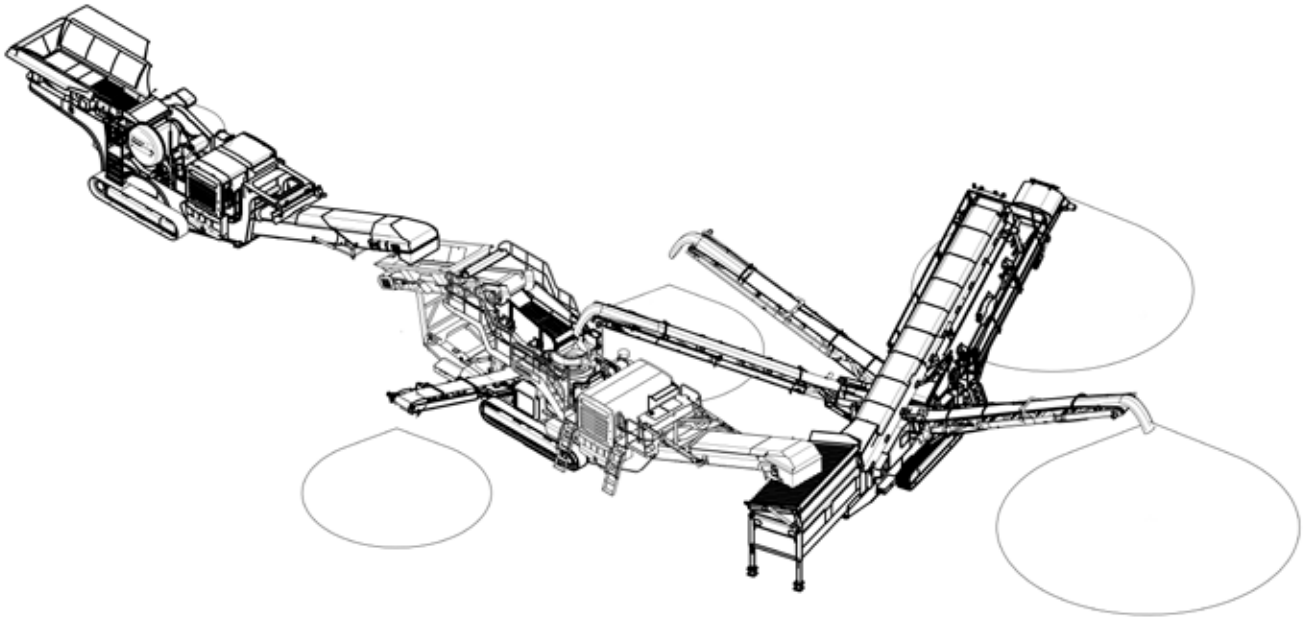
LT106 + LT200HP + ST3.8



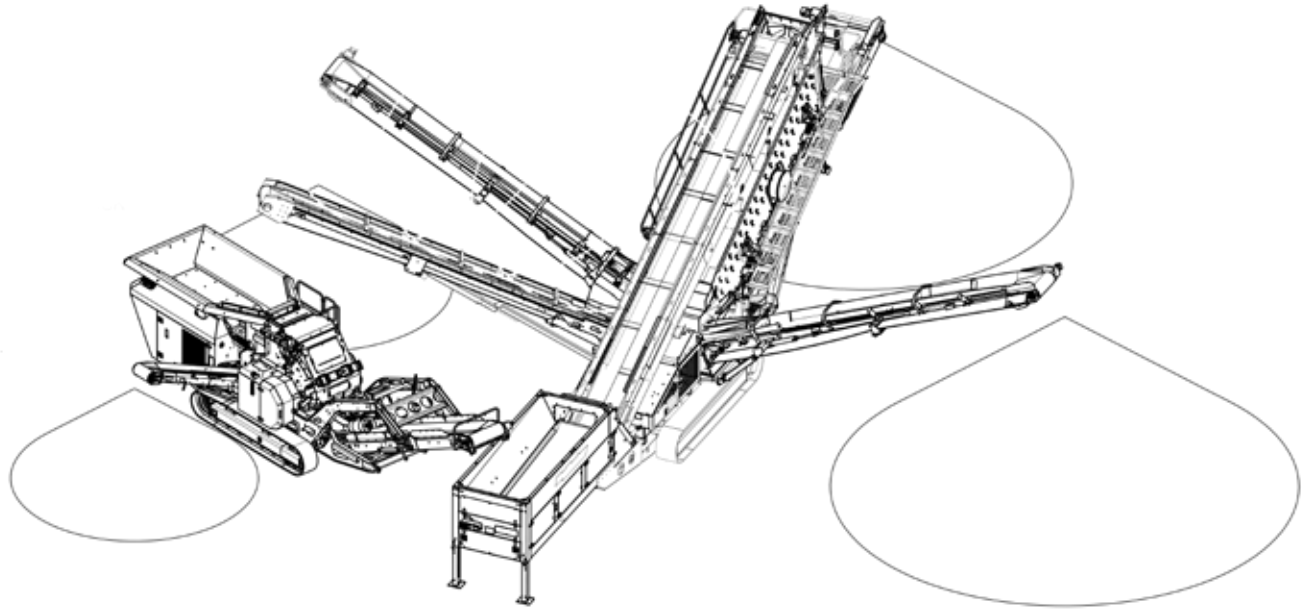
LT120 + LT300HP + ST4.10



LT106 + LT200HPX + ST4.8



I908S + S4.9




HYUNDAI
HYUNDAI
ELMER OY

Nordwheeler™ portable plants

Nordwheeler™ NW Rapid™ portable crushers and screens are wheel-mounted crushing machines that are made to process hard rock, soft rock, and recycled materials. They can operate independently, part of crushing station or as a multi-stage crushing and screening plant. Many models can be equipped with an integrated feeder and a screen into the same frame.

Thanks to transportability, the NW Rapid™ crushers and screens commonly open new business opportunities for aggregate contractors, quarry operators, recyclers, and offer flexibility in mining applications.

The NW Rapid™ portable crushers and crushing stations provide excellent size reduction performance. Electric drive ensures environment-friendly operation.

Crushing technologies

Metso's portable crusher and crushing station range consists of primary, secondary and tertiary models. All of these can be easily transported via road network between sites and can be fed with dump truck, wheel loader or excavator.

Primary units (Jaw and HSI) are equipped with an integrated feeder, crusher, and main conveyor. Secondary, tertiary, and fine crushing units often come with an integrated crusher and screen on common chassis - however single crusher on chassis is also an option when screening is not needed at the same machine.

Our basic primary crushing station is based on optional feeder with grizzly for materials loading. As standard, the primary crusher is a jaw type including various sizes according to the capacity requirements.

The side conveyor removes the quarry fines before (not after) the primary crushing before further processing. This is an option to scalp out the fines - it's not a must. If feed is clean and user chooses to send the quarry fines further down the process, it's possible to discharge the scalped fines to the primary unit main conveyor, fines bypasses the jaw in this case.

Feeding conveyor transport the material from surge hopper to crusher or to a screen depending on the application requirements. Discharge conveyor reclaims the material from a crusher and in closed circuit operation returns it to the screen, and in open circuit operation makes a stockpile of its own or sends it further down the process stream. Stockpiling conveyors are used to make a stockpile of a ready made product.

Normally, as the secondary crusher, GP or HP series cone crushers are being used.

In many cases portables secondary crusher are built with cone crusher and screen placed on the same chassis. However, separate crushers and screens are an option for an application where there isn't need for integrated solution. Same applies for tertiary plants with cone or Barmac.

Metso NW Rapid™ portable tertiary plants are like the secondary crushers, consisting of a Barmac vertical shaft impact crusher and a screen built on the same chassis.

NW Rapid™ designed for quick set-up
Metso portable NW Rapid™ range is pre-designed for fast delivery and quick set-up.

With NW Rapid™ portable solutions you can stop compromising between time, mobility, and production capacity, and tap into new business opportunities.

Designed especially for the needs of multisite quarries that must move their equipment between sites periodically, NW Rapid™ portable crushers and screens are easy to tow by a standard truck.

NW Rapid™ models are designed to be easily shipped safely in containers.

Combine crushing stations to make a complete plant
By combining primary, secondary and tertiary crushing stations, you can easily build a two-stage, three-stage or even a four-stage crushing and screening plant.

The NW Rapid™ crushing station concept consists of wheel-mounted crushers and screens combining Metso feeders, screens, crushers, and conveyors, along with all accessories necessary to build a portable station that meets needs for high capacity and high end-product quality.

Primary units can be fed with a dump truck using optional dump truck hopper, with a wheel loader using optional feed hopper extensions and with an excavator. Secondary, tertiary and fine crushing units are most often fed with conveyor via surge hopper. Surge hopper can be equipped with an optional wheel loader feed extension enabling the feed with wheel loader. In some applications, secondary or fine crushing gets its feed directly from primary without surge hopper in between the stations.

The ready-made plant layouts and flowsheets for different capacity plants make the selection easier.

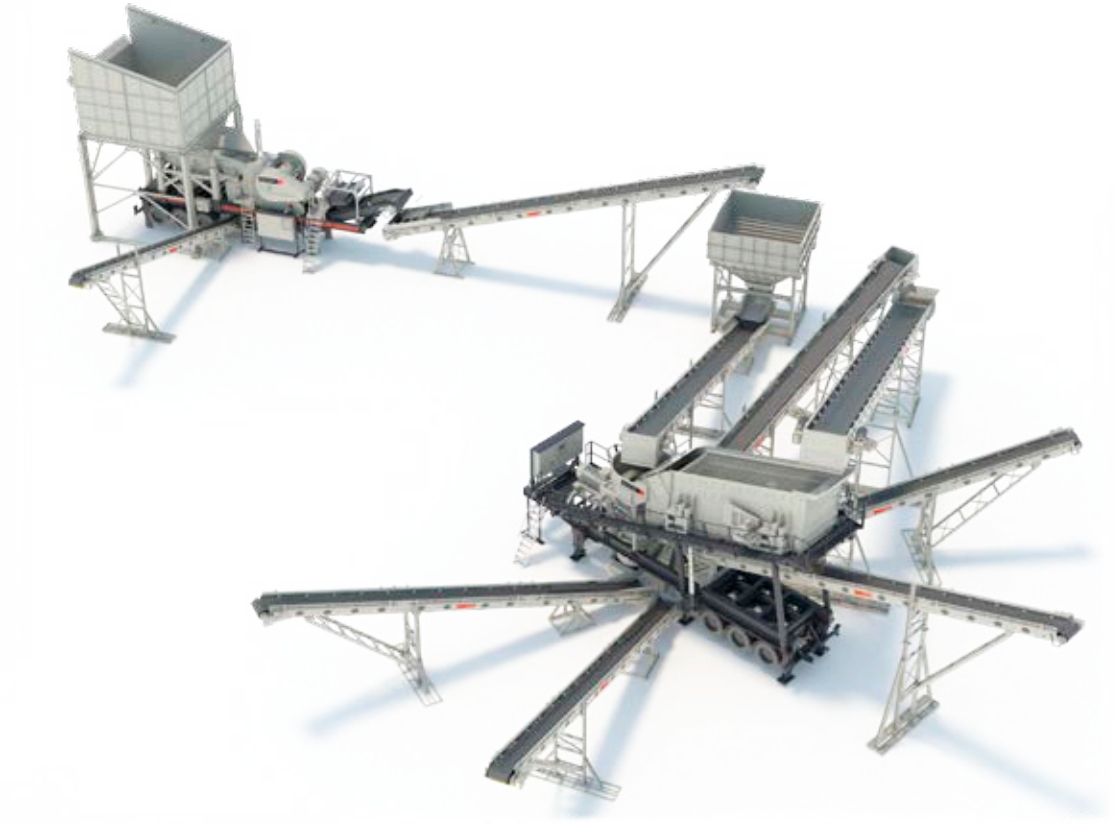
Nordwheeler plants are operated on electrical power. This environmentally friendly and reliable approach enables utilization of main power networks or generator stations, depending on availability. Operation on electrical power yields huge savings in operating and maintenance costs.

For further NW Rapid™ Series portable crushers product and technical information, please visit: www.metso.com/aggregates/products/nw-rapid

For further NW Rapid™ Series portable screens product and technical information, please visit: www.metso.com/portfolio/nw-rapid-portable-screens

Portable crushers and screens

Primary crushing station consists of dump truck hopper allowing the feed with dump truck, a primary crushing unit, side conveyor separating the quarry fines and a main conveyor extension, making the primary crushed material stockpile, or alternatively feeding the secondary crushing station surge hopper.



Secondary crushing station consists of a surge hopper receiving the material from a primary crushing station main conveyor extension or from a wheel loader, a feeding conveyor that can feed to a cone or alternatively to a screen via recirculation conveyor, a cone discharge conveyor receiving crushed material from a cone crusher, a recirculation conveyor receiving the crushed material from a cone discharge conveyor and returning the material to the screen, as well as four end product conveyors that make the stockpiles of the final products.

Conveying

1. Different areas of conveyor use and choosing of conveyor type

With over one hundred years of experience, and tens of thousands of conveyors in operation, Metso offers a range of conveyors answering different requirements for safe, reliable, and easy to maintain equipment.

Belt conveyors
Conveyors are used to handle bulk products from a machine to another one or to feed a stockpile. They are important equipment in the crushing and screening process for the plant availability.

They are installed in mobile and fixed plants.

Metso has several ranges to comply with the customers' needs and the countries.

- NC range - delivered in PrimeSite or Sitebooster solutions
- TBC range - compact design - delivered in PrimeSite, Sitebooster solutions or Modular solutions
- Nordplant range - delivered in Nordplant solutions

2. Measuring of a conveyor

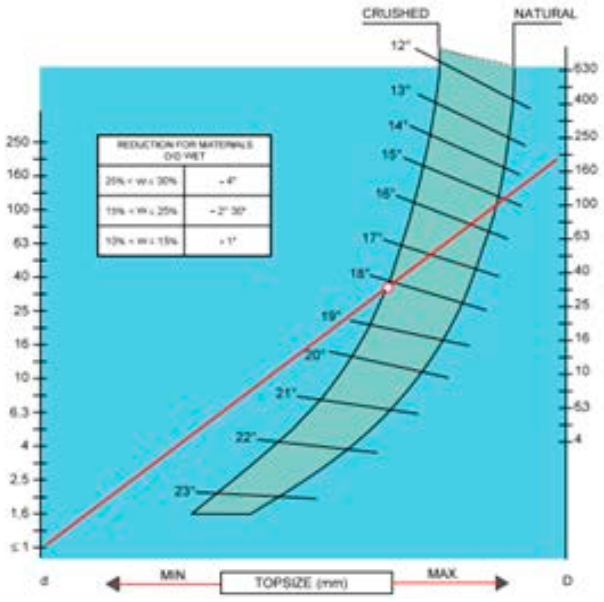
a. Conveyor selection
The belt conveyor slope is defined according to handled products characteristics:

- Product size
- Crushed or natural
- Moisture

The slope is defined on the picture.

The belt conveyor width is selected according to handled rocks size and belt trough angle.

The belt width is defined on the picture:



Belt width	Rocks dimensions in mm		
	Large with 90% fines	Large with 50% fines	Large rocks
500 Trough angle 35°	160	110	90
650 Trough angle 45°	220	150	120
800 Trough angle 45°	300	200	160
1000 Trough angle 45°	400	270	220
1200 Trough angle 45°	500	340	270

The belt conveyor capacity is defined according to speed and conveyor slope.

The belt speed is selected according to the handled products:

- Main applications: 1,8m/s
- Raw products: 1,4m/s
- Overland conveyors with end products: 2,2m/s

Surcharge angle and density are information based on the characteristics of the handled product.

The conveyor slope could be a parameter to optimize the conveyor belt selection, but most of the time 15° is considered as standard parameter.

The belt conveyor capacities are defined on the below picture:

Belt conveyors - capacities				
	Belt speed (m/s)	1,4	1,8	2,2
	Conveyor slope (*)	15*		
	Surcharge angle (*)	15		
	Density (t/m³)	1,6		
Belt width	Roller trough angle	Capacity	Capacity	Capacity
mm	°	t/h	t/h	t/h
500	35	136	175	214
650	45	285	366	448
800	45	446	573	701
1 000	45	732	941	1150
1 200	45	1071	1377	1683

b. Power calculation

The parameters which are required for the power calculation are:

- Belt width
- Conveyor length
- Handled capacity
- Belt speed
- Conveyor elevation or slope
- Skirting and loading points
- Sealing device if any

The power is calculated in 3 steps:

- Power to move the empty belt, flat conveyor
- Power to move the loaded belt, flat conveyor
- Power to lift the loaded belt, based on the conveyor slope or elevation.

It is important to take into consideration:

- For raw products from a jaw crusher: a safety factor shall be considered to take into consideration the flow variation
- Motor efficiency: an efficiency factor shall be considered between the required calculated power and the installed power
- Motor starting: DOL or VSD

3. Presentation of conveyor parts, their meaning and different options

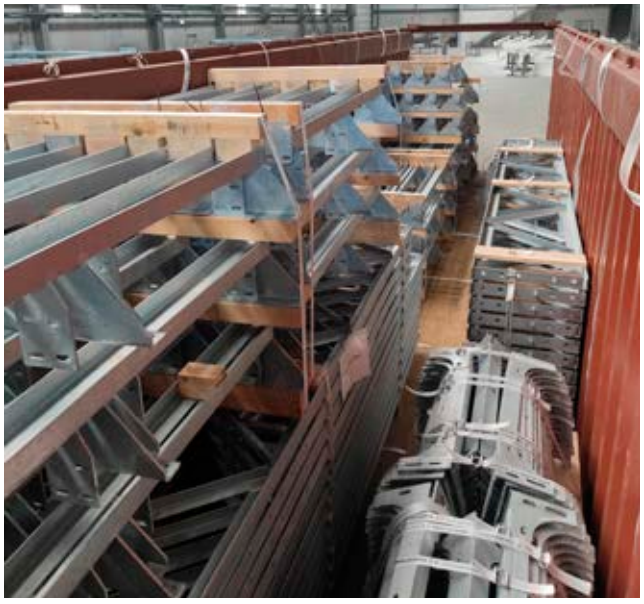
Basic design rules:

- The conveyors are designed for an operating life of 25000h, in a temperatur range of -35°C / 35°C or 0°C / 35°C
- The conveyors are designed based on the European standard EN620 and the European machinery directive 2006/42CE

Mean features:

- TBC series: compact conveyors
  - **Widths 500, 650, 800, 1000, 1200 mm**
  - **Length up to 20m**
  - **Motors powers up to 18.5kW**
  - **Without walkways**
- NC series: standard conveyors
  - **Widths 500, 650, 800, 1000, 1200 and 1400 mm**
  - **Length to 200m (for overland)**
  - **Motors powers to 150kW**
  - **Walkways as an option**

	NC	TBC
Frame	Truss / Overland	Bended design
Carrying idler through angle	45° excepted for NC05: 35°	25°
Roller standard	ISO1537	ISO1537
Tail drum profile	Crown	Crown
Drum & shaft connection	Welded Hub as an option	Welded
Walkway width (at guard rail level)	800 mm	NA
Walkway Load	150 kg/m² Option: 250 kg/m²	NA
Gearbox and pulley connection	Hollow shaft and key Hub as an option	Hollow shaft and key
Nip point safety guards	Close protection or Mesh panels	Mesh panels



Delivery
NC and Nordplant ranges
They are delivered on kit which have to be assembled on site, based on the bill of material and 3D model.

TBC range
TBC are assembled in a workshop.
For delivery on site, the TBC could be split in two parts according to the length and the transportation regulation.

4. Dust control devices

These options are available only for the NC range.

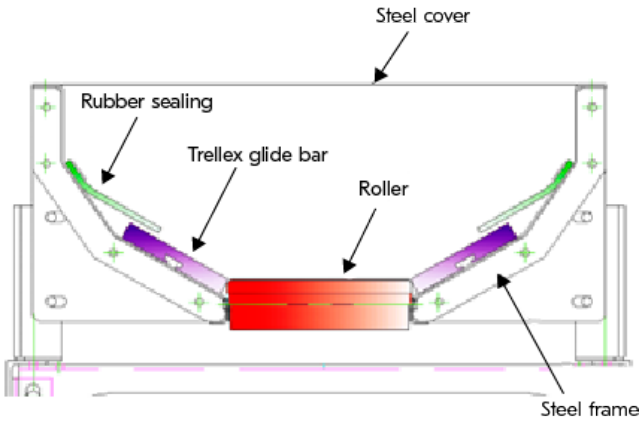
Dust contributes to atmospheric pollution and cause respiration diseases. Metso could help the crushing and screening plant user to improve the dust emissions control with 2 options.

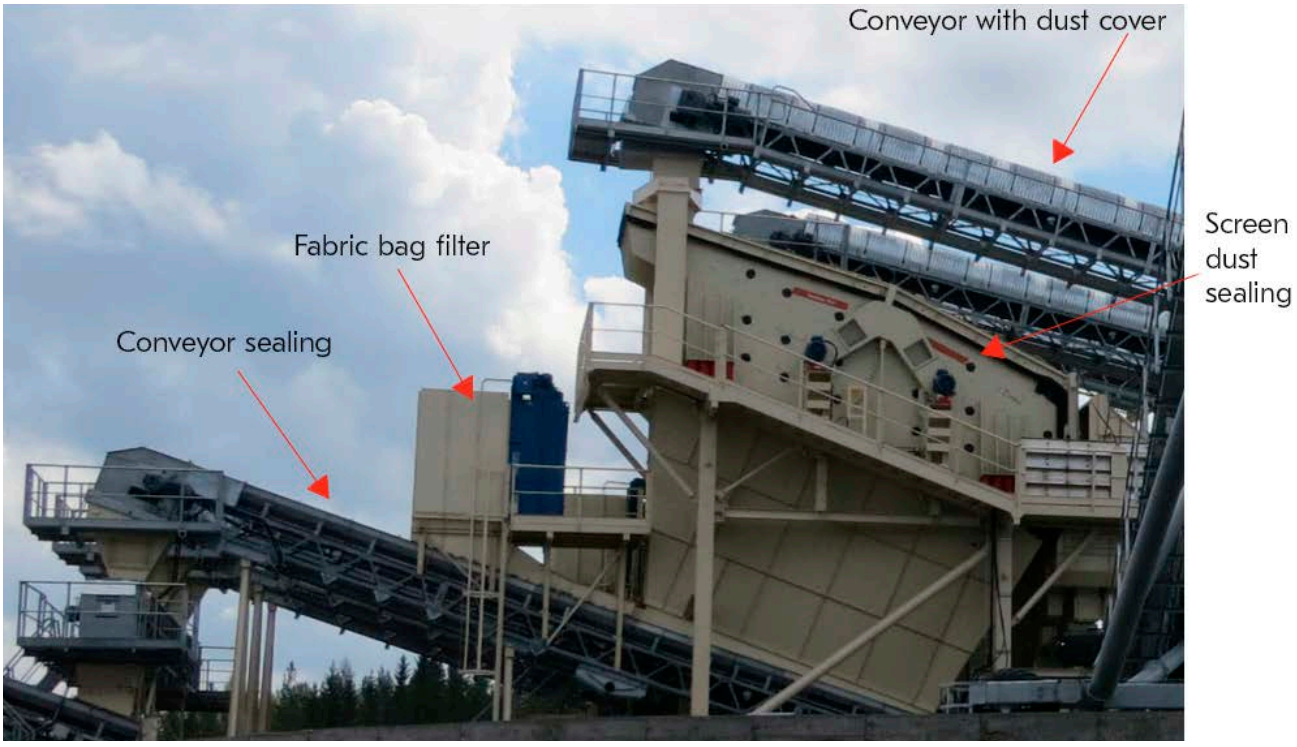
Dust sealing

The dust sealing is installed instead of the rubber skirting where fine products for dust encapsulation to protect for environmental and health reasons.

The dust sealing device is made of a steel U frame, with a top cover.

Inside the U frame, the belt is sliding on PU bars and a rubber skirting is added for an optimal sealing.

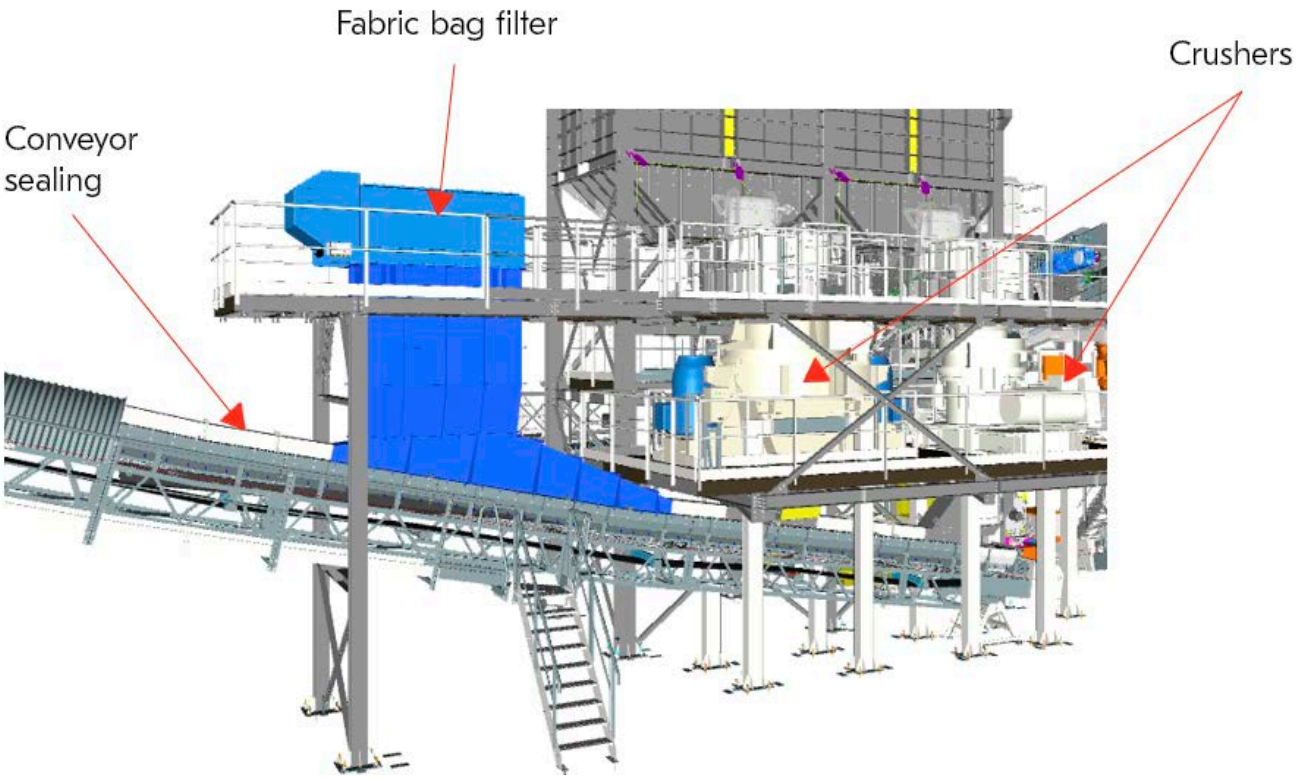




Dust local collector

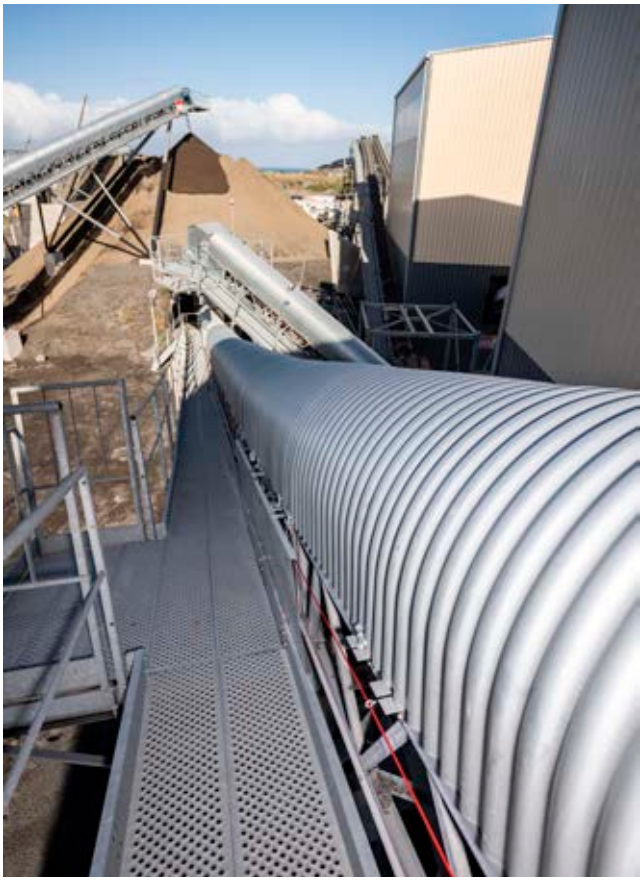
On the top of the dust sealing, just after the crusher or the screen, a local bag filter is installed to fix the airborne dust. The airborne dust is collected on the filter bags and rejected on the belt.

To obtain significant efficiency of these devices, the crusher or the screen shall be encapsulated with high performance devices, e.g., Trellex sealing for screen (see picture above).



5. Conveyor examples

Crushing and screening plant with NC series conveyors.



Examples of TBC series conveyors

Crushing and Screening Nordplant with Nordplant conveyors.

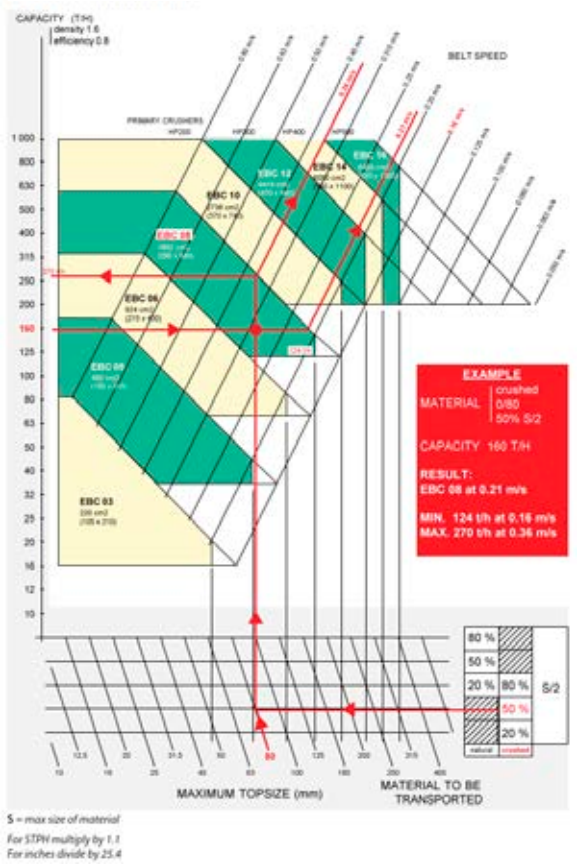
For further product and technical information, please visit:
www.metso.com/portfolio/conveyors

Belt feeders

Different types of belt feeders are available for feeding and reclaiming application. They are installed to control the process flows. Motor electrical supply shall be piloted trough a Variable Speed Drive.

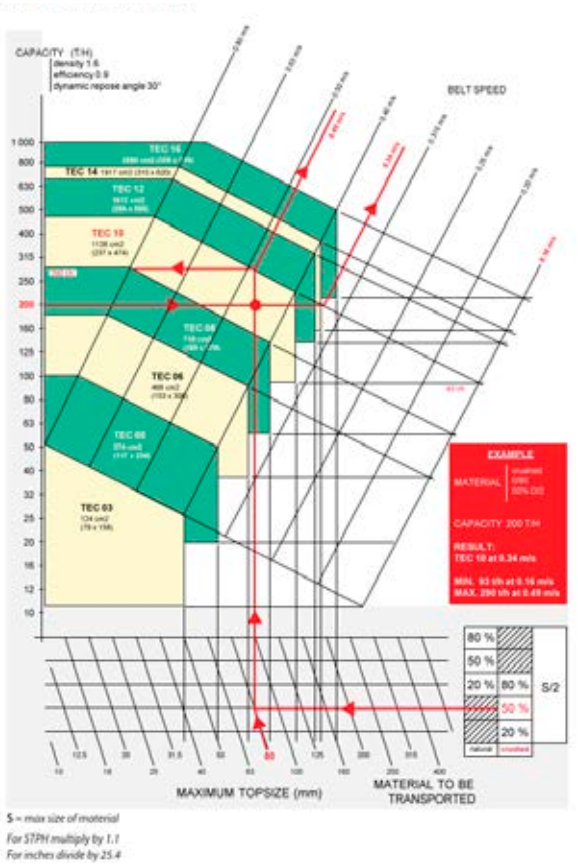
The graphics below are available for material density 1.6

EBC Belt Feeder/Selection chart



S = max size of material
For STPH multiply by 1.1
For inches divide by 25.4

TEC Belt Feeder/Selection chart



S = max size of material
For STPH multiply by 1.1
For inches divide by 25.4

1. Different areas of belt feeder use and choosing of belt feeder type

EBC - reclaiming feeders

- delivered in PrimeSite or Sitebooster solutions
- EBC is used to reclaim products under stockpiles to feed hoppers, crushers or end products loading stations

TEC - process feeders

- delivered in PrimeSite or Sitebooster solutions
- TEC are used to managed process flows

CBF - process feeders – crushers feed

- delivered in PrimeSite or Sitebooster solutions
- CBF are used to feed cone crushers

2. Measuring of a belt feeder

a. belt feeder selection

Belt feeders selection

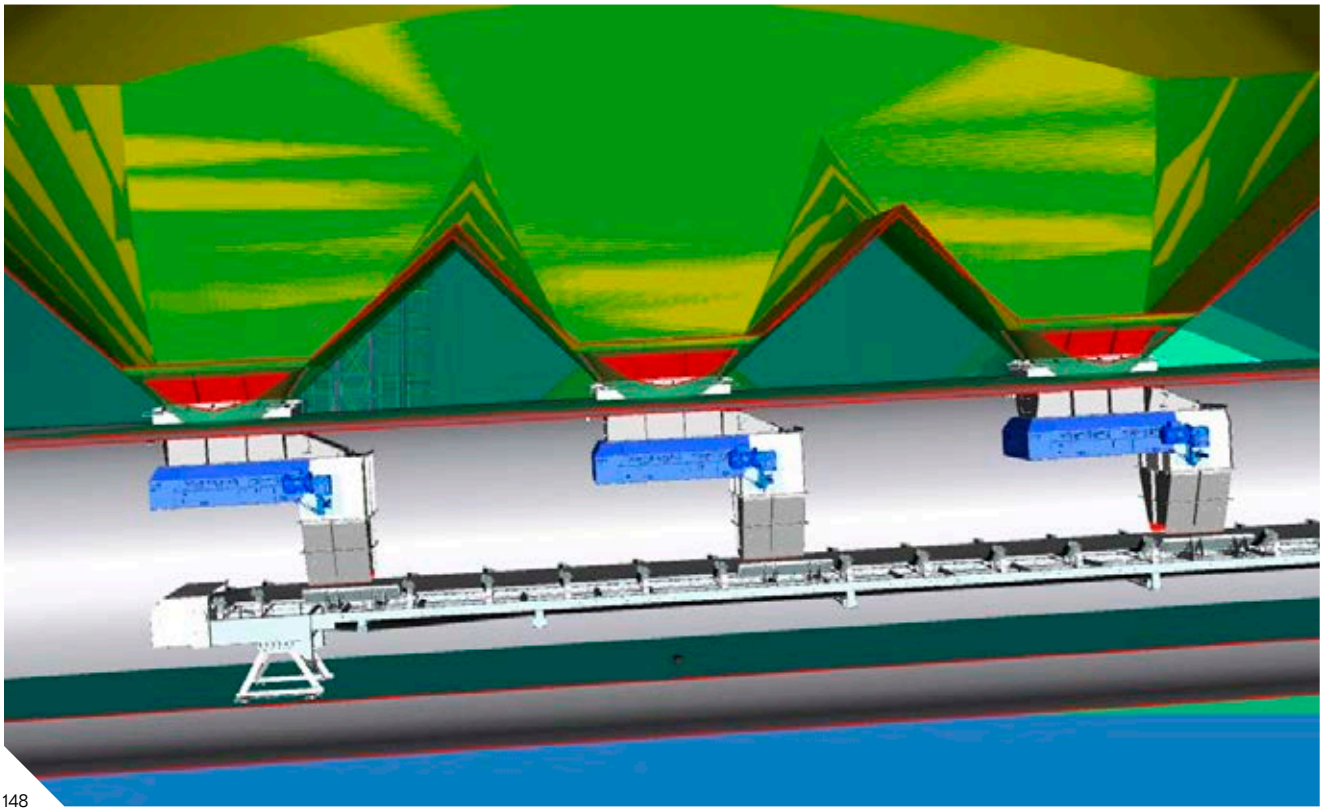
Belt feeders are the maximum top size of the handled materials, the type of material: natural or crushed, and the speed: the standard speed is 0.8m/s.

CBF belt feeder / Selection table

HP crusher	BF belt width
HP200, HP300, HP3	CBF800
HP400, HP4, HP5	CBF1000
HP500, HP6	CBF1200

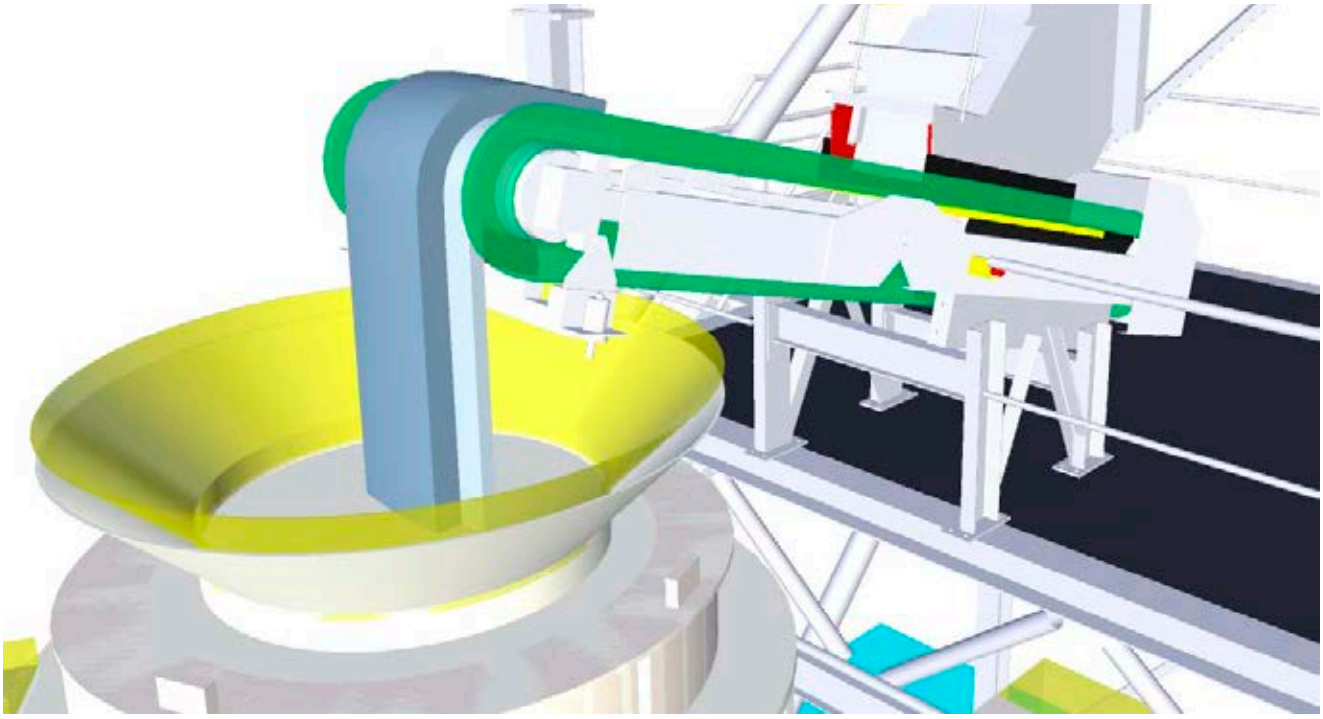
3. Belt feeders examples

EBC



TEC

CBF



Automation and electrical components

Overview

To guarantee the perfect functioning, it is essential to choose the right electrical components.

Motors

Thermal class
Motor insulation system can be of various thermal classes: A (105°C), E (120°C), B (130°C), F (155°C) or H (180°C). Motor life depends on the environmental conditions and insulation class. Metso recommends using class F or H motors.

Service shift
Is the degree of load regularity applied on the motor.

Efficiency
It is the relationship, in percentage, between the actual power produced by a motor and the power it absorbs from the electric line.

International energy efficiency classes (IE)
Induction motors are divided into four different efficiency classes according to IEC 60034-30-1, which are:

- IE1 Standard efficiency
- IE2 High efficiency
- IE3 Premium efficiency
- IE4 Super-Premium

Motor efficiency is tested, and efficiency class is defined according to the standard.

Minimum energy performance standards in EU defines what efficiency class motor should be used depending on power, duty cycle.

Power factor
Power factor (PF) is defined as the ratio between the active power (kW) and the apparent power (kVA) consumed by an electric device.

$$PF = \frac{kW}{kVA}$$

Some of the disadvantages of the low power factor in an industrial unit are:

- Larger amperage, increasing losses in the unit
- Larger voltage drops
- Reduction of the current conducting capacities of the electric conductors
- Payment of an extra fee in the consumed electric energy bill

Service factor
Service factor (DF) is the factor, which applied to the rated power, indicates the permissible load that can be continuously applied to the motor under specified conditions. It should be noted that this refers to a continuous overload capacity, i.e., a power reserve that makes the motor more capable of enduring unfavourable operating conditions.

Service factor should not be mistaken for the capacity of taking in transient overloads for a few minutes.

A service factor (DF) = 1.0 means that the motor was not designed to operate continuously above its rated power. This, however, does not change its capacity of withstanding transient overloads.

Protection degrees
Protection against intrusion of water or strange bodies in electrical components (i.e. motor) is defined in IEC standard 60529 by a code made up of the letters IP followed by a two-digit number.

The number defines what kind of protection a motor or other electrical component has against the entrance of water or strange bodies.

1st digit: indicates the degree of protection against the penetration of solid strange bodies and accidental contact.

0 — without protection
1 — strange bodies larger than 50 mm
2 — idem, larger than 12 mm
3 — idem, larger than 2.5 mm
4 — idem, larger than 1 mm
5 — protection against dust collection (hazardous to the motor)
6 — protection against penetration of dust

2nd digit: indicates the degree of protection against the penetration of water inside the component.

0 — without protection
1 — dripping water (vertical water drops)
2 — water drops with a slope of up to 15° with vertical axis
3 — spraying water (rainwater with slope up to 60° with vertical axis)
4 — splashing water (drops from all directions)
5 — water jets from all directions
6 — powerful water jets (i.e. large waves)
7 — temporary submersion
8 — permanent submersion

The combination between two digits, i.e., between two protection criteria, are summarized for the electric motors on the following table:

		First digit		Second digit
Motor	Protection classes	Protection against	Protection against strange bodies	Protection against water
Open motors	IP00	None	None	None
	IP02	None	None	Water drops with slope up to 15° with vertical axis
	IP11	Accidental hand contact	Solid strange bodies with dimensions higher than 50 mm	Vertical water drops
	IP12	Accidental hand contact	Solid strange bodies with dimensions higher than 50 mm	Water drops with slope up to 15° with vertical axis
	IP13	Accidental hand contact	Solid strange bodies with dimensions higher than 50 mm	Water drops with slope up to 60° with vertical axis
	IP21	Contact with fingers	Solid strange bodies with dimensions higher than 12 mm	Vertical water drops
	IP22	Contact with fingers	Solid strange bodies with dimensions higher than 12 mm	Water drops with slope up to 15° with vertical axis
	IP23	Contact with fingers	Solid strange bodies with dimensions higher than 12 mm	Water drops with slope up to 60° with vertical axis
Closed motors	IP44	Contact with tools	Solid strange bodies with dimensions higher than 1 mm	Drops from all directions
	IP54	Total protection against contacts	Protection against accumulation of hazardous particles	Drops from all directions
	IP55	Total protection against contacts	Protection against accumulation of hazardous particles	Water jets from all directions
	IP(w)55	Total protection against contacts	Protection against accumulation of hazardous particles	Rain Damp sea breeze

Starting methods

Direct start
It is the simplest method achieved by connecting the motor to the electric supply line at full voltage. Whenever possible, a squirrel-cage rotor three-phase motor should be started directly. Torque curves and amperage are fixed, regardless of the starting difficulty degree.

Application: Normally used for small power motor. In plants where the electric supply line and other components can withstand considerable peaks, motors can have direct on-line start.

Advantage: Maximum starting torque

Disadvantage: High starting amperage

Star-delta start
This system is used only for motors having rated voltage for delta connections equal to voltage between the electric supply line phases. The motors should have at least 6 connection terminals.

Application: This system is used for light-load start or when loading torque at start does not exceed 50% of the nominal motor torque.

Advantage: Low starting amperage (starting current is reduced to 25 to 30% of the delta-connection's starting current).

Disadvantage: Starting torque is only 1/3 of rating. Six wires (two cables) are required for the electric connection to the motor.

Normal three phased motors winding connections

Windings	Rated voltage	Star-delta start
220 / 380 220 / 380	220 V 380 V	Possible with 220 V Impossible
220 / 440 / 230 / 460 220 / 440 / 230 / 460	220 V/ 230 V 440 V/ 440 V	Impossible Impossible
220 / 380 / 440 220 / 380 / 440 220 / 380 / 440	220 V 380 V 440 V	Possible with 220 V Impossible Impossible
380 / 660	380 V	Possible with 380 V
220 / 380 / 440 / 760 220 / 380 / 440 / 760 220 / 380 / 440 / 760	320 V 380 V 440 V	Possible with 220 V Impossible Possible with 440 V

Self-compensated starter
Used for "heavy load" start.

Application: For high-powered start motors, providing start with rather favorable features.

Advantages: Limits starting current by avoiding electric supply line overload, however, leaving enough motor torque for start and acceleration. Normally, the autotransformer has two output taps corresponding to 65% and 80% of nominal voltage.

Disadvantages: High acquisition cost, limited frequency of operations, and autotransformer size causing higher volume.

Rheostat start for slip-ring rotor motors
This starting system is universal as it permits matching starting torque and corresponding amperage peaks during start with their own needs for each specific case.

Application: For heavy machines.

Advantages: Starting with maximum torque and reduced current peaks. Speed can be varied through the rheostat.

Disadvantages: High acquisition cost; resistor overheating limits the permissible number of starts per hour.

Soft starter
Advances in electronics enabled the creation of solid-state start-key that consists of a set of pair of thyristors (SCR) (or combinations of thyristors/diodes), one at each phase of the motor. The angle of elevation of each thyristor pair is electronically controlled to apply a variable voltage to the winding of the motor during start.

At the end of the start period, typically adjustable within 2 and 30 seconds, voltage reaches its highest peak after a soft-start or an ascending ramp, instead of being submitted to increments of sudden jumps. Therefore, we keep the start amperage (online) close to the nominal and with soft variation.

Besides the advantage of voltage control (current) during start, the electronic switch also presents the advantage of not having movable parts or arc generating as the mechanical switches. This is one of the strong assets of the electronic switches, for their life becomes longer.

Frequency converter
Slowly increasing the speed of the motor by adjusting the frequency, this starting method enables starting of the motor with low current but with a good constant torque. This starting method also extends the life span of belts and pulleys since there is no violent pull at the start. This starting method can also be used for continuously controlling the speed of the electric motor.

Application: This system can be used when a good constant torque with low current is needed or when speed control is beneficial.

Advantage: Good constant torque from low to high RPM`s with low current. Speed control possibility.

Disadvantage: Higher acquisition cost than soft starter.

Metso motor starter centers
Wide range of low voltage motor starter centers are available from Metso with a variety of starting methods and power ranges to choose from. With our motor starter centers, the specific demands of crusher types have been considered in specification and designing.

Metso starter centers can be used together with IC system and communication between these two assures the optimal function of the process and safety of the crusher.

Motor class selection

Crushers in general
Although there is a great variety of crushing types and models, some features and specifications of electric motors are common to all of them, among these are the following:

- Continuous use
- Totally closed external ventilation
- Service factor: 1.00
- Torque: approximately 125% at the start and 200% at the maximum torque
- Type: squirrel-cage induction motor
- Capacity to withstand radial tension, in 360°, of V-belts
- Voltage variation: ± 10%
- Adjustable base by sliding

For the best indication of the motor, according to Metso Engineering, it is necessary to gather the following data:

- Working voltage, frequency, and altitude
- Crusher type and model
- Special features, if required by the user
- The motor bearing must be properly dimensioned to withstand the weight of the pulley and the belt tensioning. The motor shaft diameter must be adequate to resist the peak torque and simultaneously bending caused by the belt tensioning and the weight of the pulley. The length of the shaft must be minimum and according to the dimensional solicitation of the motor pulley of the specified drive.

Conveyors
Motors of up to 75 HP are usually from the "N" class, with direct online start for small and mid-size motors. For motors with power above 75 HP, slip-ring rotor motor, or squirrel-cage class "N" or "H" motor with hydraulic couplings are recommended, which limits the torque, yielding soft starts.

Cables

Installation type
Type and size of the cable depends on environmental conditions. There are five common types of installation for electric cables.

1. **Directly buried**

Advantages: Good mechanical protection and thermal dissipation. During installation, cable pulling is not necessary.

Disadvantages: Difficult maintenance and cable replacement.

2. **Steel cable ducts**

Advantages: Excellent mechanical protection, easy maintenance and cable replacement.

Disadvantages: Low thermal dissipation as compared to buried cables. High cost.

3. **Trenches**

Advantages: Easy maintenance and replacement.

Disadvantages: Less mechanical protection, bad thermal dissipation.

4. **Trays**

Advantages: Easy maintenance and replacement, good thermal dissipation.

Disadvantages: Subject to mechanical damage.

5. Aerial

Advantages: Easy maintenance and low cost.

Disadvantages: Subject to mechanical damage.

Insulation

The following points should be considered when selecting electric cable insulation: operating voltage, temperature, overloads, short-circuits, resistance to acids, salts, alkalis, ozone, organic chemical agents, and installation type as well as endurance of possible mechanical stress.

For crushing plants, thermoplastic insulation cables are recommended, such as the ones based on PVC (polyvinyl chloride), PUR (Polyurethane), Pirelli sintenax, Ficap fisec (for 0.6/1 kV, or similar).

Shielded (VFD) cable

Special VFD cable or cable with proper shielding should be used with frequency converter drives. Shielding of the cable protects the nearby electrical components from the electromagnetic interference that frequency converter drive induces.

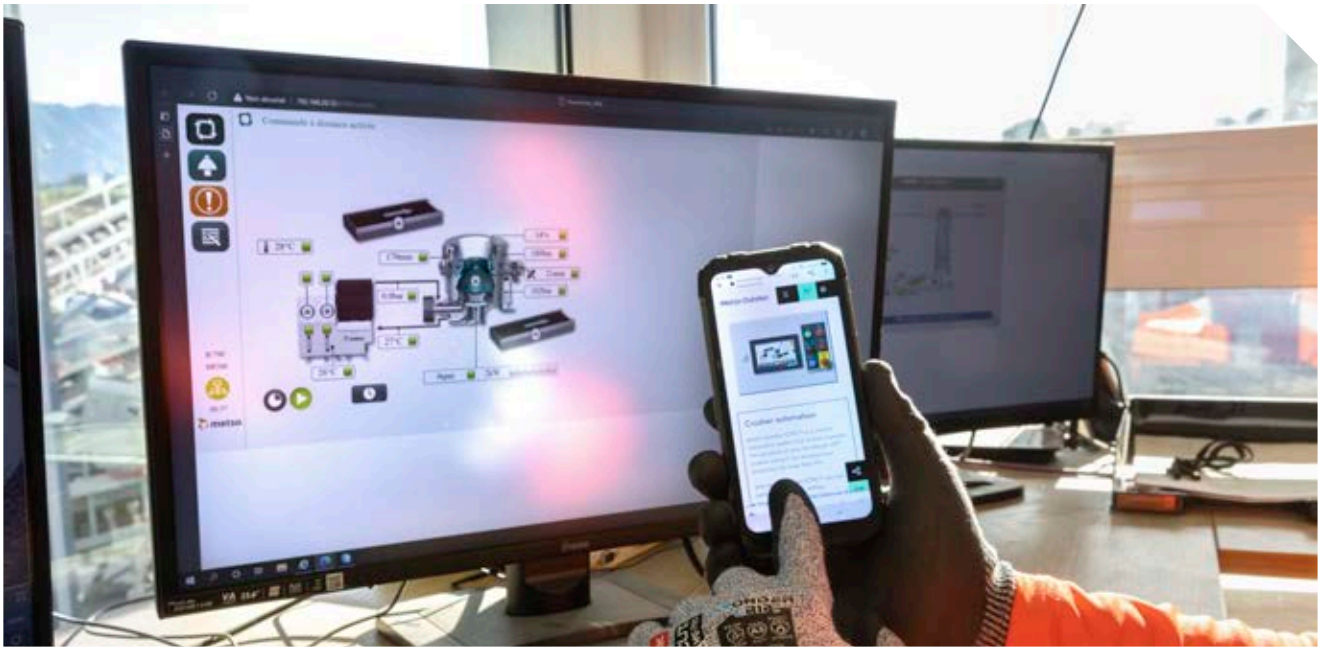

Metso:Outotec

Automation systems

Automation on crushing plants

Metso IC™ process control systems are designed for harsh conditions on crushing plants, while targeting to operate and service the machine in the most optimal way. Automated and assisted operation increases safety, performance and availability of your crushing and screening equipment.

IC are designed for each equipment to optimize the use on machine level as well as when a group of machines are operating together as a plant. While IC automation can be used as-is on a standalone plant, many modern plants have a centralized control room for optimizing the operations plant wide.



IC automation systems can be easily integrated as a part of plant controls and integration can be done on different levels.

See further information in following chapters for maximizing the potential of your equipment and integrating IC automation to your plant.

Automation benefits

Health, safety and environment
Safety is our number one priority and automation plays a key role. Automated sequences decrease risks for human errors and automation monitors equipment condition tirelessly. Remote operation is becoming a standard feature which enables the plant operator an access to crusher automation from the centralized control location and lets the operator focus on his duty.

Centralized control location is a dust and noise free location, often for example excavator cab on mobile plants or operator room on semi-mobile and stationary plants.

On the other hand, automation can prevent the machine from disturbances such as uncrushable objects but also automatically change machine parameters to adjust changing conditions. Continuous monitoring protects machine from overloading caused by changes in feed material.

All these built-in protective measures help to avoid costly downtime and to save energy.

Capacity
Maximizing the capacity of the plant starts usually from feeding as much as possible feed material to the process, while still preventing overflow and overloading as these would cause disturbances in the process and loss of production.

Automation helps to find the most optimal running parameters and especially to recover back to maximum performance regardless of interferences.

The more stable the feed rate is, the higher the average tonnage can be as the throughput is not bouncing up and down. Thus, stable control decreases process stops and helps to maximize the uptime. Automatic control reduces the need for human participation, which decreases the operator's possible limiting impact on performance.

While equipment operates at their nominal values, i.e. close to their designed best performance point, usually also the product quality and machine wear are optimal.

Product quality
Full-choke level feeding, around the circumference of the chamber, contributes to much better efficiency and lower costs. Metso IC automation systems help to maintain full choke level feeding and a constant load, offering the benefits of inter-particle crushing, which guarantees a product of better shape, with minimal liner wear and lower energy consumption per ton produced.

Also, utilizing the correct CSS (closed side setting) in the crusher - keeping it constant regardless of wear and balancing the setting within the whole process between the crusher - plays an important role in product quality optimization.

Better availability
Reducing the costly downtime is a key to profitable operation. Automation allows the crusher to operate continuously at its maximum capacity within safety margins, much more efficient compared to manual operation. By avoiding overload and subsequent mechanical failures, the automation also reduces downtime for maintenance.

On the other hand, automation can provide valuable data of the machine operation and for example estimate the lifetime of wear parts helping to schedule maintenance activities. Production logs present clear indication of daily effective runtime and capacity helping to find the bottlenecks and to improve the process conditions. Metso Metrics remote monitoring makes this information available anywhere at any time.

Operation monitoring
Automation is tirelessly monitoring the machine condition and process variables. Built-in warnings and messages guide the plant operator on a daily basis. Metso IC™ process control include clearly visible alarm messages, which give warnings of abnormal operating conditions and indicate the reason for stoppage or failure in the process.

Data logging on IC systems helps to observe the machine condition and troubleshoot issues locally; and Metrics remote monitoring brings the data available for fast remote support.

Automation for unit crushers and Nordwheeler plants

Metso IC™ process control on a unit crusher is a plant owner's best friend through the life cycle starting from plant design. Crusher automation systems are delivered in a complete and tested package together with electrical drives, sensors and actuators for crusher's lubrication, hydraulics, and other ancillary equipment.

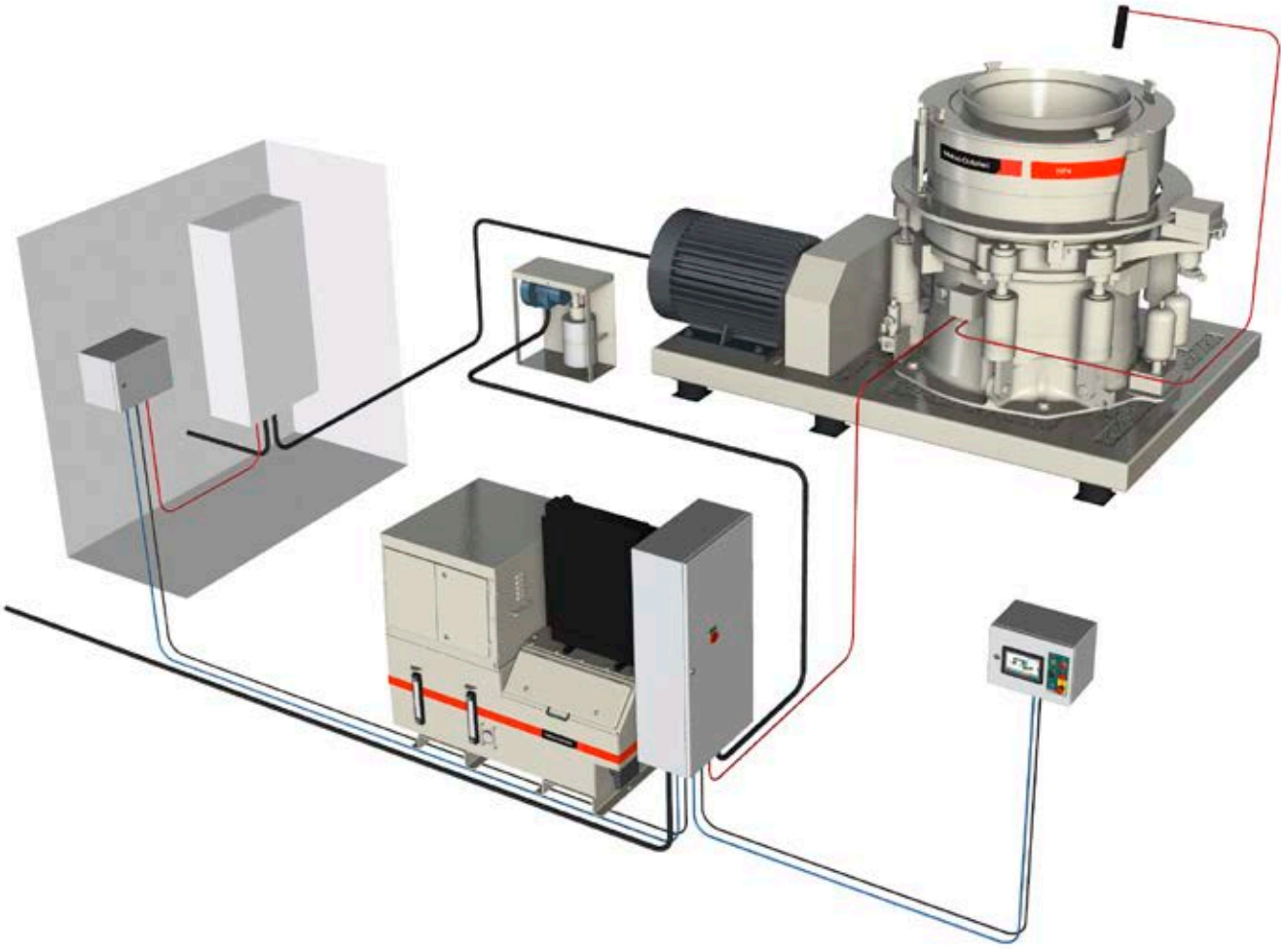
Prewired and tested controls for the lubrication and hydraulics saves you from designing and acquiring complicated electrification locally.

IC series automation for unit crushers can also control the feeding in various modes including vibrating feeder, feed conveyor and scalper. With secondary and tertiary units, the machine automation can also manage full process with screen, recycling and a number of product conveyors.

Full crushing stage can be run and monitored with one system. This option is called crusher station control. Metso portable crushers comes with crushing station option built in and it's an available option for stationary units.

Integration to plant controls can be implemented in different ways. Automation system provides extensive communication interface for plant automation controls. It is able to change machine parameters through existing plant automation while IC systems monitors machine operation.

Remote User-interface (RUI) option can be used to transfer the human-machine interface (HMI) over plant network to control room. RUI is state of the art technology which enables fast integration to plant controls without any programming on site.



IC automation can be combined with optional Metso Motor Starter Center (MMSC) for the crusher motor. This makes delivery a complete package of electrification and control system.

Automation for Lokotrack® mobile crushers
The IC series control systems for Lokotracks have been designed for easiness of use and increased productivity. It provides operator with information and control functions enabling the operator to optimize the utilization of the machine.

The main functions are:

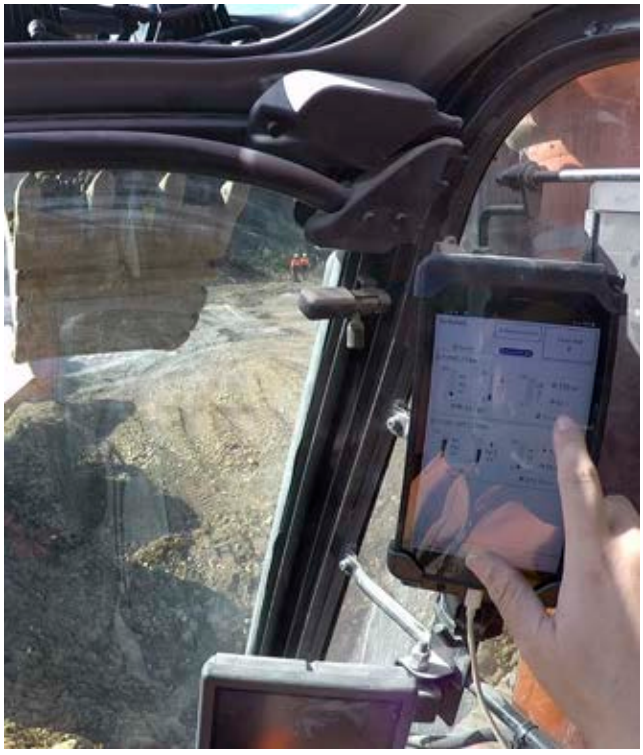
- Full process control of the equipment including automated feed rate control
- Crushing optimization with CSS control
- Track-drive via radio remote control for easy positioning
- Equipment monitoring and protection for overloads, diagnostics for troubleshooting
- Interfaces to other machines in the plant
- Remote monitoring

The control system provides protection against overloads and misuse. The control system monitors temperatures, pressures, speeds, and the whole power transmission. System diagnostics includes alarm and parameter logs, I/O statuses and sensor values and engine trouble codes. Remote monitoring brings relevant machine data available remotely.

Metso Remote IC is a process control option dedicated for Lokotrack® LT and ST plants. It connects multiple equipment together wirelessly and comes with a display which is located in the excavator feeding the Lokotrack® plant.

Remote IC is able to monitor main parameters of each Lokotrack®, temporarily pause feeding as well as adjust CSS and feed rate of applicable Lokotrack mobile crushers.

This improves safety and uptime by reducing need to jump out from excavator for process adjustments. It also increases process performance thanks to its wireless interlocks between each Lokotrack® and built-in feed controller.



Process automation

CAMEOS Solution for Aggregates & Mining Plant
Controlled Aggregates & Mining Efficient Operation System (CAMEOS) combines simplicity, availability, optimized regulations and comprehensive message history to help maintain crushing and screening plants. CAMEOS is a plant control solution developed by Metso Systems based on years of experience. It's the result of proven libraries, process and automation engineering to design a tailored solution to meet customer's needs.

Today, dozens of plants are using CAMEOS all around the world. CAMEOS is now standard for Metso Prime Sites with electrical and automation systems. Old customer systems can be upgraded to CAMEOS, as it can be installed to an existing Metso or competitors' plant.

CAMEOS control
Control is typically based on Siemens S7-1500 hardware and it consists of a main Programmable Logic Controler (PLC) and communication interfaces for Profinet, and Ethernet.

Process I/O of the automation system is based off distributed Inputs/Outputs (I/O). The I/O modules are installed in Motor Control Cabinet (MCC) and in Field Cabinet (FC).

CAMEOS Station
CAMEOS Station is based on workstation running Windows operating system.

The Server Station collects information and stores it in a databank and archives for long-term storage. At the same time, CAMEOS provides data and all services for Client Station.

CAMEOS Stations functions as plant operating stations. The process is monitored and controlled by operators through Stations located in the control room(s). The operator interface allows monitoring the process using several process displays simultaneously. The standardized display windows for individual control operations guarantee reliable and easy-to-comprehend machine controls and regulations. In addition to the displays and controls, the station is also capable of showing events and trends in real-time.

CAMEOS Mobility
CAMEOS Mobility is based on mobile tablet running Windows operating system.

This operator interface allows monitoring and controlling the process on site, near machines. It allows monitoring production. The standardized display windows for individual control operations guarantee reliable and easy-to-comprehend control machines and regulations. In addition to the displays and controls, the station is also capable of showing events and trends in real-time.

CAMEOS Engineering station (option)

CAMEOS Web (option)

Typical CAMEOS Control.

CAMEOS Control
CAMEOS Control is the main automation core design of Metso Systems. It is the full control of your plant.
The system is composed of a main controller, distributed I/O, and communicates through a Profinet or Ethernet network.

Running modes

- Automatic: The plant is fully started and stopped automatically from CAMEOS Station (one main button). Machines are started in cascade, to ensure production and process prerequisites. Machines are interlocked to guarantee that the area is running correctly. This operating mode is used for normal production operations.
- Interlocked: The plant is started and stopped from CAMEOS Station, machine by machine (one button for each machine), according to the plant process sequence (the machine can be started only if all downstream interlocks are validated). This operating mode is selected to start production step by step. As for example, it could by used after an emergency stop. This mode guarantees the correct flow of materials.
- Manual: It allows to start and stop each machine from CAMEOS Station without interlocking (machine internal interlocks remain available). This mode is selected to start machines without any interlocks. This mode is not a production mode, the operator manages the correct flow of materials.

Plant optimization
For plant performance, productivity optimizations and energy savings, Metso includes a complete optimization of the plant regulation loops. Material levels in machines and hoppers are stabilized thanks to Metso know-how and expertise.

Feeder speeds are calculated by high efficiency control loops according to all available process information such as crusher currents and levels, hopper and stockpile levels, conveyor flows (if belt scale available) and other parameters defined by Metso. All settings, thresholds and delays are available in dedicated parameter pages in CAMEOS Station and could be adjusted by operators.

CAMEOS Mobility.

CAMEOS Station
CAMEOS Station is the main operating interface designed by Metso Systems. It is the full control of your plant in at least one computer. The operator will be able to display and monitor easily the plant and machines, thanks to a dedicated synoptic and differents machines pop-up.

CAMEOS Station regroups all the features allowing a reliable and well-proven monitoring of your crushing plant:

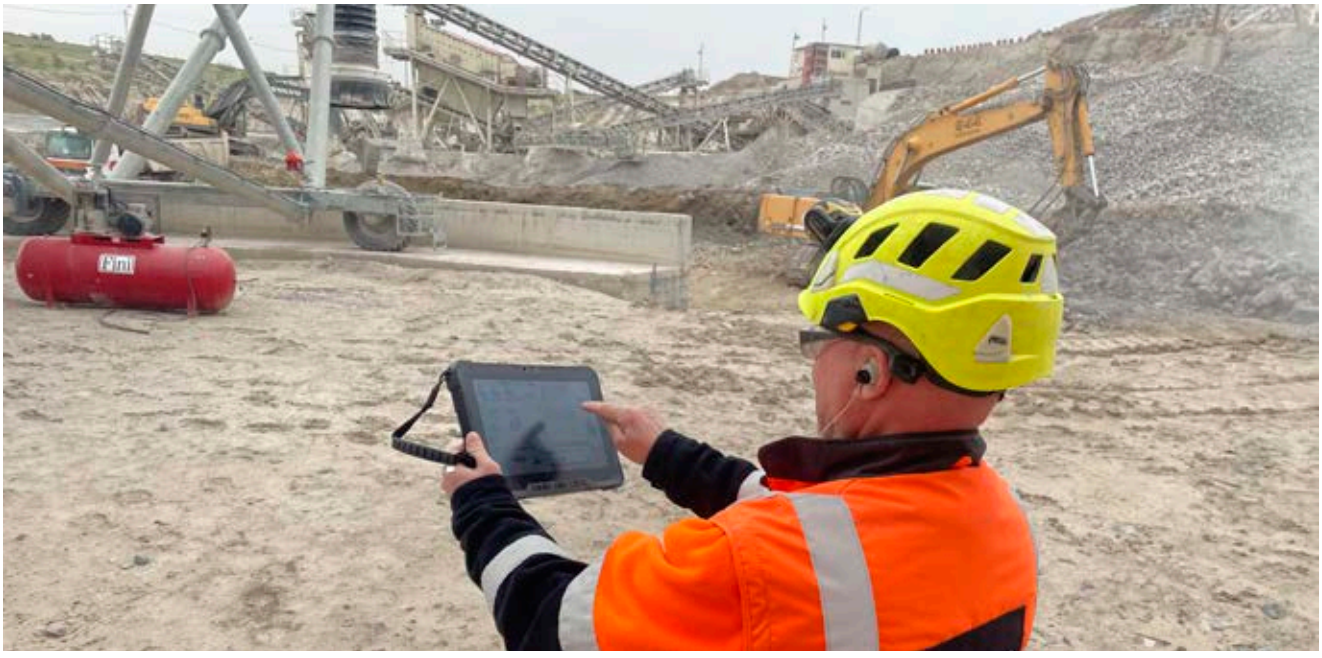
- Status of machines, status of plant
- Real time details of events, alarm & fault
- Real time and archived diagnostic tools and data
- Centralized system for flowing exchanging data
- Linkable to other system
- Ergonomic control for every running modes
- Proactive regulations
- Fully compliant with most advanced safety rules

CAMEOS Mobility
CAMEOS Mobility is the on-board interface extension of CAMEOS Station. It allows the operator to monitor and control the plant from everywhere on the site. The positive effects are numerous:

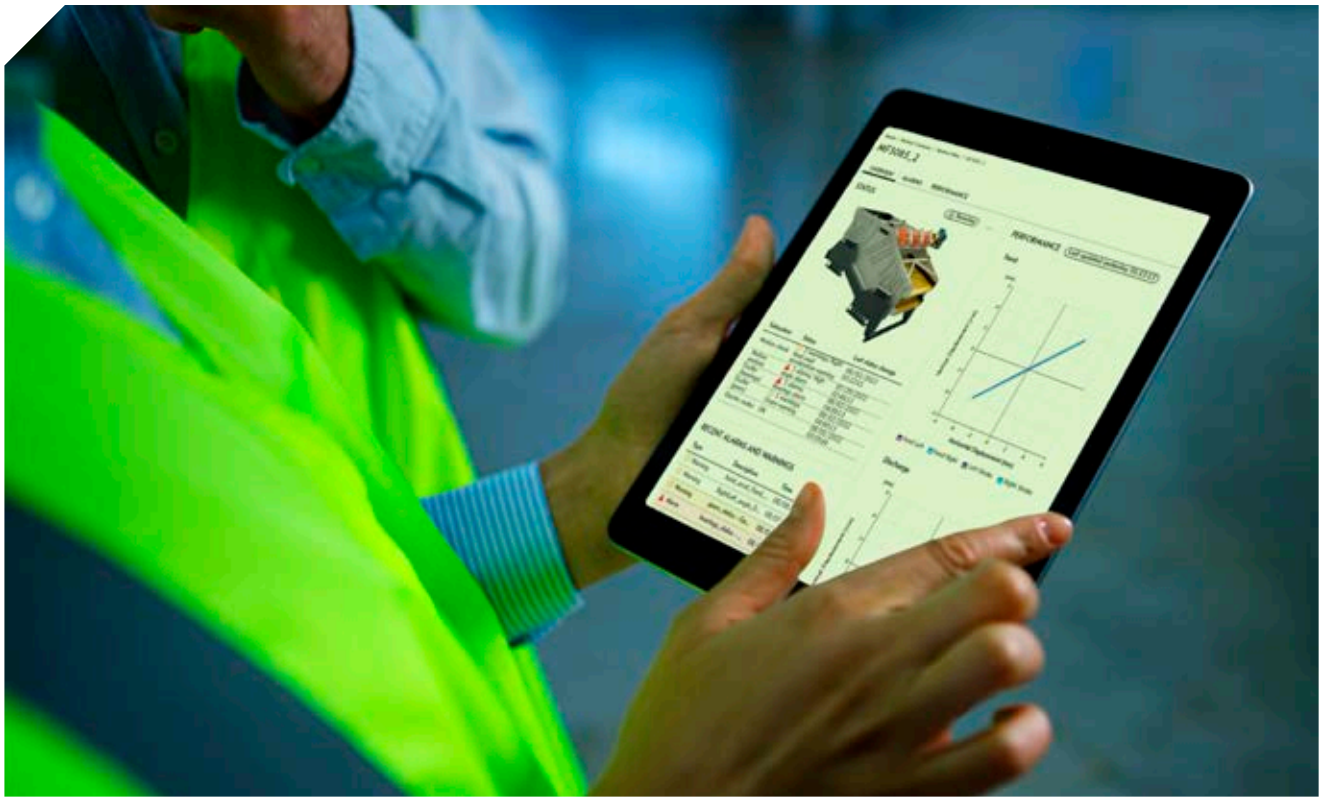
- Downtime reduced by closer control
- Quick and easy access to all machines locally
- Real time diagnostic tools
- Wireless solution
- Reduced commissioning time

CAMEOS Web
CAMEOS Web is the extension of CAMEOS Station. Its allows the customer to visualize the general synoptics, machines and plant status, trends in real time through web connection.

Note: Because of safety restrictions, machines cannot be started from the web.



A Metso supervisor with his tablet during commissioning phase.



Metrics remote monitoring

Next generation remote monitoring solution for aggregate crushing and screening equipment.

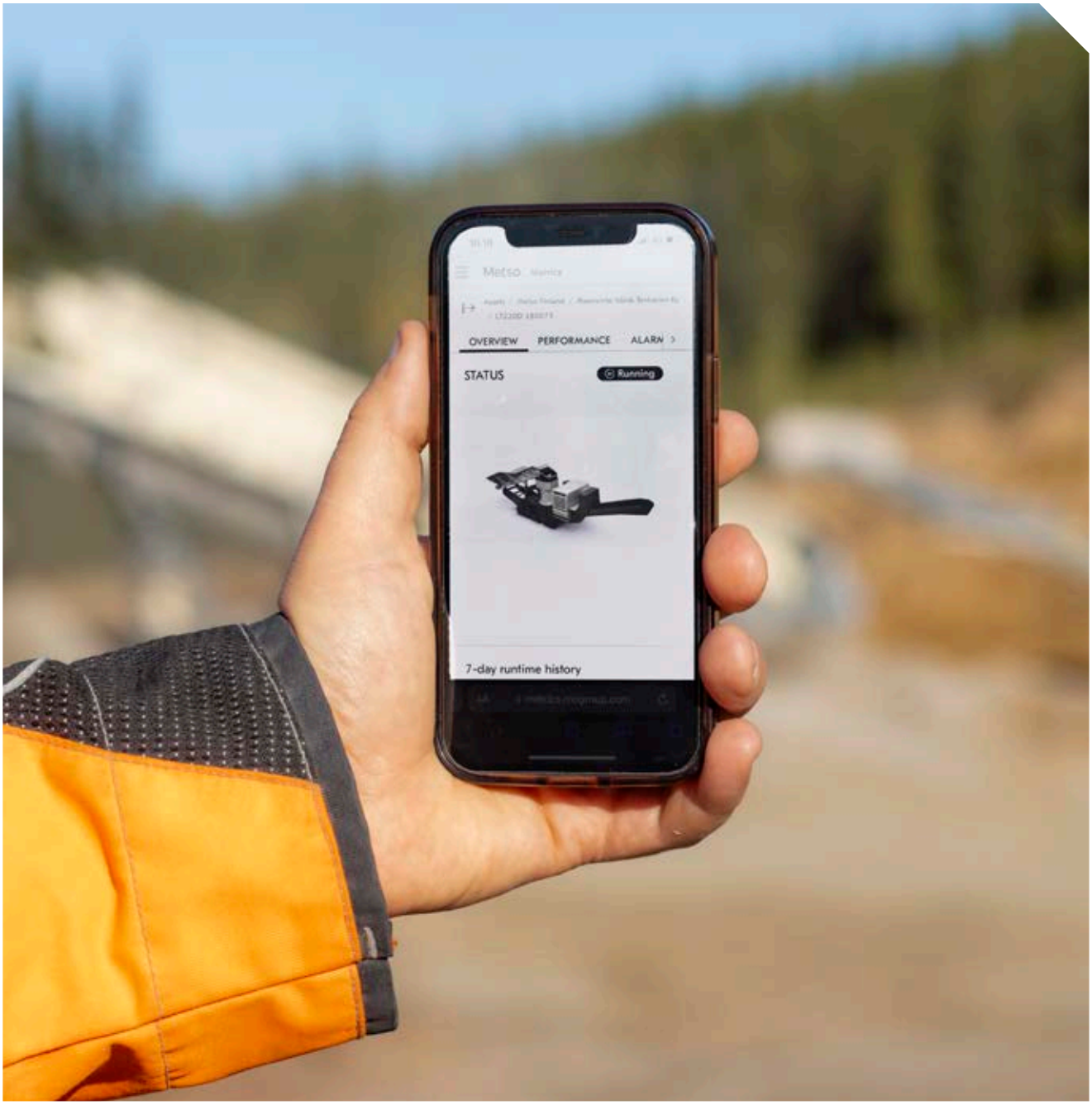
Metso Metrics connects your crushers and screens giving you data-visibility to improve:

- Availability
- Performance
- Reliability
- Profitability

The features include CO^2 tracking for sustainability benefits, 24/7 access to real-time data, a maintenance module, critical dashboards for utilization, geolocation and remote troubleshooting. New features and functions can be also updated remotely.

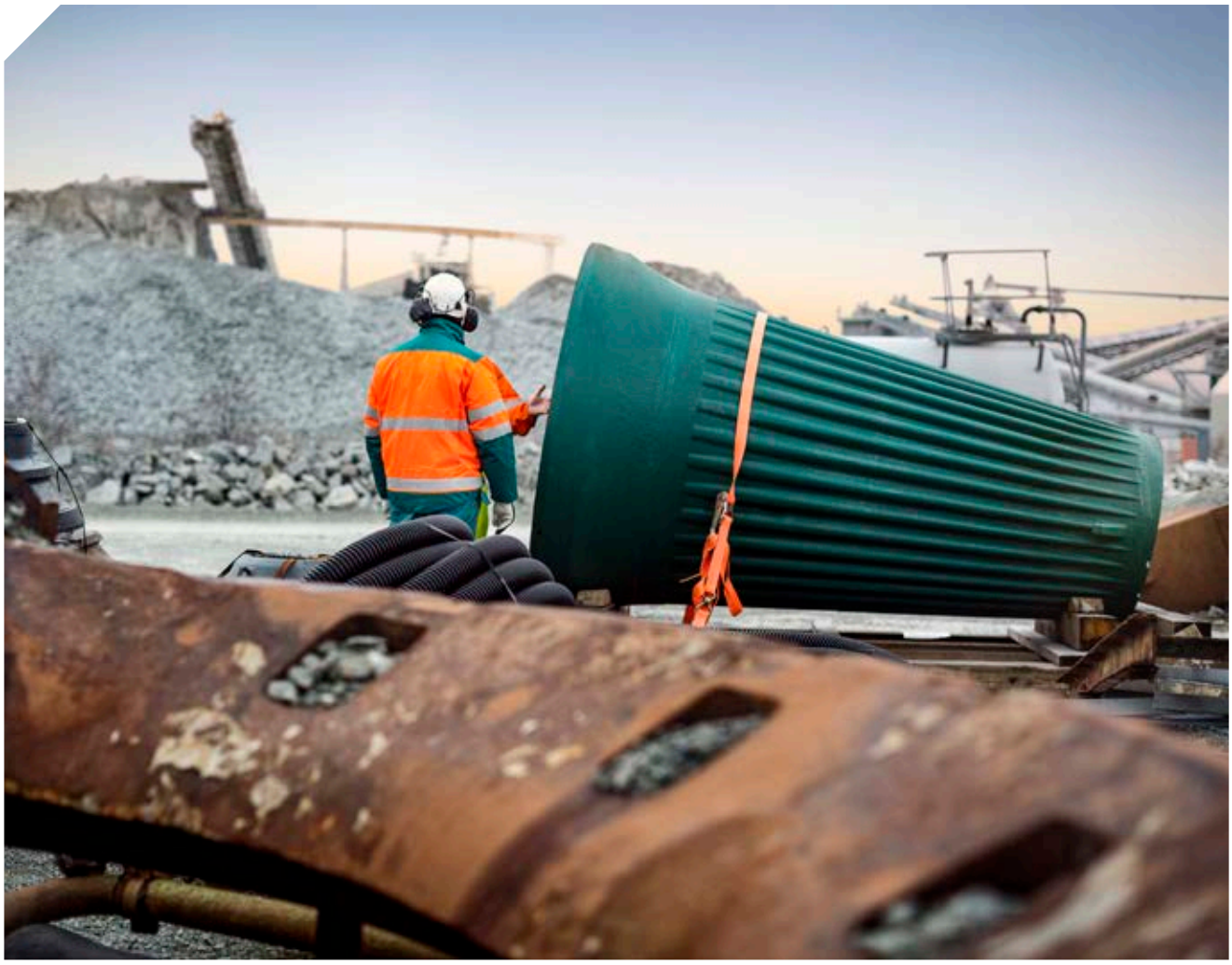
Metrics offers improved safety, increased uptime and throughput, and reduced unplanned maintenance. It enables operators, controllers and service professionals to see real-time analysis of crusher and vibrating screen performance and condition.

Metrics user interface is intuitive and customizable, and an easy-to-read screen dashboard with OEM insights and recommendations makes it possible to quickly detect potential issues and take corrective action in time.



For further Metrics with crushers information, please visit:
www.metso.com/portfolio/aggregates-metrics

For further Metrics with mobile screens information, please visit:
www.metso.com/products-and-services/services/process-optimization-connected-services/metricsforscreens



Wear parts – crushers

Wear
Wear is the loss of material on a surface by means of several different mechanisms. The main type of wear in a crusher cavity is abrasive wear. Fatigue wear also occurs, as the wear parts are subjected to multiple compression or impact loads.

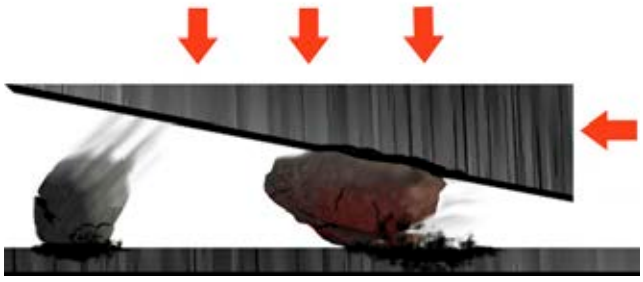
Abrasive wear (or abrasion)
Crushers typically compress the feed material between the fixed and movable wear parts. Besides the breakage of the feed material, it also wear away material from the wear part.

Micromechanisms of wear are:
- Microplowing
- Microcutting
- Microcracking
- Microfatigue

During the crushing cycle, gouging or high-stress abrasion is present, depending on the particle size of the feed material.

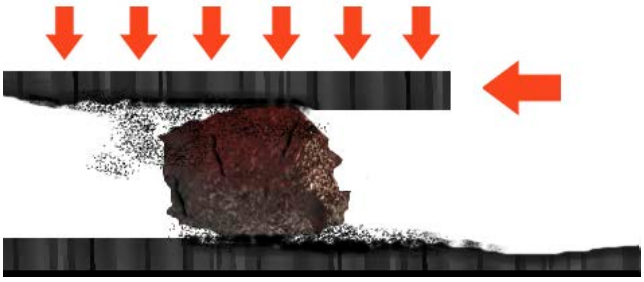
Between the crushing cycles, when particles of feed material are sliding against wear parts, low-stress abrasion is present.

Gouging abrasion
- Large particles
- High impact or compression loads
- Good work hardening on manganese



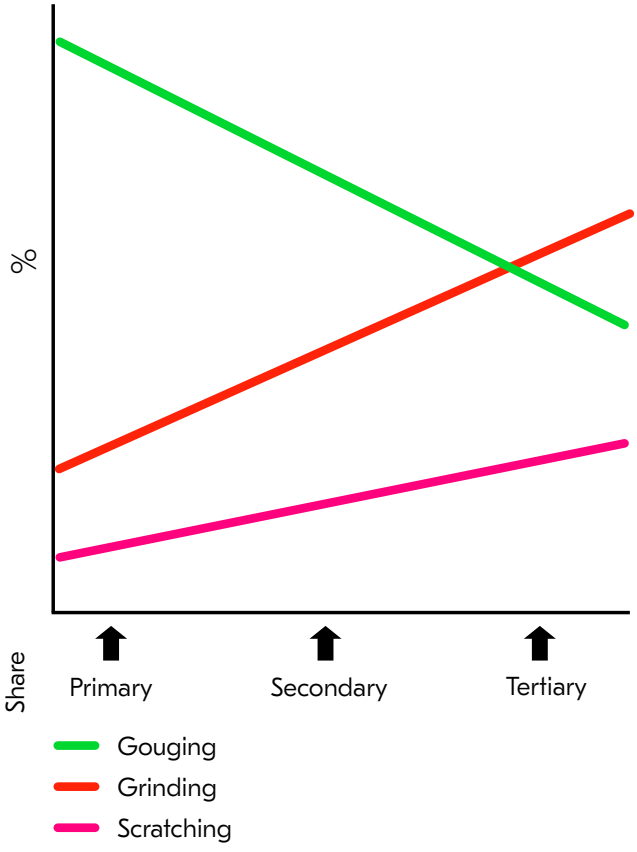
High-stress or grinding abrasion

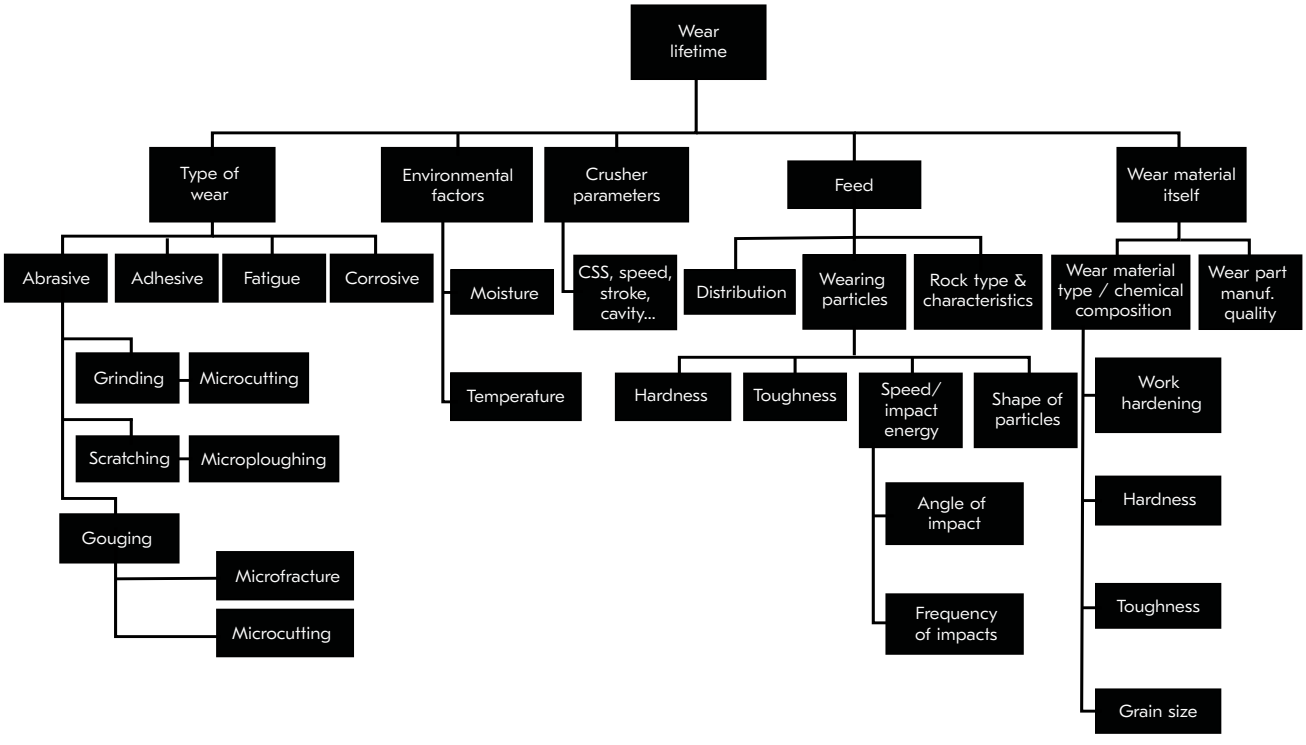
- Smaller particles
- High compression load
- Less work hardening on manganese



Low stress or scratching abrasion

- No compression load
- Scratching abrasion while material is sliding at the surface of the wear part
- Less work hardening on manganese





Abrasiveness of feed material

Several different factors affect the wear of wear parts. Type of wear, environmental factors, crusher operating parameters, feed material and wear part properties are just a few of these. However, one of the most notable factors in the wear of crusher wear parts is the abrasiveness of the feed material.

The abrasiveness of the feed material can be determined at Metso's rock laboratory using a test for abrasiveness. The following table indicates the abrasiveness of rock based on this test.

Crushability of the rock can be determined with the same equipment that is used to identify abrasiveness. Crushability indicates how easily the rock material breaks down. Difficult rock with a low crushability value requires more crushing energy than easier rocks with a higher crushability value.

Crushability classification

	Bond work index [kWh/t]	Crushability [%]	Los Angeles value	Ai-8mm product	Shatter index
Very easy	0 - 7	50 -	27 -	60 -	40 -
Easy	7 - 10	40 - 50	22 - 27	45 - 60	35 - 40
Medium	10 - 14	30 - 40	17 - 22	30 - 45	30 - 35
Difficult	14 - 18	20 - 30	12 - 17	15 - 30	25 - 30
Very difficult	18 -	- 20	- 12	- 15	- 25

Abrasiveness classification

	French abrasiveness [g/ton]	Abrasion index
Non abrasive	0 - 100	- 0.1
Slightly abrasive	100 - 600	0.1 - 0.4
Medium abrasive	600 - 1200	0.4 - 0.6
Abrasive	1200 - 1700	0.6 - 0.8
Very abrasive	1700 -	0.8 -

Manganese steel

Manganese steels have the capability to work harden under external load which improves wear resistance. Alloy selection is defined by the crushing application. Austenitic manganese steel is a very tough and ductile material with a high impact toughness. Manganese (Mn) steel is a rather soft material with an initial hardness of approx. 220-250 HV. The wear resistance of manganese steel is based on a phenomenon known as work hardening.

When the surface of Mn steel is under heavy impact or a compressive load, it hardens from the surface while the base material remains tough. The depth and hardness of the work-hardened surface vary depending on the application and Mn steel grade.

The work-hardened layer can be 10-15 mm deep and the hardness can be up to 600 HV in primary applications.

In fine crushing applications, the work-hardened layer is thinner and the hardness is usually around 350-500 HV.

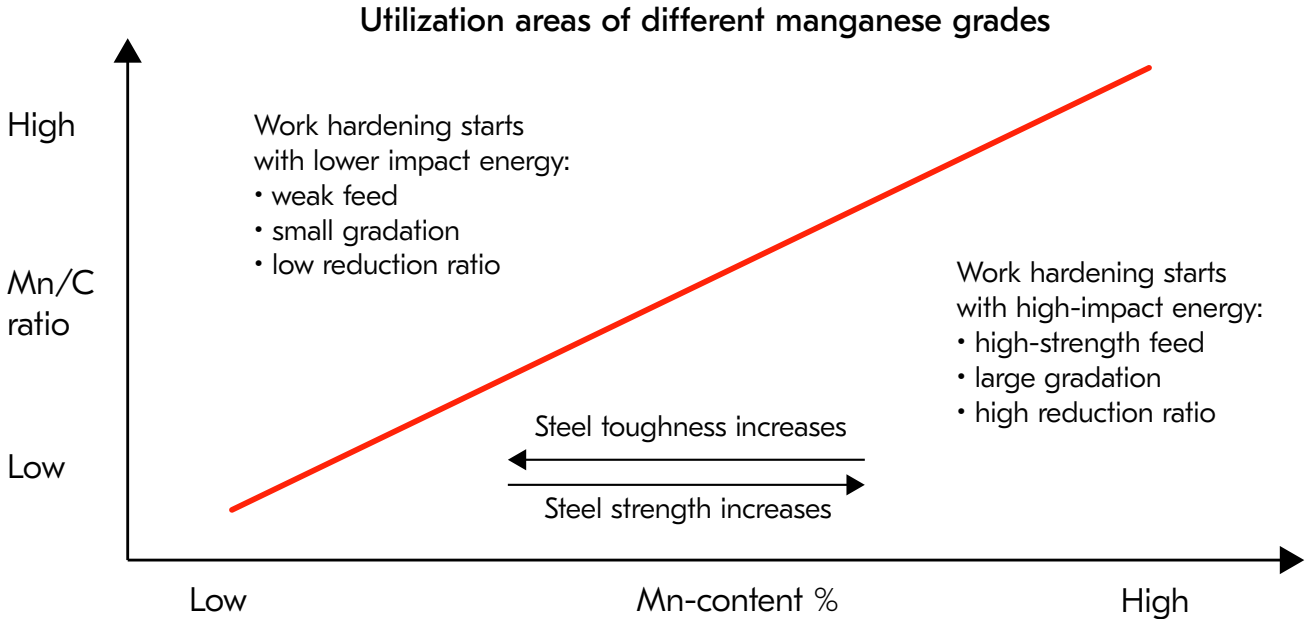
The manganese/carbon ratio and the amount of chromium are not the only relevant factors when it comes to the wear resistance of Mn steel, the entire casting process also needs to be highly optimized to produce high-quality wear parts.

Critical steps when producing high-quality Mn steel castings

Getting the material analysis to comply with strict specifications and reducing the amount of certain impurities starts with the careful selection of the raw materials for melting. During melting and pouring, the temperatures are carefully controlled in order to achieve a fine grain structure for the castings. At the same time, samples are taken to verify the material analysis and adjustments are made if necessary. Melted metal is then poured into sand molds and the metal slowly solidifies. The molds have carefully designed feeding and gating channels to ensure solid castings.

Heat treatment is another critical step in producing ductile high-quality castings. Temperature, time and quenching need to be well controlled in order to avoid grain boundary carbide formation. Once the heat treatment has been completed, the castings are machined according to strict tolerances to ensure a perfect fit to the crusher.

Besides the casting, the crushing chamber profile significantly affects the performance of the crusher and the lifetime of the wear parts. Crushing chambers are optimized by using sophisticated simulation tools and continuous testing and follow-up.

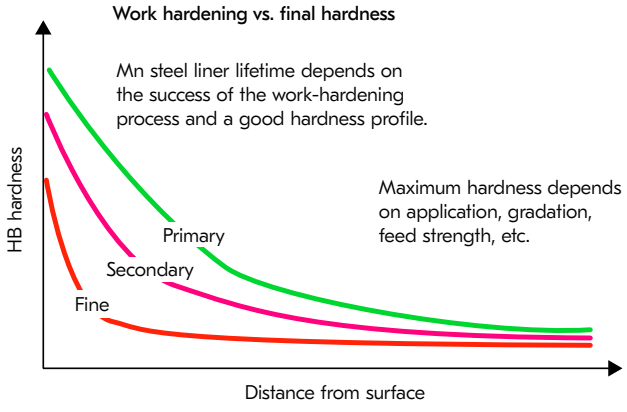


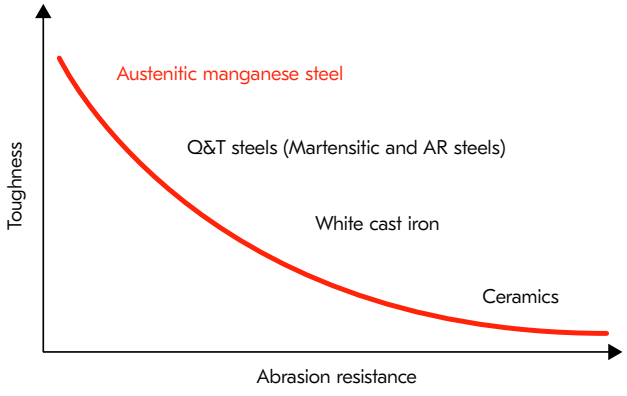
Metso XT series

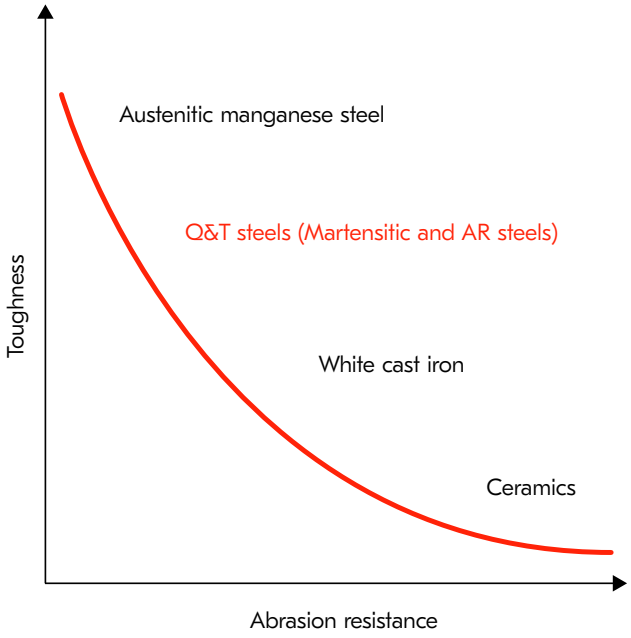
The Metso XT alloy series crusher wear parts consist of a wide range of Mn steels with different alloying to suit each customer's application and the relevant rock properties. The XT series covers Mn grades from 11% to 24% and some grades are alloyed with chromium and other alloying elements. All materials are not available for every crusher.

Consult your MetsoOutotec representative for additional info.

Metso grade	Alloying
XT510	Low grade Hadfield manganese steel
XT520	Low grade manganese steel with molybdenum alloying
XT525	Low grade manganese steel with maximized toughness
XT610	Low grade manganese steel with chromium alloying
XT712	High grade manganese steel with chromium alloying – O-series
XT710	High grade manganese steel with chromium alloying
XT720	High grade manganese steel with chromium alloying
XT750	High grade special manganese steel
XT770	High grade special manganese steel with molybdenum alloying







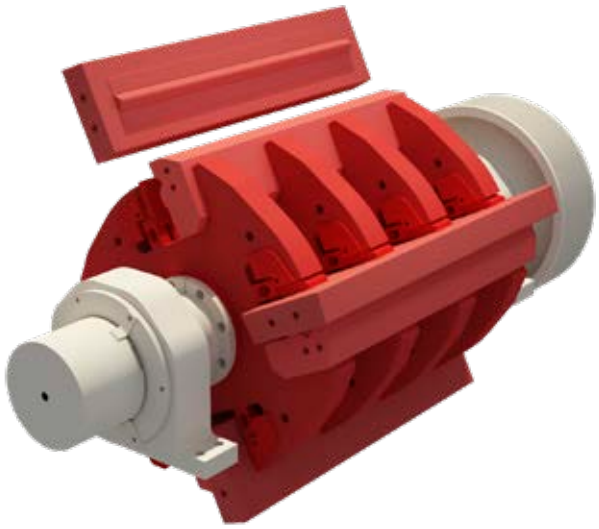
Q&T steels (Martensitic and AR steels)
This material group offers quenched and tempered (Q&T) in good toughness for various applications of impact and compression crushing.

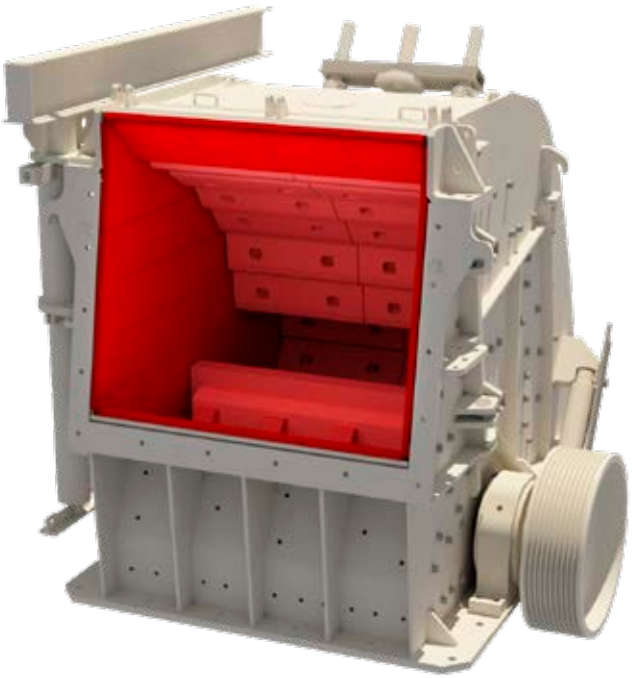
These steels have been tailored for various solutions having an optimum micro-structure with sufficient hardness and toughness achieved with a heat treatment process called quenching and tempering.

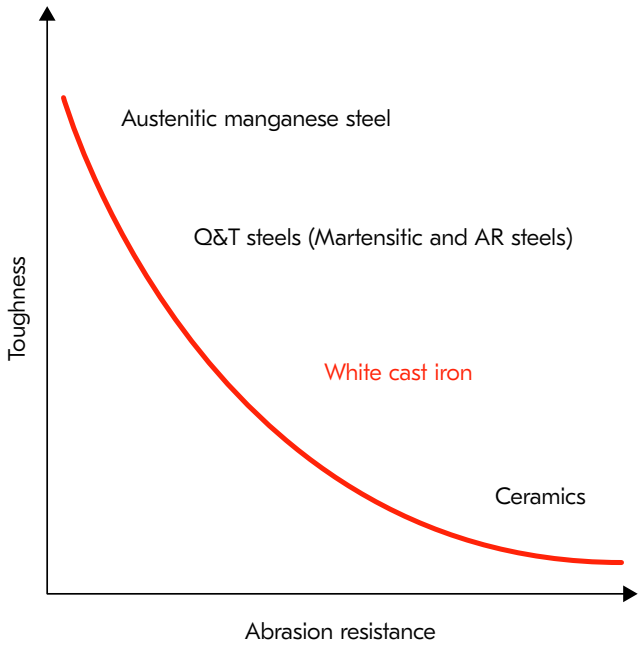
Precise control of time and temperature are the key parameters. AR steels (so-called boron steels) are thermomechanically rolled grades.

In terms of wear, these steels offer an economical and sufficient hardness and toughness combination. Typical applications include HSI and primary gyratory wear parts.

Consult your Metso representative for additional info.







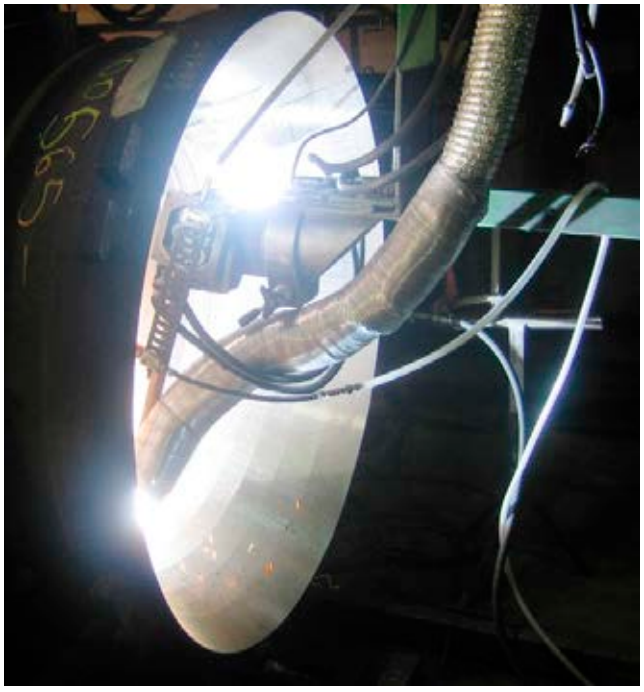
High chromium white iron
High chromium white irons are used in selected applications where high wear resistance is required.

These materials are low cost and a good choice for many applications. The wear resistance is based on the hard carbides on the relatively hard matrix, which still allows the composition and structure to be tailored considerably.

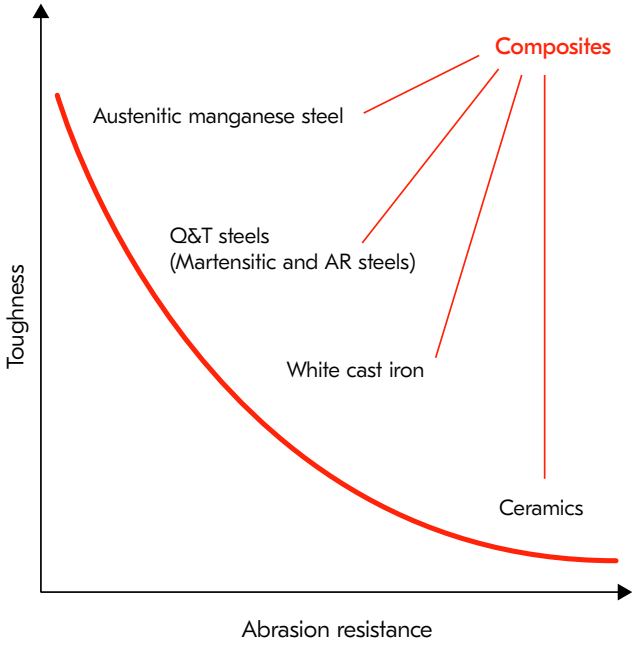
High chromium white irons are commonly used in abrasive wear applications.

Typical examples are VSI and HSI components and primary gyratory concaves. Consult your Metso representative for additional info.

Composites
Different materials can be combined in order to improve the wear resistance properties.



By using each material where it performs the best, we can help you optimize your crushing process.



Hybrid materials
More and more hybrid materials are being added to Metso's offering. Hybrid materials combine several kinds of materials and can also be called multimaterials.

These kinds of structures have clear benefits in extreme operations, they can be tailored for a specific operation, and they form functional wear-control areas. The most wear-resistant materials are located where they are needed. With multimaterial joints, even a tailored surface (topography) can be formed on wear surfaces.

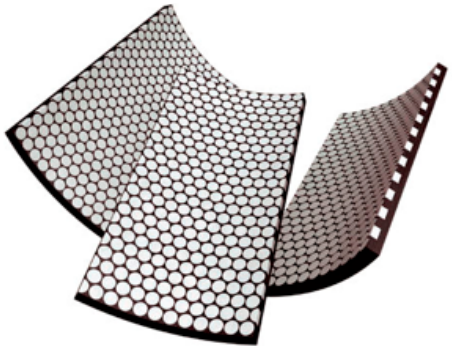
Hybrids can be a combination of several types of irons, steels and ceramics, or even rubber with ceramics or metals.

Note: Consult your Metso representative for applications and overlay selection.

Metal matrix composites (MMC)
MMC is the newest material group in Metso's offering. Metal matrix composites combine a tough metallic matrix and hard ceramic or hard metallic materials. The wear resistance of the material is combined with the optimum material strength (hardness) and toughness properties. Increasing strength (in metallic materials with sufficient toughness) has generally been observed to increase wear resistance in many wear environments. However, increasing strength generally results in a loss of toughness.

In order to achieve the higher strength and toughness of metallic material, a composite structure is the most promising solution.

Product examples include Xwin®, Recyx® and Neox® in HSI crushers. Xwin®, Recyx® and Neox® are registered trademarks of Magotteaux. Typical products are shields, guards and liners.



Metso's crusher wears product and service offering
Using its unique expertise in crushing, the core objective of Metso is to provide the best possible crusher economy for its customers. Metso acknowledges the different needs of the customers, and therefore offers three distinguished wear part product ranges: Metso O-Series, Metso Expert Series and Metso Max Series. In addition, Metso provides wear parts services to help the customers to define the optimal crusher chamber solution ranging from a quick wear part selection to a long term partnership, the Chamber Selection Service, the Chamber Expert Service, and the Chamber Optimization Service.

Metso O-Series wear parts
Metso O-Series wear parts are standard stock parts. They include quarry and standard chambers. With the Chamber Selection Service, Metso offers the best fit and function match in the wear part product catalog.

Metso Expert Series wear parts
Metso Expert Series is the widest wear part product range of Metso. It includes industry tailored chambers, which meet the specific needs of an application. The wear part products include for example coarse corrugated wear parts and thick liners. Using the simulation tools of the Chamber Expert Service, Metso experts identify the optimal chamber design for the customer needs.

Metso Max Series wear parts
Metso Max Series wear parts are highly engineered and customized wear parts. They typically feature double wear life solutions and are therefore part of the Metso Planet Positive offering. Typical products include MX hybrid composite wear parts and MaX liners. The Chamber Optimization Service is always utilized, and through it the Max Series wear parts are not limited to Metso crushers only.

Chamber Selection Service
Chamber Selection service covers the daily needs regarding crusher wears. In this service the basic customer needs are solved with a crusher wears solution. This service is designed for transactional business, and it is quickly done. This is for the "just keep my crusher running" type of customers.

The service does not require site visitation and can be done over the phone or e-mail with the customer. The Chamber Selection service delivers a suitable chamber for the customer application. This service can be done with the basic wear part selection tools such as product catalogue or technical data sheets. It does not require a deep analysis from the crushing process like the other two (2) sister services where more data and information is required to deliver the improvements.

Chamber Expert Service
Chamber Expert Service targets to deliver more crushing economy for the end customer. This service finds and delivers the improvement potential for the customer. The Chamber Expert Service aims for contractual business where customer production targets are set as Key Performance Indicators

(KPIs). This service requires some more time than the Chamber Selection Service because the crusher performance is simulated, and it requires more production and application information. This service is for the "get my crusher producing" type of customers.

This service requires site visitations to get more information regarding the crushing process. The Chamber Expert service delivers the best chamber from existing offering, the optimal crushing parameters and a service after the initial improvement is delivered. This service requires Chamber Pro simulation tool where the best performing chamber is analyzed and selected for the customer application. Chamber Expert service really aims to meet the customer performance targets and deliver the crusher economy.

Chamber Optimization Service
Each crushing process is unique, and its performance consists of a wide range of factors. Whether the challenge is smooth operation, power and energy consumption or the wear pattern of parts, Metso Chamber Optimization specialists can tailor the crusher chamber for the optimized performance of the crusher.

Crushing potential to full use with an optimized chamber
The typical target in chamber optimization is to maximize the wear life of the crusher wear parts. This will lead to less wear parts change-outs and less stops in production. Other targets are to increase crushing capacity and decrease energy consumption without endangering the components of the crusher, enabling our customers to operate with lower cost per ton.

Metso's Chamber Optimization Program is especially beneficial for high-volume crushing purposes, where tailoring enables increased production. For developing optimum crusher chambers, Metso uses a state-of-the-art computer-controlled simulation software, which has been developed in-house during several decades.

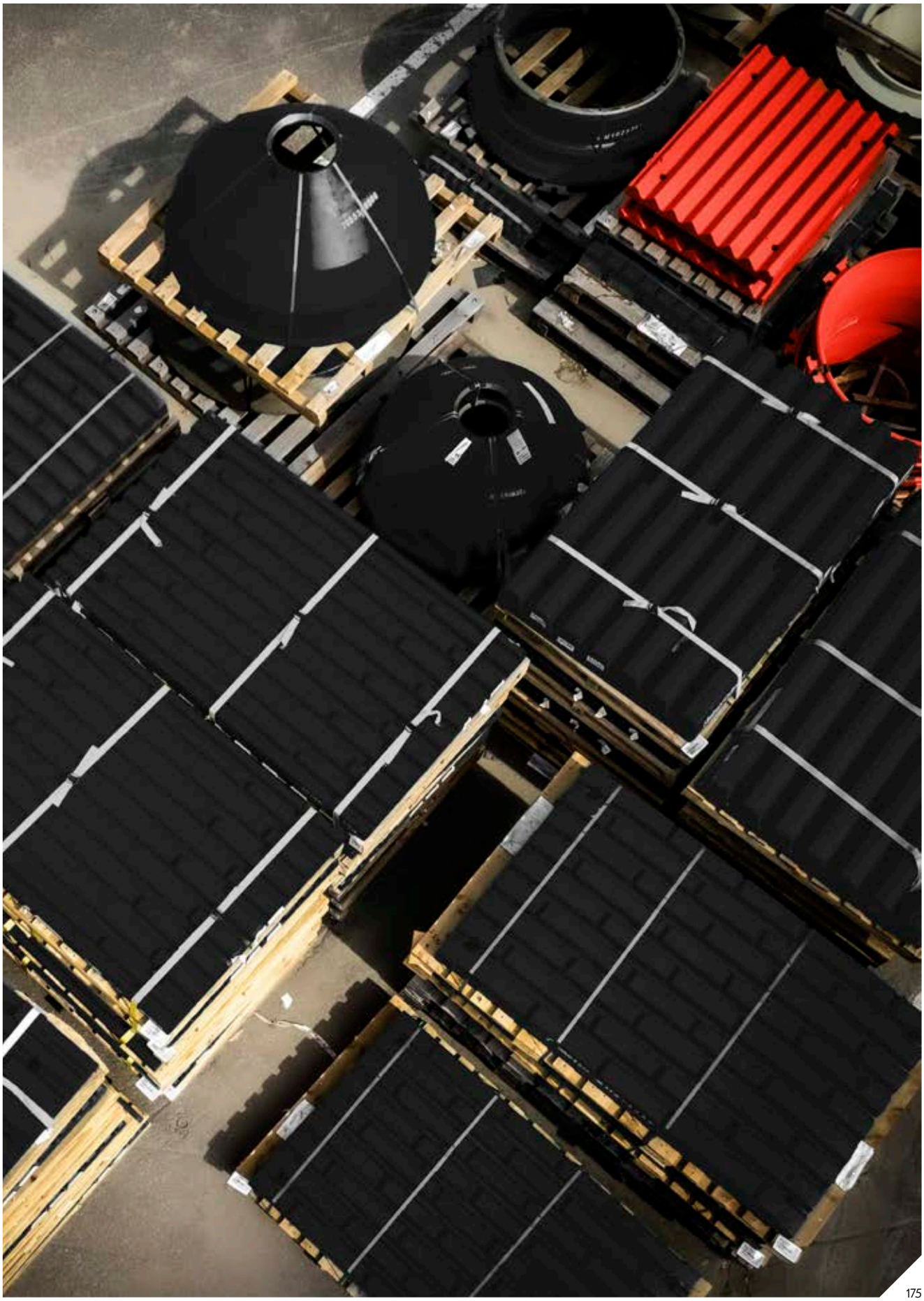
By using this tool, considering your experiences, and applying our expert-level crusher knowledge, we make sure the set production targets are achieved.

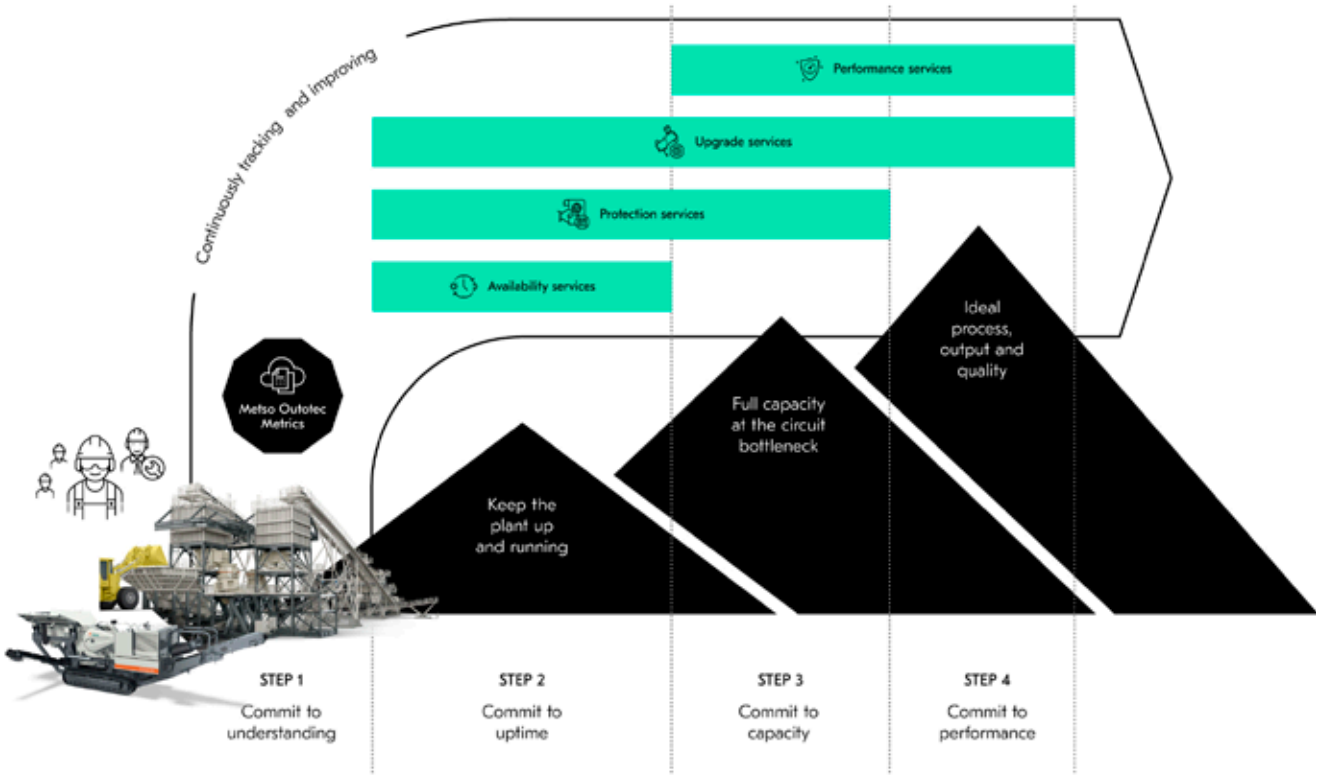
Five steps of Chamber Optimization:

1. Data collection: The optimization process starts with data collection. Our experts perform an audit to identify primary factors of your plant such as feed gradation, material samples, power draw, foam castings of wear patterns and crusher settings. This way, we make sure all necessary factors in your process are taken into account.
2. Analysis: This data is then carefully analyzed, and improvement potential is identified. Our competence center network focuses on crushing process simulation, material characteristics, improvement potential and global benchmarking.
3. Re-engineering: Global Metso expertise is utilized to re-engineer the needed components regarding metallurgy, simulation, and chamber engineering.
4. Manufacturing: Improved crusher wear parts are then manufactured in Metso's global foundry network to have full control of the supply chain. This ensures consistent quality, perfect fit, and high availability.
5. Follow-up: After the delivery, the behavior of new components is monitored intensely to see the results in capacity increase, longer wear life and lower cost per ton.

These steps are repeated for continuous long-term development.

For further product and technical information, please visit:
www.metso.com/products-and-services/parts/crusher-wear-parts





Aggregate services

Aggregate services help to bring out the best in the operations
Metso provides a wide variety of services and support for aggregate crushing and screening customers. The aggregates service portfolio features four key offerings which address the specific topics and issues related to aggregates production.

Protection service
Metso Equipment Protection Services keep your production running and reduce financial risk by making sure your equipment is in tip-top shape – with scheduled 1000h EPS inspections, extended warranties and Metrics retrofit.

Availability service
Metso Availability Services maximize the available uptime by minimizing unexpected failures with Chamber Selection service and protective wear part packages. Our Field service expertise, recommended parts lists and the new wear flow package make the service stops as short as possible.

Performance service
Metso Performance Services help you get more out of your machinery, whether it is more capacity, lower cost per ton or better end-product quality. Bruno analysis and wear part selection get the best out of your existing process, while Chamber Expert Service, Screen Optimization and Chamber Optimization Service are the tools for improving asset performance.

Upgrade service
Metso Asset Upgrade Services keep your machinery up-to-date with the most useful upgrades and retrofits. The Asset Care offering maintains your equipment performance and availability. Asset Boost offers performance-boosting options, upgrades and retrofits while Asset Improve has advanced upgrades such as automation and electrification.

Training
Training provided by Metso focuses on proper operation and maintenance procedures, as skilled operators and maintenance crews are key to keeping plants operating profitably.

Trainings are offered by Metso experienced professionals in a wide variety of languages and locations worldwide.

For further product and technical information, please visit:
www.metso.com/aggregates/services

Standards and technical information

Standards in most common aggregate applications
Standardization is needed to create common working methods and to allow communication between supplier, end user and authority more easily. Standardization increases the compatibility of different products, improves safety in all stages of production, and protects the end user and environment.

In addition to the previous points, it also creates a common language for internal and international business. In the crushing and screening business there are end product standards that have an effect on the crushing plant design.

Usually, asphalt and concrete are the applications, where specifically demand for aggregates is followed by standards. For these applications, crushing and screening process can affect the end product shape and particle fragmentation, i.e. gradation.

There are also dozens of other demands and specifications for aggregates, but feed material properties and rock type generally affect them.

Specifications (standard codes) for aggregates used in concrete, asphalt and railway ballast has been collected in the following table. As there are different standards in different countries and regions, most common ones have been shown in this table.

The table helps to detect the actual code and helps to determine which standard is valid in a country.

TABLE 1: *Few examples of application standard codes of different standards.*

Country ID	Standard	Concrete aggregates	Asphalt aggregates	Railway ballast
1	EN	EN 12620	EN 13043	EN 13450
2	ASTM	C33	D 692	AREMA /C 33
3	IS	IS:383-1970 and MOST / MORTH	MOST / MORTH	INDIAN RAILWAY STANDARD
4	BS	BS 882	BS 63	
5	GOST	GOST 32703-2014	GOST 32703-2014	GOST 7392-2014
6	JIS	JIS A 5005-1987		
7	GB/T	GB/T 14685-93	JTJ 014-97	
Country ID	Countries as example			
1	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxemburg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom			
2	U.S.A.			
3	India			
4	UAE			
5	Russia			
6	Japan			
7	China			

As can be seen in table above, there are different specifications available in the world. It has led to different shape measurement methods in each standard.

The following table shows an indicative relation between shape values defined by the different specification.

The EN 933- 3 flakiness index is set to 10. As an example, EN933-3 Flakiness index 10-% equals roughly BS-812 12% flakiness index.

All the given values indicate the share of unfavorable particles in the product fragmentation.

TABLE 2: *Shape measurement methods in different standards.*

Specification	Flakiness measurement	VALUE	MIN:MEAN SIZE
EN 933-3	Flakiness index	10	0,55:1
GOST 33053-2014	Flaky particles	7	0,42:1
BS 812 : Part 1	Flakiness index	12	0,59:1
IS 2386	Flakiness index	12	0,59:1
ASTM D4791	Flat particle test	10	0,55:1
GB/T 14685-93	Flakiness index	7	0,40:1
Specification	**Elongation measurement**	**VALUE**	**MIN:MAX SIZE**
EN 933-4	Shape index	15	1:3
GOST 33053-2014	Elongation	7	1:3
ASTM D4791	Flat and elongated	15	1:3
Specification	**Elongation measurement**	**VALUE**	**MEAN SIZE:MAX**
BS 812 : Part 1	Elongation index	35	1:1,8*
IS 2386	Indian elongation	35	1:1,8*
GB/T 14685-93	Elongation index	8	1:2,4**
Specification	**Combined measurement**	**VALUE**	
GB/T 14685-93	China EFI	10	
IS 2386	Indian EFI	40	

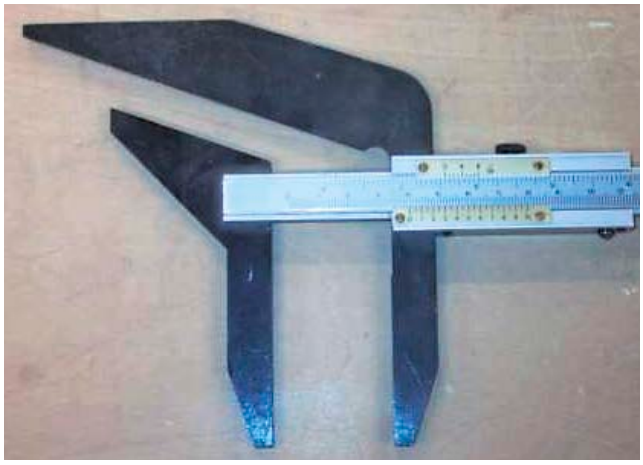
** In reality MEAN:MAX dimension can vary between 1:1,5....1:2,3*
*** In reality MEAN:MAX dimension can vary between 1:1,8....1:3,6*

The calipers of some shape measurement methods have been shown in following pictures:

EN 933-3 Flakiness index

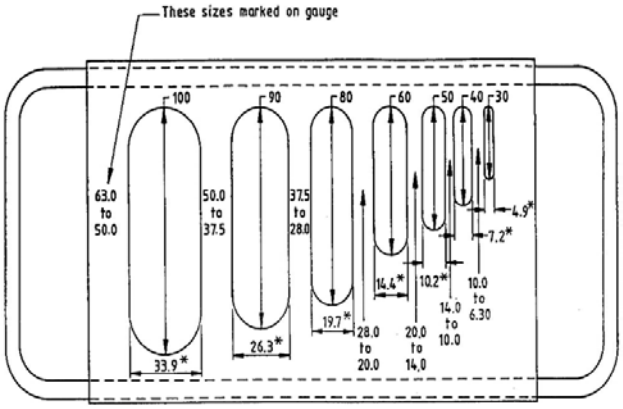
MIN:MIDDLE = 0,55:1

EN 933-3 Shape index



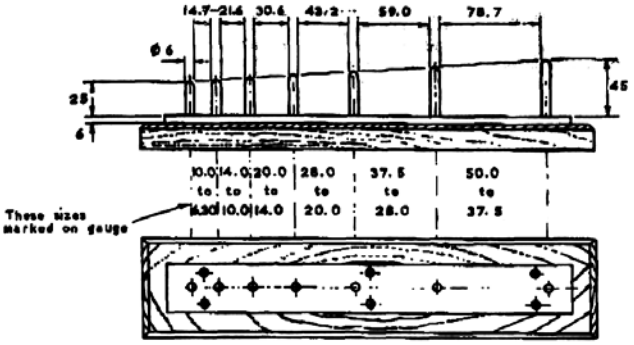
MIN:MAX = 1:3

BS 812 and IS 2386 flakiness index



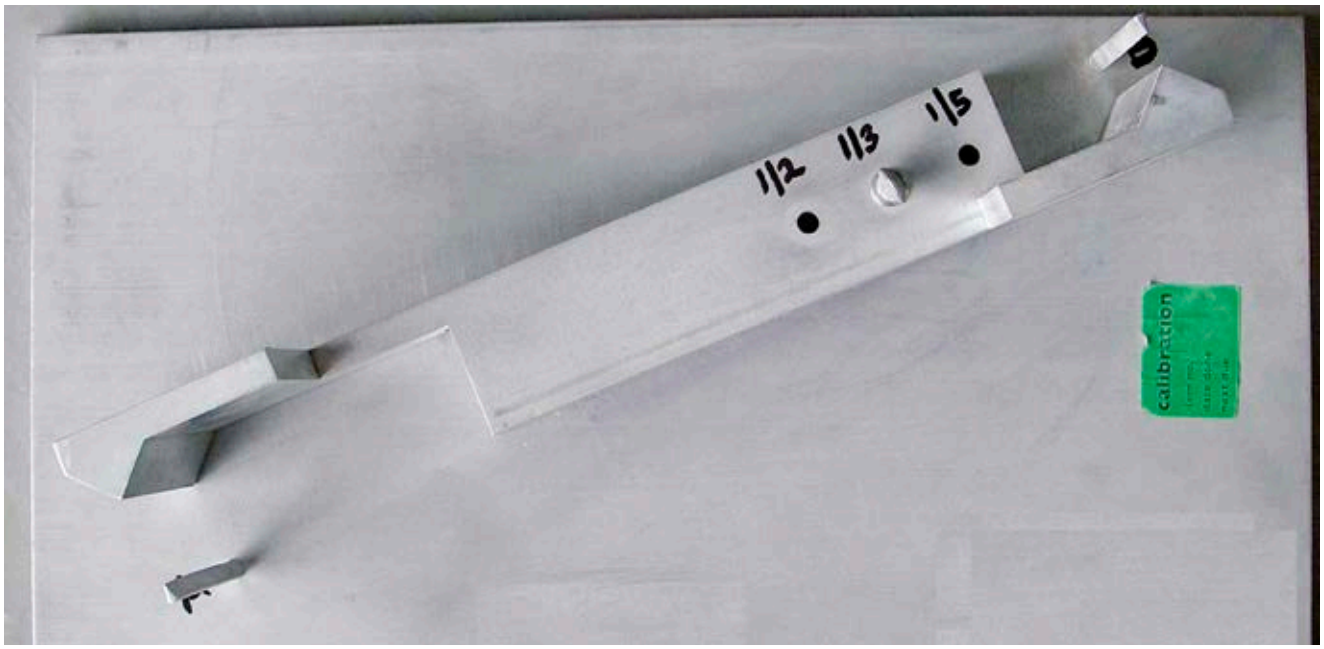
MIN:MIDDLE = 0,59:1

BS 812 and IS 2386 elongation index



MIDDLE:MAX = 1:1,8

ASTM D4791, Flat and elongated particles



Storage piles

Symbols used

α = angle of repose of material when forming pile (dynamic friction)

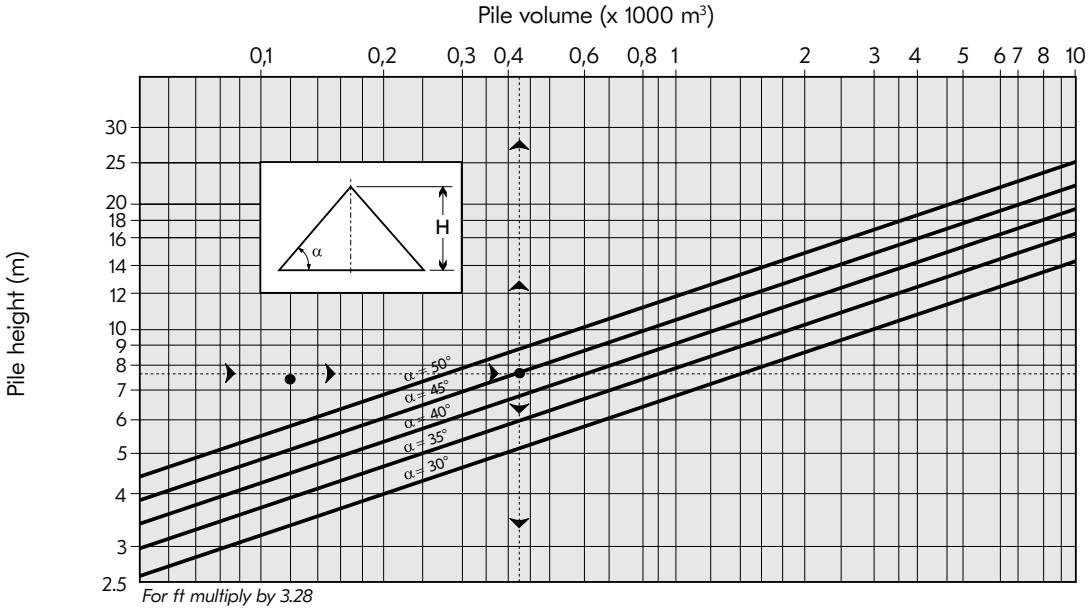
β = angle of repose of material when reclaiming under pile (static friction)

H = pile height (m)

D = pile diameter (m)

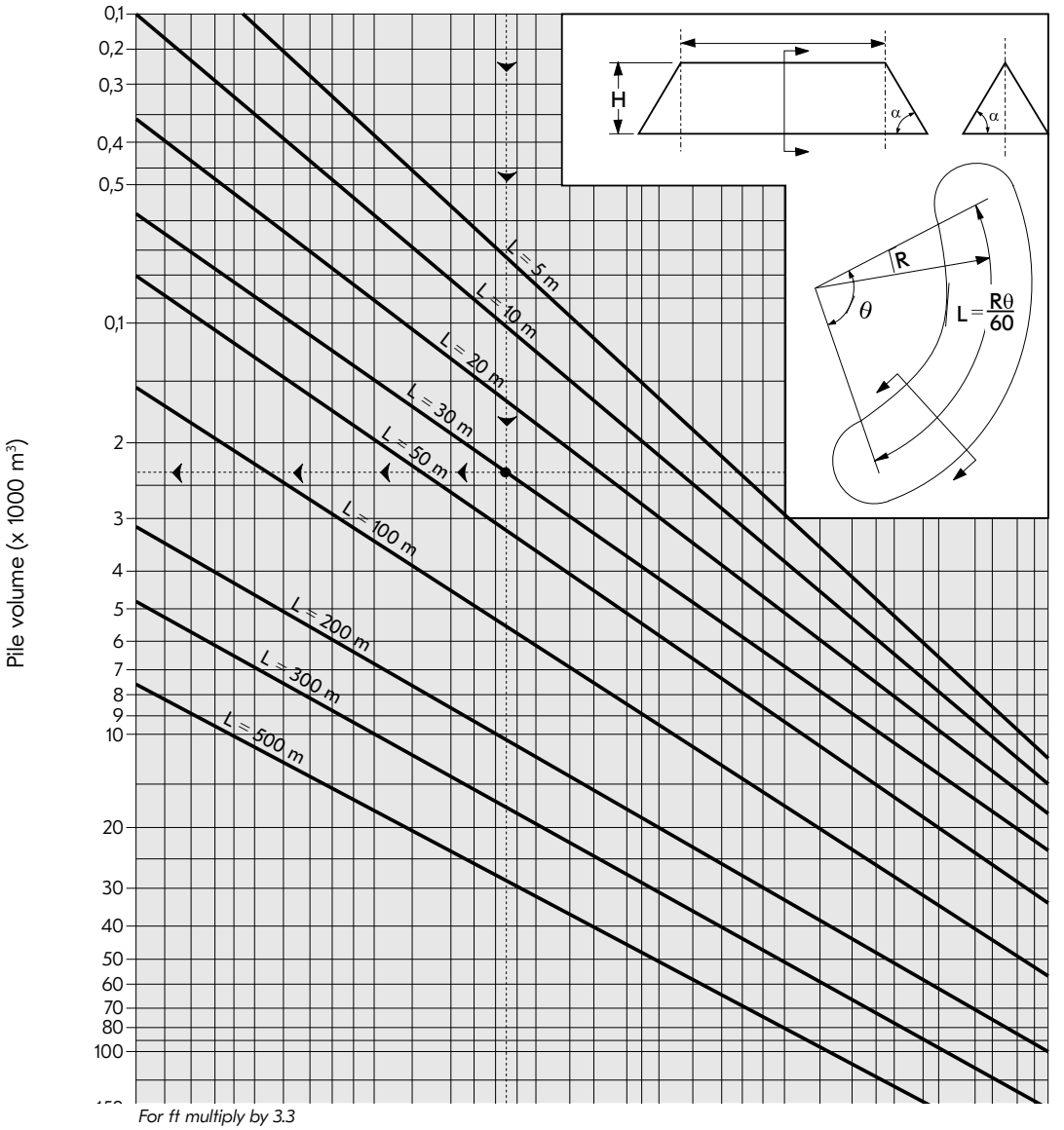
Material features

Material	Particle shape	Size (mm)	ρ_s (ton/m^3)	α (deg)	β (deg)
Natural sand	Round	0-3	1,6	35	40
Manufactured sand	Cubic	0-3	1,6	35	40
Crushed stone	Cubic	0-63	1,5	40	45
Crushed stone	Slabby	0-63	1,4	40	45
Crushed stone	Cubic	0-25	1,4	45	55
Crushed stone	Slabby	0-25	1,5	30	35
Pebbles	Round	0-63	1,5	30	35
Dry earth	–	–	1,4	40	40
Iron ore	Slabby	0-63	2,7	40	45
Coal	–	0-100	0,9	30	35



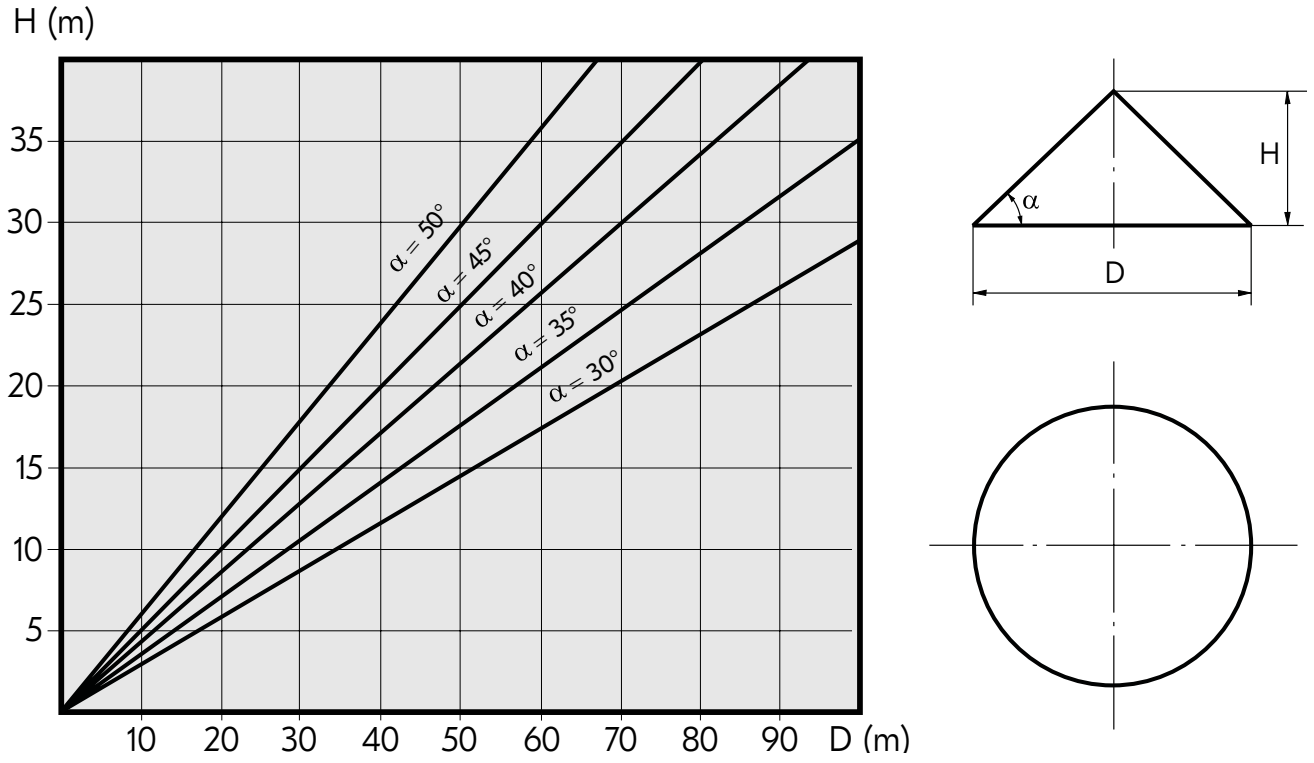
For ft multiply by 3.28
For ft³ multiply by 35.3

Cross section

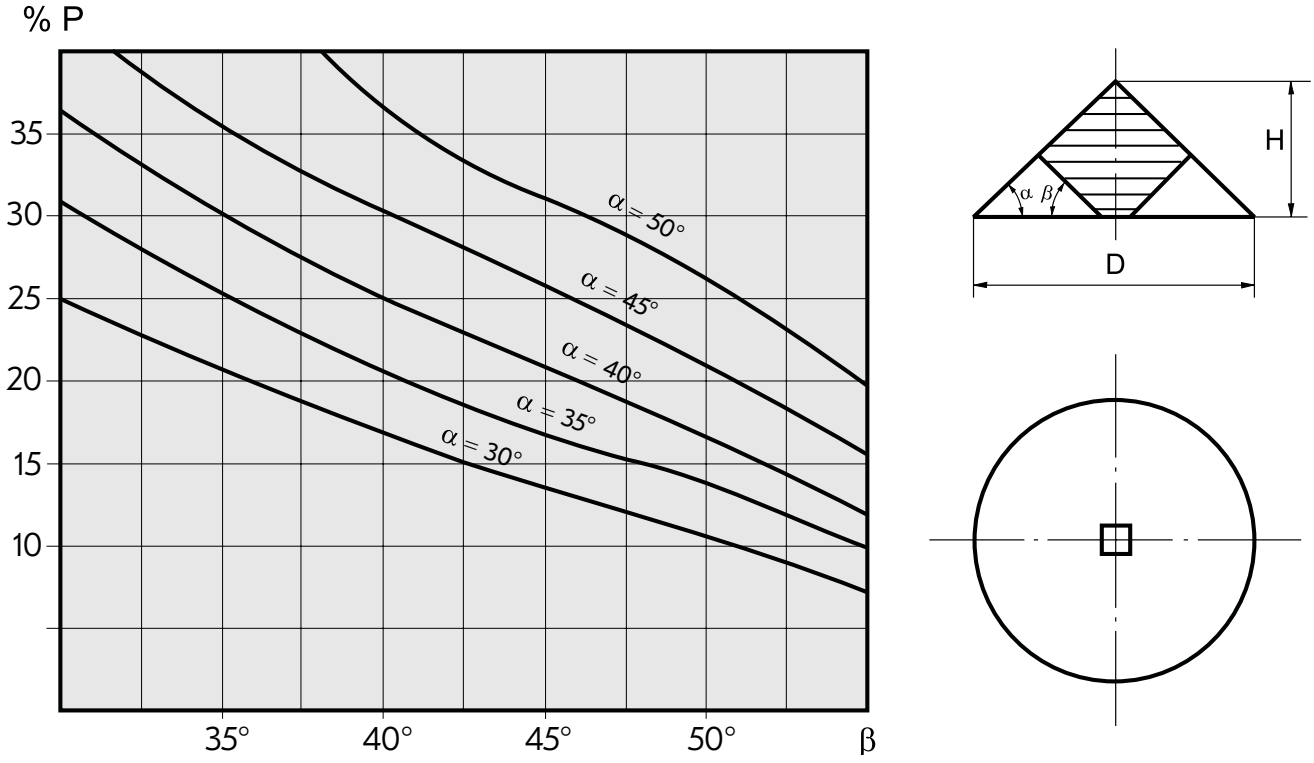


For ft multiply by 3.3

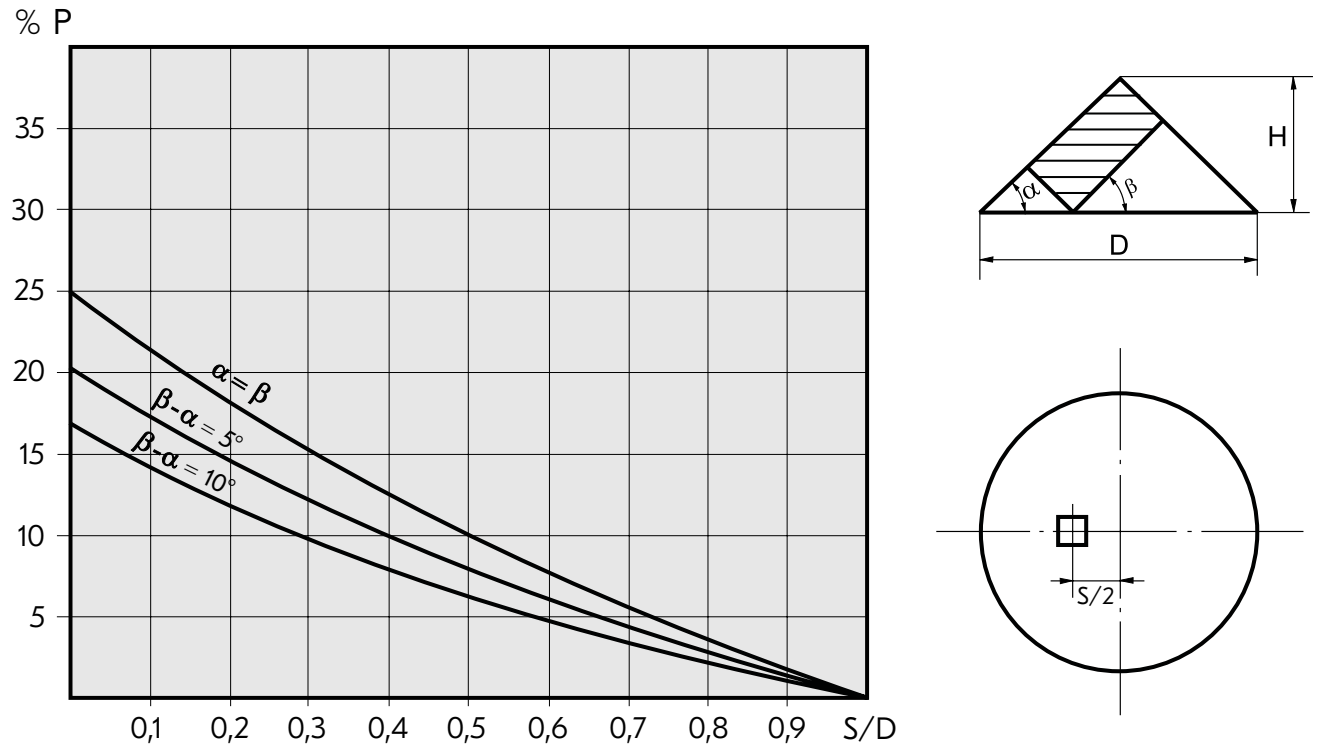
Relation between pile height H and the diameter D as a function of repose angle α.



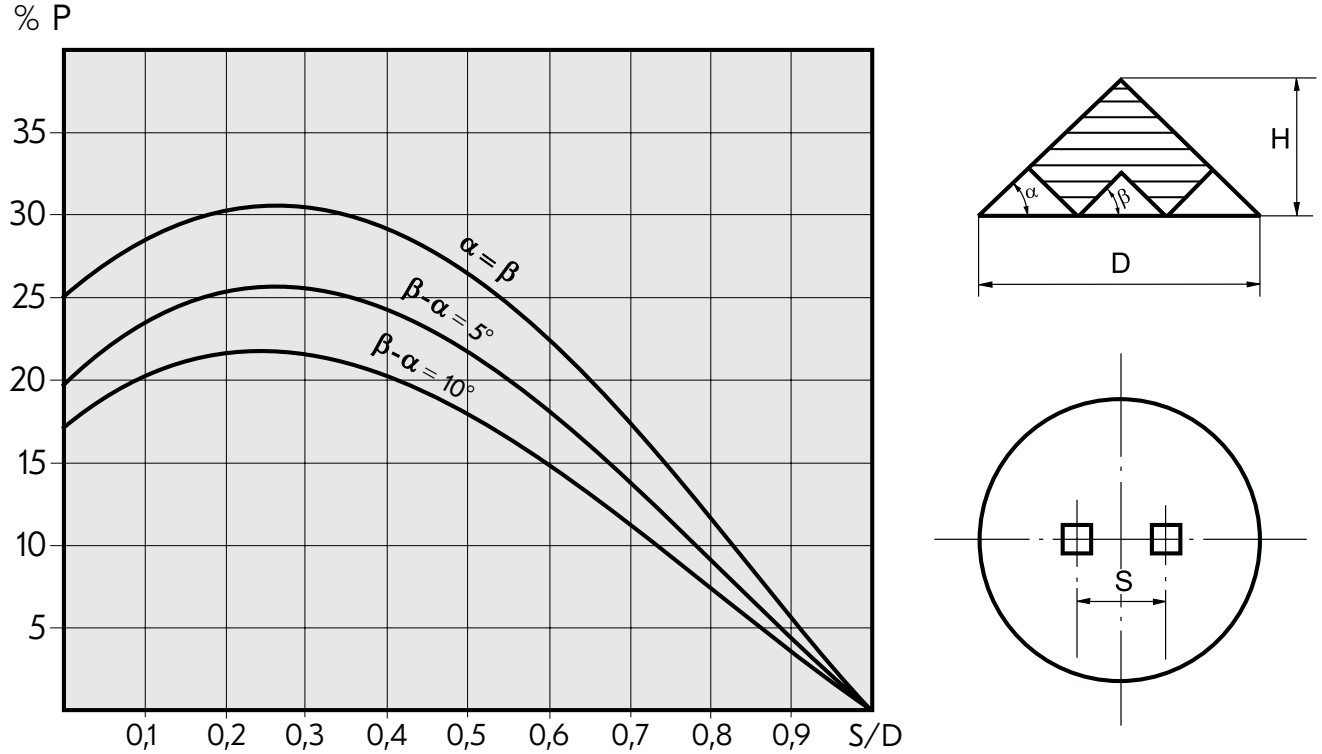
Percentage of total pile volume that can be unloaded by the central outlet, as a function of angles α and β.



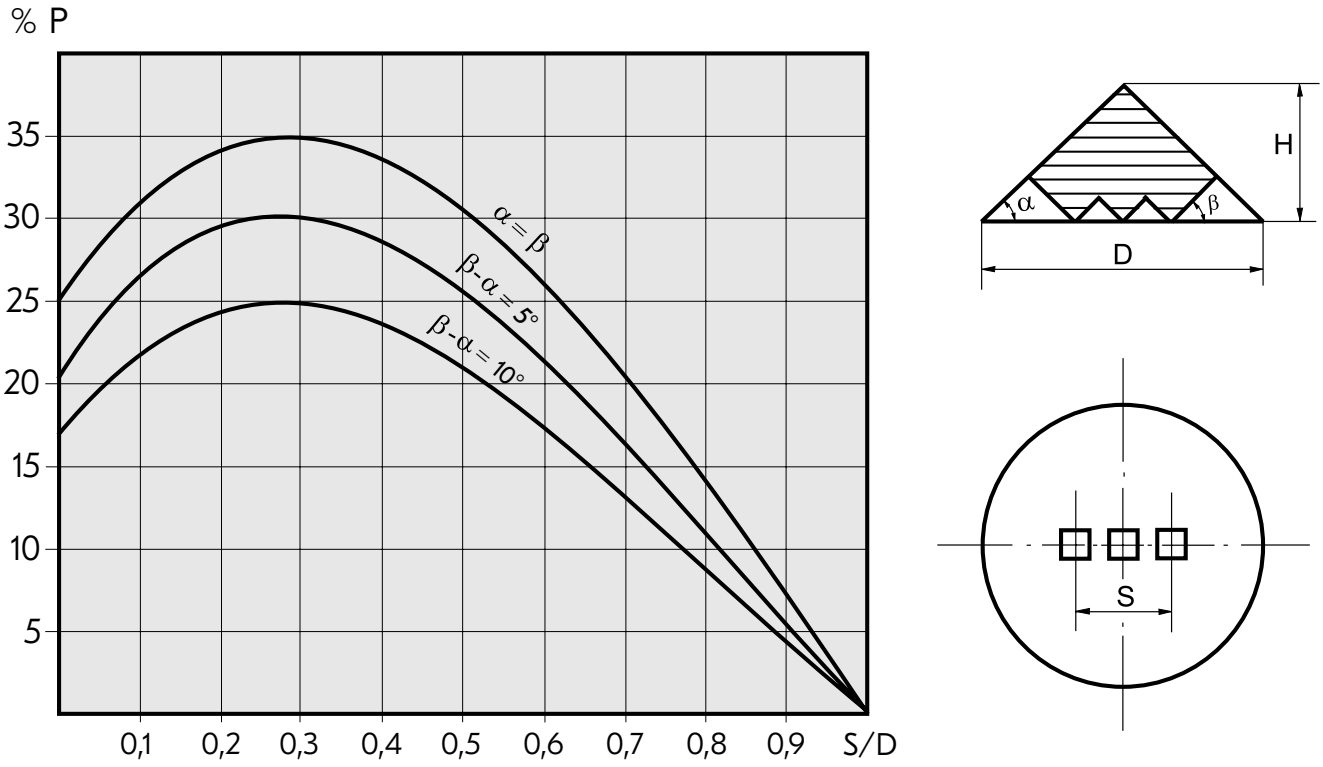
Percentage of the total pile volume that can be unloaded by an outlet off-set from center S/2, as a function of S/D and the difference between angles β and α.



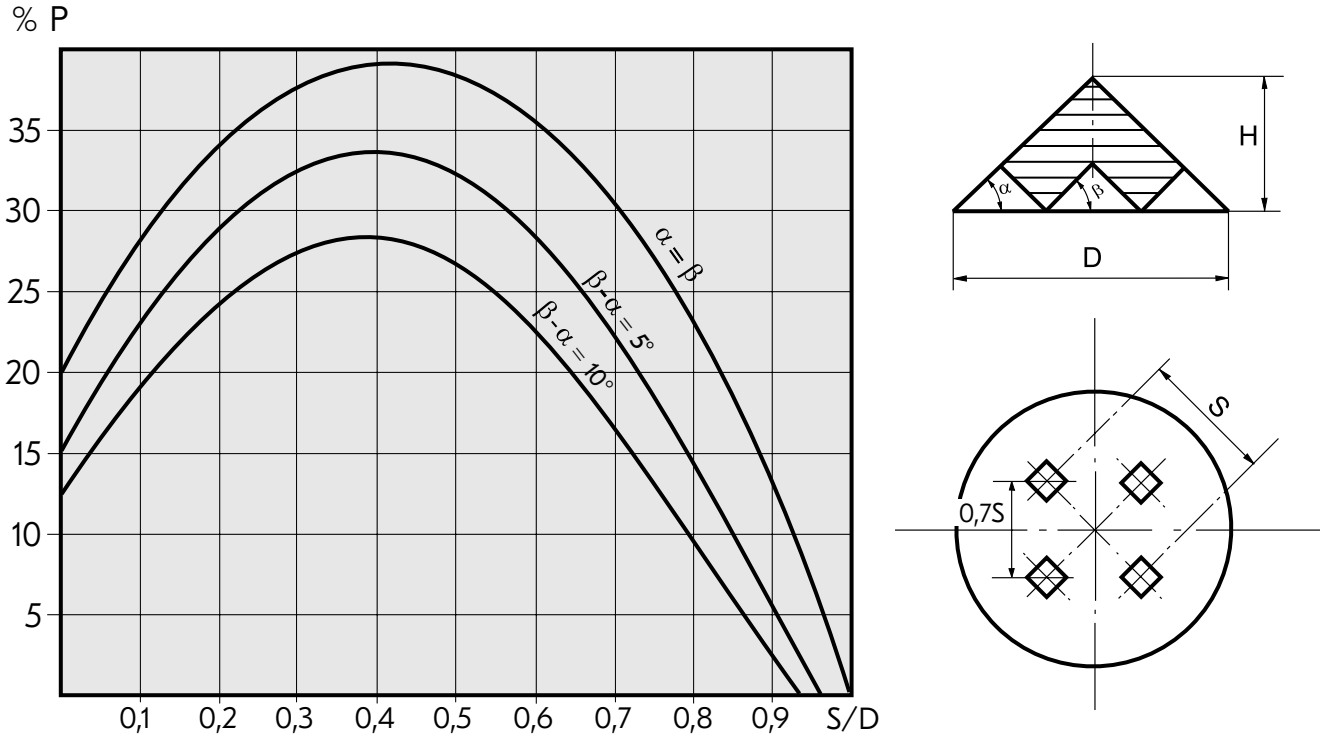
Percentage of the total pile volume that can be unloaded by two outlets with spacing S, as a function of the difference between angles β and α.



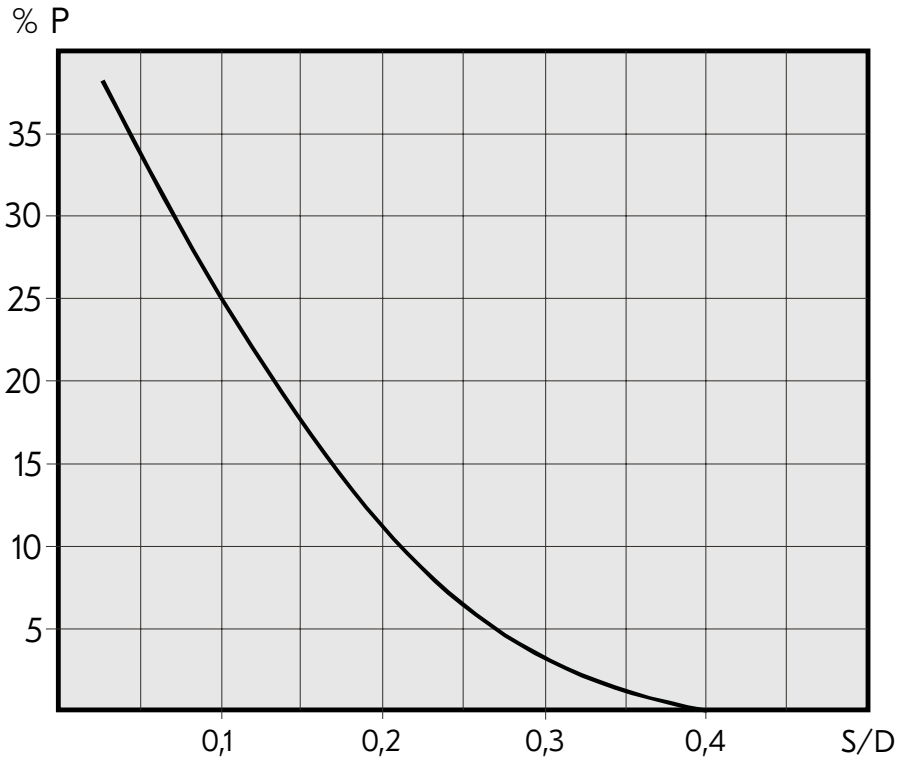
Percentage of the total pile volume that can be unloaded by three outlets, with spacing S, as a function of the difference between angles β and α.

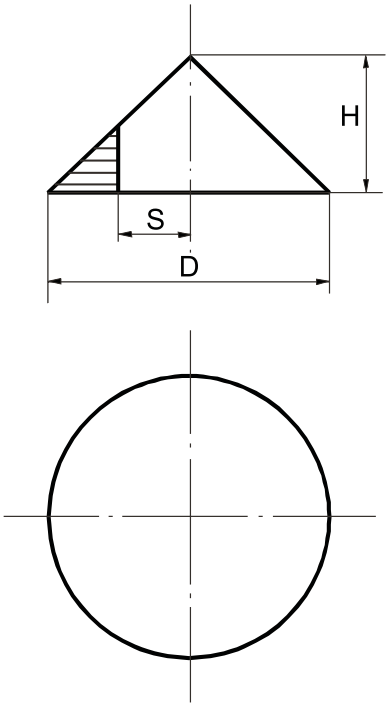


Percentage of the total pile volume that can be unloaded by four outlets with spacing S, as a function of the difference between angles β and α.

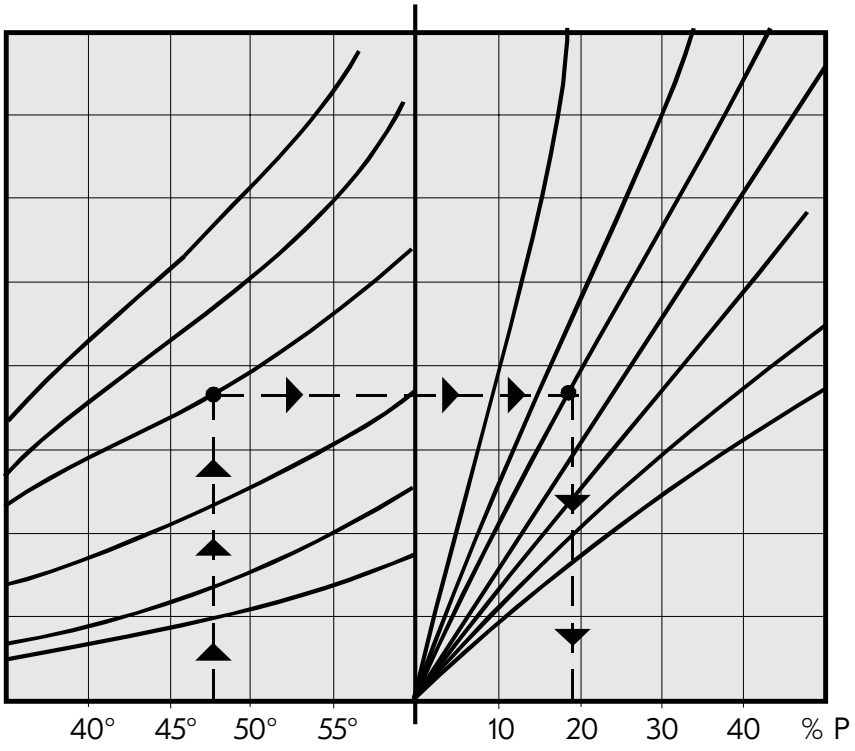


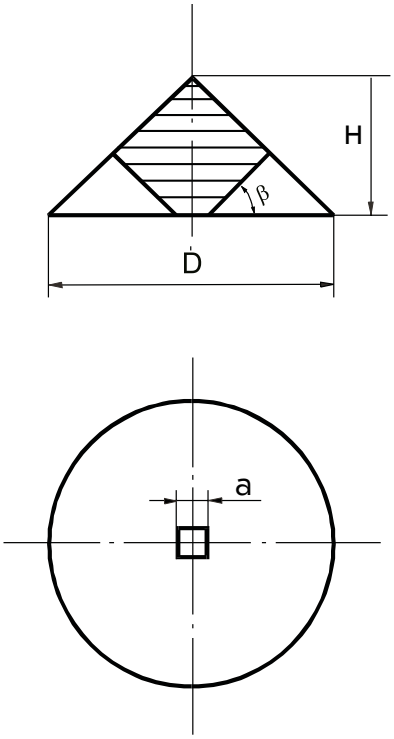
Percentage of the volume cut by a lateral wall, as a function of S/D.





Percentage increase of the volume unloaded by the bottom outlet, as a function of outlet hole size. This chart is valid for any number of outlets. To calculate usable volumes, multiply the percentage found on the charts on the previous pages by the percentage of increase on the chart below.





Unit conversion

To convert from	To	Multiply by
Technical atmosphere	kg/cm^2	1
Bar	kg/cm^2	1,02
CV	HP	0,9863
CV	kW	0,7355
Gallon (US)	Gallon (British)	0,83267
Gallon (US)	Liter	3,785
Gallon (US)	in^3	231
Gallon/min	l/sec	0,06308
Degrees Celsius	Degrees Fahrenheit	(°C*9/5) + 32
Degrees Fahrenheit	Degrees Celsius	(°F-32) * 5/9
HP	kcal/hr	641,2
HP	kW	0,7457
J (kg * m^2)	GD^2 (kg * m^2)	39,24
Yard	M	0,914
Cubic yard	m^3	0,7646
Pound/ft^3	kg/ m^3	16,02
Pound	kg	0,453
Pound	Ounce	16
Pound * in^2 (PSI)	kg * m^2	6,060
Liter	Gallon	0,2642
Liter	in^3	61,02
Pound * ft	kgm	0,1383
Pound/ft^2	kg/m^2	4,882
Mega Pascal (MPa)	kg/cm^3	10,2
Meter	Yard	1,094
Meter	Foot	3,281
Cubic meter	Gallon (US)	264,2
Cubic meter	Cubic yard	1,309
Cubic meter	ft^3	35,31
Square meter	ft^2	10,76
Square meter	in^2	1550
Meter * kilogram	lb * ft	7,233
Land mile	m	1609
Newton	kg	0,102
Ounce	g	28,349
Pascal	kg/cm^2	$1,02*10^{-5}$
Inch	cm	2,54
Square inch	m^2	0,0929
Ft	cm	30,48
Cubic ft	Gallon	7,4805
Cubic ft	Liter	28,32
Cubic ft/s	Gallon/min	448,831

To convert from	To	Multiply by
Kilogram	lb	2,205
Kilogram/cm^2	lb/ft^2	2048
Kilogram/cm^2	lb/in^2	14,22
Kilometer	Yard	1094
Kilometer	Mile	0,6214
Kilocalorie	BTU	3,9685
Kilocalorie	HP * hr	1,560*10^{-3}
Kilowatt	HP	1,341
Kilowatt x hr	Kilocalorie	860,5
Ton (short)	Pound	2000
Ton (short)	kg	907,18
Ton (metric)	Pound	2240
Ton (metric)	Kg	1016
Ton	Pound	2205
Ton (metric)	Ton (short)	1,12
Wk^2	GD^2	4

Operation and Environment – Introduction

From an environmental, health and safety point of view most mineral processing operations have some negative effects on the working environment.

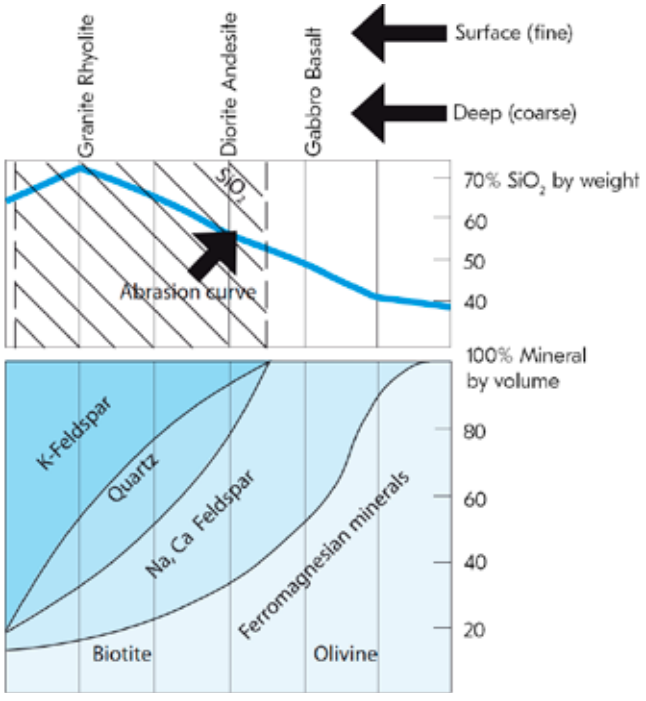
The main problems are related to
- Dust (dry plants)
- Noise (wet and dry plants)
- Pollution (emissions other than dust to air and water)

Dust

Dust - size
When energy is introduced to rock, ore or mineral, crystals will generate a dust emission. With dust in mineral processing, we practically understand particles below 100 microns in size. Above this size dry particles are easy to control and are quite harmless.

Dust - Chemical composition
A parameter of interest is the chemical composition. Hard rock in many cases is hazardous due to the silica content. Free quartz (SiO^2) is extremely dangerous and so are the rocks containing quartz like granite, gneiss a.o, see figure on the right. Fine silica can cause silicosis, a deadly lung disease. Mg-silicate of asbestos type is also very dangerous when inhaled, causing lung cancer.

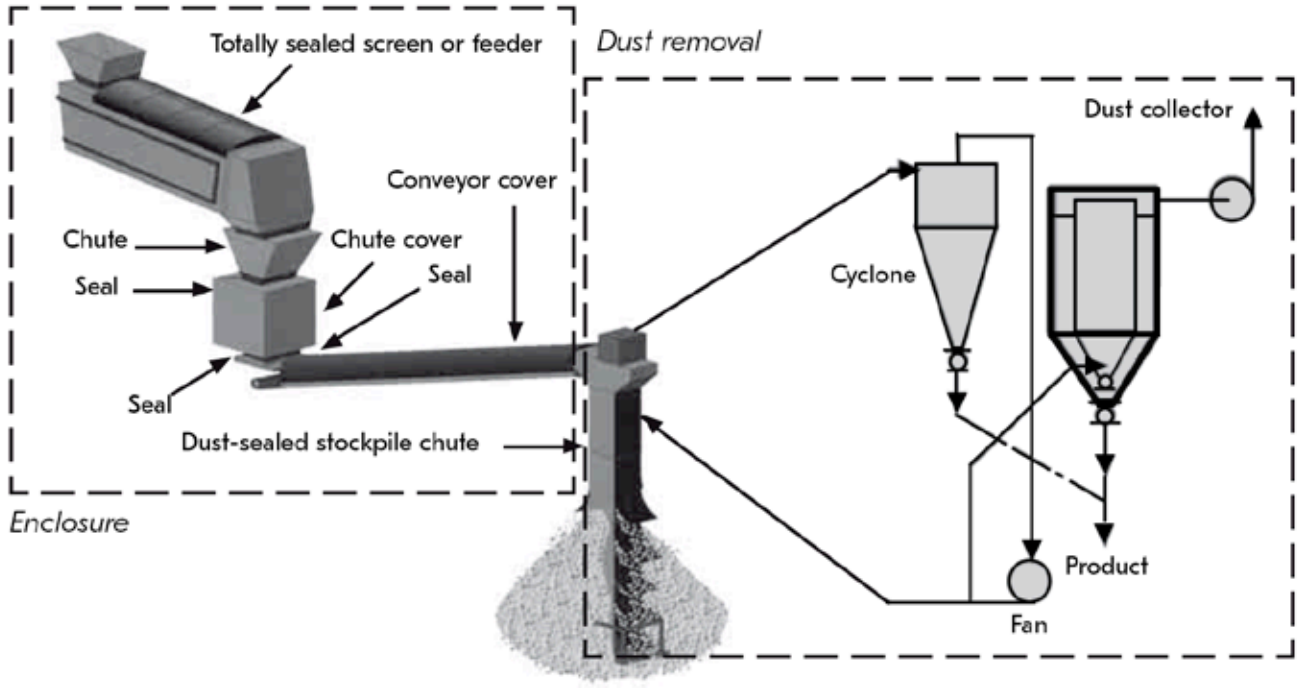
As many of the silicates are hard and abrasive, these dust fractions also are causing heavy wear when exposed to bearings, motors etc.



SiO^2 levels in magmatic rock.

Dust – SiO^2 levels
Dust fractions of non-silica type are normally not too dangerous for the operators and give more of a "housekeeping" problem.

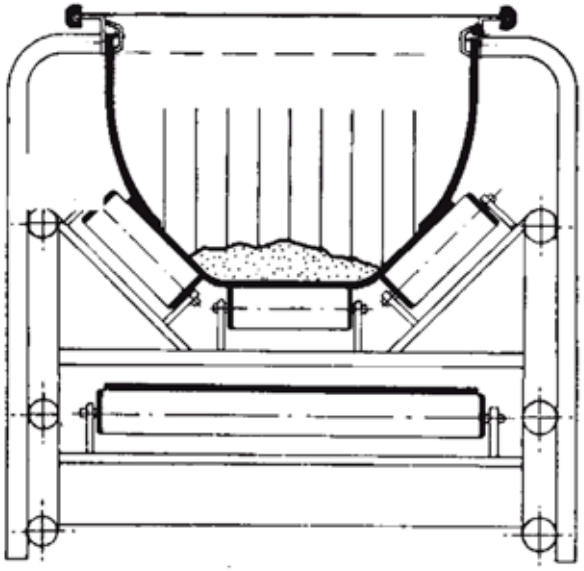
Dust control – basic



Some guidelines

1. Let dust flow with the rest of material or use dust suppression systems.
2. Suppression by water or foam is cheap and handy but can only take care of the coarser dust. Fine dust will remain a problem. If too much water is used the dust will turn to sticky clay, causing down time in operation and freezing in cold climate.
3. Enclosures of machines are very effective if you only encapsulate the dust emitting part of the machine, not drives or other moving parts. Enclosures are also very effective against wind emission of fines from conveyors and for sealing off transfer points, see below.
4. Dust removal by ventilation is used when the dust is the product (dry grinding of filler fractions) or when dust is not allowed in the final product or in the processing system, see ventilation criteria on the next page.

Equipment enclosure.



Wind enclosure.

Ventilation criteria
Dust capture velocity in m/s (ft/min)

= Ventilation criteria **(Vc)** in $m^3/s/m2$ ($ft^3/min/ft^2$)

= Air volume needed per open area of enclosure

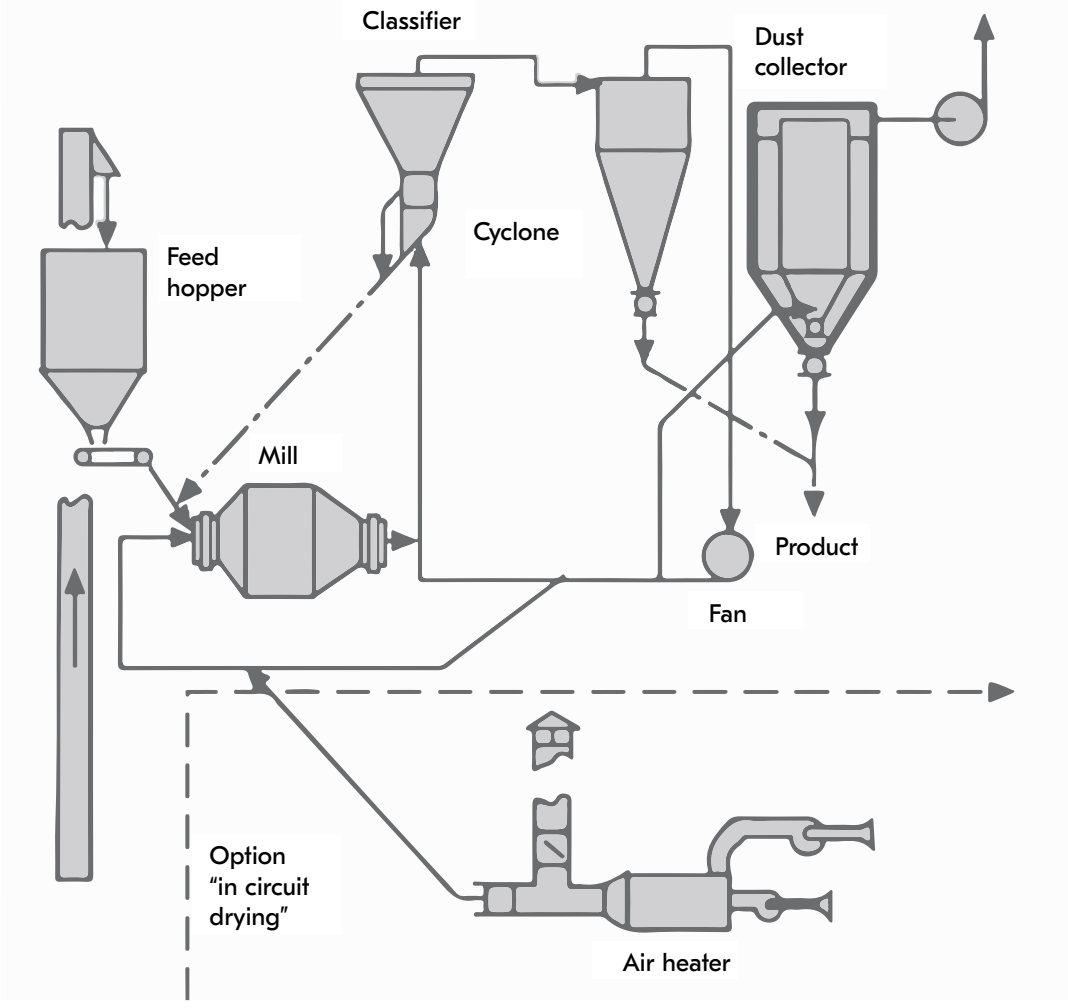
Calculation of ventilation systems for dust removal is a tricky thing. Some estimation figures below:

Application	Vc	Comments
Feeders, surge bin openings	1,02 (200)	General value for low-energy operations
Transfer points	2,33 (1500)	per enclosure area
Screens	0,26 (50)	per screen area
Crushers and dry mills	1,5 (300)	not for air swept mills

Dust collection
The dust removal and dust collecting systems are very similar to a normal dry classification circuit. Dry classification is in fact a dust removal system where the max size of the dust is controlled by a classifier (or ventilation criteria), See below.

Primary recovery of dust is normally done in a cyclone taking the major part. The final recollection is done in a wet scrubber or a fabric filter.

Wet scrubber has an advantage over fabric filter when the dust is combustible. In all other cases the dry fabric filtration is more effective as no sludge handling is required (being the case with wet scrubbers).



Noise

General
In mineral processing there are several machines considered to be very noisy (crushers, screens and grinding mills are typical). Unfortunately, these noises can generate undesirable sounds.

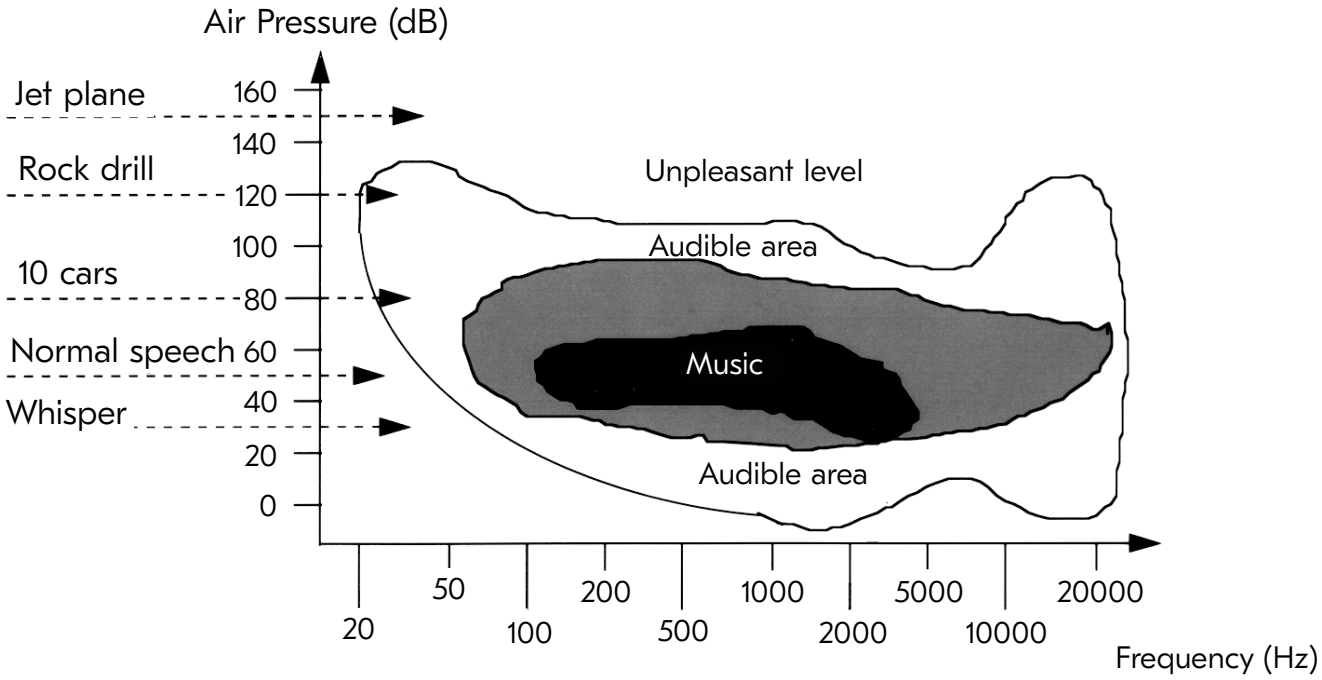
As sound is airborne and sound pressure has variations, we must find a sound pressure level that can be tolerated by the operator. Noise is not only harmful to the hearing but also affects the heart action and the ability of concentration. It also restricts verbal communication and the observation of warning signals or dangerous situations.

Sound – basic
The human sound pressure ranges from lowest sound to be heard and highest sound to stand without pain. It is from **0,00002Pa (2µPa) to 20 Pa. (1 psi = 6,89kPa).**

To be more practical the sound pressure range above is converted to a sound pressure level by the formula:

Lp = 20x log P/Po (Po = 2 µPa) converting the range above over to 0-120 dB (decibel)!

Experienced sound	**change of dB**
Double sound level	+ 10dB
Double sound sources	+ 3 dB
Double the distance to sound source	– 6 dB



Hearing range for a normal ear.

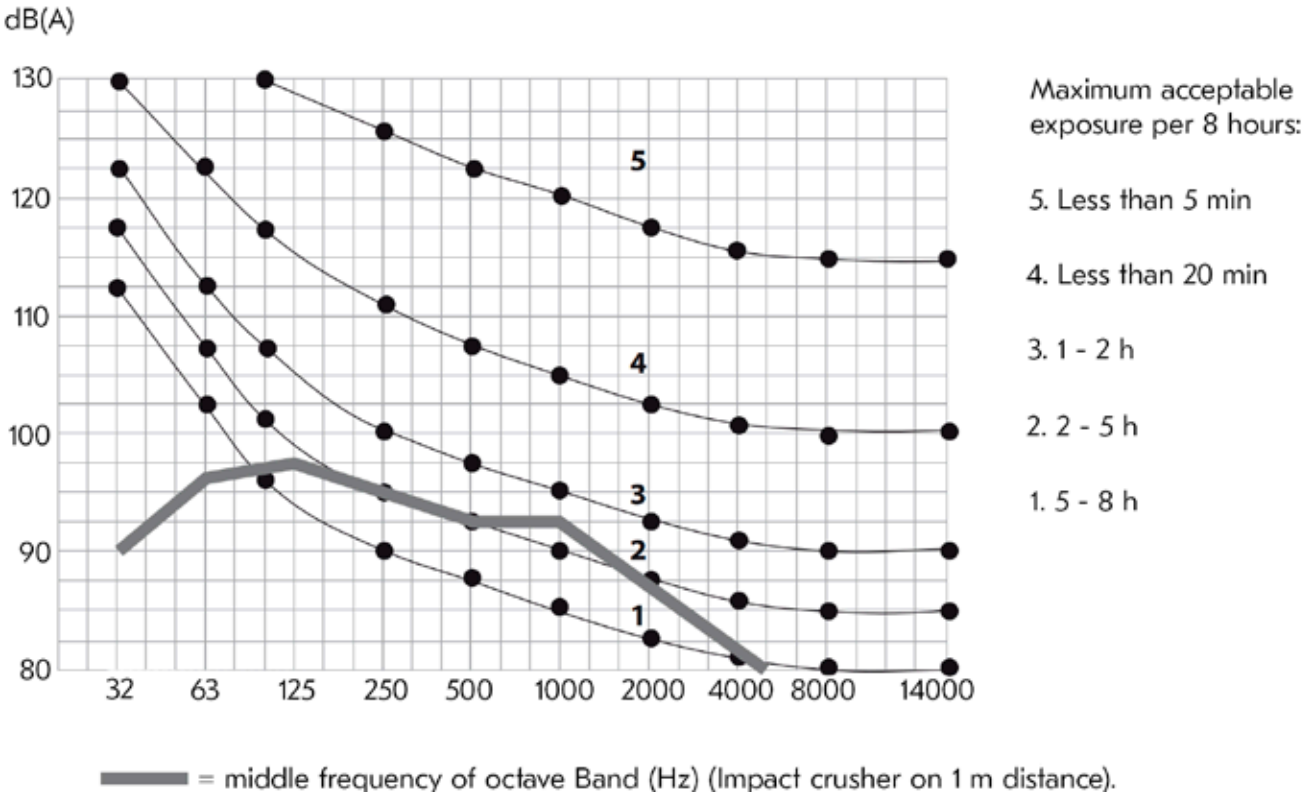
The lower limit is called the threshold of hearing and has a maximum sensitivity around 3500 Hz (resonance frequency of the ear). The upper line is the 120 dB sound pressure line (the pain line)

Mechanical noise is measured in dB (A) indicating that an A-filter is used, damping lower frequencies (of less harm to the operators).

Infra-sound is sound with a frequency below 22 Hz. (Can be harmful at longer exposures)

Ultra-sound is sound with a frequency above 18 kHz. (Can be harmful at longer exposures)

Noise – exposure risks
For continuous sound with a wide frequency range, a sound level below 85 dB(A) is acceptable for an 8-hour exposure per day with respect to the risk of hearing damage. If the sound level is higher an octave band analysis is necessary. This curve is compared to the standard risk curves, see below.



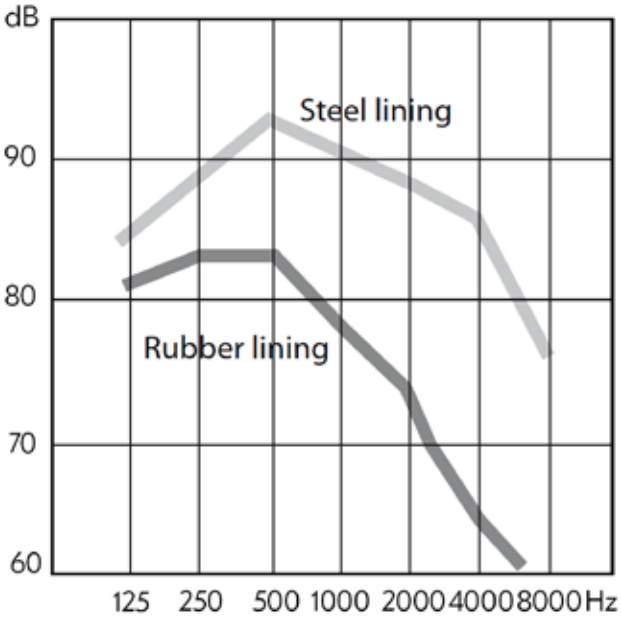
Noise reduction

There are four main ways to reduce the noise levels for processing systems including crushers, mills, and screens.

- Optimal operation
- Use of "internal" polymers (wear material and wear products)
- Use of "external" polymers (dust enclosures)
- Enclosure with noise reduction walls

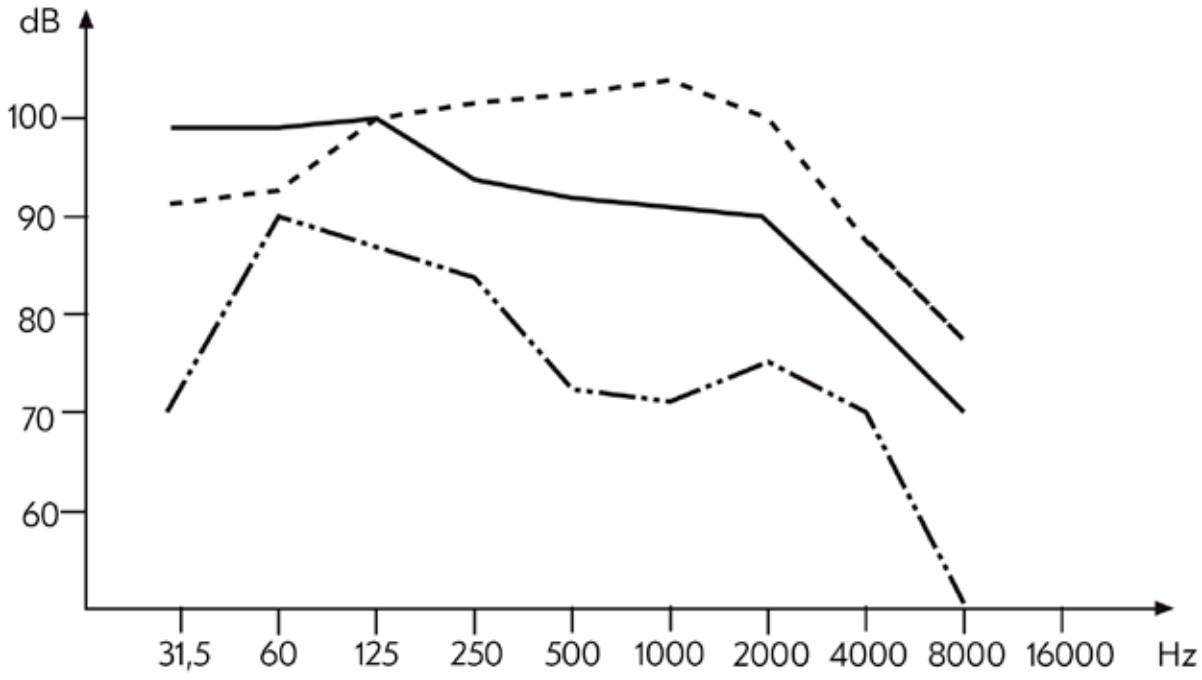
Optimum operation
Mass flow equipment like crushers and screens are normally lower in noise when they are operated under optimum conditions and the material flow is absorbing part of the noise (e.g. choke fed cone crushers). Reduced circulating loads also lead to reduced noise levels.

Internal polymers
The use of polymers as mill liners, screening media and wear protection in material handling systems (chutes and transfer points) have a dramatic effect on noise reduction. For grinding mills, a rubber lining can reduce the noise level up to 10 dB(A) compared to a steel lining.



External polymers

Using polymers as dust sealing enclosures of crushers, screens, conveyors, chutes, transfer points etc. will give a noise reduction of approx. 5-10 dB (A). The difference for a screen with steel wire deck and rubber deck is shown below.

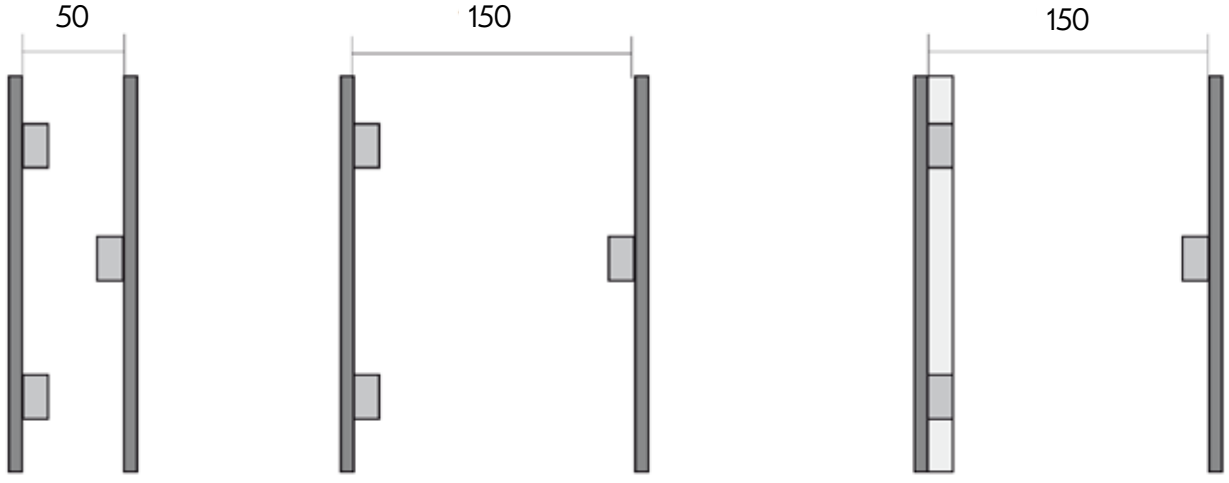


Steel wire cloth
Rubber elements
Rubber elements with dust encapsulation

A simple rule: The more polymers used for various purposes in the mineral process systems the lower the noise levels!

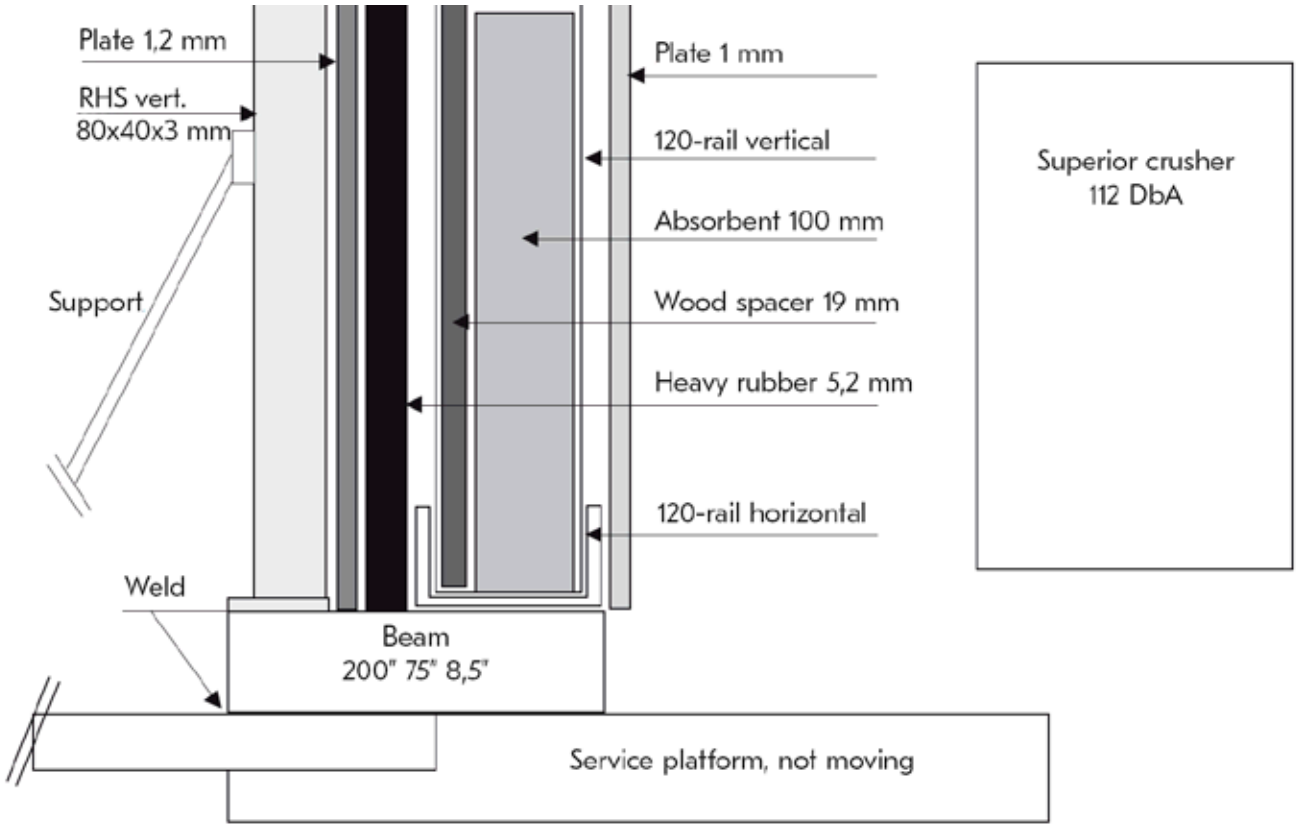
Noise reduction walls

Enclosure is an effective way of reducing noise. Enclosure can be more or less extensive (enclosure of drive or machine or both). With a total enclosure noise levels can drop by 10-15 dB (A). Depending on duty the design of the noise reduction walls can differ in design:



Light and medium duty walls.

Heavy duty crusher wall, cross section

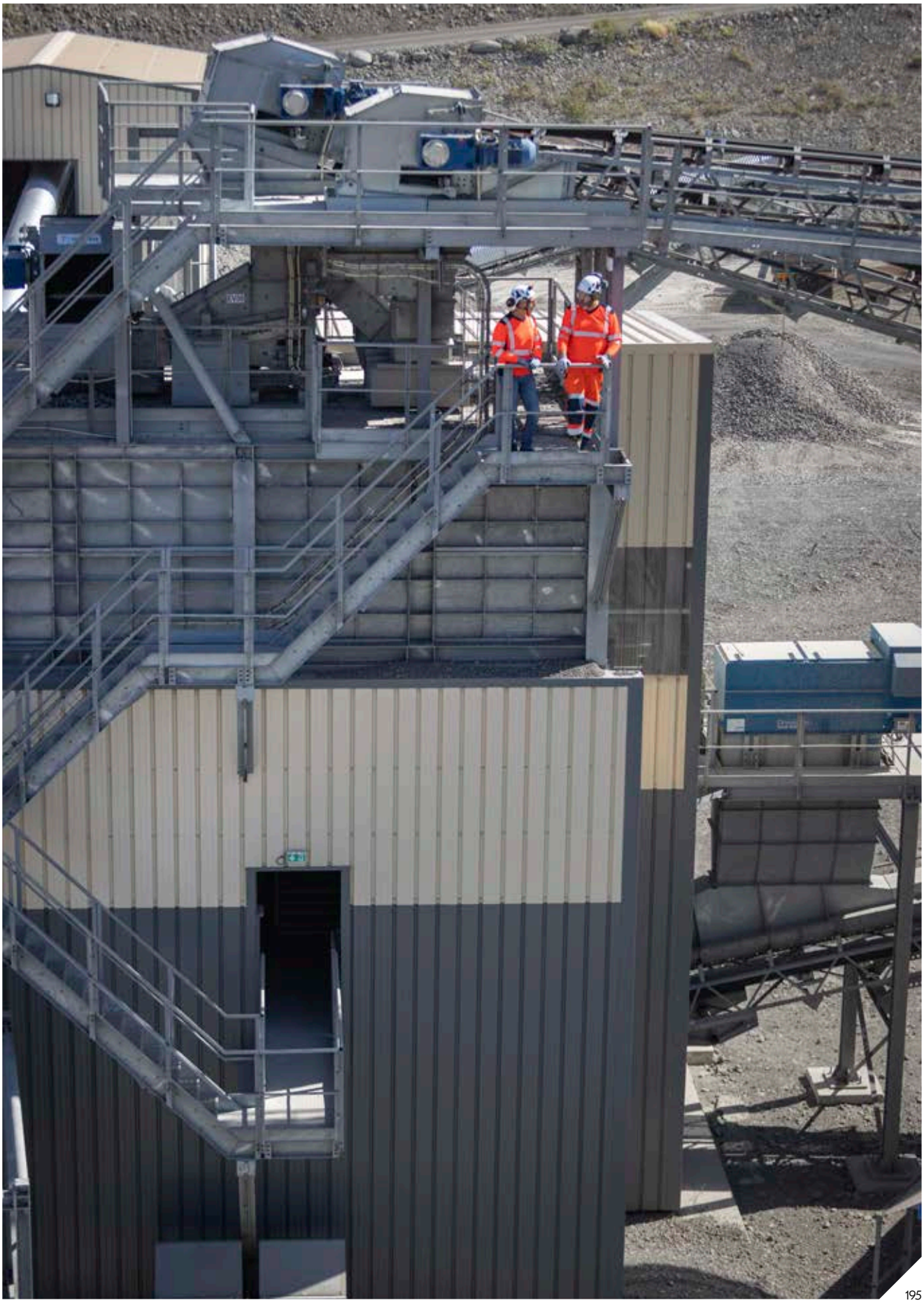


Ear protection

When working in environments with continuous and high noise levels it is important to use ear protection all the time. Also, at sound levels of 75-80 dB (A) it is to be recommended to use ear protection even if recommendation says something else. The reason is that long exposure also at these levels can cause impairment of hearing.

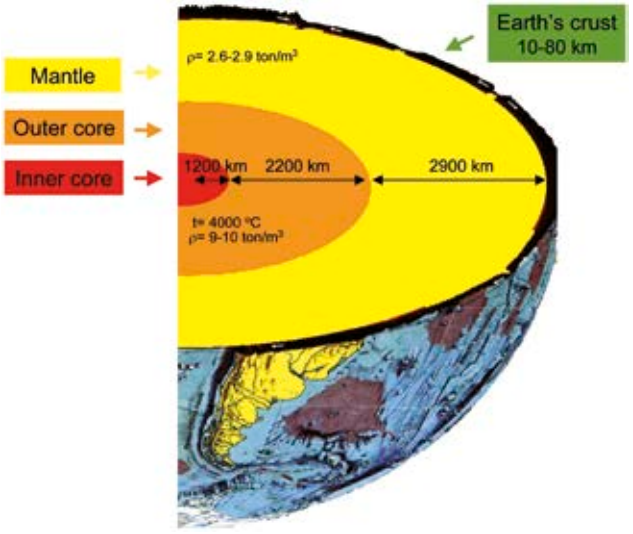
Good rules about ear protection:

- Take some "noise breaks" now and then
- Go for regular hearing tests
- Check your ear protection equipment at certain intervals



Minerology and testing

Minerals and rocks

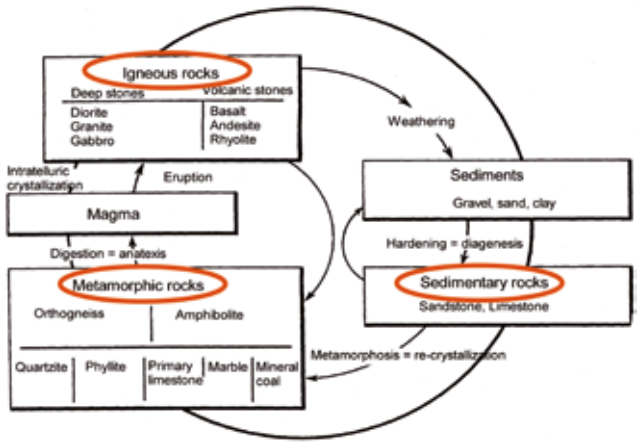


1. Geology

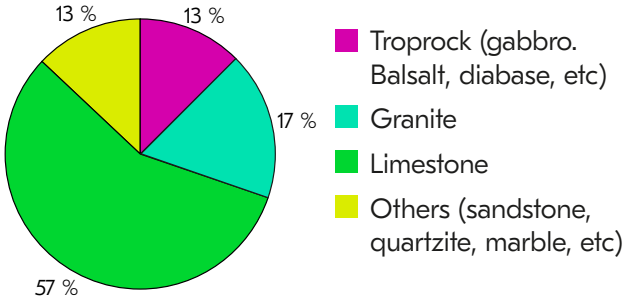
According to the prevailing assumption, our own solar system began forming from dust around 4,600 million years ago. This has been concluded from fallen meteorites. The oldest rock types, about 3,930 million years in age, have been found in Antarctica.

The structure of the globe has four main elements: the inner core, outer core, mantle, and earth's crust. The Earth's radius is about 6,370 km, its iron-nickel core accounting for 3,400 km, while the average density of the Earth is 5,500 kg/m^3. Because the density of rock in the earth's crust is 2,800 kg/m^3, the inner areas must have a very high density, up to 10,000 kg/m^3.
Source: Internet

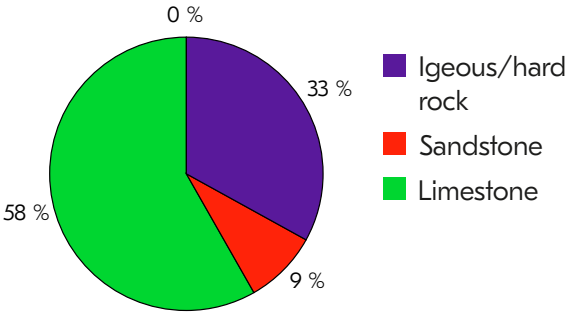
The origin of different rocks can be summarized as shown in the following diagram:



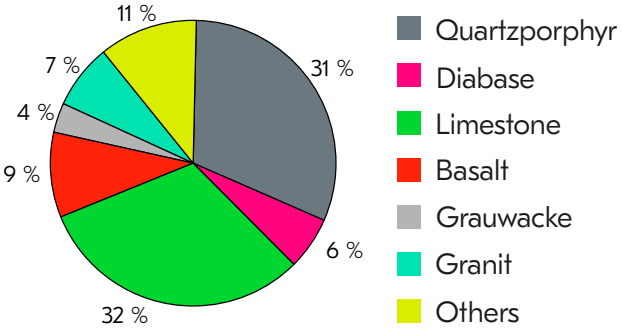
The occurrence of different types of rock varies geographically. For example, in the US, UK and Germany, the distribution of aggregate products is as follows:



U.S. Crushed stone production, by stone type.
Source: **U.S.** Geological Survey.



Crushed rock production, in **UK**.
Source: Quarry Product Association. Statistical Yearbook.



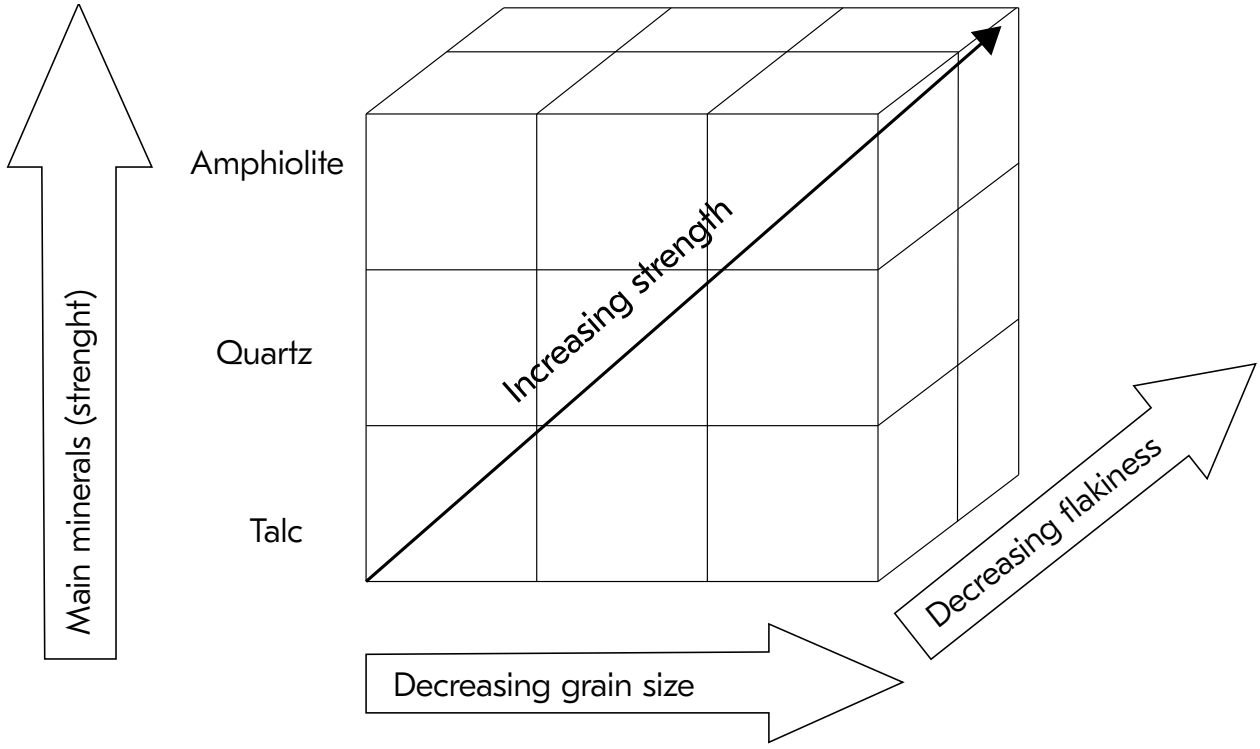
Quarried rock types in **Germany**.
Source: Naturstein Ind. Statistics.

In general, it can be said that 2/3 of all rock products is limestone.

The strength of rock depends mainly on the mineral composition and rock structure. Granite, for example, mainly comprises hard feldspar and quartz grains which interlock, creating relatively strong rock.

Shale is mainly soft clay minerals with a platy structure which flakes easily -> relatively soft. A general rule of thumb is that igneous and metamorphic rock = fairly hard; clastic sedimentary rock = fairly soft; limestone varies e.g., chalk = soft, other types of limestone can be quite hard.

A simplified approach involves summarizing the impact of different variables on a 3-D cube.



The hardness of the minerals varies in accordance with the graph.

Hardness of minerals in geology are defined based on MOHS hardness-scale:			
Hardness and mineral			**Can be marked with:**
1	talc	$Mg_3(OH)_2Si_4O_{10}$	• nail • coin • glass • hard metal
2	gypsum	$CaSo_4 \cdot 2H_2O$	
3	calcite	$CaCO_3$	
4	fluorite	CaF_2	
5	apatite	$Ca_5(F,Cl,OH)(PO_4)_3$	
6	orthoclase	$KAlSi_3O_8$	
7	quartz	SiO_2	
8	topaz		
9	corundum	Al_2O_3	
10	diamond		

2. Minerals

Mineral is a natural inorganic substance precisely defined according to its physical and chemical characteristics.

2.1. Rock

Is an aggregate of one or several minerals, forming the great mass of the earth's crust. In certain cases, rock may consist of one single mineral as in the cases of limestone, which consists only of calcite, stratified clayish rock and quartzite layers, etc. Rocks may be solid, like granite, or unconsolidated like sand.

Normally, rocks are formed by more than one mineral. Some of the minerals are predominant and form the essential components, and others, in smaller proportions, constitute the accessory minerals.

2.2 Ore

An ore is a mineral or rock containing metal ore mineral concentrations that can be economically extracted. The ore is the source from where the metal or other mineral substances are extracted.

2.3 Rocks

Rocks are divided into three main groups:

a) Magmatic, eruptive, or igneous
b) Sedimentary
c) Metamorphic

2.3.1 Igneous rocks

Igneous rocks are formed by the cooling of molten magma. According to the place of formation they are divided into:

a) Intrusive, plutonic or abyssal, formed deep in the earth's crust. Due to the slow cooling, they present large crystals, with phaneritic textures, i.e., coarse crystals.
Examples: granite, pegmatite, etc.

b) Extrusive, volcanic, or effusive, formed at the surface of the earth's crust through eruption. Due to the fast cooling (solidification) they present small crystals, with aphanitic texture. These rocks are often composed of glass.
Examples: Basalt, felsites, etc. Sometimes an intermediate group is included.

c) Hypabyssal – formed in shallow subsurface environment, they present intermediate characteristics between the intrusive and extrusive types.
Example: diabase.

A common classification for igneous rocks is the one based on the silica content. The meaning of the terms acid and base do not correspond to that used in chemistry.

2.3.2 Sedimentary rocks

Sedimentary rocks can be divided into three groups:

a) Clastic, mechanical or detritic – formed from fragments of pre-existing rock
b) Chemical – rocks formed by the precipitation of elements dissolved in water
c) Organic – formed by deposit and digenesis of vegetal or animal organic remains

2.3.3 Metamorphic rocks

Metamorphic rock is the result of the action of metamorphism agents on sedimentary and igneous rock, changing their texture and mineral composition. The main metamorphism agents are pressure and temperature.

Classification	% Silica	Quartz	Example
Acid	> 65	Present	Granite, pegmatite obsidian
Neutral	52 – 65	Small or non-existent	Syenite, diorite
Basic	45 – 52	Very rare	Gabbro, diabase, basalt
Ultra basic	< 45	Non-existent Scarce feldspar	Periodotite, dunite, pyroxenite

Minerals by value

Minerals

Industrial minerals

Abrasives
Corundum
Quartz
Diamond a.o.

Glass
Quartz
Feldspar
Calcite
Dolomite a.o.

Plastic
Calcite
Kaolin
Talc
Wollastonite
Mica a.o.

Ceramics
Quartz
Kaolin
Feldspar a.o.

Fertilisers
Phosphate
Potash
Calcite
Dolomite a.o.

Fillers and Pigment
Barite
Bentonite
Calcite
Dolomite
Felospar
Talc a.o.

Refractories
Wollastonite
Calcite
Dolomite
Corundum a.o.

Mineral Fuels

Coals
Oil shale
(Oil sand)

Rock

Aggregate, Sand & Gravel
Concrete ballast
Asphalt ballast
Rock fill
Industrial sand
a.o.

Ores

Non-ferrous

Base Metals
Copper
Lead
Zinc a.o.

Light Metals
Aluminium
Magnesium
Titanium

Precious Metals
Gold
Silver
Platinum a.o.

Rare Metals
Uranium
Radium
Beryllium a.o.

Ferrous Alloy

Alloying Metals
Chromium
Vanadium
Molybdenum
Tungsten
a.o.

Ferrous

Iron

Rock	Formation	W1 Impact	Specific wight (t/m³)	Bulk density (t/m3)	Abrasion index (A1)	Compressive strength (Kp/cm2)	Granulation	Color
Andesite	Igneous	16 ± 2	2,6 - 2,8	1,6	0,5	1700 - 3000	Fine	Black / Ash
Amphibole	Metamorphic	16 ± 3	2,8 - 3,0	1,7	0,2 - 0,45	-	Average to coarse	Dark green or black
Sandstone	Sedimentary	10 ± 3	2,7	1,6	0,1 - 0,9	300 - 1800	Average to coarse	White / Ash
Basalt	Igneous	20 ± 4	2,9 - 3,0	1,8	0,2 ± 0,1	3000 - 4000	Fine< 0,1 mm	Black / Ash
Limestone	Sedimentary	12 ± 3	2,7	1,6	0,001 - 0,03	800 - 1800	Fine to coarse	White to dark
Carbon	Sedimentary	14 ± 4	1,0 - 1,8	0,8	-	-	Fine	Ash to black
Clinker	-	-	-	1,2	-	-	Fine	Ash
Coke	-	-	-	0,6	-	-	Fine	Ash to black
Diabase	Igneous	19 ± 4	2,8 - 2,9	1,7	0,3 ± 0,1	2500 - 3500	Average to coarse	Black to ash
Diorite	Igneous	19 ± 4	2,7 - 2,8	1,6	0,4	1700 - 3000	Coarse	Black with white spots or ash
Dolomite	Sedimentary	12 ± 3	2,7	1,6	0,01 - 0,05	500 - 2000	Fine to coarse	White or ash, reddish
Gabbro	Igneous	20 ± 3	2,9 - 3,0	1,8	0,4	1700 - 3000	Coarse > 2 mm	Dark ash to black
Gneiss	Metamorphic	16 ± 4	2,7	1,6	0,5 ± 0,1	2000 - 3000	Average to coarse	Ash or rose with dark layers
Granite	Igneous	16 ± 6	2,7	1,6	0,55 ± 0,1	2000 - 3000	Coarse > 2 mm	White / ash to reddish brown
Hematite	Sedimentary	-	5,1	2,2 - 2,4	0,35 ± 0,2	-	Fine	Dark
Magnetite	Sedimentary	-	5,7	2,2 - 2,4	0,50 ± 0,2	-	Fine	Dark
Marble	Metamorphic	12 ± 3	2,7	1,6	0,001 - 0,03	800 - 1800	Average to coarse	White, yellow, red green or black
Porphyre	Igneous	18	2,7	1,6	0,1 - 0,9	1800 - 3000	Coarse > 2 mm	Dark ash to black, reddish brown or purplish
Ouartzite	Metamorphic	16 ± 3	2,7	1,6	0,75 ± 0,1	1500 - 3000	Average	White, ash or reddish
Syenite	Igneous	19 ± 4	2,7 - 2,8	1,6	0,4	1700 - 3000	Coarse	Red or black/ greenish ash
Silex (Hornfels)	Metamorphic	18 ± 3	2,8	1,65	0,7	1500 -3000	Fine	Ash, blue, green or black

Mechanical properties of some minerals.

3. Physical properties of minerals

As the comminuting process is the interaction between machines and minerals, one needs to know well the characteristics of each of these two elements. This chapter focuses on the most important physical characteristics of the minerals from the point of view of crushing.

D – relative hardness – Mohs scale
ρ – solid density – t/m^3
ρb – bulk density – t/m^3
CR – crushability – %
ABR – abrasiveness – g/t
Ai – abrasion index
Wi – work index – kWh/st
LA – Los Angeles value
UCS – uniaxial compressive strength – N/mm^2
particle size gradation
particle shape

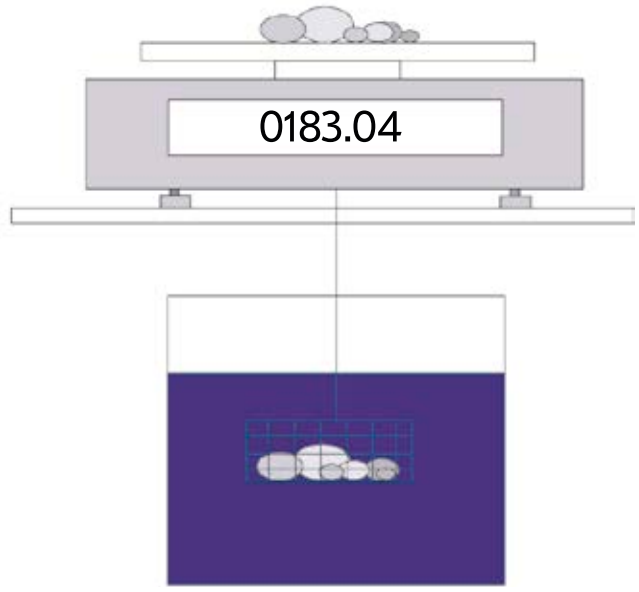
Metso has several modern research and test laboratories where the behavior of materials in comminuting processes can be determined.

3.1 Mohs scale of hardness

In 1812 the Mohs scale of mineral hardness was defined by the German mineralogist Friedrich Mohs (1773-1839). This is a relative scale with which the minerals are classified by comparing their hardness with that of the reference minerals. Each mineral scratches the preceding ones and is scratched by the subsequent.

Reference mineral	Hardness	Absolute hardness
Talc	1	1
Gypsum	2	2
Calcite	3	9
Fluorite	4	21
Apatite	5	48
Orthoclase Feldspar	6	72
Quartz	7	100
Topaz	8	200
Corundum	9	400
Diamond	10	1500

Table: Mohs scale of hardness. Measurement of specific gravity.



Measurement of specific gravity.

3.2 Solid density (ρ)

Solid density is defined as the mass of a sample divided by its solid volume (t/m3). Solid density and specific gravity are often ambiguous terms. Specific gravity is dimensionless, equal to the density of the material divided by the density of water.

Since water's density is 1000 kg/m^3 in SI units, the specific gravity of a material is approximately the solid density of the material measured in t/m3. Accurate density of water at 1 atm and 20 °C is 998.2 kg/m^3 and it varies little according to the temperature.

The reason that specific gravity is measured in terms of the density of water is because that that is the easiest way to measure it in the field. With an irregularly shaped rock, the volume can be very difficult to accurately measure.

The most accurate way is to put it in a water-filled graduated cylinder and see how much water it displaces. It is also possible to simply hang the sample from a scale and weigh it under water. A practical method uses two measurements.

First the rock sample is weighed dry in air (m1). Same time a container hanging from the scale is empty and sunken in water. Secondly the rock sample is moved to the container and weighed again with the sample immersed (m2).

The specific gravity result is the dry sample weight divided by subtraction of the dry sample weight and the weight of the sample immersed. In SI units the result is also the solid density in t/m3. $\rho = m1/ (m1 - m^2)$

3.3 Bulk density (ρb)

The most common method to determine loose bulk density uses a dry and clean container. The aggregate sample shall be dried at 110 °C to constant mass. The container is weighed (m1). The container is gently filled to overflowing with the aggregate. Whilst filling the container the segregation must be minimized.

Any surplus aggregate must be removed with a straightedge, making sure not to compact any part of the upper surface. The filled container is weighed (m2). The loose bulk density is the specimen mass divided by the volume of the container. $\rho b = (m2 - m1)/V$.

Tapped or packed bulk density is always greater than or equal to loose bulk density. Due to variation in degree of compactness the bulk density value is not as accurate as the solid density.

Bulk density is not only a measure of rock physical property but an aggregate product measure. It also depends on the gradation and the shape of the product.

3.4 Abrasiveness (ABR) and Crushability (CR)

The purpose of the crushability test is to establish crushability and abrasiveness of rock material. The crushability value can be used for estimation degree of difficulty to crush tested material.

Test consists of an inner hub, which rotates the test paddle vertically inside a cylindrical bowl. The hub with test paddle rotates 4500 rpm. The inner diameter of the bowl is 90 mm and depth 100 mm. The paddle of 50 mm x 25 mm x 5 mm must be dry and cleaned before the test. It will be weighed before the test. Rock sample for the test is 500 g of 4/6.3 mm fraction.

The paddle is clamped in the slot of the hub. A 500 g sample of material to be tested is placed in the drum. Paddle rotates inside the drum and after 5 minutes rotation the drum is emptied and tested material is screened with 1.6 mm screen. Material which passes 1.6 mm screen is weighed. The test paddle is also cleaned and weighed.

3.4.1 Result calculation

$ABR = (M_{before} - M_{after}) * 1000 / 0.5$ [g/t]

ABR = Abrasiveness
M_{before} = the mass of the cleaned and dried test paddle before the abrasion test [g]
M_{after} = the mass of the cleaned and dried test paddle after the abrasion test [g]

$CR = m_{1.6} / M$ [%]

CR = Crushability
$m_{1.6}$ = the mass of the particles smaller than 1.6 mm produced during the test
M = the mass of the material subjected to the test

Abrasiveness/Crushability is Metso standard method to test rock material abrasiveness and crushability.

Abrasion meter.

3.5 Laboratory jaw test

The purpose of the laboratory jaw test is to evaluate the behavior of a rock material sample in crushing process. In the test, laboratory scale jaw crusher performance and product quality are measured when crushing a sample of 10 kg of rock material.

3.5.1 Equipment

The following equipment is needed for laboratory jaw crusher test:

- Laboratory scale jaw crusher
- Moveable jaw with nip angle of 18 degrees
- Measurement equipment
- Sieves (mm): 0.063, 0.125, 0.25, 0.5, 1.0, 1.25, 1.6, 2.0, 2.5, 3.15, 4.0, 5.0, 6.3, 8.0,10, 12.5, 16 and 20
- Flakiness sieves (mm): 0.8, 1.0, 1.25, 1.6, 2.0, 2.5, 3.15, 4.0, 5.0, 6.3, 8.0, 10.0, 12.5

The test is conducted using a scale model of a jaw crusher. The closed side setting and rotation speed of crusher can be regulated. The jaw's of the crusher are made of manganese steel.

Measurement equipment includes rotation sensor, 3-Component force sensors, direct voltage converter, frequency converter, amplifiers, strain gages, data acquisition system and a computer.

Rotation speed, electric motor power, crushing time, eccentric shaft tension, toggle plate force and crushing forces applied to the fixed jaw are measured using the above-mentioned measurement equipment.

The measured parameters, their units and measurement devices can be found in table 1.

Measured parameter	Unit	Measurement Device
Rotation speed	[rpm]	Rotation sensor
Electric motor power	[W]	Frequency converter
Crushing time	[s]	Data Acquisition System
Crushing forces applied to the fixed jaw	[kN]	3-component force sensors
Toggle plate forces	[kN]	Strain gauges
Eccentric shaft tension	[MPa]	Strain gauges

Table above. The measured parameters of the laboratory scale jaw crusher and measurement equipment.

3.5.2 Rock material sample

For the jaw test 10 kg of dry rock material with size-fraction of 10 - 20 mm is needed. If sample rock material is bigger than the above-mentioned size, it should be prepared with laboratory screens and crushers to meet the size specification. In that case 40 kg of rock material is needed for the test. Material is crushed and then screened using 10 mm, 12 mm, 16 mm and 20 mm sieves. There are no specifications for the weight distribution of different size-fractions or the particle shape.

Test Procedure

The moveable jaw with nip angle of 18° is installed to the laboratory scale jaw crusher. The nip angle of the cavity is measured. The closed side setting of laboratory scale jaw crusher is set to 4.5 mm and rotation speed to 360 rpm. Laboratory scale jaw crusher is fed manually keeping the cavity full during the test.

Tests products are screened using the dense series of sieves and flakiness sieves mentioned in part 1: Equipment.

3.5.3 Results and documentation

Crusher throughput is calculated dividing the mass of the crushed material by the measured crushing time.

$$T = \frac{m}{t} \times 3.6$$

T = throughput [t/h]
m = crushed material mass [kg] = 10 kg
t = crushing time [s]; t is determined from the power measurement diagram.

The specific energy consumption of the comminution is calculated dividing the root mean square power of electric motor to the throughput of crusher.

$$E = \frac{PRMS}{T} \times 1000$$

E = energy consumption [kWh/t]
PRMS = root mean square power [W]
T = crusher throughput [t/h]

Calculated throughput and energy consumption, product and flakiness gradation curves as well as the maximum and RMS values of the measured electric motor power, toggle plate force, eccentric shaft tension and crushing forces applied to the fixed jaw are documented to the test report.

3.6 Nip angle test

The Nip Angle Test evaluates the behavior of a rock material sample in crushing process. The test determines the effect of the changes in the cavity nip angle to the performance of a Jaw Crusher and also to the product gradation and shape. The test gives thorough information of the best nip angle to be used running a jaw crusher to stress the crusher the least and to obtain the highest throughput and best energy efficiency.

3.6.1 Rock Material Sample

For the complete series of nip angle tests including all the six angles (18, 20, 22, 24, 26 and 28 degrees) 60 kg of screened feed material is needed. For each nip angle test 10 kg of dry rock material with size-fraction of 10 - 20 mm is needed. Rock material sample containing rocks bigger than 10 - 20 mm should be prepared with laboratory screens and crushers to meet the size specification. In that case 20 kg of rock material is needed for each nip angle test and total amount of 120 kg of rock material for the complete series of nip angle tests.

After being crushed, material is screened using 10 mm, 12 mm, 16 mm and 20 mm sieves. There are no specifications for the weight distribution of different size-fractions or the particle shape.

3.6.2 Test procedure

The moveable jaw with nip angle of 18 degrees is installed to the laboratory scale jaw crusher. The nip angle of the cavity is measured. The closed side setting of laboratory scale jaw crusher is set to 4.5 mm and rotation speed to 360 rpm. Laboratory scale jaw crusher is fed manually keeping the cavity full.

This test is repeated using moveable jaws with other nip angles. The closed side setting and rotation speed are the same as at the first run.

Tests products are screened using the dense series of sieves and flakiness sieves mentioned in part 1: Equipment.

3.6.3 Results and documentation

Crusher throughput is calculated dividing the mass of the crushed material by the measured crushing time.

T= **mt** ×3.6**T**= **mt** ×3.6
T = throughput [t/h]
m = crushed material mass [kg] = 10 kg
t = crushing time [s]; t is determined from the power measurement diagram.

The specific energy consumption of the comminution is calculated dividing the root mean square power of electric motor to the throughput of crusher.

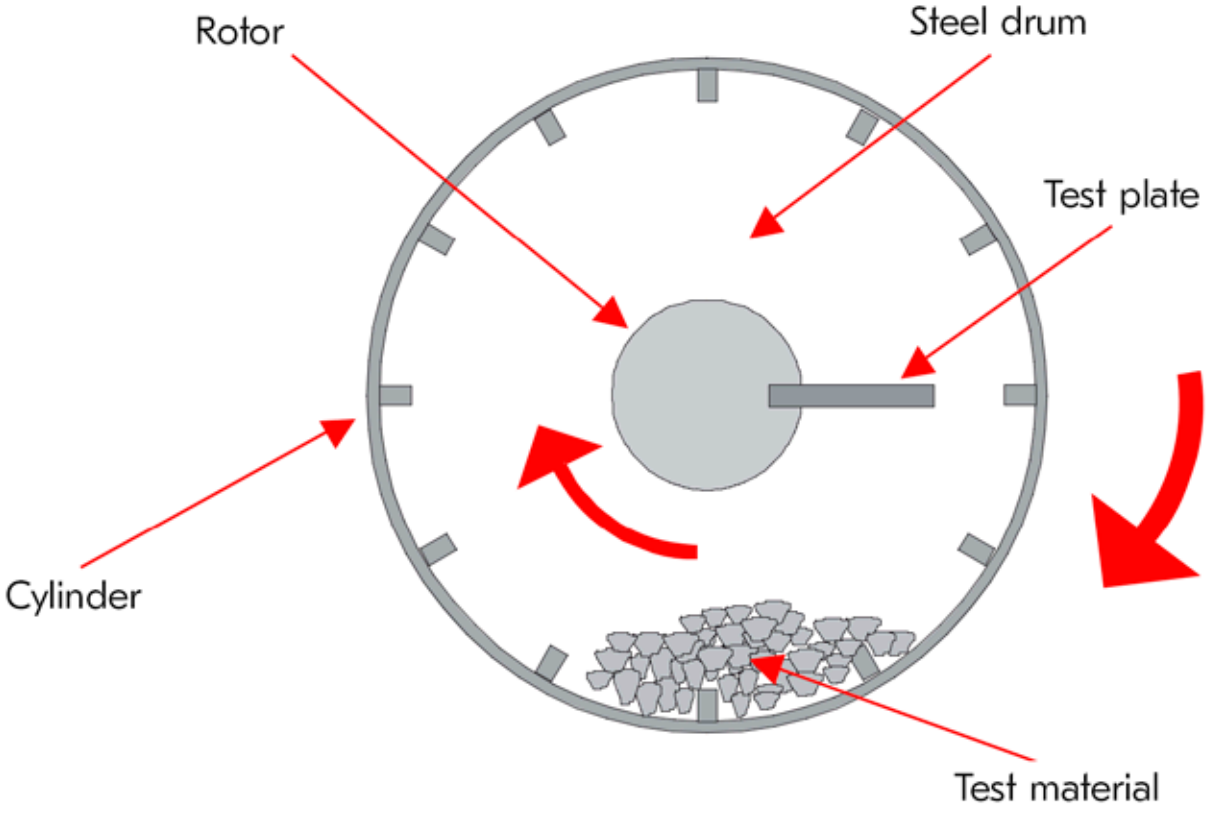
E= **PRMST** ×1000**E**= **PRMST** ×1000
E = energy consumption [kWh/t]
PRMS = root mean square power [W]
T = crusher throughput [t/h]

Calculated throughput and energy consumption, product and flakiness gradation curves as well as the maximum and RMS values of the measured electric motor power, toggle plate force, eccentric shaft tension and crushing forces applied to the fixed jaw are documented to the test report.

3.7 Abrasion index (Ai)

The abrasion index is a parameter showing the abrasion power of a material, normally proportional to the percentage of free silica content. The test is carried out in a small rotating drum with concentric rotor, to which is attached a standard steel plate.

The objective is to wear the plate by driving the drum and the rotor together with the sample. The abrasion index is numerically equal to the weight loss (grams) of the plate.



Pennsylvania (Bond) abrasion machine.

3.8 Work index (Wi)

Energy demand is one of the most important factors in all size reduction processes. In addition to its high cost, the energy needed to perform the work is also a decisive factor in the selection and dimensioning of some of the main process equipment. Several methods have been developed to calculate the energy required for the fragmentation of minerals.

The best known, and probably the most accurate and largely proven is the method developed by F. C. Bond, in the Allis Chalmers test center.

According to the F. C. Bond method the power requirements of mineral grinding processes are determined by the factor known as "Work index" (Wi).

This factor expresses in kWh, the value of the work required to reduce the size of a short ton of material with a theoretically infinite feed size to a product with a passing percentage of 80 % in a 100 µ sieve. The diameter of the outer cylinder is 305 mm, and the diameter of the inner hub is 110 mm. In the surface of the cylinder there is 12 small shelf plates.

When the drum rotates these shelf plates pick up material and carry it until it is dropped and hit against the test paddle or the bottom of steel drum.

Paddle preparation: Before the test the paddle is dressed with a fine file for any burrs and sharp edges. The cleaned and dry paddle is weighed.

Rock sample: The material to be tested is a composition of 200 g of 12/16 mm fraction and 200 g of 16/19 mm fraction. Total amount 4x400 g = 1600 g of 12/19 mm fraction.

Test procedure: The paddle is clamped in the slot of the inner hub. A 400 g sample of material to be tested is placed in the drum. The drum and the test paddle rotate for 15 minutes. The paddle rotates to the same direction than the drum but about nine times faster.

After 15 minutes rotation the drum is emptied, and the process is repeated three times with a new material so that the paddle is subjected to wear for an hour. After an hour rotation the paddle is removed, cleaned, and dried. The paddle is weighed. The weight loss in grams is the Abrasion Index (Ai) of the tested material.

The empirical formula to calculate the energy required for reducing one short ton is the following:

$$E = 10 * Wi * [1/\sqrt{P} - 1/\sqrt{F}]$$

E = required energy (kWh/st)
Wi = work index (kWh/st)
P = mesh in microns through which passes 80 % of the product
F = mesh in microns through which passes 80 % of the feed The Wi factor is determined with a twin pendulum breakage device or in ball or rod mills.

12"x24" Rod mill (Bond rod mill) Twin pendulum breakage device.

12"x12" Ball mill (Bond ball mill)

3.9 Los Angeles value (LA)

This test is a measure of degradation of mineral aggregates of standard grinding procedure. This test has been widely used in aggregate quality measurement. Standards related to this test method: ASTM C 131, ASTM C 535, EN 1097-2.

The Los Angeles machine consists of a cylinder having an inside length of 508 mm and 711mm internal diameter. Its axis of rotation is mounted horizontally. An internal shelf, 90 mm in depth and 25 mm thick, is mounted across the inside of the cylinder.

A sample of aggregate, weighing 5000 g, is introduced into the cylinder through a hatch. A charge of 6, 8, 11 or 12 steel balls depending on the sample gradation, each about 46.8 mm

in diameter, is also added. The hatch lid is then closed, and the cylinder rotated for 500 revolutions at a rate of 30-33 rpm. The hatch is opened, and the contents of the cylinder are emptied into a tray set underneath the opening. The balls are removed, and the aggregate is then sieved through a 1.70 mm (1.6 mm EN 1097-2) sieve. The fraction retained on the sieve is dried to constant mass and weighed. The result, the Los Angeles Value, is calculated as:

LA = (5000-m)/50

Where m is the mass retained on a 1.70 mm sieve, in grams.

Los Angeles Value is not only a measure of rock physical property but an aggregate product measure. It also depends on the shape of the product.

3.10 Uniaxial compressive strength (UCS)

Uniaxial (or unconfined) compressive strength is a common measure what is used for many purposes in mining and crushing fields. The common method uses cylindrical core specimens. The length of the specimen must be at least 2.5 times the diameter and the ends are parallel. The sample is then compressed with slow speed until it breaks down and the compressive load decreases. The force and the displacement are recorded during the test. UCS is calculated as follows:

UCS = F / A

Where F is the peak compressive force (N).

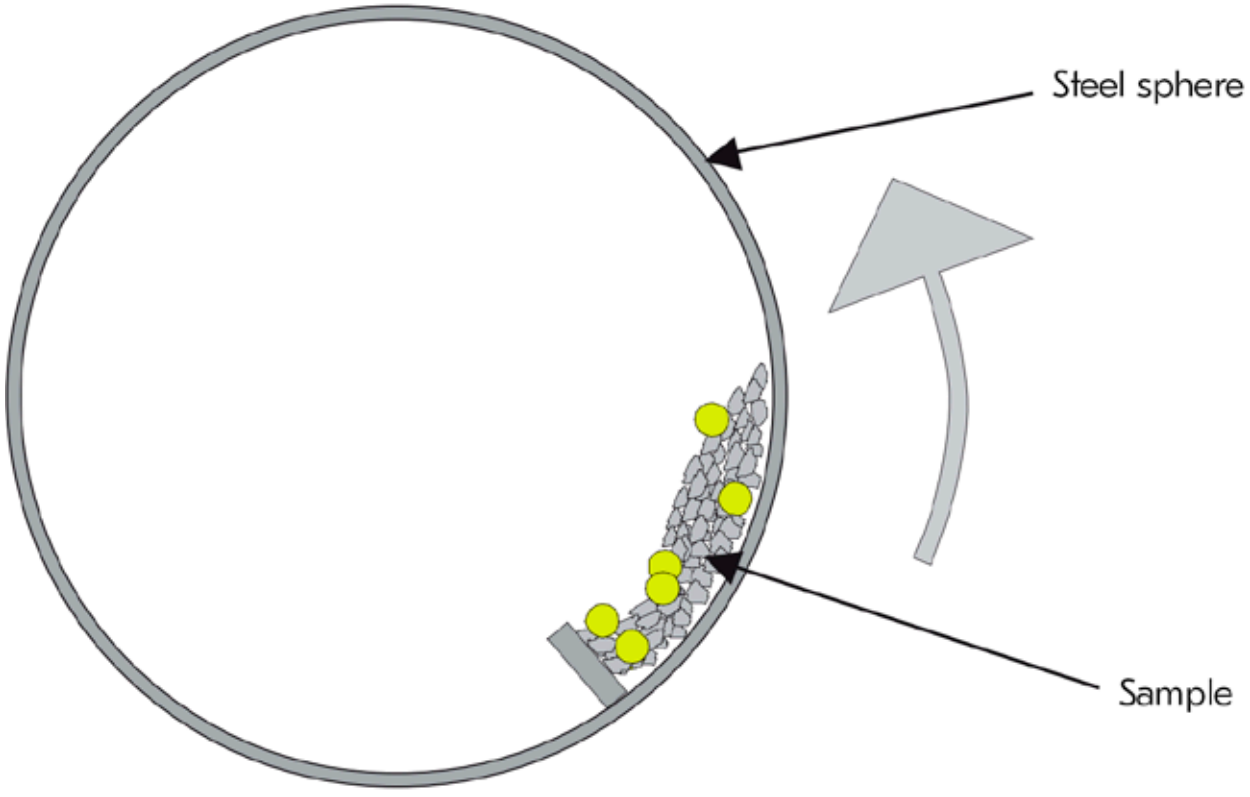
A is the cross-sectional area of the specimen (mm^2).

The Young's modulus can be determined from the stress-strain curve. It is a very useful measure when estimating the toughness of the rock. Advanced compressive loading machines can also measure the Poison's ratio of the rock.

3.11 Statistics

When measuring rock properties, the sampling action and the sample preparing are very decisive reasons for the results. In these laboratory tests the size of the sample is always small and the results are valid only for the sample.

You must keep this in mind when taking the sample. Metso laboratories have tested thousands of rock samples. Following tables show the statistics of different test results and give a baseline for the rock evaluation. Results for the statistic are gathered from all the tests made in Ahmedabad, Danville, Macon, Tampere and Tianjin rock laboratory. Both aggregates and minerals related tests are included in the statistics. Notice that samples are from selected materials for the use at aggregates and mining and doesn't give view from the overall statistics of rock materials.

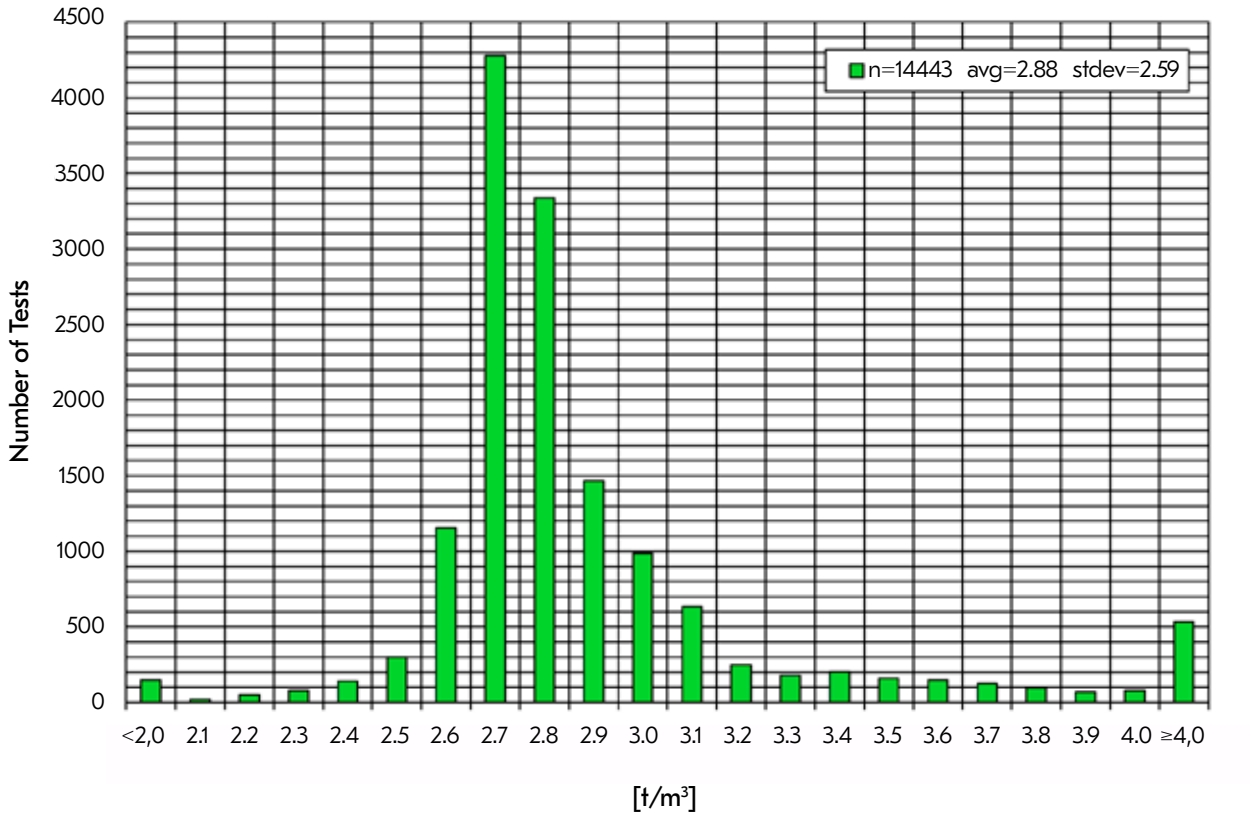


Los Angeles test machine.

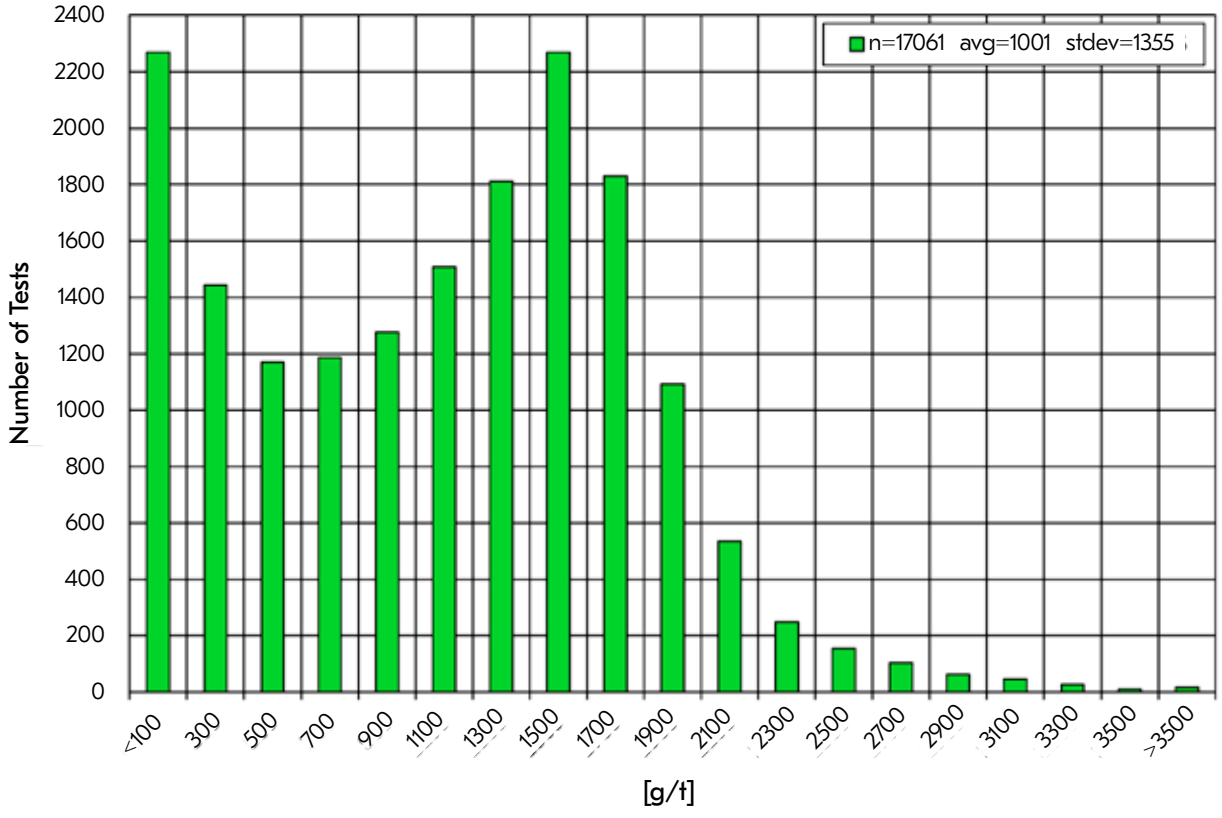
Test	Standard	Ahmedabad, India	Arequipa, Peru	Danville, USA	Macon, France	Sala, Sweden	Sorocaba, Brazil	Tampere, Finland	Tianjin, China	York, USA	Comment
Solid density ρ (Specific Gravity)	EN 1097-6	X	X	X	X	X	X	X	X	X	Coarse material
Solid density ρ (Pycnometer)	ASTM D5550 -06		X		-	X	X		-	X	Fine material
Bulk density ρb	EN 1097-3		X		X		X	X	-	X	
Crushability CR	AFNOR NF P18-579	X	X	X	X		X	X	X	X	French standard
Abrasiveness ABR	AFNOR NF P18-579	X	X	X	X		X	X	X	X	French standard
Bond Impact Work Index Wi	Industry standard		-	X	X		-	X	-		Bond pendulum hammer
Paddle Abrasion Index Ai	Industry standard		X	X	-		X	X	-	X	Also called Bond abrasion
Abrasion test	ASTM G65		X		-		-		-		
Los Angeles test	EN 1097-2		-		-		-	X	-		Standard ASTM C131 is optional
Particle size distribution	ISO 2591:1994, EN 933-1:2012	X	X	X	X	X	X	X	X	X	
Flakiness	EN 933-3:2012		-		X		-	X	-		
Shape index	EN 933-4, DIN52114		-		X		-	X	-		
Flakiness index	BS 812		X		X		X		-		
Uniaxial Compression Strength UCS	ASTM D4555:2010, EN 1926:2006		-		-		X		-		
Dynamic fragmentation	BS 812, NF P18-574		-		X		-		-		Barmac sizing data
Point load test	ASTM D5731-16		X		-		X	X	-		
Cone test	EN 933-6		-		X		-		-		
Sand flow	NZS 31111:1986		-		X		-	X	-	X	
Methylene blue test	EN 933-9: 2009		-		X		-		-		
Acid dissolution	EN 12620+A1:2016		-		X		-		-		
Shatter index for coke	ISO 616:1995		-		-		X		-		
Lab jaw test	Metso specific standard		X		-		X	X	-		Nip angle test only in Tampere
Packed bed test	Metso specific standard		-		-		-		-	X	HRC sizing
HRC 300 pilot test	Pilot test		-		-		X		-	X	
Barmac pilot plant	Pilot test		-		-		X	X	-		
Crushing and screening pilot plant	Pilot test		-		-		X	X	-		

Table: Testing at Metso crushing and screening laboratories.

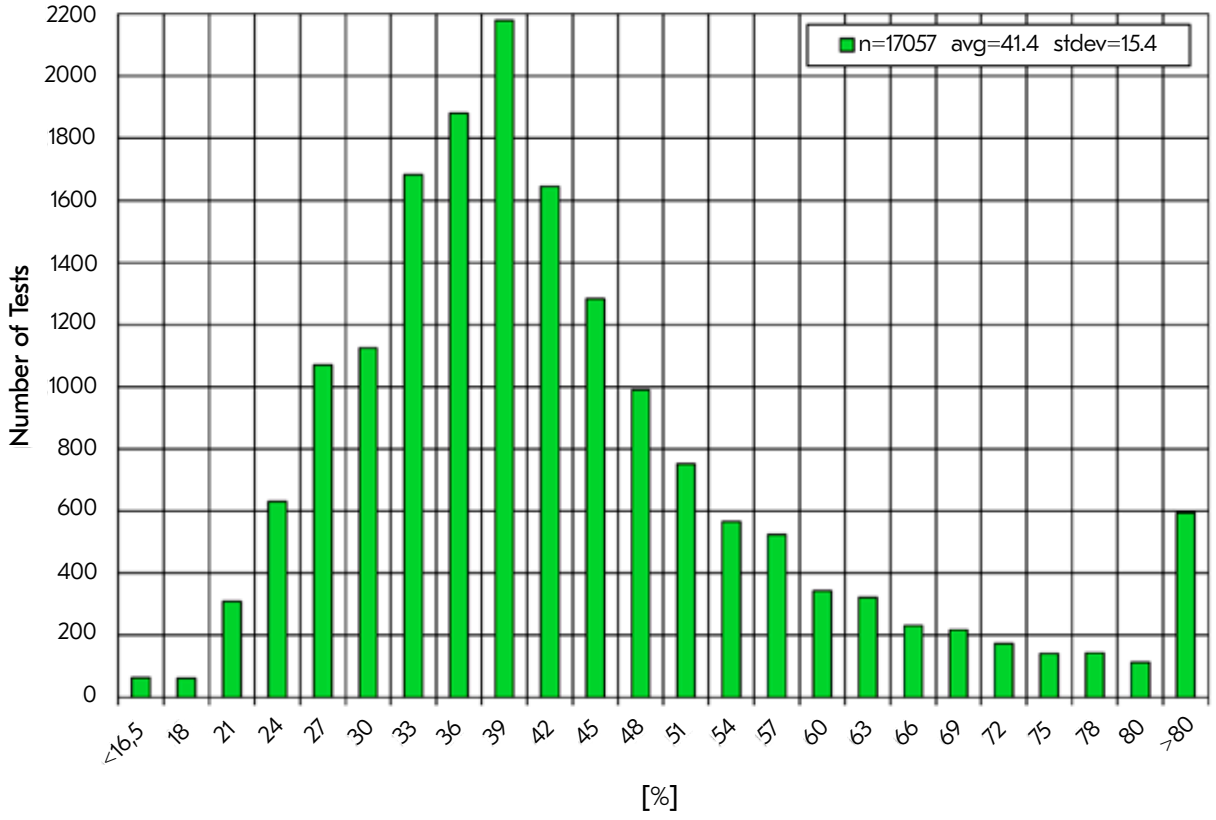
Solid Density



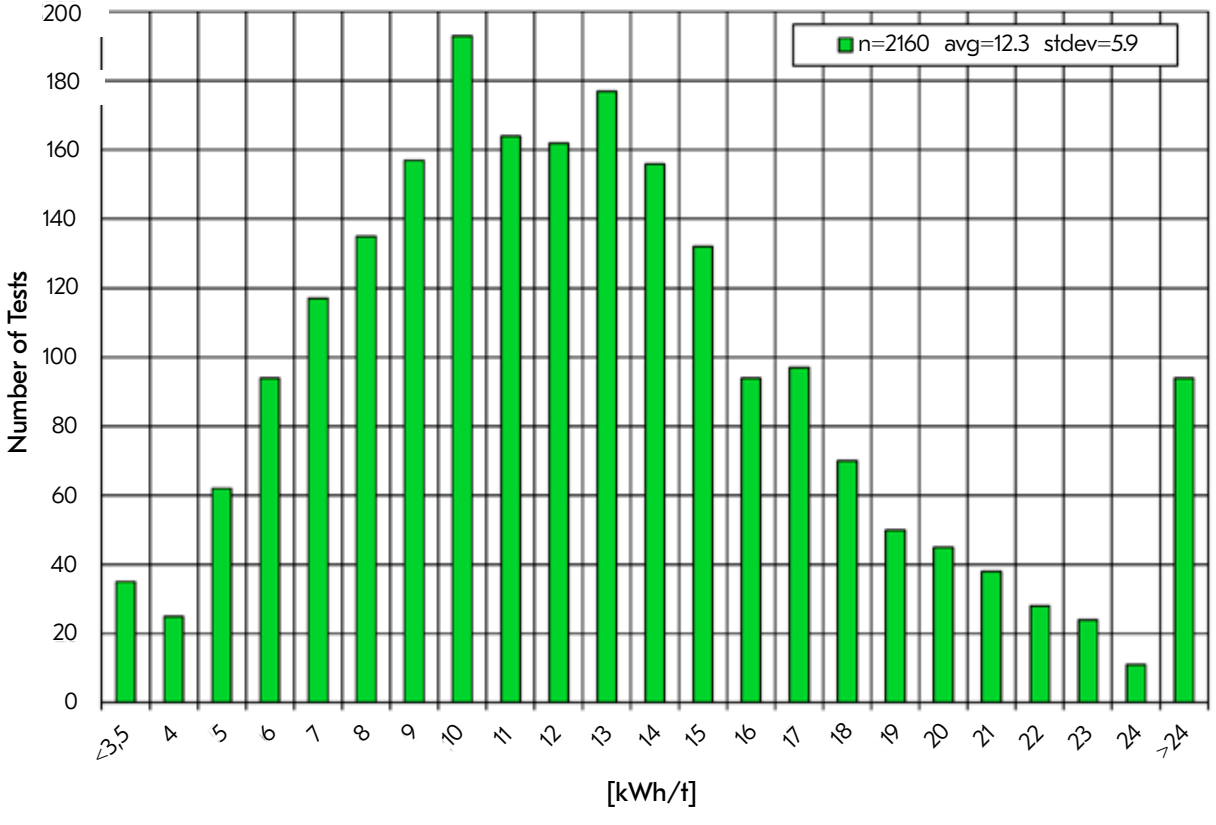
Abrasiveness

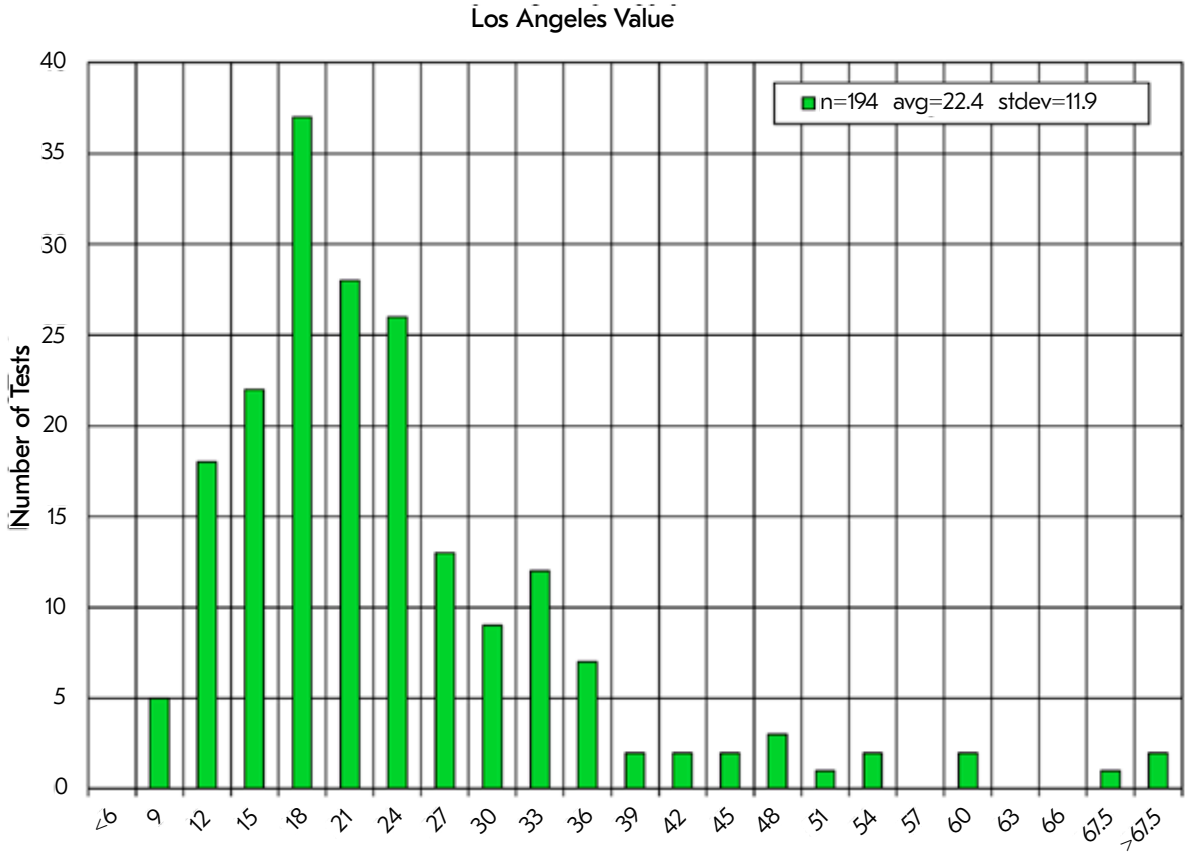


Crushability

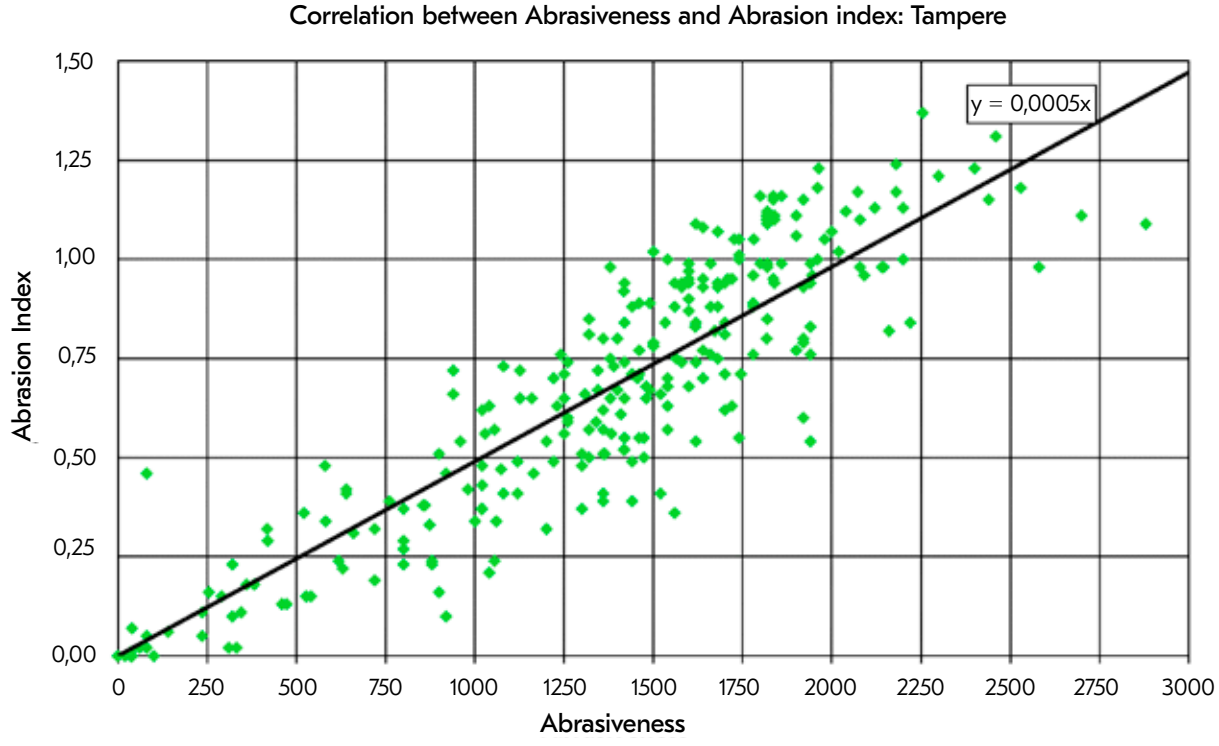


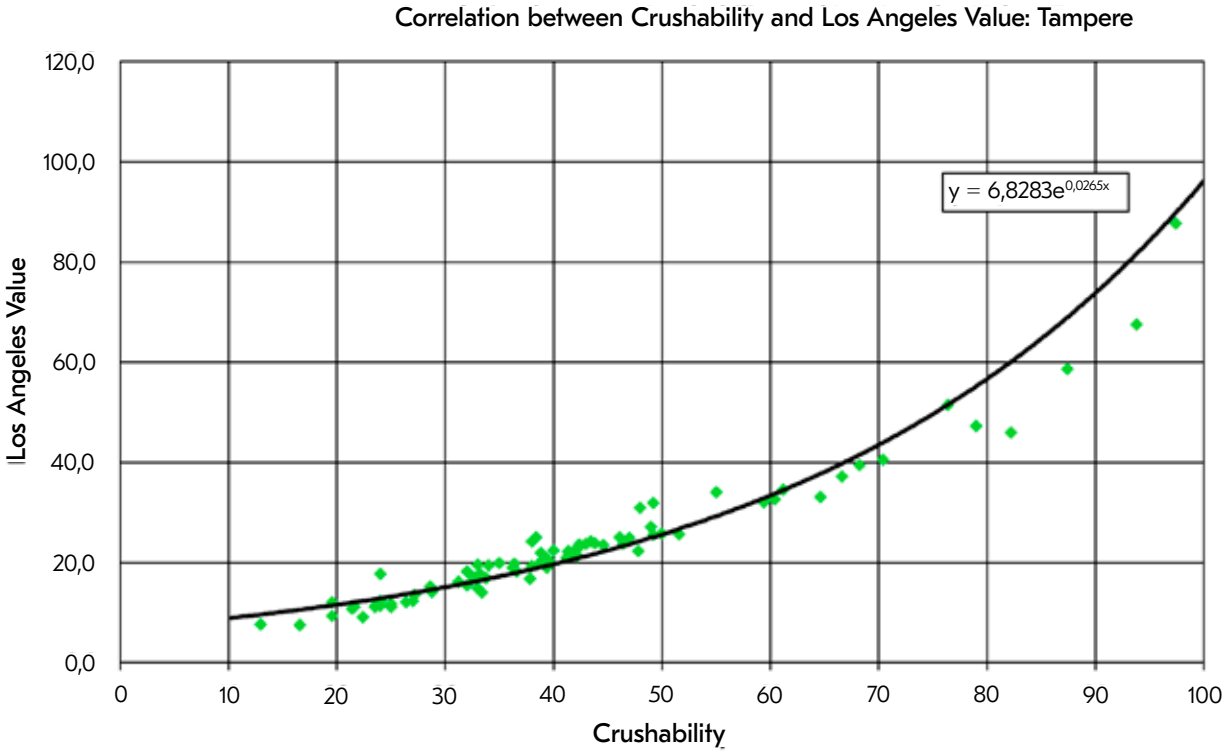
Bond Impact Work Index





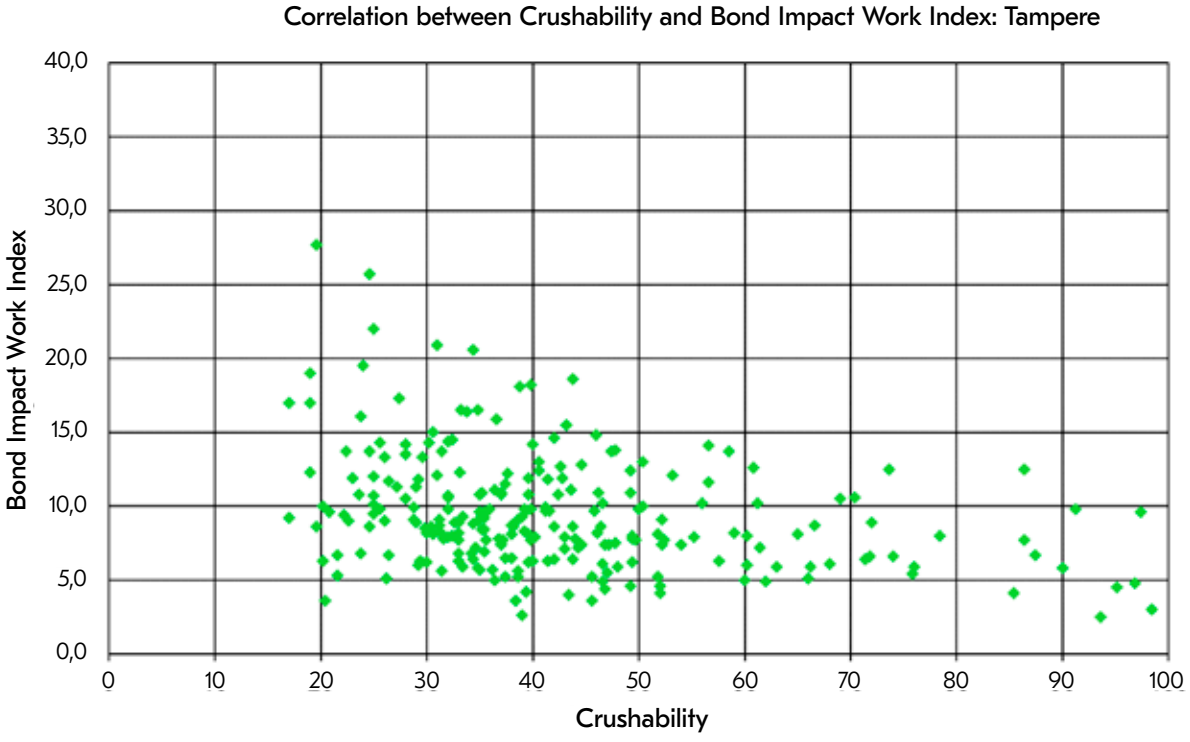
3.12 Correlations





The correlation between Abrasiveness and Abrasion Index is satisfactory and the thumb rule is that Abr = 2000 * Ai.

The correlation between Crushability and Los Angeles Value is very good but Work Index seems to measure different property than Crushability.



Crushability classification

Bond work index [kWh/t]

very easy	0 - 7
easy	7 - 10
medium	10 - 14
difficult	14 - 18
very difficult	18 -

Crushability [%]

very easy	50 -
easy	40 - 50
medium	30 - 40
difficult	20 - 30
very difficult	- 20

Los Angeles value

very easy	27 -
easy	22 - 27
medium	17 - 22
difficult	12 - 17
very difficult	- 12

Ai- 8 mm product

very easy	60 -
easy	45 - 60
medium	30 - 45
difficult	15 - 30
very difficult	- 15

Shatter index

very easy	40 -
easy	35 - 40
medium	30 - 35
difficult	25 - 30
very difficult	- 25

Abrasiveness classification

French abrasiveness [g/ton]

non abrasive	0 - 100
slightly abrasive	100 - 600
medium abrasive	600 - 1200
abrasive	1200 - 1700
very abrasive	1700 -

Abrasion index

non abrasive	- 0.1
slightly abrasive	0.1 - 0.4
medium abrasive	0.4 - 0.6
abrasive	0.6 - 0.8
very abrasive	0.8 -

Metso technology research

Metso has a full-scale test plant in Tampere, Finland. This test plant is used both for product development and full-scale pilot tests.

Additionally, we have rock laboratories all over the world. In testing, most modern methods, such as image analysis for gradation distributions and Taguchi type methods for statistically reliable testing, are used. Modern on-site usable measurement and data collection equipment are in continuous use.

Typical research support & services

- Development of simulation tools for process and cavity calculations
- Process consultation & optimization
- Rock testing
- Full-scale pilot testing with dedicated machines
- Crusher kinematics and cavity analysis
- Prototype testing in test plant and field
- Strain gauge measurements
- Training support
- Publications, such as this book

Crushing and screening terminology

Crushing terminology
Choke feeding: A type of feeding arrangement for the crusher, which keeps the crushing cavity full.

Choke point: The point in the crushing cavity where the volume of material to be crushed is smallest. This determines the capacity of the crusher.

Closed circuit: A crushing process feature, in which part of the material produced by the crusher is circulated back to the same crusher for further crushing.

Cone head: A conical part which supports the liner.

Concave: The external part of the tools used for crushing.

Critical speed: The speed is critical when the cone head oscillation speed is the same as the falling speed of the crushed material.

Crushing cavity: The space between the liner and concave, where the crushing action itself takes place.

Crushing ratio: The ratio between the size of the feed and the emerging product. This is normally measured at the 80% point; Crushing ratio = Feed 80/Product 80, describing the work done with respect to the comminution of the feed into the finished product.

CSS: Closed side setting – the minimum distance between the liner and concave at the discharge end of the cavity.

Cubicity: Describes the shape of rock. There are different standards available, and, in this thesis, the DIN standard is used.

Flakiness index: Describes the shape of the rock, very similar to cubicity.

Interparticular crushing: Rock crushing is achieved by crushing particles against each other, not only the crushing tools.

Liner/Mantle: The inner part of the tools used for crushing. Fitted onto the cone head.

Nip angle: The angle between the liner and concave when rock is caught, or nipped, between them.

OSS: Open side setting, the maximum distance between the liner and concave at the discharge end of the cavity.

Packing: Occurs when rock is compressed to the extent that its density increases to the point of solidity.

Reduction ratio: See crushing ratio.

Segregated feed: Feed into the crusher in such a way that fine and coarse particles in the feed are led to different sides of the crushing cavity.

Stroke: Difference between OSS and CSS.

Screening terminology
Coarse fraction: Particles which pass over the screen deck.

Fine fraction: Particles which pass through the screen deck.

Separation size:

- **Split size:** Particle size at which feed separates into two products (coarse fraction and fine fraction).
- **Overflow/Oversize:** Material larger than the hole size.
- **Underflow/Undersize:** Material smaller than the hole size.
- **Half size:** Material smaller than half of the hole size.

Screening capacity (Q): The amount of material passing through the screen deck in tons/hour.

Feeding capacity: The amount of material fed into the screen deck in tons/hour.

Efficiency of screening (efficiency of undersize recovery): Amount of material smaller than the hole size in undersize compared to the total amount of material smaller than the hole size in the feed.

Metso is a frontrunner in providing sustainable technologies, end-to-end solutions and services for the aggregates, minerals processing and metals refining industries globally. By helping our customers increase their productivity, improve their energy and water efficiency and environmental performance with our process and product expertise, we are the **partner for positive change.**

Metso

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