Instituto Superior de Engenharia do Porto

DEPARTAMENTO DE ENGENHARIA GEOTÉCNICA

Modelling an aggregate processing unit. Case study: Fornelo processing plant

Daniel García de la Torre Fernández

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Modelação de uma unidade de processamento de agregados. Caso de estudo: instalação de Fornelo

Daniel García de la Torre Fernández

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Dedico esta dissertação à minha Mãe, quem orgulhosa ainda vela por mim…

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Palavras-chave
Britadoras, Crivos, Agregados, Granulometria, Pedreira de Fornelo

Resumo

O presente trabalho consiste no desenvolvimento de um modelo para estimar a produção, em massa relativa e granulometria, de uma instalação de processamento de agregados situada em Fornelo (concelho do Porto, Portugal).

Assim, e previamente ao projecto desenvolvido, faz-se uma referência às técnicas de fragmentação de rocha com vista à redução de calibre dos fragmentos obtidos no desmonte, bem como das técnicas de classificação de partículas, crivagem e os seus principais modelos, assim como à importância dos agregados face às respectivas aplicações.

Com a ajuda do *software* Microsoft Excel foi possível desenvolver e criar um modelo de cálculo para avaliar de forma precisa, por meio de diversas iterações, as quantidades e características granulométricas dos materiais britados e recirculados, assim como dos produtos finais obtidos no processamento.

Para a sua elaboração foram tidos em conta os valores e parâmetros apresentados noutros trabalhos experimentais sobre processamento de agregados. Este documento pretende ser uma alternativa aos outros *softwares,* nomeadamente o *PlantDesigner* ou o Bruno (Metso), concebidos para o projeto e o controlo de instalações de produção de agregados.

A ferramenta permitirá ao utilizador alterar os vários valores apresentados nos catálogos dos equipamentos, ou os destinos dos diferentes produtos finais e intermédios com as suas respectivas massas e granulometrias para obter os diversos produtos finais, permitindo um controle mais assertivo da quantidade e qualidade granulométrica dos produtos finais a comercializar.

Palabras clave

Trituradoras, Cribas, Agregados, Granulometría, Cantera de Fornelo

Resumen

El presente trabajo de final de máster trata del proceso de diseño y cálculo de un sistema para la estimación de la producción en masa relativa y granulometría de una planta de procesamiento de agregados situada en Fornelo (Oporto, Portugal).

Previo al proceso de diseño, se ha realizado un pequeño desglose de las técnicas de trituración, fuerzas aplicadas, así como de las técnicas de cribado y sus principales modelos, además de hablar de los agregados como recursos y sus múltiples usos.

Con ayuda del programa Microsoft Excel, es posible calcular a través de diversas iteraciones las recirculaciones de material triturado con el fin de obtener los resultados finales de forma precisa.

Para su elaboración se han tomado en cuenta valores y parámetros dados por otros trabajos experimentales sobre procesamiento de agregados. Este documento pretende servir como alternativa a otros softwares como PlantDesigner o Bruno, dedicados al diseño y control de plantas de producción de agregados.

La herramienta permitirá al usuario alterar valores variables dados por los catálogos de los equipamientos o los destinos de los diferentes productos finales e intermedios con sus respectivas masas y granulometrías para variar los productos finales, permitiendo un control exhaustivo de la calidad y cantidad de la granulometría de los productos.

Keywords

Crushers, Screens, Aggregates, Granulometry, Fornelo Quarry

Abstract

This work contains the final master's project, which is about the process of design and calculous of a computer system to the estimation of total relative mass and granulometry of an aggregates processing plant in Fornelo quarry (Porto, Portugal)

Before the design process, it has been done a brief introduction of the crushing techniques and applied forces as well as the screening techniques and its principals' models, also introducing the aggregates as resources and its multiples uses.

With the help of the software Microsoft Excel, it is possible calculate over diverse iterations the recirculation of crushed material with the purpose of getting the final results precisely.

For its preparation, is has been taken values and parameters given by other experimental projects of aggregates processing. This document tries to being an alternative for other softwares as PlantDesigner or Bruno, involved in the design and control of the production plants of aggregates.

The tool will allow the users to modify variable values given by brochures and some of the destination of the different final or intermediate products with its respective masses and granulometries in order to vary the final pile products, allowing an exhaustive control of the quality and quantity of the final pile's product granulometry.

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VSI – Vertical Shaft Impactor
HIS – Horizontal Shaft Impactor
CSS – Closed Side Setting
OSS – Open Side Setting
W_i – Work Index

Chapter I

Introduction

1. Introduction

This document constitutes the project of the master in geotechnical and geoenvironmental engineering (MEGG), taught in the second year of this programme by the Department of Geotechnical Engineering of School of Engineering (ISEP), Polytechnic of Porto for the conclusion of the second cycle of studies, the master in geotechnical and geoenvironmental engineering, in the academic year 2017/2018.

2. Objectives

The main objectives are the following.

1. Create an excel tool with an easy interface to work with, has to be easy to operate with by any user.
2. The operations taken by the calculator have to be precise and never get to any error, so the input information of the calculator is limited in order to avoid any user to break the whole system.
3. The calculator has to fit any initial granulometric curve given by the user up to a limit value where no block could be transport for crushed.
4. The whole system has to be freely modifiable but respecting the existing limitations on the real design of the processing plant to avoid infinite recirculation of unnecessary crushing of screening processes.
5. The goal is to obtain an easy method of estimate the mass and curve granulometric of one or all desired final products.

3. The Aggregates

3.1. Introduction

Aggregates are considered one of the most basic commodities such us water or electricity, as it is used in mainly any construction developing project. Being indispensable in any developed or underdeveloped country.

As a worldwide production and consumption, some quality standards have to take place in order to regulate the value of the different aggregates produced. The main two groups are Granulometric characteristics (such as granulometry, density, shape…) and physic and chemical characteristics (such as composition, existence of chemicals, reaction to others, permeability…)

All aggregates are regulated in the European Union by the CE marking for the European Economic Area, and European standards such as EN 13043:2002/AC:2004.

Some of this regulated product such us ballast, can be made out of several types of rocks, as long as they satisfy several specific conditions to enter in that category. For this, ballast has to be durable in time, dense impermeable solid rock, with no ferrous impurities that can cause corrosion and further fragmentation of the aggregate. These conditions are attained only by few aggregates, for this specific purpose.

Not all aggregates are the same; many of them will have different destinations according to the material, size and properties. The most common materials used for aggregates are the following: Limestone, granite, trap rock, sandstone, quartzite, dolomite, volcanic cinder and scoria, marble, slate, dacite, shell, calcareous marls and recycled materials (Willett, J. C. (2018)).

Each of these materials is suitable for a number of uses and unsuitable for others.

The decision of choosing the right one will be crucial in the project success (Table 1).

3.2. Main uses of aggregates

The table 1 shows the main uses of the aggregates.

Table 1 Main uses of aggregates (Adapted from http://www.audemard.com/en/aggregate/).

ROADS	Crushed gravel for the foundation layer Untreated gravel for the base layer Fine gravel, filler sand for the surfacing layer
RAILWAYS	Gravel for sub-base and ballast
DIKES, SILLS, DAMS	Blocks of 1 to 6 tons, and aggregates in general
BRIDGES, TUNNELS	Gravel and sand for concrete
STRUCTURES CAST ON SITE	Fine gravel and sand for concrete
PREFABRICATED STRUCTURES	Fine gravel and sand for prefabricated concrete
FACINGS	Fine gravel and sand for prefabricated concrete Stone for coatings Sand for facade plaster
DECORATION	Building Stone Facing stone Tiles
TRENCHING	All types of fill Gravel
FOOTPATH COATING	Colored fine gravel Fine gravel for exposed aggregate concrete Paving stone

4. Document chapters

This work is organized in eight chapters.

The first chapter, Introductions, is about the work situation in the aggregates sector, objectives of this project, and the work process to reach them.

The second chapter contains basic information of the crushing and screening equipment's and methodologies, a brief description and explication is made to help the reader to understand the whole work.

The third chapter is about the location, geology information of the quarry and technical data of the actual equipment's located in the Case of study, a brief introduction to the methodologies of product estimation and the data and values chosen for its calculous.

In the fourth chapter, guide-description of the excel interface is explained and procedures and results are discussed and illustrated.

The fifth chapter contains the conclusions and perspectives for a further work.

The sixth chapter contain the references.

The brochures of the equipment's used in this work are in the annexes.

Chapter II

Crushing and screening methodologies

1. Crushing principles

1.1. Forces applied

When talking about size reduction methods for solid materials, several processes exists, but only the ones that implied mechanical forces are respectful with the material composition and open natural cracks where the rock should be naturally eroded, maintaining the same look as the eroded material aggregate, we do not have access to.

There are four basic forces implied to reduce a material size, those are **impact, attrition, shear**, and **compression** (Figure 1).

- **Impact** refers to an instantaneous collision of moving material against other. They are two variations of impact, *gravity impact* and *dynamic impact*. When crushed by gravity impact, the material is stopped by the stationary rigid solid. In dynamic impact, material is hammered in order to break it, and the reduced particles are accelerated towards other breaker or hammers. By usage, Dynamic impact is the only one that appears in crushers.
- **Attrition** consists of the reduction of materials by scrubbing it between two surfaces. This method is reserved for small materials due the need of usage of surface of the crushers or mills, and also for less abrasive materials.
- **Shear** is a term for a trimming or cleaving action. Shear crushing is normally called for under the conditions when material is somewhat friable or when a relatively coarse product is desired. This force is never applied alone, due the difficulties on positioning single pieces of material between the edges of two hard surfaces moving tangentially. Only is applied alone to get the demanded shape (flat surfaces, cubes…)
- **Compression** crushing is done between two surfaces, with the work being done by one or both surfaces. As a mechanical reduction method, compression is to be used if the material is hard and tough, if the material is abrasive, if the material is not sticky, and where the finished product is to be relatively coarse.

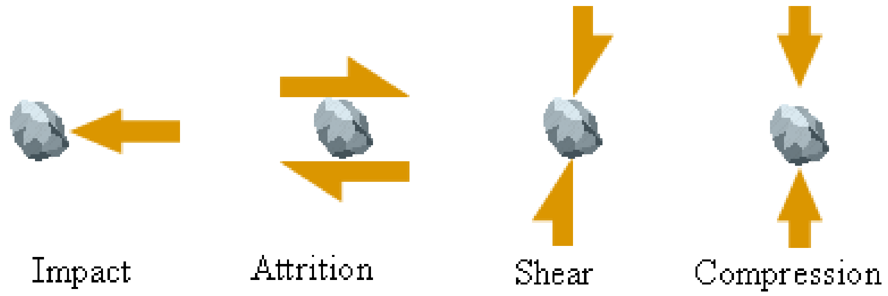


Figure 1 Crushing forces.

In mining, were the ore must be separated from the waste in order to purify as much as possible the final product, the rock should be studied for choosing the best way or ways of separation to reach the fastest, cheapest product with high purity.

1.2. Energy consumption

When a force is applied in order to break a particle, as any other material, the particle suffers a deformation and the energy is stored in the material. If the force continues over the elastic limit of the material (depends on the rock), the particle breaks, creating new surface in the divided particles; this consumes certain amount of energy. In practice, the rest of the energy is transformed in heat, noise, kinetic energy, among others.

The key in any operation of rock fragmentation is to calculate the energy requirement to break a certain amount of rocks into certain number of particles. Several laws try to solve this calculous.

1.2.1. Rittinger's Law

The energy needed to reach certain size reduction is proportional to the new surface created. (Equation 1)

$$W = K \cdot \left(\frac{1}{d_{80}} - \frac{1}{D_{80}}\right)$$

Equation 1 Rittinger's law (Thomas, L. F. (1998)).

1.2.2. Kick's Law

The energy needed to reach certain size reduction is proportional to the reduction of the particles volume. (Equation 2)

$$W = K \cdot \log\frac{D_{80}}{d_{80}}$$

Equation 2 Kick's law (Thomas, L. F. (1998)).

1.2.3. Bond's Law

Defined by energy needed to reach certain size reduction is proportional to the new length of the cracks created. (Equation 3)

$$W = 10W_i \cdot \left(\frac{1}{\sqrt{d_{80}}} - \frac{1}{\sqrt{D_{80}}}\right)$$

Equation 3 Bond's law (Thomas, L. F. (1998)).

D_{80} is the size of the screen where an 80% of the feed pass, in microns

d_{80} is the size of the screen where an 80% of the product pass, in microns.

The W is defined as the gross energy required in KWH/short ton of feed to reduce a very large or "infinite" size of feed to such a size that 80% of the product passes a 100mm screen.

The value of W_i is also known as “work index” or “Bond index” and refers to the resistance of the material to be crushed and is dependent mainly of the nature of it (Table 2).

Table 2 Bond index (Adapted from https://es.scribd.com/doc/171524745/Bond-Work-Index-Tables-Wi).

Material	Bond Index (kWh/st)
Sandstone	13.1
Basalt	20.2
Limestone	11.1
Coal	12.5
Quarcite	12.9
Diorite	20.1
Dolomite	12.8
Gabbro	15.9
Granite	16.0

2. Crushers classifications

The entire material reduction machine can be classified depending on the main force applied, the stage in a size-reduction plant, and the size result among others (Table 3).

Table 3 Classification of crushers by Final size, Stage and Force applied (Adapted from Álvarez, R. (1996)).

By size of final product

Crushers (coarse and fine)	Jaw crushers Gyratory crushers Crushing rolls
Grinders (intermediate and fine)	Hammer mills; impactors Rolling-compression mills Attrition mills Tumbling mills
Ultrafine grinders	Hammer mills with internal classification Fluid-energy mills Agitated mills
Cutting machines	Knife cutters; dicers; slitters

By stage

Primary crushing	Jaw Crushers Gyratory Crushers Crushing rolls
Secondary crushing	Cone Crushers Hammer mills; impactors Crushing rolls
Tertiary crushing	Cone Crushers

By the principal force applied

By Compression	Cone Crushers Crushing rolls Jaw Crushers Gyratory Crushers
By attrition	Crushing rolls
By shear	Knife cutters; dicers; slitters
By impact	Hammer mills; impactors

2.1. Jaws

This kind of crusher is used commonly as primary crusher, as its price is the lower comparing to other kinds, and the mechanism is simpler, so repairing and replace parts are easier to obtain.

Jaw crushers consist on two metal plates, one fixed and the other is mobile, situated forming usually a 26º angle and slightly separated, where the mobile one oscillates over an eccentric pivot compressing the material between both and breaking it into smaller parts that fits the bottom gape.

These crushers are classified in 3 different types depending on the pivot position (Figure 3).

2.1.1. Blake

Blake jaws crushers are the most common mechanism used in the jaws type.

In this one, the pivot is located on the top of the movable or swinging jaw, “fixing” the entrance, and letting the bottom describe an elliptical movement combined by the eccentric pivot and the toggle recovery. This system makes easy to regulate the output size of the jaws in order to adjust the final size of the product.

In this category, two main systems are defined by position of the flywheel shaft and the non-crushable items protection system, known as tramp iron release.

Single Toggle

In this machine, the single toggle goes from the bottom of the s movable jaw to affixed point at the back of the jaw crusher. The eccentric is located at the top of the movable jaw and is part of the shaft. With this system, the movable jaw describes two motions.at the same time, circular and up and down, resulting on an elliptical path in the bottom part of the movable jaw. This creates an attrition force between fixed jaw, material and movable jaw.

Double Toggle

In this case, the motion of the movable jaw is just a swinging motion, with a pivot in the upper part and a Toggle attached to the lower part. Here the eccentric shaft and flywheel is on a pitman, which moves up and down, causing the jaw moving like a swinging door, preventing the shaft and bearing from shock loading caused by great pieces of material being crushed.

The election of simple effect versus double effect is determined by economy, as the simple are more lighter and cheaper, this might be a better option when the material is not very abrasive, causing lots of attrition because of the attrition force described by the up and down swinging movement described by the movable jaw (Figure 2).

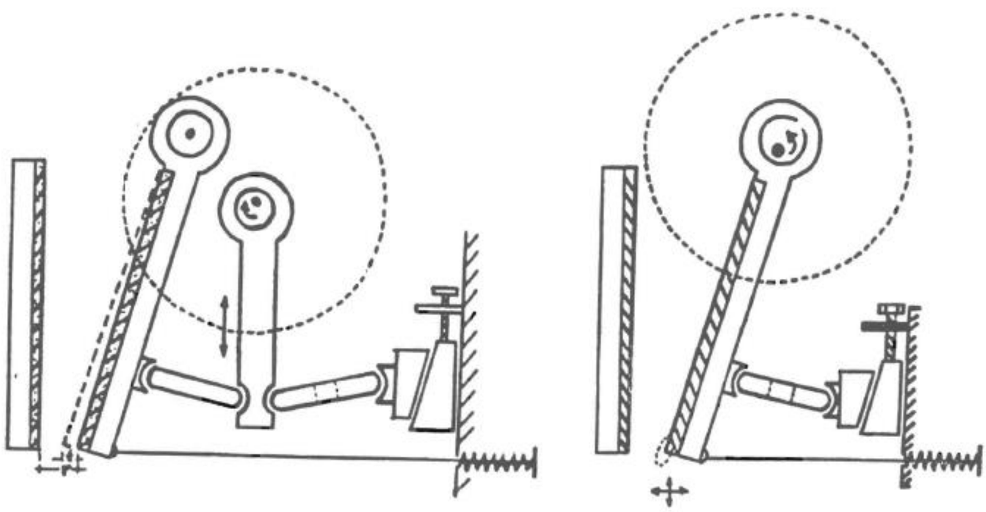


Figure 2 Double toggle jaw and Single toggle jaw (Adapted from Álvarez, R. (1996)).

2.1.2. Dodge

As opposite to the Blake jaws, Dodge situates the pivot in the lower part of the movable jaw. This causes to get a greater precision of the output material sizing, and also is way more favourable in material crushing, as the greater swinging is caused in the top, where bigger pieces got crushed. As disadvantage, this system do not have a tramp iron release system.

2.1.3. Universal

Universal jaw crusher is the term for those crushers where the pivot is located in the middle of the movable jaw, causing it to swing closing and opening the entrance and the discharge with the same amplitude.

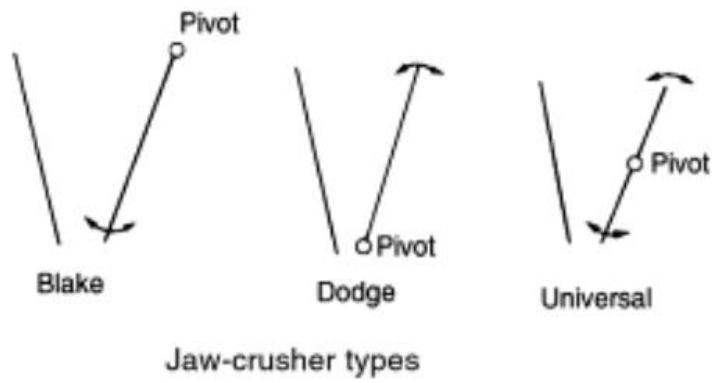


Figure 3 Blake, Dodge and Universal jaw working principles (Adapted from (https://www.911metallurgist.com/blog/jaw-crusher-working-principle)).

2.2. Gyratory

Gyratory crushers were invented to eliminate the dead times of the jaw crusher where the movable jaw moves back.

This machine consist of a fixed concave surface, and a gyratory conical head, were the pivot is on the top and the lower part of the shaft rest in an eccentric mechanism, in this machines the head do not rotate, but it moves eccentric to the edge (Figure 4).

This system provides a constant crushing o the material, while in one part the gap is opening, in the opposite is closing, crushing the material, as a result of this continuous operation, flywheel is not needed.

Usually the head is built in one single piece, and the concave is made out of several plates.

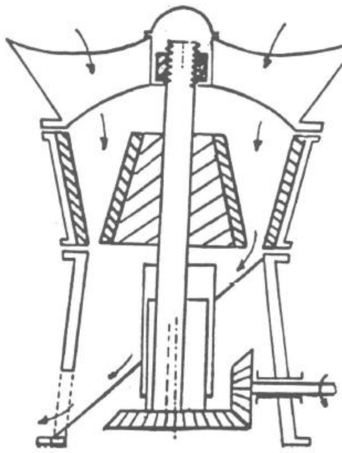


Figure 4 Gyratory crusher (Adapted from Álvarez, R. (1996)).

2.3. Cones

By design, cones are quite similar to gyratory crushers. The speed and eccentricity of the head are higher, the space between concave and head are mainly parallel, making every grain being crushed at least once.

Also, the cones do not have any union in the top, but a plate to distribute the material into the concave chamber.

Cones are classified by their tramp iron release system. This is shown in Figure 5.

2.3.1. Symons

Cone Symons has a Spring with a specific tension that rises the head when an overpressure is made in the chamber, in order to release the non-crushable.

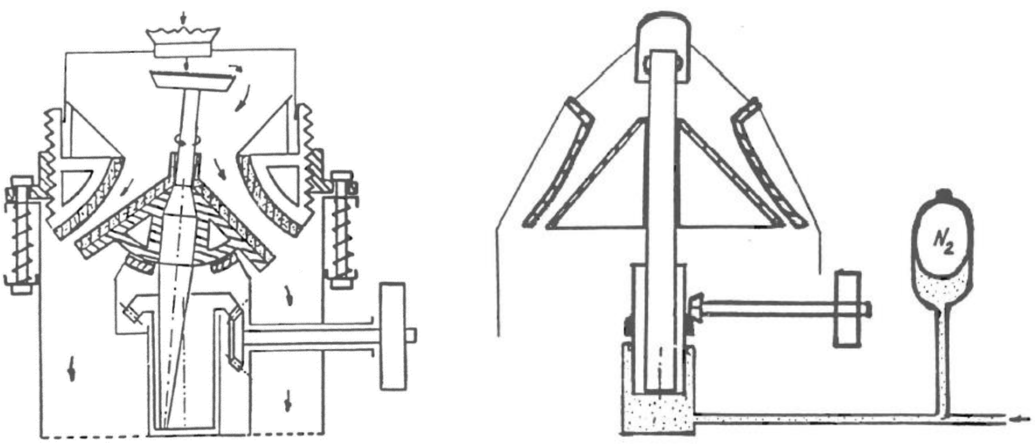


Figure 5 Cone Symons and Hydrocone (Adapted from Álvarez, R. (1996)).

2.3.2. Hydrocone

Similar to Symons, Hydrocone uses a hydraulic system where an oil deposit and a pressurized nitrogen chamber hold the pressure up to a point when the head is lowered to release the non-crushable item.

2.4. Cylinders

A cylinder crusher is mainly one or two cylinders that trapped the material between them smashing and forcing it to break.

There are 2 types: Smooth roll and Spiked roll.

Due the differences between both types, we'll talk about them separately.

2.4.1. Smooth roll

Smooth rolls actuate by applying pure compression forces. It is composed by two rolls with parallel axis and separated a determined distance which rotates as the same speed, one of them is fixed and the other is supported by a spring or hydraulic mechanism, this is used to avoid blocking by a non-crushable (Figure 6).

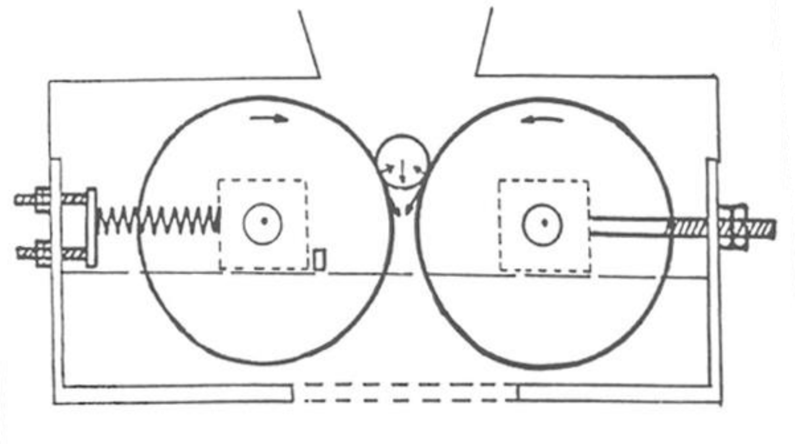


Figure 6 Smooth rolls. (Adapted from Álvarez, R. (1996)).

2.4.2. Spiked Roll

Spiked rolls work similar to the smooth ones. In these, shear and minced works with compression forces. The rolls are covered with teeth or spikes situated alternatively ones from others, (Figure 7).

Despite the fact this system provides a better crushing, spiked mills are sensible to abrasiveness of the material, breaking, losing or smoothing the spikes.

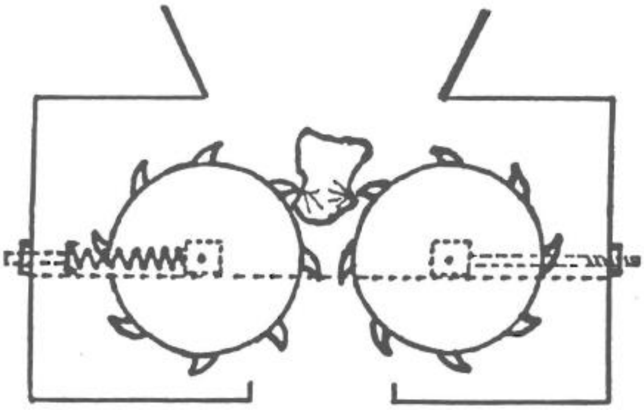


Figure 7 Spiked rolls (Adapted from Álvarez, R. (1996)).

2.4.3. Spiked Roll and plate

This system consists mainly in one spiked roll and a fixed metal jaw, the material is crushed in between of both, and the plate can move backwards by a spring in order to release a non-crushable item, (Figure 8).

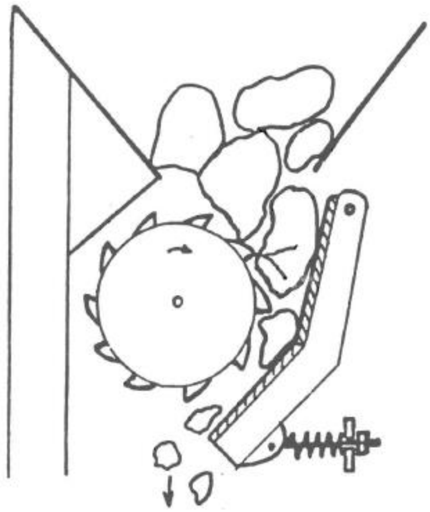


Figure 8 Spiked roll and plate (Adapted from Álvarez, R. (1996)).

2.4.4. Impactors

Impactors are mainly used in materials with different minerals in its compositions, making them to break in the weak boundaries between them.

2.4.5. Horizontal shaft impactors (HSI)

Impactors are based in a horizontal axis mill where the material is loaded from the top. Within the first impact, the arms of the mill launch the material to the internal parts of the walls of the crusher, the shock between the material and the walls manage to break the material in several parts (Figure 9).

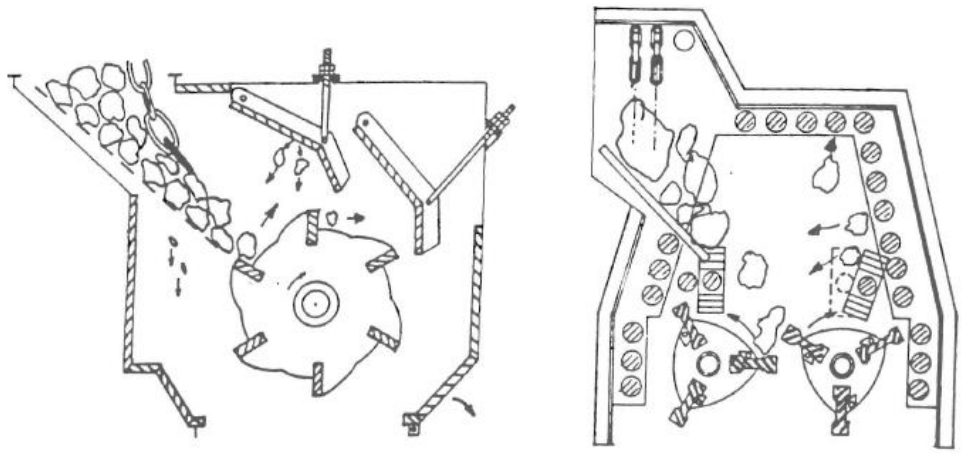


Figure 9 Single and Double HIS (Adapted from Álvarez, R. (1996)).

Hammermills

Hammermills are similar to the HSI, but in the lower part of the machine, a screen is located at a specific distance of the maximum hammer external circumference, were all the material that can't fit in the screen gets hit by those hammers until it breaks into small pieces that fit. A special chamber (called trap iron pocket) is created to store all the non-crushable items that the hammers push without breaking them, (Figure 10).

Also, the hammers are moving in its own shaft, swinging freely and being on max range by the centrifugal force, but able to move back when impacted on a big material or non-crushable item to prevent damage the main shaft of the rotor caused by the shock.

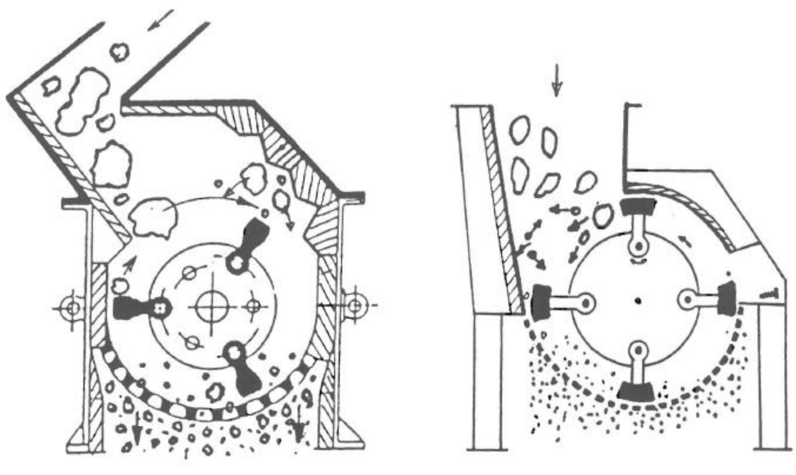


Figure 10 Hammermills. (Adapted from Álvarez, R. (1996)).

2.4.6. *Vertical shaft impactors (VSI)*

In these machines, the rotor rotates horizontally, and the material that is fed in the centre of the crusher is launched to the inner fixed plates of the case by the centrifugal force applied by the rotor motion. As bigger the material is, higher is the kinetic energy within, causing it to break in many pieces (Figure 11).

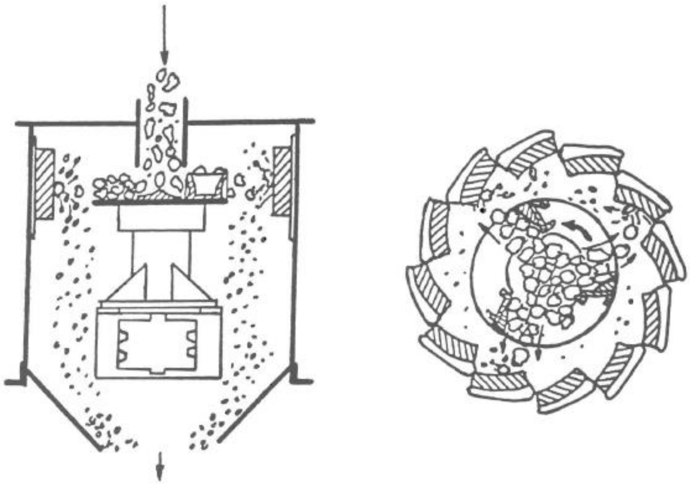


Figure 11 VSI (Adapted from Álvarez, R. (1996)).

VSI has quite more attrition than HSI, therefore, other techniques to reduce de abrasion in hammers and plates, plates have been replaced to some concave space where crushed material get stuck there, making the collision rock to rock., with only attrition in the hammers; (Figure 12).

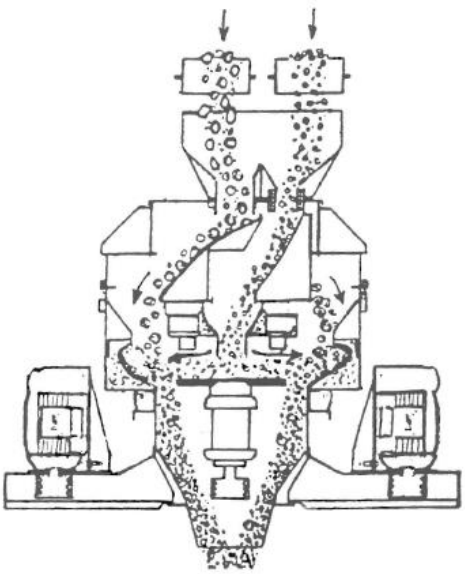


Figure 12 Autogenous VSI (Adapted from Álvarez, R. (1996)).

2.5. Abrasion in crushers

All those crushers work with different principles, and therefore que abrasion suffered by the machines are slightly different, depending on the system and the material.

This chart allows identifying the differences in using one and other crusher ant their material used to cover the crushing part.

The three main forces implied in the abrasion of the crushing plates, jaws, hammers… are Compression, Impact, and Attrition. The Shear force the less applied in mostly all general crushers.

Depending on the equipment's, these forces can make significant difference for the materials used to prevent abrasion: Metals, Polymers and Ceramics.

2.5.1. Compression

Compression forces appear in primary and secondary crushers like jaws, gyratory and cones. Those three bases on replaceable plates made of Manganese Steel.

The percentage of Mn use to be around 14%, rising up to 18% for extra resistance, but raising also the brittle. Perfect for more abrasive and less hard rocks.

2.5.2. Impact

Secondary crushers like HIS and VSI mainly apply this force. (except autogenous)

The mainly plates for not autogenous are metallic, where many options are suitable for this crusher.

Manganese is reliable against impacts.

Chrome is more fragile to impact, but highly resistive against attrition.

Ni is between both Manganese and chrome options.

2.5.3. Attrition

As we could see, metals are not the proper option when attrition forces are applied in the crushing process; other materials like rubber, polymers and ceramic are a more suitable option for those cases.

3. Screens

Screens are all those equipment's used to classify mechanically some grain material by its particle size. This kind of operation never manages to separate perfectly those particles over and below screen size, because many factors are implied and there are several screening systems to fit any porpoise.

3.1. Screen media

All the screens can be divided in two main groups by its screen media composition:

3.1.1. Metallic

Grizzly bars

This system allows holding very heavy materials as the section of the bars can be any, while the size selector is the space between them. Grizzly bars are positioned parallel, but increasing the distance in between in the download side, in order to let upper critical sizes to pass through and don't get stuck on it (Figure 13).

Sometimes they are placed over rubber bases. This make the rubber to absorb the vibrations and gives the bar a slightly mobility to prevent blinding.

Figure 13 Grizzly bars 3 stages screen (Taken from (https://www.dismet.com/productos/precribadores/)).

Perforated plate

Several orifices are performed in a plate, obtaining a mesh look, but made out of a single solid metal piece. That makes this system perfect for heavy materials or big sizes, as the total surface of holes by the total surface of the screen compared to the wire cloth (Figure 14).

Alternates holes guaranteed that in a long lineal path described by a material, it will eventually find a gape.

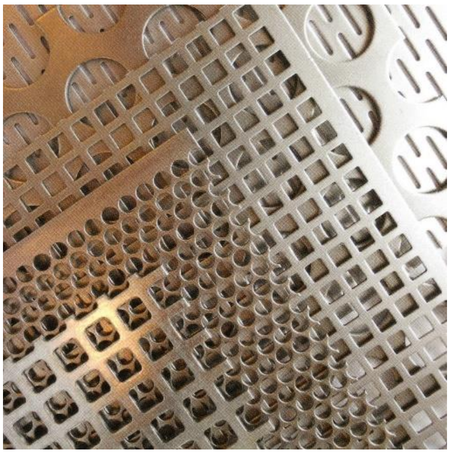


Figure 14 Perforated metal plates (Taken from http://www.metalmesh.com.au/product/perforated-metal-mild-steel/).

Wire Cloth

These screens are made out of interwoven wires with a proper diameter to make square or rectangular orifices (Figure 15). This surface are much flexible as the wire is thinner, mounted prestressed to obtain a flatter screen surface.

The diameter of the wire and distance between them makes it the most adaptive, for sizes between 0.04-75mm.

Figure 15 Metallic mesh or cloth (Taken from http://www.conveyall.com/screens.html).

3.1.2. *Organic*

Organic plates are made out of rubber or plastic, with perforated and flared orifices the same as the metal plates.

Those are more difficult to block or blind, as the holes in the plates are more elastic that the metal ones.

The water actuates as lubricant, and by its conditions, plastic or rubber are noise reducers and resistant to corrosion and to very abrasive materials.

Sadly rubber plates (Figure 16) are quite flexible, unable to stand still horizontally flat when the material is loaded, so they come often reinforced with internal metal or organic material in the core of the mesh. Using polyurethane panels solves this rigidity problem.

Figure 16 Organic screen panels (Taken from https://www.multotec.com/photo-gallery/screening-media/screen-panels).

Organic vs Metallic

Organics screens use to be more expensive and less resistant to high temperatures, but with it comes many advantages:

-Water actuates as lubricant, and they do not suffer from corrosion.

-They are lighter, comparing to a same dimension metal screen.

-They are more resistant to high abrasive materials.

-By its innate flexibility, they are able to unblock some blind holes, also absorbing better noise

3.2. Types of mechanical screening

When material separation occurs, relative movement between the screen and the material takes importance, where the coarse grain particles moves to let the fine ones pass throw the screen.

This relative movement can be attained by several systems:

3.2.1. Fixed screens

This system takes the height difference to feed the screen with the material, where the movement is caused by the gravity. These types of screen are inclined to allow the non-passing material to roll over the screen, letting the fine grain space to pass.

The two main types of screens are **Fixed bars** and **Fixed mesh**.

Both have the same mechanical principle, where all the grains roll over the inclined screen due by gravity, passing throw the fine grain, and sliding up the rejection zone the coarse ones.

3.2.2. Moving screens

In the moving category, the material is loaded over an inclinated screen that moves or vibrates, displacing the material slowly towards the discharge zone, the speed and displacement has its importance depending in the size of the grain fed.

Fast

Moving bars: Same as the fixed bars, but one end is fixed to a crankshaft where the bars moves alternatively back and forward longitudinally, making the material to roll between them.

Grill Ross: Used as ultra-coarse grain prevention in feeding process. This system bases on a conveyed belt with bars that opens apart when turning back. The big materials get stuck in them, forcing it to release when the bars opens (Figure 17).

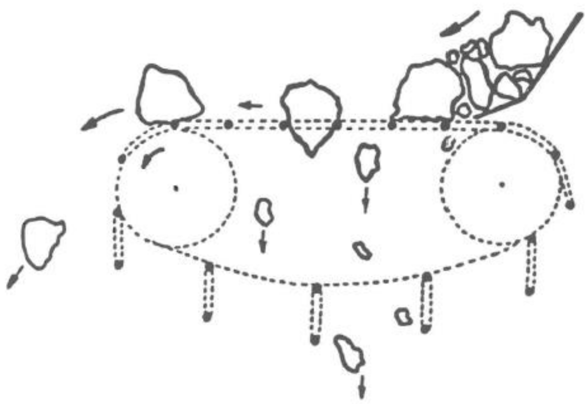


Figure 17 Grill Ross. (Adapted from Álvarez, R. (1996)).

Rollers: Similar to the roll crushers, rolls screen consist in a group of spiked rolls that rotates in the same direction. The fine material passes between the spikes or stripes, and the big grains gets pushed by the spikes or stripes, moving forward and abandoning the screen.

Trommels: Are cylindrical screen slightly inclined where material is fed inside, as the cylinder rotates, fine grain passes throw, and coarse grain moves forward (Figure 18).

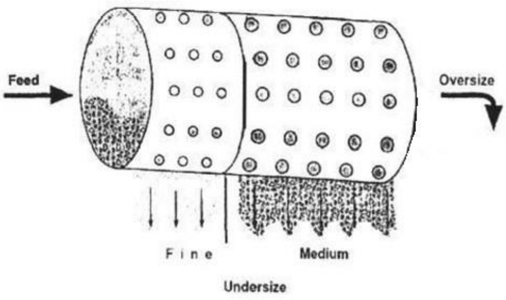


Figure 18 Trommel (Adapted from https://www.researchgate.net/figure/Basic-Trommel-Screen-Design-Brentwood-2016_fig1_303723673).

Slow

Shaking: Consists in a inclined screen with a gear crank attached to it. This mechanism makes the whole screens moves back and forward. Because of the great amount of energy, a flywheel is commonly used.

Resonance: Based in the Shaking screen, resonance solves the energy problem by moving both screens (when having) alternatively back and forward, only applying the energy losses caused by friction.

Circular vibrating: The circular motion gets into the screen and material by a motor attached to a single eccentric load at the end of the shaft, making the screen to describe a slightly circular movement while resting or hanging on springs (Figure 19)

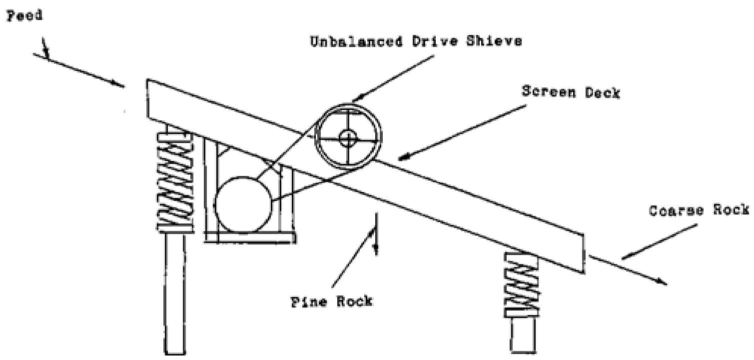


Figure 19 Circular vibrating screen (Adapted from Álvarez, R. (1996)).

Line vibrating: Linear vibrating uses the same principle, by obtain the transversal movement by two motors, with the eccentric shaft moving faced, describing mirror symmetrical moves, resulting in a linear movement (Figure 20)

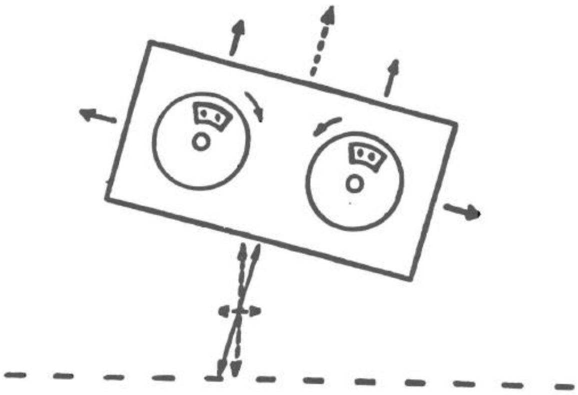


Figure 20 Linear vibrating mechanism (Adapted from Álvarez, R. (1996)).

3.3. Auxiliary mechanisms

The screening by itself takes place when several conditions occurs in its process, where factor as the inclination, direction of vibration, humidity takes importance, and some bring other problems.

3.3.1. Inclination

In fixed and moving screens, most of the movement is done by gravity, for that, the surface must be inclined to split the fine and coarse grain, one by freefall and the other by rolling over the screen.

Because of that, the force of gravity applied vertically causes that the effective surface of the holes or gapes in the screen to be smaller, by projecting it over the horizontal plane, reducing the longitudinal dimension of the holes in the direction of the material movement when sliding over the screen (Figure 21).

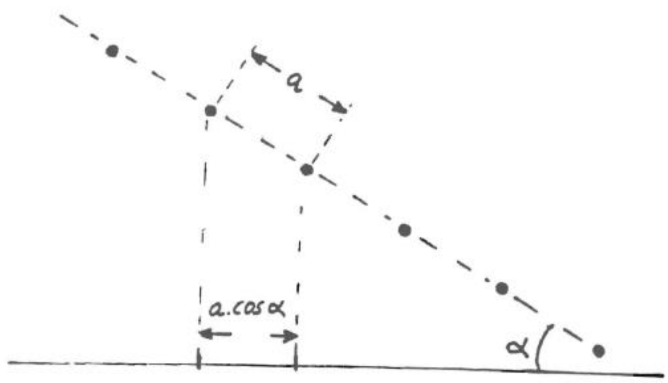


Figure 21 Effective surface depending on the inclination (Adapted from Álvarez, R. (1996)).

3.3.2. *Probability of screened*

The probability of a fine grain to get throw the screen is mainly the opportunity this one has to get into a hole. This count with many factors like the non-spherical size of the grain, the shape of the screen and screen holes, the blind holes, the existence of another grain that tries to pass throw the hole where the fine is trying to.

3.3.3. *Use of screen surface*

When some material is getting screened, the feed distribution along the screen surface has to be the best distributed. Loading material in the centre of the screen makes a cone-shape when the material is moving towards the rejection zone, leaving the initial edges of the screen untouched (Figure 22)

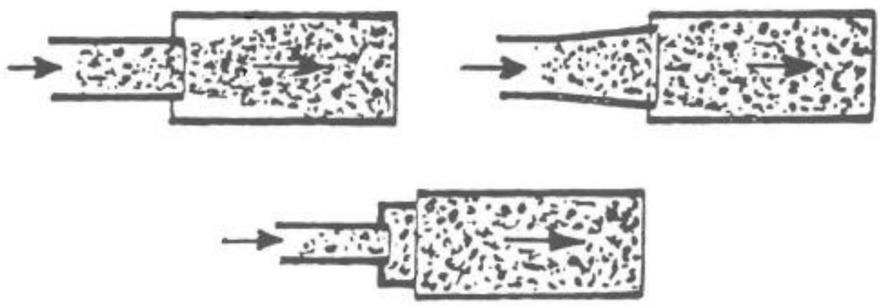


Figure 22 Use of screen surface (Adapted from Álvarez, R. (1996)).

3.3.4. *Critical sizes*

Critical sizes are mainly all the grains which sizes are between 0,5 and 1 times the mesh of the screen holes (undersize) and those between 1 and 1,5 times the mesh of the screen (oversize). Grains which size is below 0.5 times, are so tiny that passes throw easy and fast (halfsize)

Grains in the undersize are those that can fit into the holes, but not that easy, taking more time to get screened or rejected. They have low passing probability.

Finally, those from the oversize use to get stuck into the screen (especially in plates or mesh), blinding the hole, blocking it for another fine grain to get screened.

3.3.5. *Blinding*

Blinding, as we introduce it in previous paragraph, reduces drastically the efficiency as stuck materials reduce the total surface of available holes.

This can be reduced by flaring the exit (lower part) of the plates or bars, to let the stuck grains pass throw once they get to the hole.

To unblock the holes, other solution could be the use of sphere beds. This consists on place below the screen, other with large space e which contains a series of rubber spheres. When the upper screen is moving or vibrating, some of the grains stuck in the holes get kick out of the mesh, letting the hole free for new grains.

3.3.6. *Vibration*

Related with the probability, vibration or shaking is used to increase the movement of all grains to repeat the “trying” process to pass throw a free hole.

3.3.7. *Feeding*

The feeding capacity is also an important factor in the screening.

Overfeeding creates a grain bedding that preventing upper grains to even touch the screen, and if the feeding is insufficient, the effect of the motion or vibration launches all the few grains that rest over the screen to a further distance or even the rejection zone, and never get screened (Figure 23)

Usually the perfect feed or flow is about 70%-80% of the 100% feed specification of the screen.

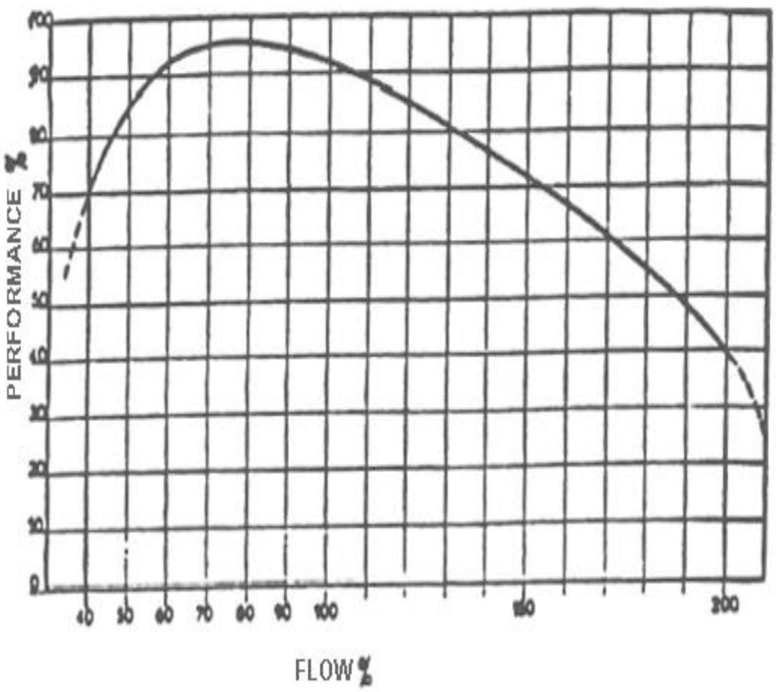


Figure 23 Flow over performance on a screen (Adapted from Álvarez, R. (1996)).

3.3.8. *Efficiency*

The efficiency of the screen can be represented either the amount of fine material that stills in the rejection, or the percentage of the total fine material got screened over the total spected by a granulometric curve.

This implied several assumptions, like the theoretical curve versus the real one, the existence of water, extreme dry material, inclination of the screen, work capacity of the screen…

$$E_f = 100 \cdot \frac{P \cdot p}{F \cdot f}$$ Equation 4 Efficiency formula (Álvarez, R. (1996))

Where:

F=Feed mass

P=Pass mass

R=Rejected mass

f,p,r=percentage of all grains with inferior dimensions than "m=mesh" in the feed, pass and rejection respectively

Being:

$$F = P + R \qquad Ff = Pp + Rr$$

$$R = F - P; Ff = Pp + (F - P)r$$

$$F(f - r) = P(p - r); \frac{P}{F} = \frac{f - r}{p - r}$$

Therefore:

$$E_f = 100 \cdot \frac{p(f - r)}{f(p - r)}$$ Equation 5 Expanded Efficiency formula (Álvarez, R. (1996))

Simplified:

$$e = 100 - r$$ Equation 6 Simplified Efficiency formula (Álvarez, R. (1996))

Were:

e=efficiency in %

r=rejection in %

3.3.9. *Humidity*

Humidity causes particle agglomeration, especially on fine grain and dusty materials, blocking the screen.

Some methodologies can solve the humidity problem.

Drying: Drying by hot hair blowing into the material before the screen can be a nice solution, but depending on the material, if it is clay-based, the fine grain particles and dust can joint together when drying as a clay pot. Also, the energy required to evaporate a 3 to 10% of humidity make this method mainly impracticable.

Watering: The water distribution by sprinklers of pressurized, can help to destroy agglomerations, dissolve some materials and cleaning surfaces. But also, can produce corrosion or oxidation in some parts of the screen. Also, a proper system for water disposal should be planned, in order to clean contaminated waters from the watering process.

Compressed air shoots: Periodical shoots of compressed air manages to break down the agglomerations into smaller ones that could pass throw the screen.

Electric heating: Electrical heating of a metal screen instead of the material dries the screen, making the agglomerations unable to stick into it.

3.3.10. Dust

In every crushing process, several amounts of dust can be produced, for very dry feed can results in an over production of ultra-fine grain and dust.

This can cause a pile of dust stored in every parts of the machine that had not a way to remove it, and this might cause obstruction or reduction of the movement in the movable parts.

Chapter III

Case study: Vila Verde Quarry

1. Localization and Geology

The quarry of Vila Verde is located in Oporto district (Portugal), county of Vila do Conde, inside of Fornelo's parish.

1.1. Accesses

The main accesses to the Vila Verde quarry are the M534, union between the N318 and the N104, but significantly closer (about 300m) to the first (Figure 24).

Figure 24 Accesses to Fornelo (Adapted from Google Earth).

1.2. Geology

Fornelo is located in the Variscan Granites zone of the north-centre of Portugal, as we can see in map (Figure 25).

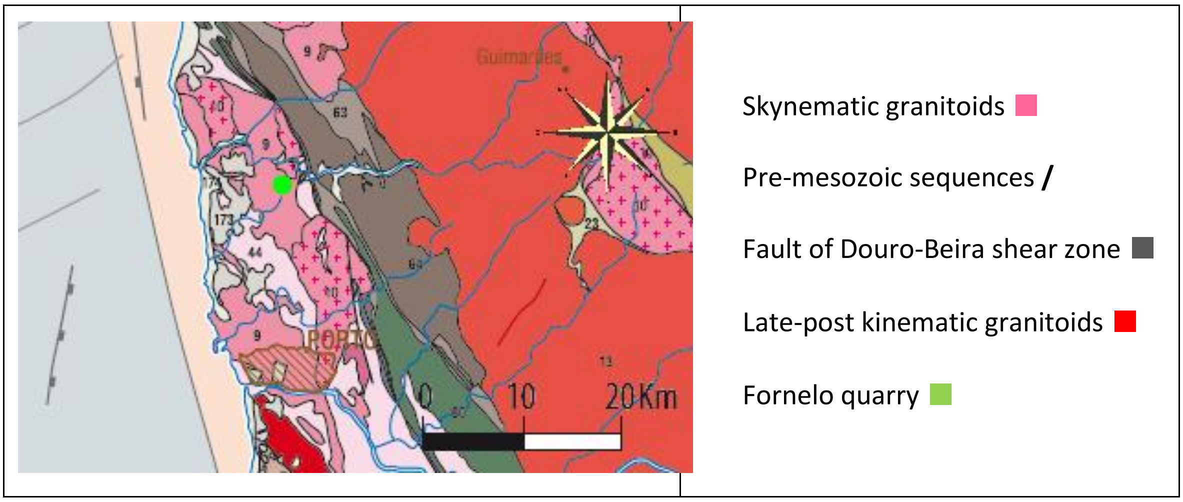


Figure 25 Geology of Fornelo (Data adapted from IGME cartography geological data (http://info.igme.es/cartografiadigital/geologica/Geologicos1MMapa.aspx?Id=Geologico1000_(2015))).

As exposed in the *Elevo Agregados Site*, the product material is an *"Igneous plutonic Granit, constituted essentially by quartz (2-8mm), feldspar (2-20mm), and micas (0.5-2mm) among others. Compact structure, with holocrystalline texture, phaneritic, medium-coarse grain with porphyritic."*

2. Quarry production process

2.1. Distribution of processing plant

Vila Verde quarry counts with a linear production of aggregates. Three crushers are implied, the Jaw crusher as a primary, and two cones as secondary and tertiary. Two screens of four decks each classify the aggregates by its size, and several conveyor belts take those back to the crushers, or to the pile mount where it gets stored and loaded in trucks

As we can see in the figure 26, a road path is made to get to the Jaw's feeder, which is in the top of the hill, them the material gets crushed in the primary, and transport to the main pile. Another conveyor takes material from the pile and unloads it in the hopper of the secondary. The crushed material gets to the first screen and depending the distribution of the other conveyors for the requirements of production, material can get back to secondary, moves to the tertiary or go the final pile. Tertiary and second screen repeat this process.

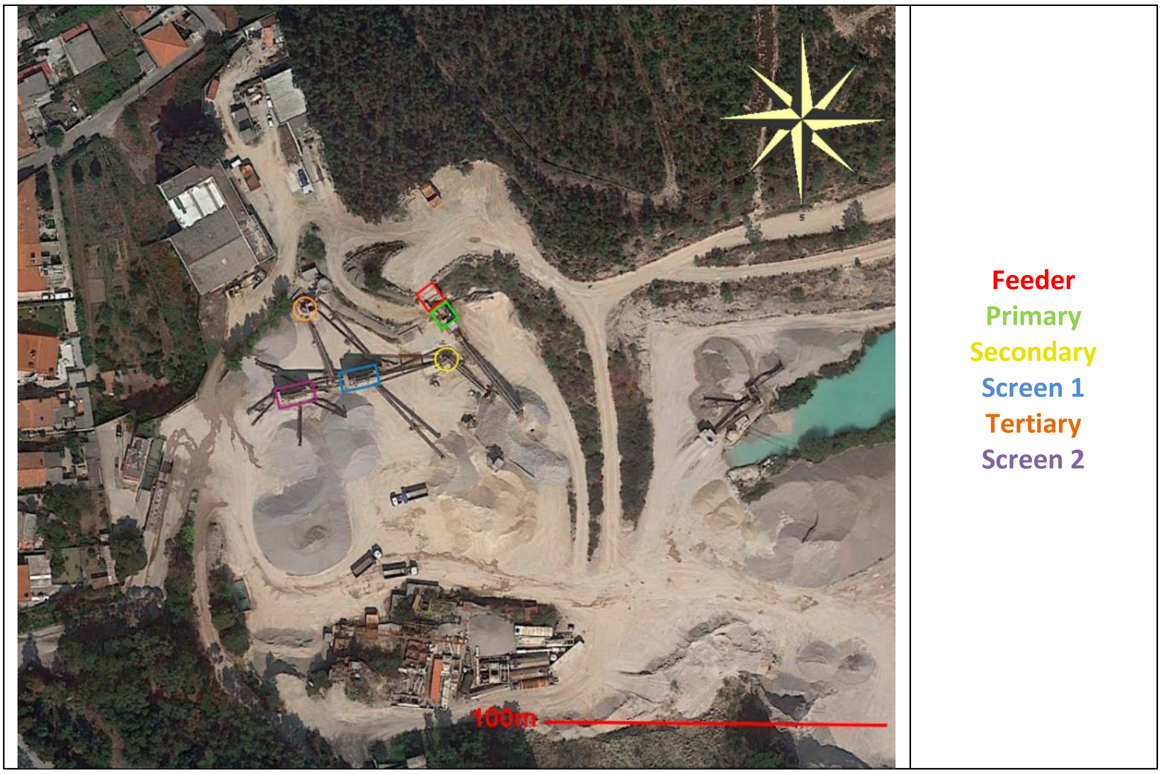


Figure 26 Vila Verde processing plant (Adapted from Google Earth).

2.2. Layout

The main layout of Vila Verde quarry represents a scheme of the process that takes place and its order (Figure 27).

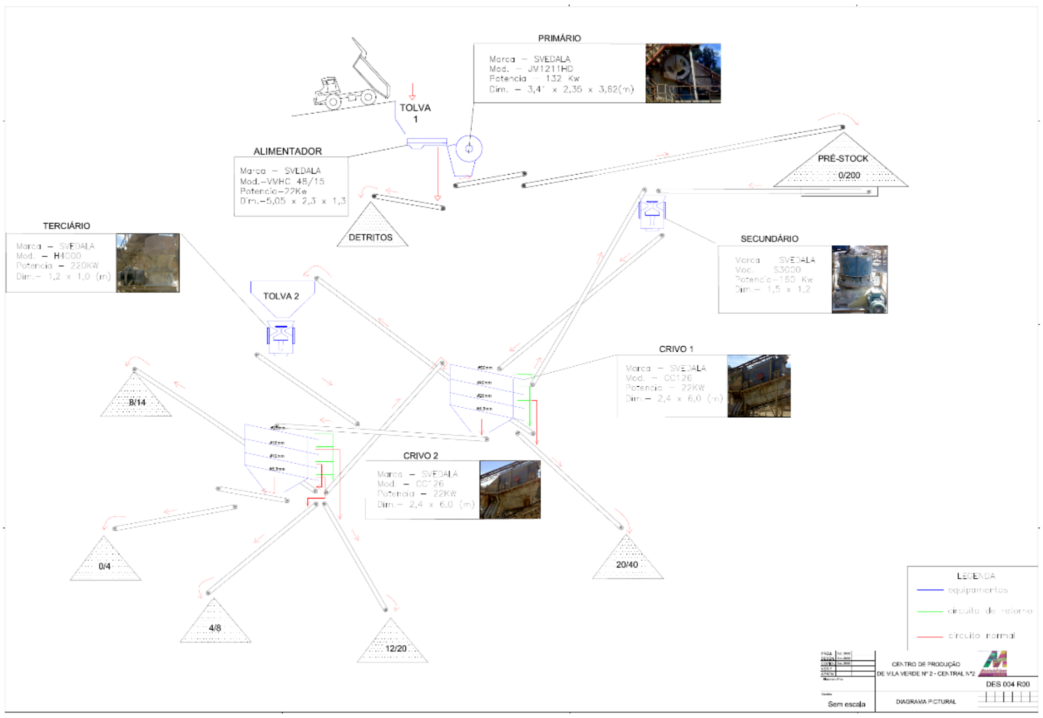


Figure 27 Layout of Vila Verde (Image conceded by Elevo Group).

2.3. Aggregate processing

The whole process of aggregates production in Vila Verde quarry is the following:

- Blasting operation in open pit
- Mechanical crushing of oversize blocks by hydraulic hammer
- Transport to the processing zone
- Dumping in the feeder hopper
- Primary Jaw crushing
- Deposit of crushed rock after the primary. As the blasting operations are not done continually, all the rock result of blasting are crushed in the primary jaw crusher and moved by a conveyor belt to a space, where it waits to be crushed in the secondary.
- Another conveyor belt is set underground to transport the whole deposit pile from below, feeding the secondary.
- Secondary crushing
- First screening
- Tertiary crushing (if needed)
- Second screening (if needed)

During the process, several distributions of the conveyor belt can be made in order to get more variety of product sizes, when required. Causing material recirculation.

2.4. Equipments data

Due the age of the equipment's, the technical data has been simplified by using the newest version of the equipments. Those contain mainly the same specifications, but with an update name, variations in the results are not expected.

Equipment's are defined in this work by the model (old and updated), motor power and measurements.

2.4.1. Feeder

Figure 28 shows the main data of the Feeder.

Model information: VMHC 48/15 22KW 5,05 x 2,3 x 1,3 **Actual Equipment:** SV1253E or SV1252E	

Figure 28 Feeder (Taken from Sandvik brochures).

2.4.2. Primary

Figure 29 shows the main data of the Primary crusher.

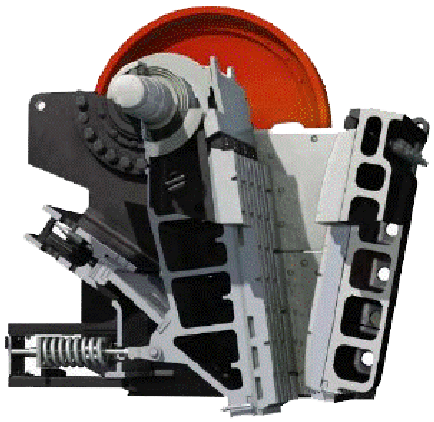
Model information: JM1211HD 132kw 3,41 x 2,35 x 3,62 **Actual Equipment:** CJ612	

Figure 29 Primary crusher (Taken from Sandvik's brochures).

2.4.3. Secondary

Figure 30 shows the main data of the Secondary crusher.

Model information: S3000 160KW 1,5 X 1,2 **Actual Equipment:** S3800 or CS430	

Figure 30 Secondary crusher (Taken from https://www.mascus.es/construccion/trituradoras-usadas/sandvik-cs430-cone-crusher/9lhm6qiw.html).

2.4.4. *Tertiary*

Figure 31 shows the main data of the Tertiary crusher.

Model information: H4000 220kw 1,2 x 1,0 **Actual Equipment:** H4800 or CH440	

Figure 31 Tertiary crusher (Taken from http://www.aggbusiness.com/sections/quarry-profiles-reports/features/swerock-supplies-diverse-product-range-from-swedish-quarry/).

2.4.5. *Screen (1 & 2)*

Figure 32 shows the main data of the screens

Model information: CC126 22kw 2,4 x 6,0 **Actual Equipment:** SK246	

Figure 32 Screen model (Taked from Sandvik's brochures).

2.4.6. Screen media

All careen media are metal mesh media, produced by *Produtiva Lda*.

The two main screen media used are a regular metal wire screen and a self-cleaning one.

Figure 33 Screen media: regular and self-cleaning (Taken from *Produtiva Lda*).

Further information of the equipments and the screens can be found in the annexes.

3. Processing sheet with Excel

The main idea of this project if to create a way to estimate the production mass and size of the different aggregates produced in the quarry by modifying the values of the equipment's. By using an Excel sheet, we can design an easy to operate input, and a clear output of the estimated results.

3.1. Equipments data

Some of the parameters used to create this sheet are unmovable, as they are mainly the rock properties or fixed values of the equipments parameters.

Some of the parameters were provided by Vila Verde quarry engineers, others can be found in the brochures of the equipments and screen media, and others were taken from manuals from general equipments performances under similar conditions.

3.1.1. Material

The material will be defined by its Work Index, determined as 16 (https://es.scribd.com/doc/171524745/Bond-Work-Index-Tables-Wi).

3.1.2. Feeder

Feeder has to main values, the undersize cut, which is 42mm (Information provided by Vila Verde Quarry) and the upper cut of oversize's, this will be determined by the maximum feed size of the Primary crusher, which is usually around 80% of the biggest side of the opening (Álvarez, 1996).

3.1.3. Primary

According to the Work Index of the material to crush and screen, the output will be defined by production curves that appear in the brochures. This will be represented as 75% of passing material through a mesh of the same size of the crusher's CSS.

CSS will be modifiable between 125mm and 275mm, and OCC is determined as three halves of the SCC

3.1.4. Secondary

The chamber used in the secondary crusher is the EC, or Extra Coarse. (Information provided by Vila Verde Quarry), with a 60% of passing material through a mesh of the same size of the CSS (Álvarez, R. (1996)).

The max feed size is 360mm according to the brochures. The CSS is modifiable between 16mm and 83mm, being the OSS also three halves of the CSS.

3.1.5. Tertiary

For the tertiary crusher, the chamber selected is the M for Medium, with an 80% of passing material through a mesh of the same size of the CSS, as described in the chart graphics.

The maximum feed size is around 110mm according to the brochures; The CSS is modifiable between 4mm and 70mm, being the OSS also three halves of the CSS.

3.1.6. Screen 1

First screen counts with 4 screen decks; each one has a different mesh size. The first 3 meshes are regular type, of 50, 40 and 25mm respectively. The las one is a self-cleaning mesh, with a size of 6,3mm.

3.1.7. Screen 2

Similar to the first screen, secondary screening counts with also four decks, being the first the regular one of 25mm, and the rest three are self-cleaning meshes, with 16, 10 and 6.3mm size respectively.

3.1.8. Conveyor belts

All the conveyor belts coming each for one of the rejection parts of each mesh (5 per screen) has a destination that can be modified.

Chapter IV

Results

1. Using the calculator

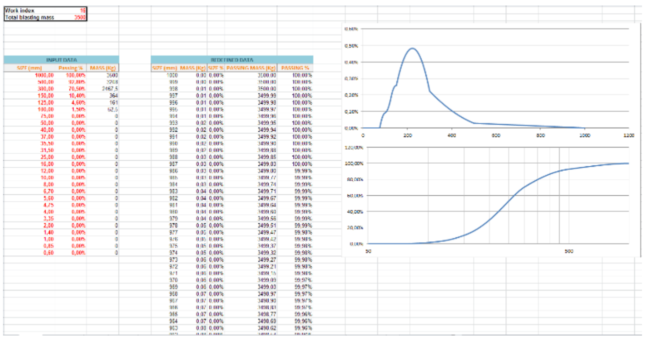
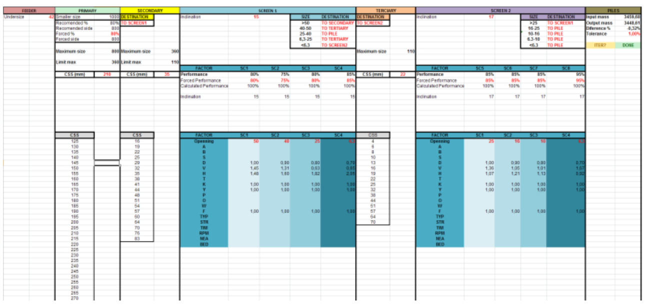
The excel document is divided in 9 basic sheets (Figure 34).

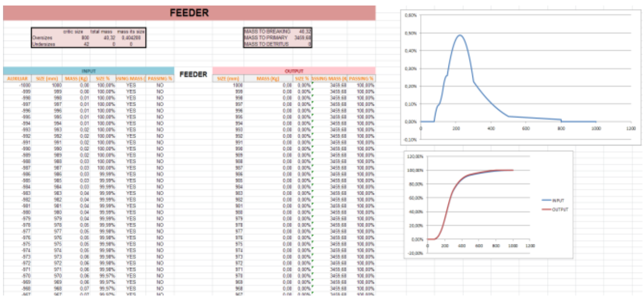
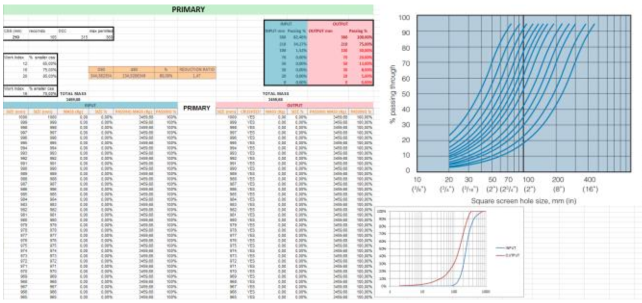
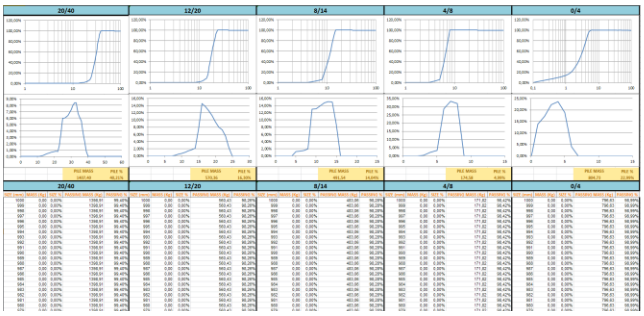
Figure 34 List of excel sheets.

This sheet attempt to create an easy interface, neither complex of simple, but using the Microsoft Office Excel, many users will feel familiarized with this software, simplifying its use.

The table 4 shows the basic information found in each characteristic sheet used in the calculations. Further information of the whole process will be explained.

Table 4 Excel sheets basic information

Sheet name	Image	Description
Main		This sheet contains the main basic info of the blasting product pile. In red, Work index, total pile mass and granulometric input data (size and passing %) should be added.
Adjustment		In this sheet all adjustments has to be made. Only data in red can be modified. This includes the output opening of crushers, product destinations and performances of the screens.

Feeder		Feeder sheet works automatically using the input data of the adjustment sheet. Removing oversize and undersize material.
Crushers		Same design for primary, secondary and tertiary with data differences. This sheet need to create the output red curve based in the brochures production curve.
Screens		Same design for screen 1 and screen 2. This sheet works automatically with the screens size and performance of each deck.
Piles		Final results, depending on input curve and equipment's adjustments.

Users will be able to modify nothing but only the red-colored values in the tables, rest of the process is completely automated.

In the first one, MAIN, users have to add the main data of the initial blasted material. This includes granulometry, Work Index (Wi) and total mass. The granulometric curve could be modified in passing size and percentage as long as the biggest size correspond to the 100% of passing material in the top of the input.

In the second, ADJUSTEMENT, user can modify all the processing plant by selecting the undersize material in the feeder, the opening sizes of the crushers exit, performances and destinations of productions in crushers and screen decks... Each equipment has its data to be modified, each with different modifiable or fixed values, taken from the brochures (Figure 35).

This sheet also includes all the destinations of products. This includes the secondary and tertiary crushers output and all granulometries rejected by each screen deck and transported in conveyors (in first and second screen). As users can see, not all options are available, this is because design limitations in the layout design provided by Elevo Group (Figure 36).

SIZE	DESTINATION
>50	TO SECONDARY
40-50	TO TERTIARY
25-40	TO PILE
6,3-25	TO TERTIARY
<6.3	TO SCREEN2
DESTINATION	
TO SCREEN2	
SIZE	DESTINATION
>25	TO SCREEN1
16-25	TO PILE
10-16	TO PILE
6.3-10	TO PILE
<6.3	TO PILE

Figure 35 Destinations of Screens and tertiary crusher products.

As the sheet is calculated by doing iterations, at the right part of the sheet you can find a zone called "piles" reserved to determine if the solution is accurate enough by calculating the difference between input and output total mass. 1% of difference has been set by default, by this value can be modified to attain a more precise solution. When the "ITER" is set to "Continue", more iterations are needed, if "Done" appears instead, the solution is precise enough.

PILES	
Input mass	3459,68
Output mass	3448,61
Diference %	-0,32%
Tolerance	1,00%
ITER?	DONE

Figure 36 Comprovation of iterations.

Third sheet, named FEEDER is calculated automatically. No further modification is needed.

In the PRIMARY sheet, the main work remains into find the convergence between the percent of passing material through a mesh with the same size of the CSS, and the CSS size in the output chart of the primary crusher. Once this is done, and a curve is selected, user has to add several percentage-size points of this chart into the red output table

All the red values are those to fill by the user. The garnet data represents the maximum estimated size in the output and its percentage of passing, and the second one is the CSS and its percentage. Blue side is the actual material in the input with the sizes in the output and its percentage. Just to represent in the image (Figure 37) the input already represents the 81.71% of the material, but only 33.55% is smaller than the CSS, will be raised to 75%.

INPUT		OUTPUT	
SIZE mm	Passing %	SIZE mm	Passing %
360	81,71%	360	100,00%
210	33,55%	210	75,00%
100	1,42%	100	30,00%
70	0,00%	70	20,00%
50	0,00%	50	13,00%
30	0,00%	30	8,00%
20	0,00%	20	5,00%
0	0,00%	0	0,00%

Figure 37 INPUT-OUTPUT Table.

Curve selection is better represented by Figure 39.

Exactly this same process has to be done with the SECONDARY and TERTIARY crusher sheets. This can be done before all calculations, as only the CSS and the material type takes relevance.

No further modification is required in the SCREEN1 and SCREEN2 sheets.

After calculating all, production piles will update. All interpolations will be done when the production mass gets close to input total mass. (less than 1%). This operation is found in the MAIN sheet.

Additionally, another sheet was made in order to calculate each screen deck performance by determine several factors of a single equation and resulting in the actual performance of each deck. This calculation has to be done by hand, as many factors depends one of the others and has to be taken from several tables, according to (http://vibfem.com.au/resources/vibrating_screens_and_feeders/Screen_Capacity_Paper.pdf).

Users has to make hand calculations taking care of specific units to determine each factor and fill the two tables (for SCREEN1 and SCREEN2) located in the ADJUSTMENT sheet. This will calculate the performance of each deck. Notice that the used performance will be the lower between the calculated and the forced one, colored in Red.

FACTOR	SC1	SC2	SC3	SC4
Openning	50	40	25	6,3
A				
B				
S				
D	1,00	0,90	0,80	0,70
V	1,09	1,31	0,64	0,65
H	1,46	1,60	1,82	2,05
T				
K	1,00	1,00	1,00	1,00
Y	1,00	1,00	1,00	1,00
P				
O				
W				
F	1,00	1,00	1,00	1,00
TYP				
STR				
TIM				
RPM				
NEA				
BED				

Figure 38 Table to fill manual data for actual screen decks performance calculation.

The last sheet is reserved to visually compare the excel results with the typical output product of Vila Verde quarry.

It is very important to say that this entire document will only be possible to calculate products once the tool ***SRS1 Splines*** is installed.

1.1. Making the iterations

Excel allows making iterations in its calculation for recirculating flow of data between its sheets.

After making any modification in the red values of the sheet, users have to enable iterations by going to Options and them opening Formulas and selecting “Enable iterative calculation”.

We recommend to also deselecting in the “Workbook Calculation” the option “Automatic” and selecting “Manual”. Also started setting the “Maximum Change” to 100, and a “Maximum Iterations” set to 300. Calculations will start when pressing the “Calculate” button located in the lower left corner of the Excel sheet.

2. Results

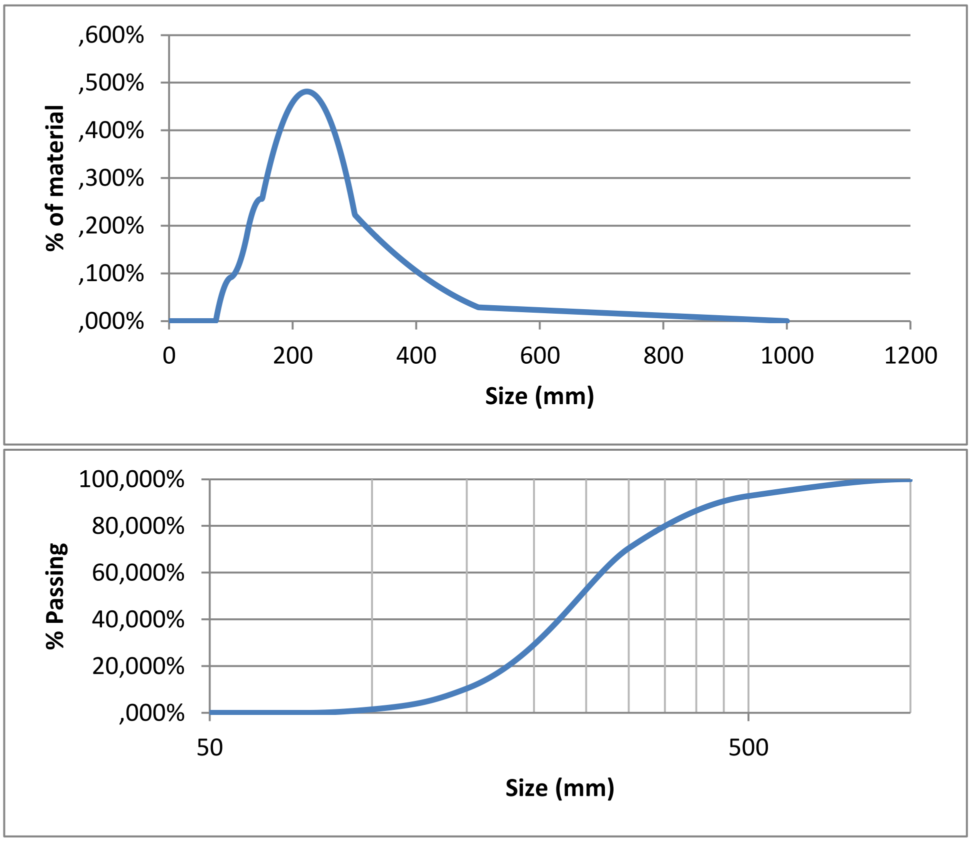
Knowing that the results depends on the input curve, we can study the differences in the result by differences in the parameters chosen, like denying one pile, producing all in the smaller size granulometry.

For a given granulometric curve, as an example in Table 4.

Table 5 Input distribution.

Mass Input (kg)	*Size Input (mm)*	*Percent Input (%)*
3500	1000,00	100,00%
3248	500,00	92,80%
2467,5	300,00	70,50%
364	150,00	10,40%
161	125,00	4,60%
52,5	100,00	1,50%

By using the ***SRS1 Splines*** tool, we can transform this data in this other two curves, uprising the input data precision as show in Graphic 1.



Graphic 1 Granulometric distribution of the input.

Later, the feeder sheet will clean the distribution by removing all elements below 42mm (modifiable value) and all above the maximum size allowed by the Primary Crushing (Usually 80% of smaller entrance).

In reality, the oversize material is selected before the feeder, and disposal to hydraulic breaking or blasting.

Next step is the primary crushing, which depending in the CSS regulation, output of this process will be modifiable.

We have selected a CSS of 210mm, being the OSS 315mm.

This will result in a maximum size of 315mm but looking at the maximum size input in the secondary (360mm) we accept that the maximum is 360mm. We can apply this increment of 45mm of size because of non-spherical material that can pass through the OSS, called slabs.

To calculate the output, we took the brochure of the Jaw Crusher to get the results. The percentage of material passing throw a mesh of the same size of the CSS depends on the Work Index of each material (Table 5). As the brochure provides the relation between the bond index and the percentage of material passing through a mesh of the same size of the crusher's CSS.

Table 6 Percentage of material passing through a mesh of CSS size depending on the W_i (Data taken from Sandvik brochures).

Work Index	% smaller css
12	65,00%
16	75,00%
20	85,00%

Being granite with a Work Index around 16 (https://es.scribd.com/doc/171524745/Bond-Work-Index-Tables-Wi), the percentage of material passing through a mesh of the same size of the CSS will be 75%.

With the percentage and the CSS we can get the representative curve of the output (Figure 38)

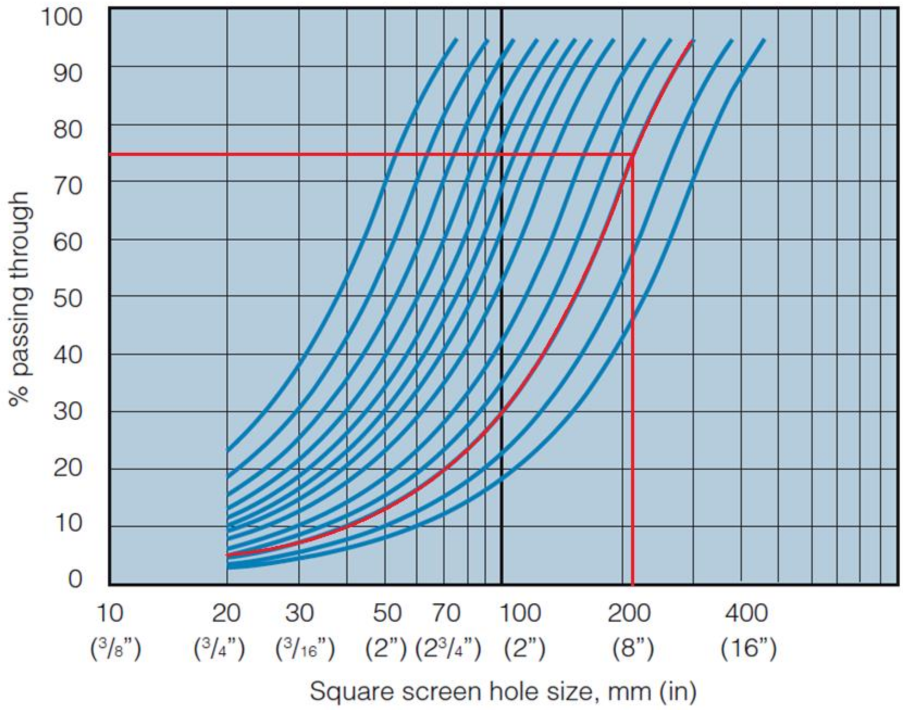
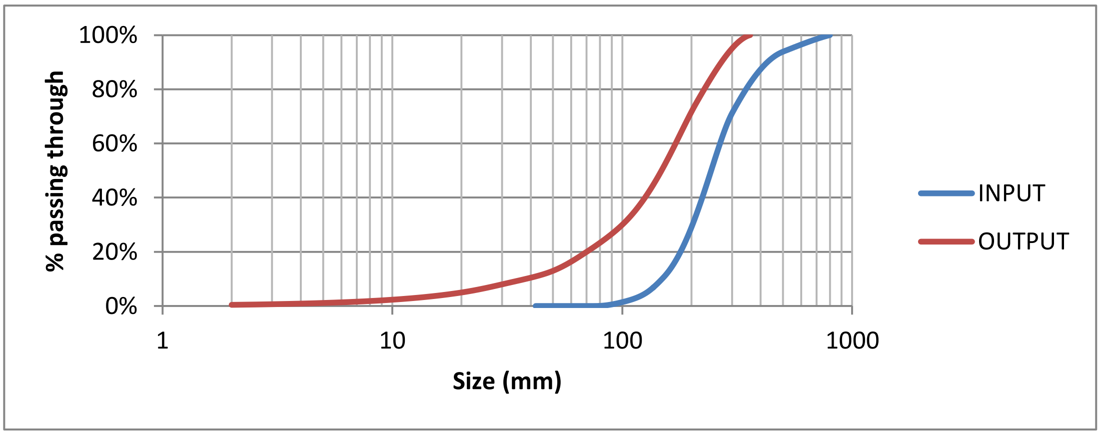


Figure 39 Primary crusher product graphic (Taken from Sandvik brochures in the Annexes)

Extracting some size-percentage points of the chosen graphic to the output table, it calculates the relation between both curves, the ratio of reduction (D80/d80). Manual configuration of output curve (Figure 37)

This manual operation of points extracting has to be done for each crusher.

According to mass-size input, the excel will calculate the mass-size output according to the representative production curve extracted from the brochures (Figure 38), obtaining the results of the input and output in the same graphic (Graphic 2) and the reduction ratio of the crusher.



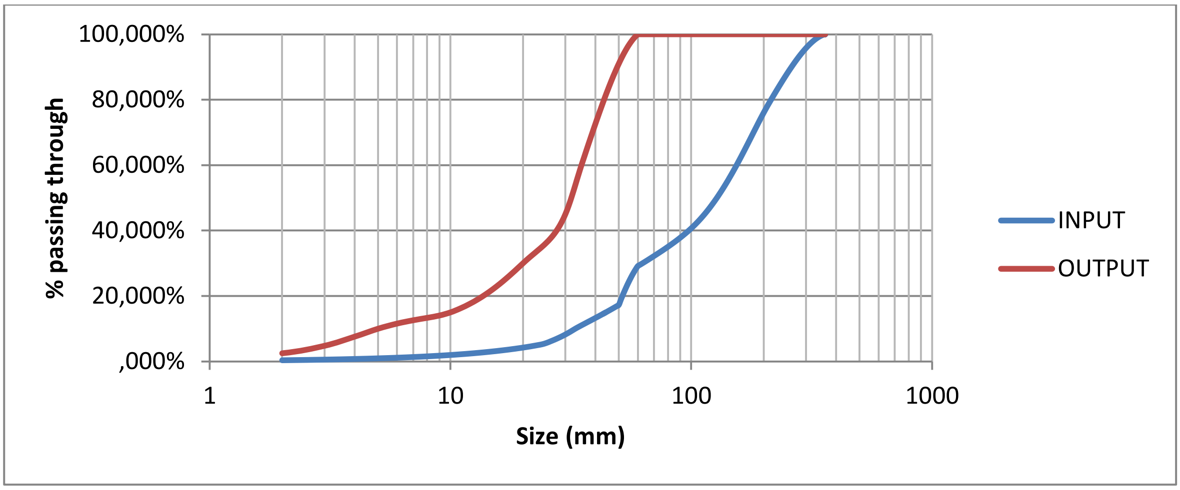
Graphic 2 Curves after and before primary crusher.

As exposed in the layout image, the secondary crusher takes place right after the primary, but we have to add also all the rejection after the first crushing (size above 50mm) so the crushing product will be transported to the first screen, causing a circular flow.

This is represented by a circular reference, which takes about 3000 iterations to be calculated. The iterative process is done when the initial mass is equal to the mass on the final piles.

If any of the parameters are modified, calculations have to be done once again.

For the secondary crushing the results are exposed in Graphic 3.

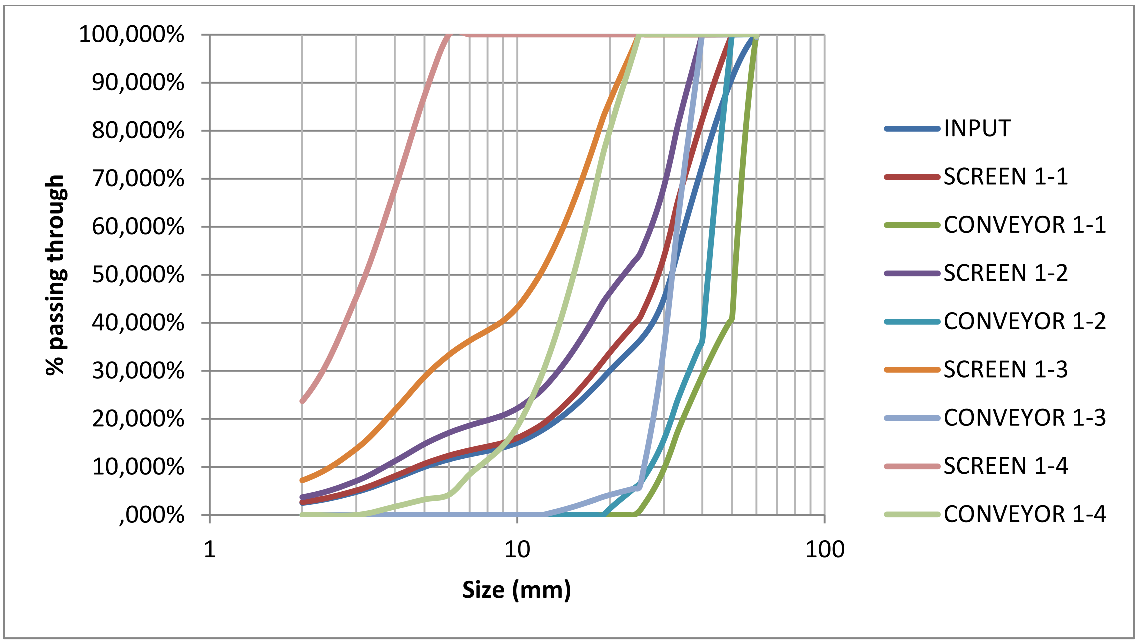


Graphic 3 Curves after and before secondary crusher.

As we can see in the input curve, there is a slightly elevation above the 50mm of material size, this extra material is the recirculated, rejected by the 50mm initial mesh in the first screen.

Once the first screen process takes place, we have supposed that the material within 0mm and half the mesh size will always pass through the mesh, the material larger than the mesh size will be rejected; and the material between half the mesh size and the mesh size will suffer the performance efficiency of each screen deck.

This can be appreciated in the first screen results of Graphic 4.



Graphic 4 First screen input, rejections (conveyors) and results (screens).

Being the screened material, the data for the next deck calculation; and the conveyor, the material rejected.

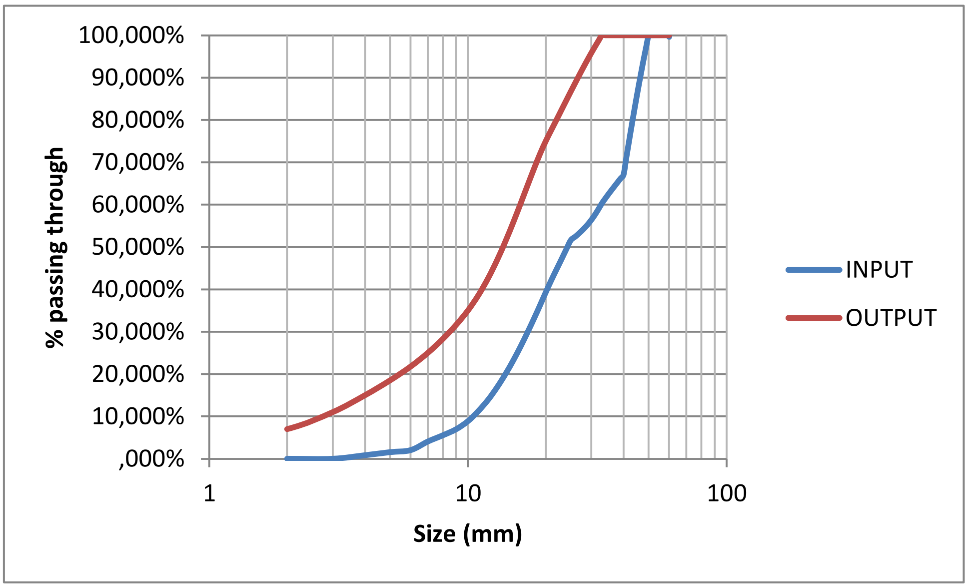
Depending on the initial adjustments, the output conveyors (rejected material) will be transport to the tertiary crusher, to the piles, to the second screen or back to the secondary. (Not all conveyors have all options, process limited by the Vila Verde Layout, not all configurations are possible.)

In this case, we set this configuration for the destination of conveyors and tertiary crusher (Table 6).

Table 7 Configurations of product destinations in excel sheet. First screen, tertiary crusher and second screen.

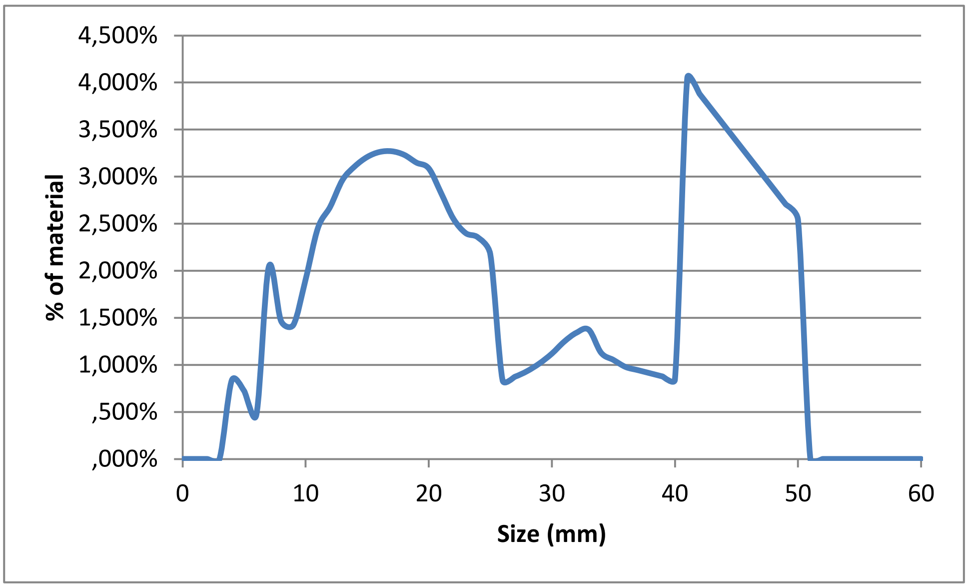
SIZE	DESTINATION
>50	TO SECONDARY
40-50	TO TERTIARY
25-40	TO PILE
6,3-25	TO TERTIARY
<6.3	TO SCREEN2
DESTINATION	
TO SCREEN2	
SIZE	DESTINATION
>25	TO SCREEN1
16-25	TO PILE
10-16	TO PILE
6.3-10	TO PILE
<6.3	TO PILE

So, the tertiary crusher has an input adding the rejections of the 40-50mm, 6.3-25. These values will be slightly "contaminated" of material of other granulometries due the performances of each screen deck. This can be appreciated in Graphic 5.



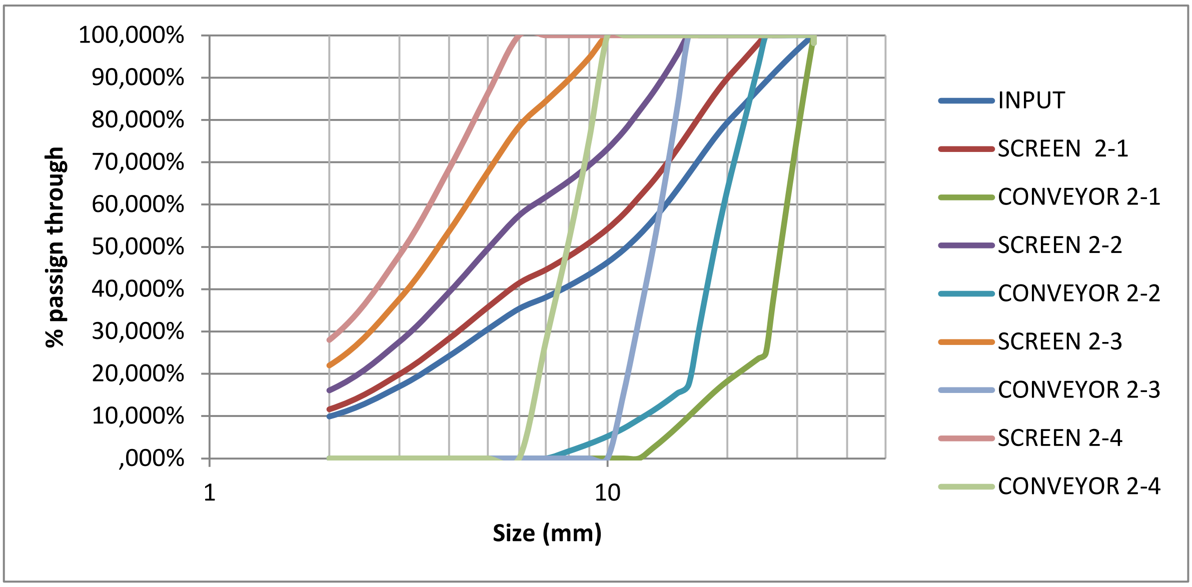
Graphic 5 Curves after and before tertiary crusher.

This is the distribution percentages for each grain size, as we see, they are two main values, one between 6.3mm and 25mm and the other between 40-50mm as we saw in last paragraph. This is also because most part of the size between 25mm and 40mm has been deposit to its pile. For a further representation, Graphic 6 indicates percentual concentration of each size.



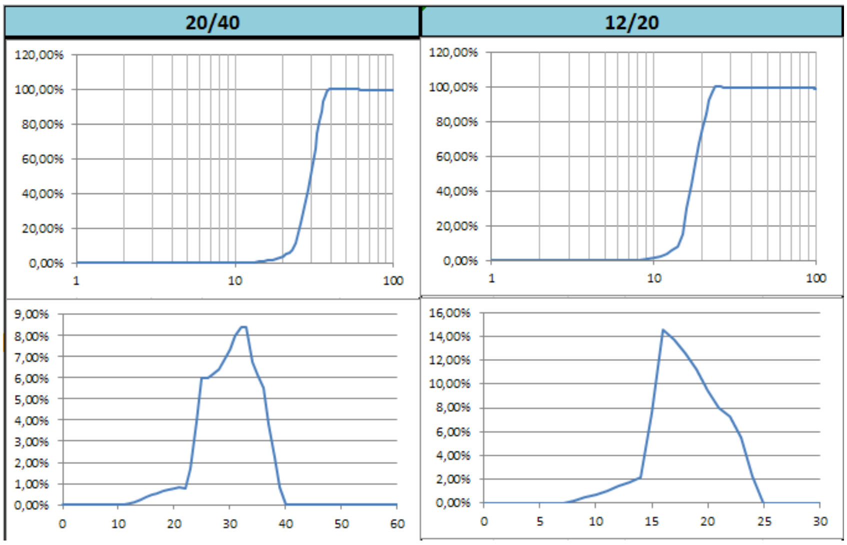
Graphic 6 Distribution of sizes in the tertiary input.

Setting also the fixed performances of each screen deck, the results in the second screen can be found on Graphic 7.



Graphic 7 Second screen input, rejections (conveyors) and results (screens).

And for the end of the operations, as we set the output to finish in the crushed piles, the distribution and granulometric curves of the piles as exposed in Figure 39.



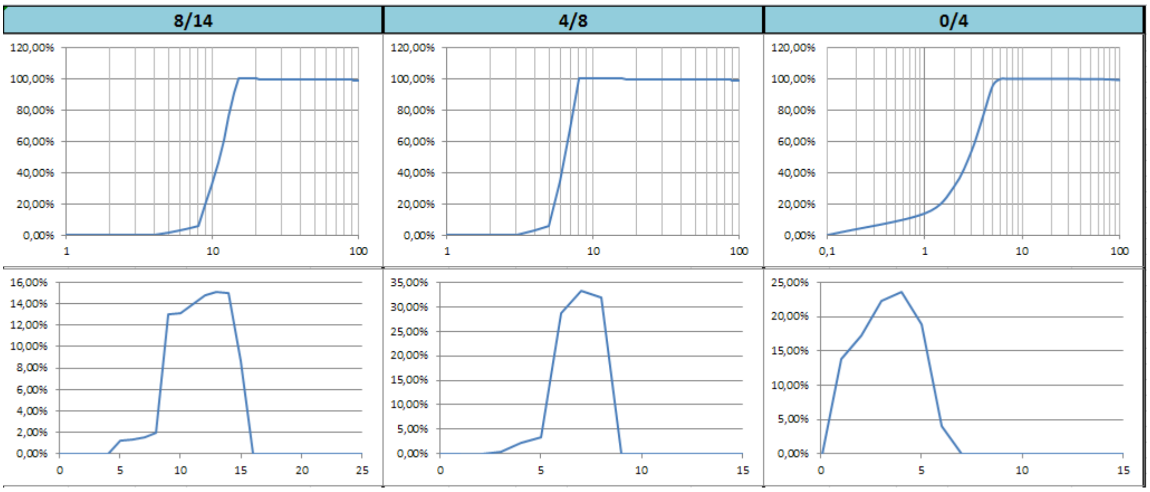


Figure 40 Final piles granulometries and distributions.

We can appreciate how clean 0/4 curve is. This is because all the material passing through the last screen deck correspond to the dust part, separating perfectly the rejection and the passing through.

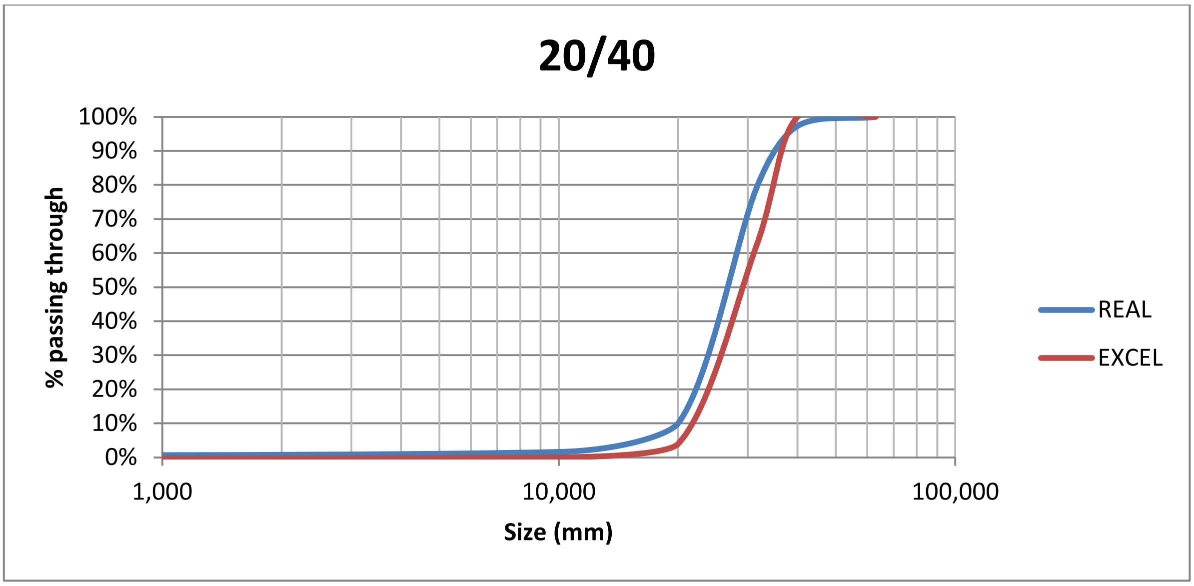
3. Accuracy of results

All these results were obtained by calculations based on other papers estimations, brochures performance data and other formulas used to get the efficiency of the screens.

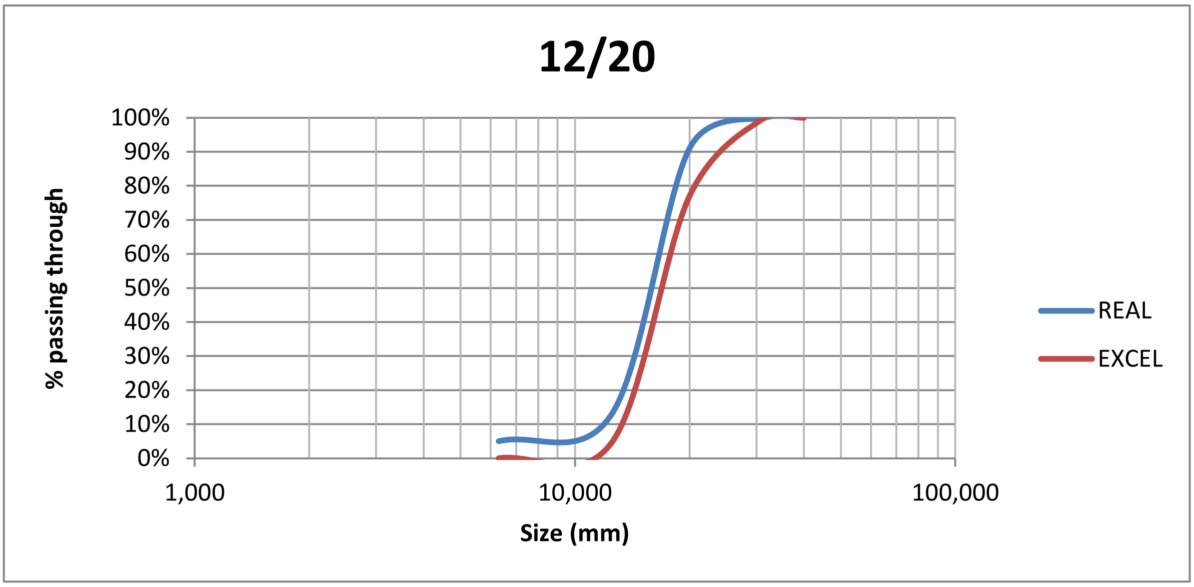
According to the products report in the site of Elevo Group produced by Vila Verde quarry, we can make a simple comparison between official reports and estimative calculations for each product.

3.1. Each result

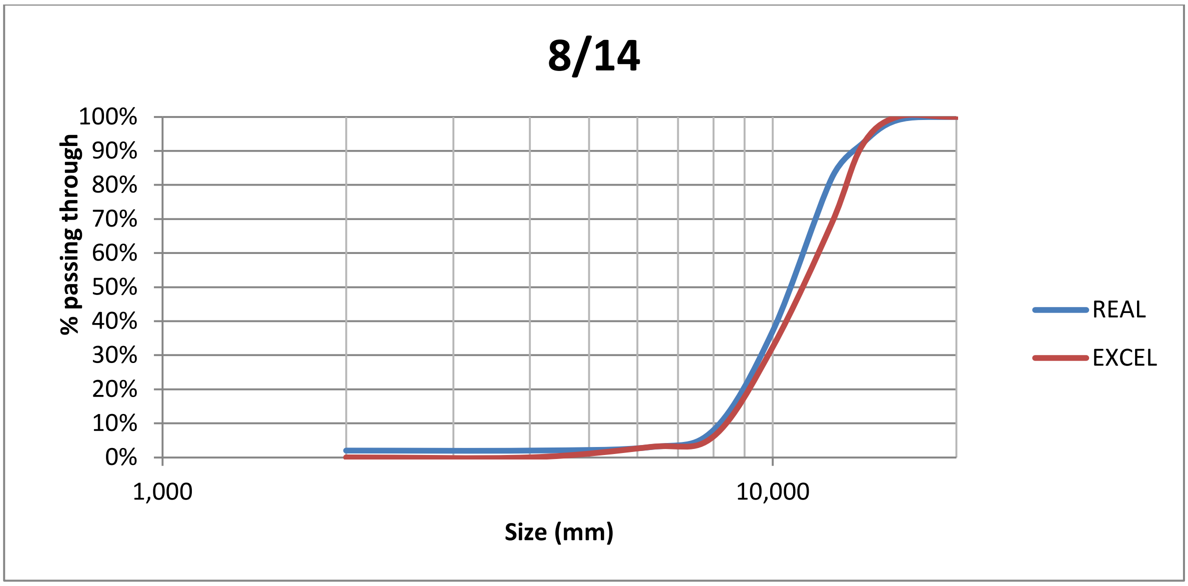
Graphic 8, 9, 10, 11 and 12 shows the data and granulometric curve of 20/40, 12/20, 8/14, 4/8 and 0/4 product respectively.



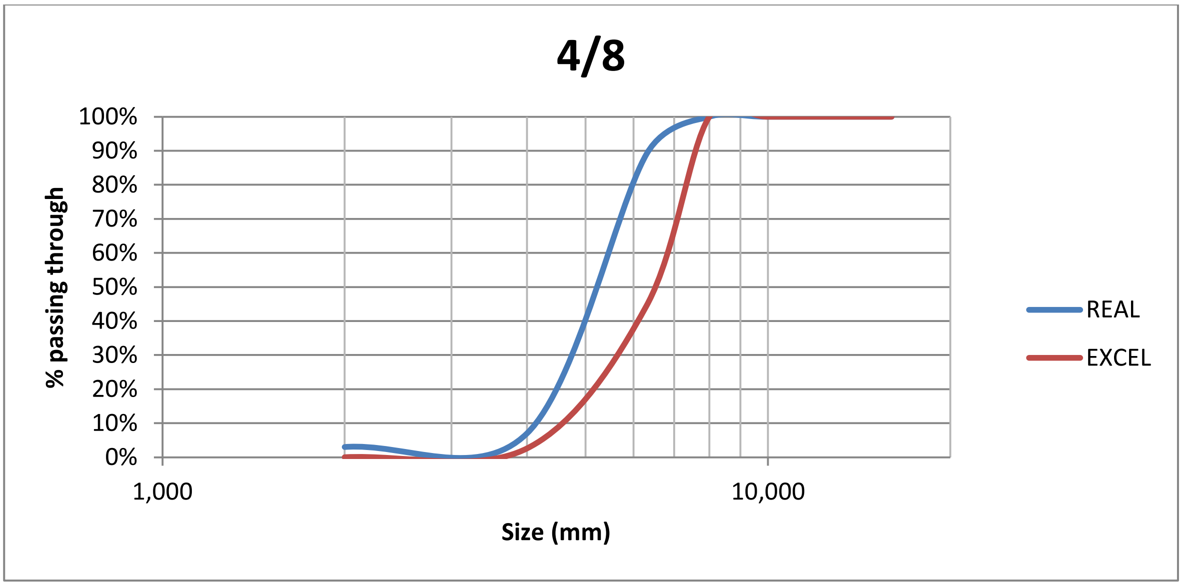
Graphic 8 Comparison of results of 20/40.



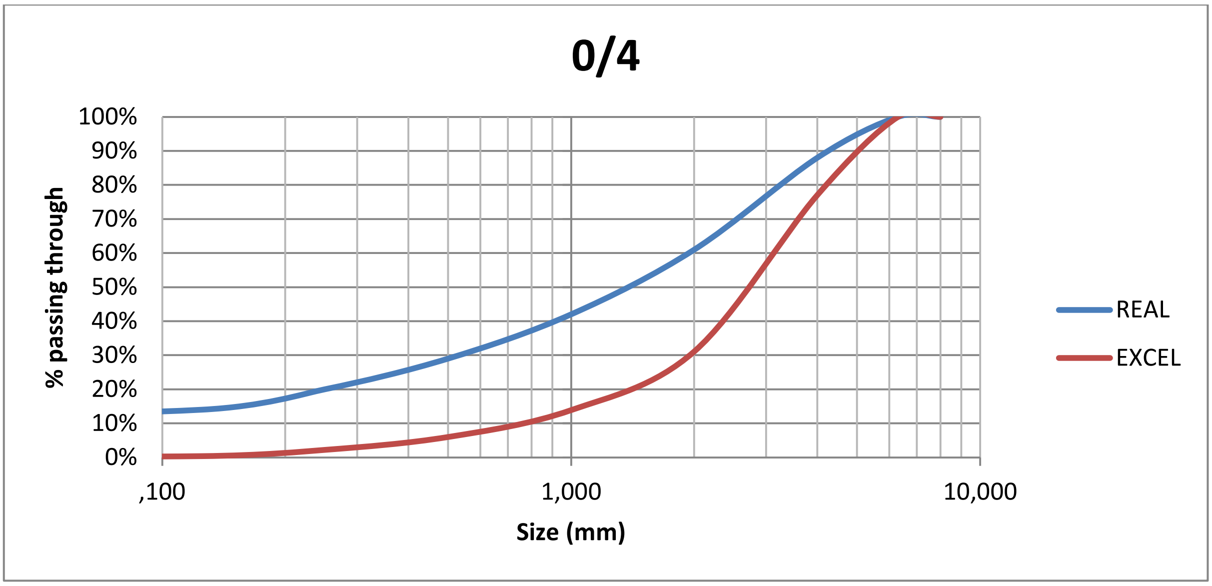
Graphic 9 Comparison of results of 12/20.



Graphic 10 Comparison of results of 8/14.



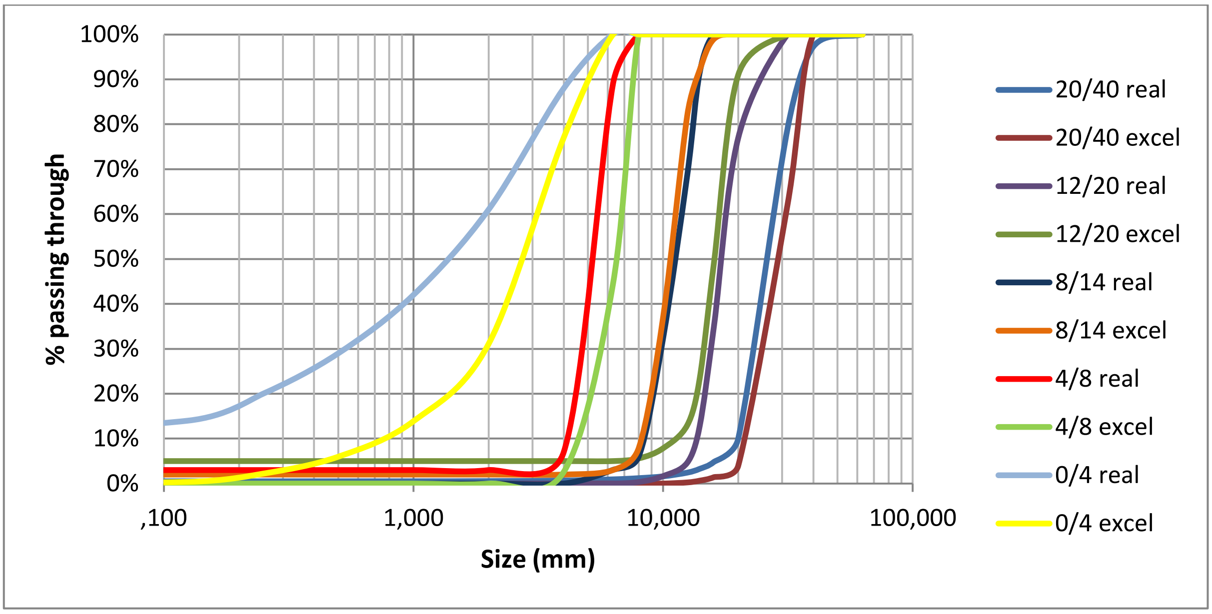
Graphic 11 Comparison of results of 4/8.



Graphic 12 Comparison of results of 0/4.

3.2. All results

Graphic 13 shows the data and granulometric for all the production curves, comparing real and excel.



Graphic 13 Comparison of all results

By looking at all comparison graphic, we can see a clearly difference in granulometries between the real typical Vila Verde product granulometric curve and the excel calculated, especially in the two lower granulometries

This can be result for the filled value in all the three crusher sheets, for the size of 0mm with a 0% of passing material, creating by a spline interpolation all the passing percentage for sizes between 0 and 20mm for primary crusher and for sizes between 0 and 1mm for secondary and tertiary crusher (as we could see in the production curves in the excel sheet), resulting in a great loss of fine grain mass information, creating excel granulometric curves with less quantity of fine grain material (dust).

Chapter V

Conclusions

1. Conclusions

- With this excel document as a calculator of the whole procedure, the user can modify the conditions of the calculator to simulate the real process that is taking place in Vila Verde.
- This calculator has its limitations, as the formula for the screen capacity is calculated for several parameters only obtainable by tables, graphics and values; this calculation to get the real efficiency has to be done manually or by an apart calculator in the last sheet.
- For each crusher, user has to adapt manually the output curve as the brochure shows. This has to be done only when modifying the CSS of the crusher.
- This tool helps to understand the way to get the exact size material desired, depending on the configuration of the whole plant. Were the final output product could be the same, may one of the configurations in crushing, screening and conveyor recirculation may not be the most efficient one.
- We can assume that this Excel document has its limitations. As it was originally planned to serve the Vila Verde quarry, no other uses can result from this document, neither in other quarries will (configuration and equipment's be different) neither the same one with other conditions (like high humidity…)
- This system is not an automatic in real time calculator of the actual process that is taking, but more as a tool to determine the output percentages and mass of crushed stone when some conditions are fixed.
- As shown in the comparison part of the results, granulometric curves are slightly different to the real data values. This difference caused by the lack of information for low granulometries in the production curves of the three crushers could be adjust by a estimation of the dust and low granulometries to get a similar curve to the actual production curves in Vila Verde.
- We can assume that objectives have been reach. For a basic estimation of production mass, the sheets can perfectly be used before real equipment's modifications. But production must determine the usage of the sheet to estimate the granulometric curves of the fine grain product, as dust and fines cannot be measured with the sheet.

Future work perspectives

As this work is concluded, further work can be done related to this project. For increasing productivity, a study of modifying the initial processing plant conditions can be made, as screening with high water content.

Also, could be interesting to relate this excel directly to a software or another excel sheet that calculates the initial granulometric curve of the blasted material.

The continuation of this project has tones of potential, to amplify the crusher options, screen types, mesh, and number of decks and conveyors, to be able to recreate any other real aggregates plant, using data from several other crushers and screens from other companies.

For a fully automatic redesign of the excel, all production curves of the crushers and the curves related to the parameters to determine screen efficiency can be created into excel data, removing images and redirecting all data input to new automatic formulas, removing all manual calculations.

Chapter VI

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Annexes

1. *Primary Crusher*

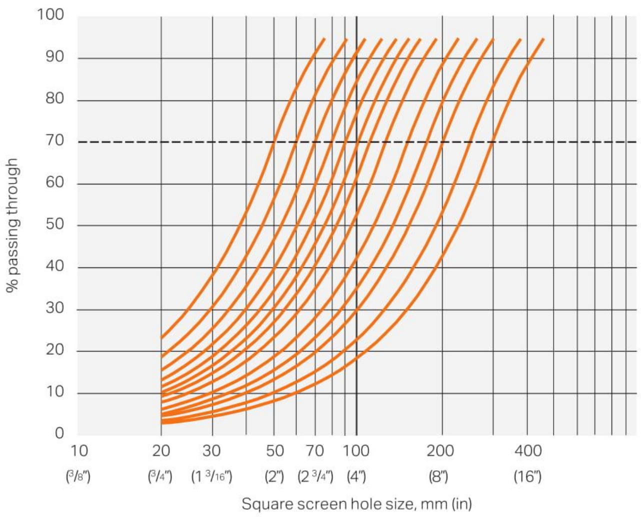
PERFORMANCE DATA

PRODUCT CURVES

The figure shows product distribution curves which are representative for medium-hard material [Impact Work Index (Wi = 16)], with approx. 70 % of the product smaller than the crusher's Closed Side Setting (CSS).

The shape of the product curve and the proportion of the product which will be smaller than the CSS depend on the characteristics of the feed material.

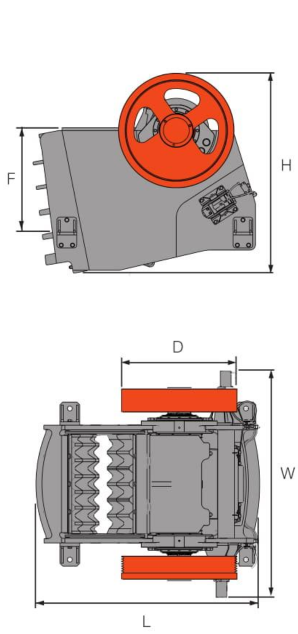
Operation with common rock materials with different crushabilities (Work Index between 12 and 20) normally results in a product curve that is between 65 %–75 % smaller than the crusher's CSS.



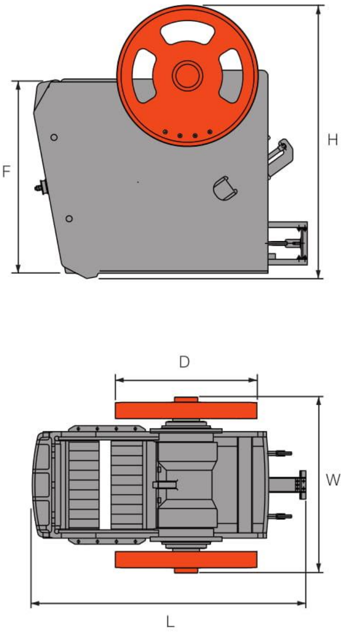
CAPACITY MTPH (STPH)

Closed side setting (CSS)		Crusher model							
mm	in	CJ211	CJ409	CJ411	CJ412	CJ612	CJ613	CJ615	CJ815
50	2		85 –1 15 (95 – 125)						
60	2	110 – 160 (115 – 165)							
75	3	127 – 192 (140 – 212)	100 – 160 (110 – 175)	150 – 200 165 – 220)	165 – 220 (180 – 245)				
100	4	160 – 250 (175 – 275)	125 – 200 (140 – 220)	200 – 265 (220 – 290)	220 – 290 (240 – 320)				
125	5	195 – 310 (215 – 340)	150 – 235 (165 – 260)	245 – 325 (270 – 360)	270 – 355 (300 – 390)	300 – 395 (330 – 435)	330 – 430 (365 – 475)	385 – 495 (425 – 545)	
150	6	230 – 370 (250 – 410)	175 – 275 (195 – 305)	295 – 390 (325 – 430)	325 – 430 (360 – 475)	355 – 465 (390 – 515)	385 – 505 (425 – 555)	445 – 590 (490 – 650)	480 – 625 (530 – 690)
175	7	265 – 430 290 – 475)	200 – 320 (220 – 350)	340 – 445 (375 – 490)	385 – 505 (425 – 555)	405 – 530 (445 – 585)	440 – 575 (485 – 635)	505 – 665 (555 – 735)	545 – 710 (600 – 785)
200	8	300 – 490 (330 – 540)		385 – 505 (425 – 555)	445 – 580 (490 – 640)	455 – 595 (500 – 655)	495 – 650 (545 – 715)	570 – 745 (630 – 820)	610 – 800 (675 – 880)
225	9			430 – 565 (475 – 625)	495 – 650 (545 – 715)	505 – 660 (555 – 730)	550 – 730 (605 – 805)	630 – 825 (695 – 910)	675 – 885 (745 – 975)
250	10				550 – 720 (605 – 795)	560 – 735 (615 – 810)	605 – 810 (670 – 895)	700 – 920 (770 – 1015)	745– 975 (820 – 1075)
275	11				605 – 790 (665 – 870)	610 – 805 (670 – 890)	660 – 885 (730 – 975)	765 – 1000 (845 – 1100)	820 – 1070 (905 – 1180)
300	12						715 – 960 (790 – 1060)	(825 – 1085) (910 – 1195)	885 – 1160 (975 – 1280)

The capacity figures given in the table above are approximate and are intended only to give an indication of what the crushers can be expected to produce. They apply for the open-circuit crushing of dry blasted granite with a bulk density of 1600 kg/m3 (100 lbs/ft3) and a maximum size which can be fed into the crushing chamber without difficulty. The lower values apply for a feed from which the material finer than the crusher's CSS has been removed. The higher values apply for a feed which includes the fine material. The minimum CSS at which the crusher can be operated depends on the feed size distribution, the material's crushability (Wi), the degree of contamination and moisture in the feed, the type of jaw plates fitted and the condition of the manganese.



CJ211



CJ400/600/800-series

OTHER DATA

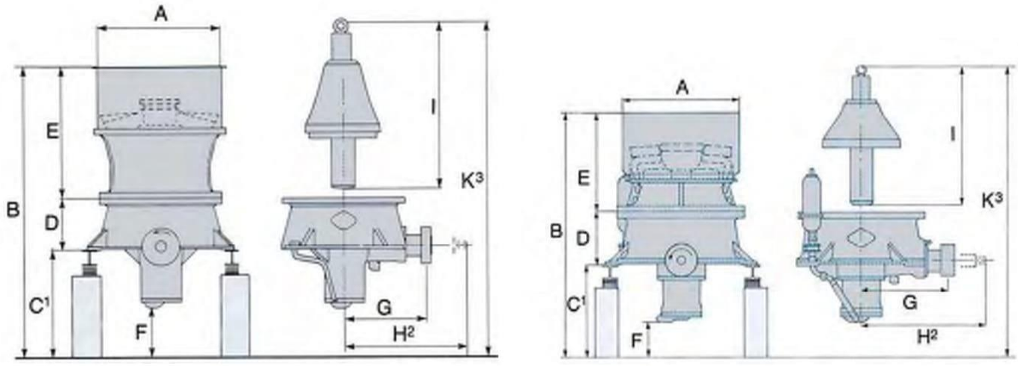
	Crusher model							
	CJ211	CJ409	CJ411	CJ412	CJ612	CJ613	CJ615	CJ815
Feed opening mm in	 1 100 × 700 43 × 27	 895 × 660 35 × 28	 1 045 × 840 41 × 33	 1 200 × 830 47 × 33	 1 200 × 1 100 47 × 43	 1 300 × 1 130 51 × 45	 1 500 × 1 070 59 × 42	 1 500 × 1 300 59 × 51
L = Max length m in	 2.39 94	 2.55 101	 2.99 118	 3.23 127	 3.61 142	 3.76 148	 4.11 161	 4.50 177
W = Max width m in	 2.45 96	 1.88 74	 2.09 82	 2.57 101	 2.35 92	 2.47 97	 3.00 118	 2.90 108
H = Max height m in	 2.17 86	 2.38 94	 2.82 111	 2.95 116	 3.51 138	 3.85 152	 3.33 131	 4.19 165
D = Flywheel diam. m in	 1.23 48	 1.60 63	 1.86 74	 1.86 74	 1.86 74	 2.17 86	 1.76 70	 2.17 86
F = Feed height m in	 1.12 44	 1.58 62	 1.88 74	 1.93 76	 2.50 98	 2.68 105	 2.39 94	 3.05 120
Shipping volume m^3 ft^3	 14.1 498	 13 447	 20 704	 23 810	 32 1127	 38 1329	 48 1690	 58 2042
CSS min–max mm in	 60–200 2.3–8	 50–175 2–7	 75–225 3–9	 75–275 3–11	 125–275 5–11	 125–300 5–12	 125–300 5–12	 150–300 6–12
Total weight kg lbs	 14 300 31 500	 13 200 29 100	 20 600 45 400	 25 800 55 600	 34 500 86 000	 41 500 91 500	 53 000 116 800	 63 500 140 000
Motor power kW hp	 90 125	 75 100	 110 150	 132 200	 160 250	 160 250	 200 275	 200 275
Crusher speed rpm	 270	 270	 240	 240	 210	 225	 200	 200

SANDVIK JAW CRUSHERS 11

Figure 41 Primary brusher brochure (Taken from https://www.rocktechnology.sandvik/en/products/stationary-crushers-and-screens/stationary-jaw-crushers/cj612-jaw-crusher/).

2. Secondary and Tertiary Crushers

Dimensions, mm



Note: Reference line (not floor level) giving minimal dimensions for removal of: 1. Hydroset cylinder, 2. Pinion shaft, 3. Main shaft

Dim.	CS420	CS430	CS440	CS660	CH420	CH430	CH440	CH660	CH870	CH880
A	Ø 1285	Ø 1635	Ø 2000	Ø 2800	Ø 1078	Ø 1360	Ø 1540	Ø 2104	Ø 2450	Ø 2660
B	2902	3485	4075	5100	2560	2992	3410	4215	5475	6456
C[1]	1020	1125	1300	1600	1020	1125	1300	1600	2200	2870
D	540	655	745	860	540	655	745	860	1228	1186
E	1342	1705	2030	2640	1000	1212	1365	1755	2045	2400
F	400	422	452	631	400	422	452	631	998	1151
G	843	1061	1280	1497	843	1061	1280	1497	1824	2073
H[2]	1270	1705	1900	2156	1270	1705	1900	2156	2850	3100
I	1703	2050	2420	2895	1425	1688	1985	2344	3095	3545
K[3]	3600	4250	4930	5355	3000	3570	4000	4835	6600	7770

Dimensions are intended only as a guide for preliminary planning of the installation and should not be used for the construction of foundations, etc.

Approximate Weights, kg

	CS420	CS430	CS440	CS660	CH420	CH430	CH440	CH660	CH870	CH880
Heaviest lift during maintenance	2300	5100	8100	16500*	1400**	2900**	4700**	7800**	13000**	22000**
Total weight	6800	12000	19300	35700	5300**	9200**	14300**	24200**	50000**	70000**

* 16500 kg = topshell assembly + spider assembly. 9700 kg = topshell assembly only.

** Applies to crusher with fine crushing chamber. With coarse crushing chamber, these weights are reduced by approximately 380 kg for the CH430, by 600 kg for the CH440, by 600 kg for the CH660, by 600 kg for the CH870 and by 3800 kg for the CH880 model.

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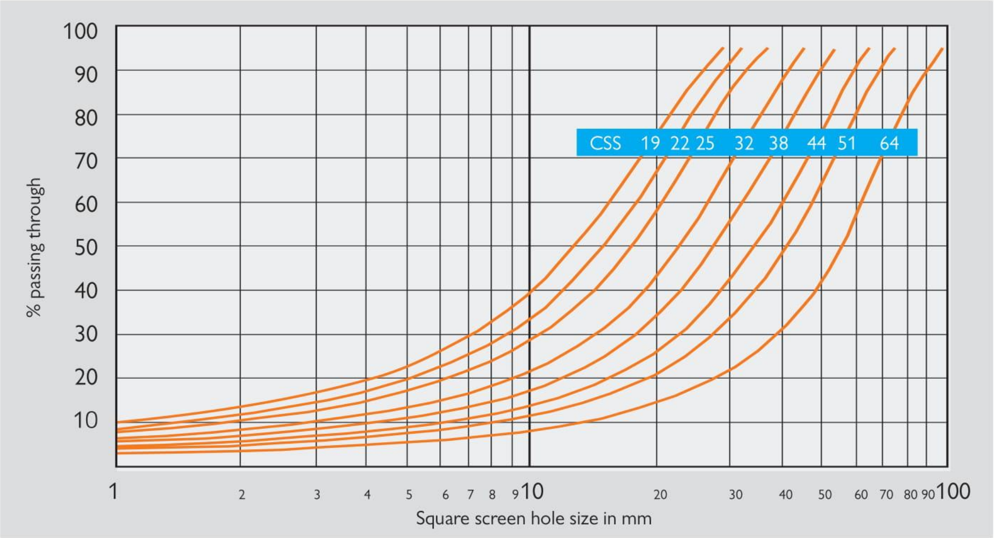
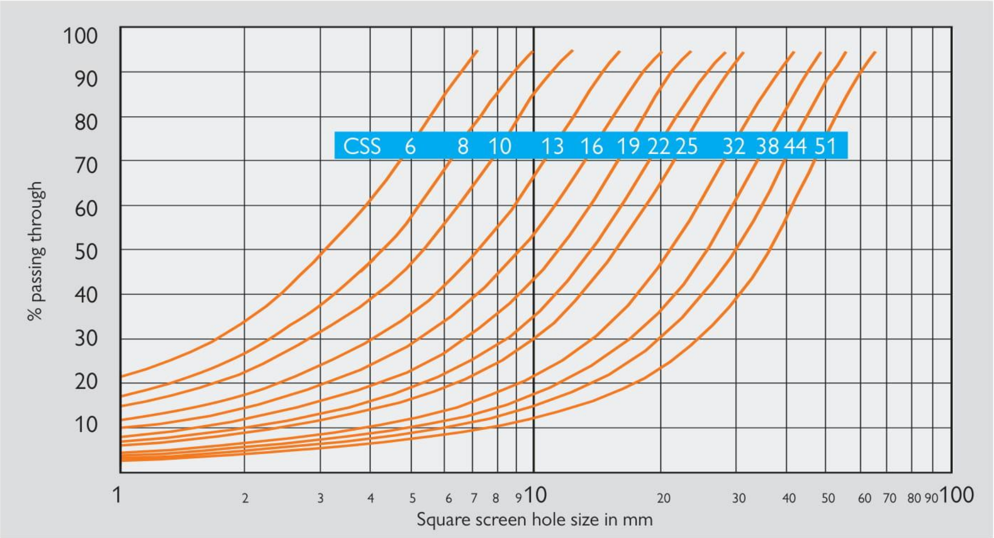
Product Curves

The product curve and the percentage of the crusher product that is smaller than the closed side setting (square hole, mm) is dependant on the crushability (W_i) of the material, the size distribution of the feed and other factors.

CS-crushers



CH-crushers



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Crushing Chambers

CS-crushers

Three standard crushing chambers are available:

MC = Medium Coarse
C = Coarse
EC = Extra coarse

CH-crushers

Several standard crushing chambers are available:

EEF = Extra Extra Fine
EF = Extra Fine
EFX = Extra Fine Xtra
F = Fine
MF = Medium Fine
M = Medium
MC = Medium Coarse
C = Coarse
CX = Coarse Xtra
EC = Extra Coarse

Capacity, MTPH

Performance figures are approximate and give an indication of what the crusher can produce.

They apply to open circuit crushing of dry material with a bulk density of 1600 kg/m^3. It is assumed that material much finer than the crusher's closed side setting (CSS) is removed from the feed.

Consult us regarding the application of the crusher since the chosen eccentric throw, degree of reduction, the material´s crushability (W_i), the size analysis of the feed, the design of any recrushing circuit and the moisture content in the feed all affect performance of the crusher.

CS-crushers

	Max motorsize kW		Max feed size mm	19	22	25
CS420	90	EC	240		85	92-115
		C	200	70	76-95	82-128
CS430	132	EC	360			126
		C	300		108	116-145
		MC	235	91	98-123	106-166
CS440	220	EC	450			
		C	400			
		MC	300			195
CS660	315	EC	560			
		C	500			

CH-crushers

	Max motorsize kW		Max feed size mm	4	6	8
CH420	90	EC	135			
		C	90			
		M	65			36-44
		MF	50		36	38-67
		F	38	27-34	29-50	31-54
		EF	29			
CH430	132	EC	185			
		C	145			
		MC	115			
		M	90			
		MF	75			61
		F	50		48-78	51-83
		EF	35			
CH440	220	EC	215			
		C	175			
		MC	140			
		M	110			
		MF	85			
		F	70			90-135
		EF	38			
CH660	315	EC	275			
		CX	245			
		C	215			
		MC	175			
		M	135			
		MF	115			
		F	85			
		EF	65			
CH870	520	EC	300			
		C	240			
		MC	195			
		M	155			
		MF	100			
		F	90			
		EF	80			
CH880	600	EC	370			
		C	330			
		MC	260			
		M	195			
		MF	130			
		F	120			
		EFX	100			
		EF	85			
		EEF	75			309-356

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Figure 42 Secondary and tertiary crusher brochures (Taken from https://www.rocktechnology.sandvik/en/products/stationary-crushers-and-screens/stationary-cone-crushers/cs430-cone-crusher/ and https://www.rocktechnology.sandvik/en/products/stationary-crushers-and-screens/stationary-cone-crushers/ch440-cone-crusher/).