The shape factor of quarry rock

Reassessment of the value and study into parameters of influence

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Preface

This document is written in fulfilment of my master program in the field of hydraulic engineering at Delft University of technology. It reports on the research project I performed on the value and variability of the shape factor of quarry rock. With this research I hope to have enhanced the available theoretical knowledge for the practical application of this particular parameter.

Foremost I am grateful to Delft University of Technology for providing me with state of the art knowledge throughout both the bachelor and master programs. Also I am grateful to Van Oord Offshore for facilitating my research project at their offices in Gorinchem as well as outside in IJmuiden, the Netherlands and in Sløvag, Norway.

I would like to acknowledge the members of my exam committee; Marcel Stive, Dominique Ngan-Tillard, Cor-Jan Stam and in particular Henk Jan Verhagen, for supervising me. I highly appreciate the time you all have invested in me. I would also like to thank Jan Vlak and Bert van Dulmen for actually organizing the fruitful cooperation of Delft University of Technology and Van Oord Offshore. Of course also a big thank you to Harro Vaags for making me feel at home at Van Oord Offshore and sharing your extensive practical knowledge on quarry rock with me.

Also I thank my friends and fellow students and all the others that made my time as a student in Delft a wonderful period of my life. In particular I thank Margot Lassche for the valuable exchange of thoughts on my research project, the many motivational advices and for actually being there for me.

Finally I would like to thank my parents. I warmly appreciate the unconditional support you gave me throughout my entire life. I doubt if I would have made it an engineer without your encouragement. Thank you mom, thank you dad.

Dennis Witteman

Gorinchem, March 2015

Summary

In the field of hydraulic engineering **quarry rock** is a frequently applied construction material. For example breakwaters, bed bank and shore protections and subsea pipeline covers often contain quarry rock. The main reason is its unique stability capacities in environments of high hydrodynamic activity. Furthermore, quarry rock is produced and handled relatively easily and is available at numerous locations across the globe.

The **shape factor** of quarry rock is derived from equation [1].

$$m = F_s \cdot \rho \cdot d^3 \quad [1]$$

Here m denotes the rock mass [kg], F_s is the shape factor of quarry rock [-] in a primitive form, ρ the rock density [kg/m³] and d the rock diameter [m]. For d, the **sieve diameter** [m] is used. The sieve diameter of rock is defined as the mesh width of the smallest square sieve the rock is able to pass. By introduction of F_s^*, the cubic root of F_s, equation [1] can be rewritten in equation [2].

$$F_s^* = \sqrt[3]{\frac{m}{\rho}}/d = \sqrt[3]{V}/d = \frac{d_n}{d} \quad [2]$$

The cubic root of the volume of the rock [m³], denoted by V, is referred to as the **nominal diameter** [m] of rock, denoted d_n. It is concluded that the value of the shape factor in its commonly applied form F_s^*, is equivalent to the ratio of the nominal diameter and sieve diameter of rock. In hydraulic engineering practice both rock diameters are applied in various phases of the realisation process of granular hydraulic structures. The overlap of these phases requires the ability to convert the nominal diameter into the sieve diameter and vice versa. As a result, the value of the shape factor is indispensable for the realization of granular structures in hydraulic engineering.

Note that in equation [2] the definition of the shape factor is based on one individual rock. Quarry rock however consists of a large number of individual rocks occurring in a practical infinite variety of rock sizes and shapes. As a result quarry rock is typically graded. The **grading** of rock is usually characterized by rock diameters associated with specific cumulative mass percentage exceedance limits. Among these diameters the **median** nominal diameter d_{n50} [m] and median sieve diameter d_{50} [m] are the most frequently applied ones, since they yield insight in a mean diameter value which one can expect in the grading. Provided that the individual rocks have been ranked in order of increasing mass, the median nominal diameter value represents the nominal diameter of the rock that accumulates fifty percent of the mass of the grading. The median sieve diameter is the sieve diameter that should be applied to separate fifty percent of the mass of a rock sample by sieving. For quarry rock gradings, the shape factor F_s^* is defined by the ratio of the median nominal diameter and median sieve diameter, denoted d_{n50}/d_{50}.

The earliest documentation found on the value of the shape factor of quarry rock is a report by Van Bendegom (1967). For the shape of rock Van Bendegom assumed a sphere, which is in equation [2] represented by a volume of $\pi/6 \cdot d^3$. Here d denotes the diameter [m] of the sphere. This approach yields a shape factor value of approximately 0.81. In the 1980's the value of the shape factor was examined in more detail by Laan. In one of his reports (1981) by conducting experiments Laan determined the value of the shape factor to be **0.84**. Unfortunately, Laan passed away and the concerned report is missing from the libraries. Despite the resulting lack of theoretical background the value of 0.84 is still widely applied in hydraulic engineering practice, as is recommended by - amongst other literature - the Rock Manual (2007).

In this report the value as well as the variability of the shape factor is reassessed. Moreover, the dependency of the shape factor on both **elongation** and **blockiness** - two parameters to describe the shape of a rock - is examined. In order to do so, on multiple rock samples a series of experiments has been performed, viz.:

- Weighing of individual rock masses within the samples in order to determine nominal diameters and sieve fraction masses.
- Density tests in order to determine rock densities and eventually nominal diameters.
- Sieve tests in order to determine sieve diameters.
- Shape tests in order to determine elongation and blockiness.

The rock samples were extracted from five rock gradings with the following commercial names: 22-90 mm, 2-5 inch, 2-8 inch, consisting of Gneiss rock and 1-5 inch, 5+ inch, consisting of a Basalt-Gneiss/Granite rock mixture. In total 21 rock samples were taken, each consisting of 200-250 rocks. In accordance with the euro code regulations NEN-EN 13383-2 (2013) for sieve tests. Based on statistical analyses on the acquired dataset, the following conclusions have been drawn:

- Rock samples consisting of 200-250 rocks yield insufficiently reliable values for the shape factor of quarry rock. For rock samples consisting of approximately 1000 rocks sufficiently accurate values are found.
- Based on the results of the 21 samples, the shape factor for quarry rock gradings is approximated reasonably well by means of a Gaussian distribution. The average value and standard deviation are 0.86 and 0.024 respectively.
- The value of the shape factor is not constant within a grading. For an increase of rock size, the value of the shape factor decreases. The relation is approximated by F_s^*=-0.00075*CMP+0.898. Where CMP is the cumulative mass percentage [%].
- Based on the tested gradings no relations can be distinguished between the value of the shape factor and either the average elongation in the grading or the percentage of high-elongated rock in the grading. For blockiness the same holds.
- On average, the value of the shape factor for individual rocks weakly increases for an increase of elongation. This relation is described by means of the formula: F_s^*=0.012*LT+0.814. The value of the individual shape factor however fluctuates too extensively over elongation to be estimated by means of this relation.
- On average, the value of the shape factor for individual rocks weakly increases for an increase of blockiness. This relation is described by means of the formula: F_s^*=0.0052*BLC+0.609. The value of the individual shape factor however fluctuates too extensively over blockiness to be estimated by means of this relation.

- Based on 969 rocks, the individual shape factor is approximated reasonably well by means of a Gaussian distribution. The average value and standard deviation are 0.84 and 0.083 respectively.
- For rather elongated and/or blocky rock, the individual shape factor may exceed the value of 1.0.
- Dependency of the shape factor on either coarseness or the width of a grading has not been clearly distinguished.

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It is concluded that the reassessed value of the shape factor 0.86 differs relatively little from the commonly applied value of 0.84. Nonetheless it is recommended to apply the newly derived value ***0.86*** *in hydraulic engineering practice. The main reason is the theoretical justification provided in the present report.*

To a greater or lesser extent, the value of the shape factor has been related to parameters that describe quarry rock. In general however, the influences are considered relatively small. The resulting variability of the shape factor value is rather well accounted for by means of the representation of the shape factor value by a Gaussian distribution, based on an average value and standard deviation of 0.86 and 0.024 respectively.

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According to the test results, no firm conclusions can be drawn for the shape factor of significantly finer or coarser gradings compared to the tested gradings. Subsequent research into this particular subject is recommended, especially for very coarse uncrushed gradings. In order to do so, despite nearly impracticable, the determination of nominal diameters is inevitable. Furthermore, for the tested gradings, the influence of elongation and blockiness on the value of the shape factor is not clearly distinguished. For gradings consisting of a significantly higher percentage of relatively elongated or blocky rock, a significant increase of the shape factor value can be expected. It is therefore recommended to examine the value of the shape factor for such gradings.
In case it is decided to perform subsequent research, it is recommended to consider the potential of remote sensing techniques to three-dimensionally observe rock shapes. Moreover, various other parameters that describe rock, such as the volume and the sieve diameter can be analysed integrally. It is assumed that by means of remote sensing techniques the accuracy and efficiency of the measurements can be significantly enhanced.

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Appendices

1 Introduction

This introductory chapter is intended to provide general background information on the shape factor of quarry rock. Firstly, the motivation of the present research project is clarified by the discussion on the concept of the shape factor and its importance in hydraulic engineering. Subsequently, the goal and research questions of the project are provided, followed by the methodology that is applied to achieve this goal and to answer these research questions. The chapter concludes with an outline of the report structure. For readers already familiar with the general background of the shape factor it is recommended to skip the present chapter.

1.1 Background

Information on the application of quarry rock in hydraulic engineering is given in paragraph 1.1.1. The general concept of the design of hydraulic structures composed of quarry rock is discussed in paragraph 1.1.2. Subsequently, in paragraph 1.1.3 the shape factor of quarry rock is introduced and its definition is derived. Thereafter, an overview of the current state of the knowledge on the value of the shape factor is given in paragraph 1.1.4. The importance of the value of the shape factor in terms of its influence on the design and resulting performance of the structure is discussed in paragraph 1.1.5.

1.1.1 Application of quarry rock in hydraulic engineering

In the field of hydraulic engineering quarry rock is a frequently applied construction material. Examples of structures composed of quarried rock - or granular structures - in hydraulic engineering are, amongst others: breakwaters; bed, bank, and shoreline protections and pipeline covers. Quarry rock is highly available at a vast amount of locations across the globe and is relatively easy to produce and handle. Furthermore, the material is practically free of maintenance. Presumably the most important reason for the frequent application of quarry rock however, is its unique behaviour in terms of strength and stability in environments of high hydrodynamic activity.

1.1.2 The design of granular hydraulic structures

Stability plays a vital role in the design of granular hydraulic structures. In order to be able to fulfil its function, for the structure it is required to maintain its position and configuration. Stability of the structure is usually resolved through application of dedicated design formulae which are based on a balance of forces exerted on the quarry rock. In these formulae the gravity of rock is the most important stabilizing force[1]. According to Newton's second law of motion gravity is defined by the product of mass and gravitational acceleration. Since gravitational acceleration is practically constant across the earths (sub-sea) surface, only mass can be freely chosen to attain sufficient gravitation and thus stability. As a result, the aforementioned design formulae generally yield the rock mass required to assure a predefined level of stability. For practical reasons however, often rock mass is expressed by means of the product of density and volume. As a result these parameters are introduced as the most important design parameters for granular hydraulic structures.

[1] Interlocking and slope angle are other important stabilizing features regarding granular structures.

1.1.3 Introduction of the shape factor

The volume of a geometrically perfect shape is generally calculated by means of the product of a certain shape specific dimension to the third power and a certain shape specific factor. Consider for example a perfectly spherical shape. The volume [m³] is calculated through application of equation [3].

$$V_{sphere} = \frac{\pi}{6} d^3 \quad [3]$$

Where *d* is the diameter [m] of the sphere, its shape specific dimension. The term π/6 [-] is the shape-specific shape factor of the sphere. Quarry rock however does not consist of geometrically perfect shapes. Instead, rock volumes occur in a practically infinite variety of shapes. As a result no trivial shape specific dimension is available. This problem has been overcome by application of the sieve diameter as an approximation of the shape specific dimension in the calculation of rock volumes. The sieve diameter of rock is defined as the mesh width of the smallest square sieve that the rock is able to pass. The value of the shape factor of rock in this approach however remains unknown. Concerning the above, equation [4] is obtained to calculate the volume of quarry rock.

$$V_{rock} = F_s \cdot d_s^3 \quad [4]$$

Where d_s is the sieve diameter [m] of a rock, and F_s the shape factor [-] of quarry rock (in a primitive form). In order to assess the value of the shape factor of quarry rock equation [4] is rewritten in equation [5].

$$d_n^3 = F_s \cdot d_s^3 \quad [5]$$

Where d_n is the nominal diameter [m] of rock, defined by the cubic root of the rock volume. Subsequently, by introduction of the shape factor F_s^*, equal to $F_s^{1/3}$, equation [5] can be rewritten in equation [6] which ultimately yields the definition of the shape factor of quarry rock.

$$F_s^* = \frac{d_n}{d_s} \quad [6]$$

It is concluded that the shape factor of quarry rock [-] in its commonly applied form, denoted F_s^* is defined as the ratio of the nominal diameter d_n [m] and sieve diameter d_s [m] respectively. This specific definition is applied to assess the value of the shape factor.

1.1.4 The value of the shape factor

In literature hardly any information is available on the theoretical background of the shape factor. The oldest document found which discusses the parameter is by Van Bendegom (Algemene waterbouwkunde, deel IIa, de natuur, 1967). In this report an expression for rock mass as a function of the density and diameter in the form of equation [7] is presented.

$$m = F_s \cdot \rho \cdot d^3 \quad [7]$$

Where *m* denotes the rock mass [kg], F_s denotes the shape factor [-] in its primitive form and *d* denotes 'the rock diameter' [m]. Van Bendegom estimated the value of F_s under assumption of perfectly spherical shaped rock. In paragraph 1.1.3 it has been already shown that this results in a value of π/6 - approximately 0.524 - for the shape factor in its primitive form. Van Bendegom corrected for the fact that quarry rock does not consist of geometrically perfect spherical shapes by decreasing the value of the primitive shape factor from 0.524 to 0.5. By the cubic root of 0.5, a first estimate for the value of the shape factor in its commonly applied form is found; F_s^* approximately is 0.79. The prefix 'commonly applied' in the parameter name of F_s^* is omitted in the rest of the report.
Later in time, a researcher named Laan performed further research into the value of the shape factor for quarry rock. In one of his reports, Laan (1981), the value of the shape factor was determined based on experiments on relatively fine gradings. For the primitive shape factor a value of 0.6 was found, which - by the cubic root - yields an approximate value of 0.84 for the value of the shape factor. Unfortunately however, Laan passed away and the concerned report is missing from the libraries. Despite the resulting lack of theoretical background for the value of 0.84, by numerous literature - for instance the Rock Manual (2007) - it is still recommended to apply this value in hydraulic engineering practice.

1.1.5 Importance of the value of the shape factor

The shape factor is frequently applied throughout hydraulic engineering in numerous ways. For instance, the parameter occurs in many rock stability formulae and is applied to convert nominal diameters into sieve diameters and vice versa. The resulting influence on the design of granular hydraulic structures therefore is vital.
An example is the determination of rock gradings to be applied in granular hydraulic structures through physical model tests. Nowadays the value of 0.84 is assumed applicable to all rock gradings. However, it is believed that this value is not constant and fluctuates over rock size. If so, the determination of a rock grading to be applied in a structure based on model tests requires revision.
Another example is the uniform application of the shape factor over elongation and blockiness of rock. In appendix [E] however, from a theoretical point of view it is suggested that the value of the shape factor is dependent on the elongation and blockiness of quarry rock.

Furthermore, the value of the shape factor has its influence on the performance of a granular hydraulic structure, which is eventually reflected by the costs of a project. Consider for example the application of the Van der Meer formulae. An underestimation of the value of the shape factor may have as a result that the required rock size to be applied in the structure is overestimated. Since the price of rock in general increases for an increase of rock size, the structure is more expensive than strictly required.

At the other hand, an overestimation of the value of the shape factor may have as a result that the required rock size is underestimated. As a consequence the structure could turn out to be unstable and as a result damage may occur. Repair of (submerged) granular hydraulic structures usually is relatively expensive and therefore undesired. It is concluded that dependent on the specific application of the shape factor either an increase or decrease of the value of the shape factor may appear desirable.

1.2 Research goal and methodology

The main goal of this report is to enhance the theoretical background for the practical application of the shape factor. The core focus therefore is to reassess the value of the shape factor and obtain insight in its possible variability. Moreover, the dependency of the shape factor on a variety of parameters is examined, viz.: elongation, blockiness, coarseness and grading width. In order to be able to successfully meet the above defined goal, a research methodology has been developed. In chronological order the approach consists of: performing a literature study, acquiring a dataset, analysing the data and finally, interpreting the obtained results.

A literature study has been performed in order to create a theoretical starting point for the research on the shape factor. Moreover, this study has yielded an inventory of parameters that are expected to influence the value of the shape factor. Furthermore, the general background and current state of the knowledge on the shape factor, which have been already discussed in the previous section, have been studied. The assessment of the value and variability of the shape factor is based on research data, which is acquired in two measurement campaigns. In order to do so, a series of experiments has been performed on multiple rock samples of various gradings. Those consisted of; sieve tests, density tests, shape tests and weighing. On the acquired datasets statistical analyses have been performed that provide insight in the value and variability of the value of the shape factor as well as the parameters that describe rock. Thereafter, these results have been interpreted in order to discern, describe and quantify possible relations between the value of the shape factor and the rock describing parameters. The research methodology is visualized by means of a flow chart that can be found in appendix [H].

1.3 Report Structure

Generally, the report structure follows the research methodology described in section 1.2. In chapter 2 an overview is given of the relevant theory and the most important definitions required to describe rock and to calculate the shape factor. As the chapter provides references to comprehend the further process, it can be considered as the theoretical starting point of the research project and. In Chapter 3 information on the experiments is given. The tests performed are briefly introduced, the tested gradings are listed and the sampling techniques are discussed. Chapter 4 contains the results of the experiments. These are based on calculations on the raw data acquired in these experiments. The data and the calculations can be found in appendices [C] and [D] respectively. In chapter 5 these results are interpreted, resulting in an elaboration upon the dependencies of the value of the shape factor on a set of rock describing parameters. In chapter 6 the application of the newly obtained insights in hydraulic engineering practice are reconsidered. Ultimately, the conclusions of the research project and recommendations for subsequent research are presented in chapter 7 and 8 respectively.

For readers already familiar with the general theory of the shape factor it is recommended to skip chapter 2.

2 Theory and definitions

The information provided in this chapter can be considered as the theoretical fundament for the present research project. Throughout the report this chapter can be used as a reference for theoretical background and parameter definitions. For readers already familiar with the theory and definitions concerning the shape factor it is recommended to skip this chapter.

2.1 Median diameter values

In chapter 1 the definition of the shape factor has been derived as the ratio of the nominal diameter and sieve diameter of an individual rock. Since quarry rock is usually applied in bulk quantities it is illogical to address the shape factor to one individual rock. Furthermore, in paragraph 1.1.3 it has been discussed already that rock does not consist of geometrically perfect volumes. In contrary, a practically infinite variety of rock shapes and sizes is found in quarry rock. As a result the material is typically graded. For rock gradings the definition of the shape factor is extended; the shape factor of quarry rock is defined as the ratio of the so-called **median nominal diameter** and **median sieve diameter**. By means of the application of those median diameters the representativeness of the shape factor for a grading is enhanced.

2.1.1 Median nominal diameter

Recall that the nominal diameter is defined as the cubic root of the volume of an individual rock. Provided that the rocks are ranked in order of increasing mass, the median nominal diameter [m], parameterized by d_{n50}, is defined as the cubic root of the volume of the particular rock in the grading[2] which accumulates **50 percent of the mass**. It is concluded that the individual rock masses and (average) density of the rock are required in order to assess the value of the median nominal diameter. Plotting the values of the nominal diameters versus the associated cumulative mass percentages results in a so-called nominal diameter curve. Please consult appendix [D] for more detailed information on these nominal diameter curves.

2.1.2 Median sieve diameter

Recall that the sieve diameter of a rock is defined as the mesh width of the smallest square sieve that an individual rock is able to pass. The median sieve diameter [m], parameterized by d_{50}, is defined as the mesh width of the square sieve which **50 percent of the mass** of a rock grading[4] is able to pass. The value of this parameter is determined by means of a sieve test. Plotting the mesh width dimensions of the applied sieves versus the associated passing cumulative mass percentages results in a so-called sieve curve. Please consult paragraph 3.1.3 and appendix [D] for more detailed information on sieve tests.

\- *Intermezzo* -

The nominal diameter can be interpreted as an expression of rock mass in terms of dimension. The parameter has a purely theoretical character which is contributory to design formulae.

In both parameter names the use of the term median is confusing. It does not refer to the parameter applied in statistics that indicates the middle item in a sequence of items that are put in order of increasing value. Instead, it refers to 50 percent cumulative mass of a sample.

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[2] Since analyzing all rock in a grading is practically unfeasible, usually a representative sample is extracted and analyzed. More details on sampling can be found in section 3.3.

2.2 Individual shape factor

In the previous section it has been explained that the value of the shape factor for quarry rock is derived on basis of median values for the nominal diameter and sieve diameter. Nonetheless the application of the shape factor for individual rocks remains useful in examining the expected influences of for example elongation and blockiness on the value of the shape factor for gradings.

Recall that the definition of the shape factor of an individual rock - or individual shape factor - is given by the ratio of the nominal diameter and sieve diameter of a single rock. It has been explained that in order to determine the nominal diameter of each individual rock, only the individual rock masses and the average rock density are required. In order to determine the sieve diameter of the individual rocks however, a practically infinite amount of sieves is required. This approach is considered practically unfeasible. By application of the dimensions of the smallest enclosing box *X*, *Y* and *Z*, obtained in the shape tests this problem is resolved. Please consult paragraphs 2.4.2 and 3.1.4 for detailed information on those dimensions.

It has been assumed that for each individual rock the maximum dimension *X* does not determine whether or not a rock is able to pass a specific sieve. Only the remaining dimensions *Y* and *Z*, orientated perpendicular to the dimension *X*, determine whether or not a particular rock is able to pass a specific sieve. The dimensions X,Y and Z thus can be applied to determine the sieve diameter vice versa. This approach, referred to as virtual sieving is elaborated upon in appendix [E].

By means of 'virtual sieving', elaborated upon in appendix [E], these dimensions are applied vice versa to determine the sieve diameter of an individual rock. By Verhagen (2014), equation [8] has been developed in order to recalculate the so-called virtual sieve diameters [m], denoted d_{sv} based on of *X*, *Y* and *Z*.

$$d_{sv} = \frac{Y}{1 + 0.45 \cdot \left(1 - \frac{Z}{Y}\right)} \qquad [8]$$

For each individual rock that has been examined in the shape tests, the value of the individual shape factor is defined by the ratio of the nominal diameter and the virtual sieve diameter.

2.3 Grading specifications

Due to the natural resource and whimsical breaking in the production process, quarry rock is highly irregular in both size and shape. As a result quarry rock is typically graded. The grading of quarry rock is an important property since it enhances both stability and filtering capacities of a granular structure. In other words insight in the distribution of rock sizes within a grading is vital for the design and performance of granular hydraulic structures.

The in section 2.1 introduced parameters, median nominal diameter and median sieve diameter, basically represent a mean rock size one can expected in a grading. Insight in the diameter values of the relatively small and relatively large rocks within a grading is yielded through introduction of comparable parameters. In order to do so, specific diameters associated with certain cumulative mass exceedance percentages are applied, similar to the indication of the median nominal and median sieve diameter. The 5 and 15 cumulative mass percentages are often applied to represent the diameter of the relatively small sized rocks within a grading. Respectively, the 85, 90 and 98 cumulative mass percentages are often applied to represent the diameter of the relatively large sized rocks within a grading.

2.3.1 Coarseness

According to the Rock Manual (2007) three main classes for the coarseness of a grading are distinguished, viz.:

- Heavy: roughly 300 plus kg rocks[3].
- Light: roughly 5-300 kg rocks[3].
- Coarse: roughly 45-250 mm rocks[3].

This report focusses mainly on the shape factor of coarse gradings. In this report the median nominal diameter d_{n50} [m] is applied to indicate the coarseness of the tested gradings.

2.3.2 Width

According to the Rock Manual (2007) the width of a grading is defined by the ratio d_{85}/d_{15} [-]. This value yields insight in the relative proportion of large sized and small sized material.

- narrow: $d_{85}/d_{15} < 1.5$ also called single sized or narrow gradings.
- wide: $1.5 \leq d_{85}/d_{15} < 2.5$
- very wide: $2.5 \leq d_{85}/d_{15}$ also called quarry run grading.

2.4 Rock shape

The shape of rock is presumed to influence the value of the shape factor for quarry rock. In order to illustrate this hypothesis, consider two rocks of equal sieve diameter. However, the shape of the two rocks significantly differs; rock A is significantly more elongated and blocky than rock B. As a result rock A has a larger volume than rock B. As a consequence the nominal diameter of rock A is larger than the nominal diameter of rock B. However, it was given that both rocks were of equal sieve diameter. As a consequence rock A has a larger shape factor value than rock B. In appendix [E] this approach is elaborated upon in more detail based on geometrically perfect extreme shapes. The parameters elongation and blockiness are briefly discussed in paragraphs 2.4.1 and 2.4.2. The shape tests to determine elongation and blockiness are elaborated upon in paragraph 3.1.4.

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[3] Note that the heavy and light coarseness classes are defined by mass, as sieving is practically impossible for these rocks. In contrary, coarse grading classes are defined by dimension, as weighing is practically impossible for these rocks.

2.4.1 Elongation

The shape of rock is often described by the ratio of its length and thickness, which is referred to as the length-to-thickness ratio, aspect ratio or elongation of rock, denoted *LT*. According to the Rock Manual (2007) elongation is defined as '*the maximum length, L [m], divided by the minimum distance, d [m], between parallel lines through which the particle would just pass.*' In this report, the symbol *d* is replaced by *T* to prevent confusion with the sieve diameter already parameterized *d* [m]. *T* logically refers to the expression 'thickness' of the rock. Please consult Figure 2-1 for clarification. The tool - a calliper - to measure the length and thickness is depicted in paragraph 3.1.4.

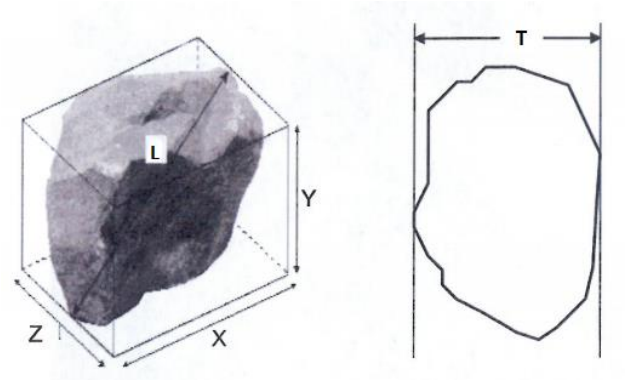

Figure 2-1 - definition of elongation, courtesy Rock Manual (2007)

2.4.2 Blockiness

Besides elongation also blockiness, denoted *BLC*, is used as a parameter to describe the shape of rock. According to the Rock Manual (2007) blockiness is defined as '*the volume of a rock divided by the volume of the enclosing XYZ orthogonal box with a minimum volume*'. In this report blockiness is expressed by a percentage value. Blockiness is also referred to as compactness or rectanguloidness. In equation [9] the formula to calculate blockiness is given:

$$BLC = \left(\frac{m}{\rho} * \frac{1}{X * Y * Z}\right) * 100 \qquad [9]$$

In this equation *BLC* denotes blockiness in [%], *m* is the mass of the rock in [kg] and ρ the density of the rock in [kg/m³]. *X*, *Y* and *Z* represent the orthogonal dimensions of the smallest enclosing box, as can be consulted in Figure 2-2; rocks of decreasing blockiness are depicted from left to right; 80, 60 and 40%. The tool to measure the dimensions the smallest enclosing box - a blockiness-meter - is depicted in paragraph 3.1.4.

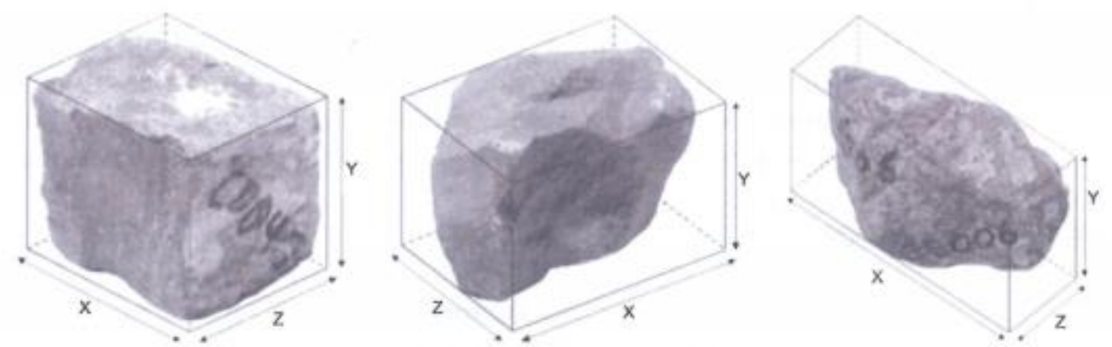

Figure 2-2 - definition of blockiness, f.l.t.r.: 80%, 60% and 40%, courtesy Rock Manual (2007)

2.4.3 Roundness

A third parameter to describe the shape of rock is roundness. In the Rock Manual (2007) several methods to assess the roundness of rock are introduced. These methods do have in common that they are based on the visual comparison of the rock shape with a given set of figures representing roundness categories. It is stressed that as a consequence of the visual character of the comparison method, the assessment of roundness is rather arbitrary, inaccurate and therefore unreliable. As a result roundness is seldom applied to describe rock shape.

2.5 Rock density

Nominal diameters are calculated by means of the cubic root of rock volumes. Due to a practically infinite variety of rock shapes however, the rock volumes are not easily determined. By application of the definition of rock volume as the ratio of rock mass and density this difficulty is overcome. It is concluded that rock density is an indispensable parameter for a practical determination of nominal diameters.

Depending on the specific application, various definitions for rock density are given in literature. In this report, for rock density the ratio of the mass and volume[4] of a rock, referred to as apparent mass density, Rock Manual (2007) is applied. The volume of rock is measured by submersion of the rock into water and application of the Archimedes principle as is discussed in more detail in paragraph 3.1.3. The mass is determined simply by weighing the surface dried rock. Note that some water may be present in the pores. For the determination of rock density only rock passing the 125 mm sieve and retained on the 63 mm sieve have been considered. For those rocks the relative influence of the pore volume on the determination of the rock volumes therefore is considered negligible.

2.6 General statistical parameters

One of the core focusses of the present research project is the examination of possible dependencies of the value of the shape factor on specific parameters that describe rock. This study is primarily based on statistical analyses. The most important statistical parameters applied in those analyses are the;

- Average or expected value, yielding insight in mean values of the datasets;
- Minimum and maximum values, yielding insight in the extremes of the datasets;
- Variance and standard deviation, yielding insight in the variability of the datasets;
- Skewness and kurtosis, yielding insight in the asymmetry and peakness of the distributions of the datasets.

Consult for example Dekking *et. al.* (2005) for definitions and calculation methods of these parameters.

[4] Note that still the volume of rock is required to be calculated. However, not for each individual rock!

3 Experiments

In sections 1.1 and 2.1 the definition of the shape factor for quarry rock is defined by the ratio of the median nominal diameter and median sieve diameter of the grading. To determine the value of these parameters specific tests are performed, which are briefly discussed in section 3.1. Also, the shape of individual rocks in terms of elongation and blockiness is measured to enable the research into the influence of shape on the value of the shape factor. To assess the variability of the shape factor these tests have been performed on multiple samples extracted from various gradings. The selected gradings are listed in section 3.2. The structure and methods of sampling are discussed in section 3.3. The results of the tests are presented in chapter 4.

3.1 Tests

In order to assess the value and variability of the shape factor, various parameters are required to be examined by means of testing. An overview of the tests and the yielded parameters is given in Table 3-1. In paragraph 3.1.1 to 3.1.4 these tests are briefly discussed. More elaborate information on these tests and the measurement campaigns is found in appendix [A].

Table 3-1 - Tests and yielded parameters

Test	Yielded parameter(s)
weighing	individual rock masses, nominal diameters
density tests	individual rock densities, nominal diameters
sieve tests	sieve diameters
shape tests	elongation and blockiness

3.1.1 Weighing

The nominal diameter of an individual rock is calculated by means of the cubic root of its volume. In section 2.5 it has been shown that rock volumes cannot be measured straightforwardly from a practical point of view. Fortunately, rock volumes can be calculated by means of the ratio of rock mass and density. These parameters are both measured relatively easily. It is concluded that for each individual rock its mass is required to be measured. Moreover these individual rock masses have been applied to calculate the sieve fraction masses in the sieve analysis. Paragraph 3.1.3 can be consulted for more detailed information. The tests required to determine rock density are discussed in paragraph 3.1.2.

Rock masses are determined rather straightforwardly by weighing. A calibrated scale with a capacity of 25 kg and accuracy of 1 gr was applied. The weighing was performed indoors on a stable desk to avoid the influences of weather conditions and vibrations on the measurements.

3.1.2 Density tests

In paragraph 3.1.1 the importance of density tests - for the determination of individual rock volumes and eventually nominal diameters - has been pointed out already. Furthermore, the possible influence of density on the value of the shape factor has been examined in section 5.3. As explained in section 2.5, for the determination of rock density, the ratio of rock mass and volume has been applied. To determine the volume of an individual rock, a tank filled with water was put on a scale and weighed. Subsequently an individual rock was submerged[5] in the tank. As a result the water level in the tank rises and the mass indicated

[5] The rock should not touch either the side or the bottom of the tank. In that case (a fraction) of the mass of the rock is weighed. Only the increased volume in the tank is to be measured!

by the scale increases. According to the Archimedes principle[6], the difference in mass indicated by the scale before and after submersion equals the mass of the displaced volume of water. Logically, the displaced volume of water equals the volume of the submerged rock (neglecting the pore volume). The density of the rock is simply calculated by means of the ratio of the rock mass and the just determined rock volume. During testing it was concluded that the procedure of the density test is relatively labour intensive and as a result time consuming. Therefore it is decided to perform the tests on one sample per tested grading only. By applying these test results on the remaining samples also, it has been implicitly assumed that these test results are sufficiently reliable and representative to be applied on the remaining samples. In section 5.3 this assumption has been evaluated.

3.1.3 Sieve tests

In section 2.2 it has been discussed that the determination of sieve diameters of individual rocks is practically unfeasible. The determination of sieve diameters is therefore always based on a normalized set of square sieves with predefined mesh widths.
According to the NEN-EN 13383-2 regulations (2013) a set of sieves of standardized mesh width was applied, viz.: 31.5, 45, 63, 90, 125, 180 and 250 mm. A rock sample consisting of at least 200 rocks is sieved by application of these sieves, yielding so-called sieve fractions. The mass of each sieve fraction is calculated by the summation of the individual rock masses in the specific fractions. For each specific sieve the mass that is able to **pass** the sieve is accumulated and plotted versus the associated mesh width dimension. The resulting graph is referred to as a so-called sieve curve. Through interpolation, specific values of the sieve diameter can be obtained. For instance the sieve diameter associated with 50 percent cumulative mass passing, the median sieve diameter, denoted d_{50}. Please consult appendix [D] for more information on sieve curves.

3.1.4 Shape tests

To describe the shape of rock, the parameters elongation and blockiness have been introduced in section 2.4. The dimensions required for the determination of elongation (*L* and *T*) are measured by application of a calliper, depicted in Figure 3-1. The dimensions required for the determination of blockiness (*X*, *Y* and *Z*) are measured by application of the so-called blockiness-meter, depicted in Figure 3-2. It is stressed that the placement of the rocks in the instruments by the researcher to some extent has an arbitrary character and is therefore not completely objective. As a result the measurement data may contain some biasedness. Furthermore, the measurement errors as a result of reading the calliper and blockiness-meter are approximated to be in the order of 1 mm and 1-5 mm respectively.

Figure 3-1 - impression of the applied calliper

Figure 3-2 - impression of the applied blockiness-meter

[6] On a body submerged in a fluid an uplift force is exerted equal to the gravity force of the displaced volume of water.

3.2 Tested gradings

The selection of the gradings was mainly based on availability and manual practicability in terms of size and weight of the rock. Furthermore, it was desired for the set of selected gradings to represent a certain range of coarseness, width and density. The specifications of the tested gradings as given by the producers, have been summarized[7] below. The 22-90 mm, 2-5 inch and 2-8 inch gradings were tested at a transhipment quay in IJmuiden, the Netherlands. The 1-5 inch and 5+ inch gradings were tested at a production quarry in Sløvag, Norway. Reports on these measurement campaigns can be found in appendix [A].

IJmuiden - 22-90 mm

- Grain size distribution: 22-90 mm, which is comparable to 1-3 inch
- Rock type: Gneiss
- Expected approximate density: 2650 kg/m³
- Origin: Halsvik Aggregates, Sløvag, Norway

IJmuiden - 2-5 inch

- Grain size distribution: 2-5 inch, which is comparable to 50-125 mm
- Rock type: Gneiss
- Expected approximate density: 2650 kg/m³
- Origin: Oster Pukk OG Sand AS, Eikefet, Norway

IJmuiden - 2-8 inch

- Grain size distribution: 2-8 inch, which is comparable to 50-200 mm
- Rock type: Gneiss
- Expected approximate density: 2650 kg/m³
- Origin: Halsvik Aggregates, Sløvag, Norway

Sløvag - 1-5 inch

- Grain size distribution: 1-5 inch, which is comparable to 22-125 mm
- Rock type: Mainly Basalt, with a minor Gneiss/Granite fraction
- Expected approximate average density: 2950 kg/m³
- Origin: Halsvik Aggregates, Sløvag, Norway

Sløvag 5+ inch

The rock in this grading consists of the rock that was retained on a 5 inch sieve installed in the crusher. This grading is therefore also referred to as the oversize material of the above 1-5 inch grading.

- Grain size distribution: 5+ inch, which is comparable to 125+ mm
- Rock type: Mainly Basalt, with a minor Gneiss/Granite fraction
- Expected approximate average density: 2950 kg/m³
- Origin: Halsvik Aggregates, Sløvag, Norway.

[7] The information is commercial. The units mm and inch are both used by the quarries. In the analyses of the gradings the dimensions are all expressed in millimetres.

Sløvag 1-5+ inch (virtual)

This virtual grading is obtained by the combination of the data of the 1-5 inch and 5+ inch gradings from the Sløvag quarry. Detailed information on this approach is found in paragraph 3.3.3.

3.3 Sampling

In paragraph 3.3.1 the structure of the sampling program is discussed. The sampling techniques applied and their resulting effects on the representativeness of the samples for the tested grading are discussed in 3.3.2. The implications of the composition of the virtual 1-5+ inch are explained in detail in 3.3.3.

3.3.1 Structure of sampling program

In the measurement campaigns in IJmuiden, the Netherlands and Sløvag, Norway respectively three and two gradings have been tested. In IJmuiden per grading 5 samples have been extracted from the stockpiles (indicated: A, B, C, D and E). In Sløvag, per grading 3 samples have been extracted from the stockpiles (indicated: A, B, and C). As a result in total 21 separate samples were taken. The euro code NEN-EN 13383-2 (2013) prescribes a sample size of approximately 200-250 rocks for sieve tests. This quantity was assumed sufficient also for the assessment of the shape factor. In paragraph 4.1.1 and this assumption is evaluated.

On all samples a sieve test has been performed. Also, for each individual rock in those samples the mass has been determined in order to calculate the nominal diameters and sieve fraction masses. Furthermore, on sample A of each of the gradings density tests and shape tests have been performed. Since these tests are highly labour intensive and only restricted time was available, it was decided not to perform these tests on every sample. The results of these tests are assumed sufficiently representative for the entire parent grading and are therefore applied to the remaining samples. In section 5.1, 5.2 and 5.3 this approach is evaluated for elongation, blockiness and density respectively.

Furthermore, for each grading a sample has been virtually created on basis of the combination of the data from the separate samples. These compound samples are indicated A-E for the IJmuiden gradings and A-C for the Sløvag gradings.

3.3.2 Representativeness

In literature a vast amount of information can be found on sampling techniques for rock gradings. It is concluded that a high order of complexity is introduced by the requirement of representativeness. The rock sizes should be distributed equally in the sample and the parent grading. Unfortunately rock sizes segregate when rock is put in a stockpile; the relatively large rocks are more frequently found at the sides of a stockpile; due to their larger masses they roll down lowest. This phenomenon is most pronounced for wide gradings. To compensate for segregation, according to NEN-EN-932-1 (1996)[8] rock should be extracted in specific fractions taken from multiple locations in the stockpile in order to compose a representative sample. It is however stressed that despite following the predefined euro code norms, rock sampling remains an arbitrary process. As a consequence, the distribution of rock sizes and thus the grading unfortunately differs somewhat from sample to sample. Through the examination of multiple samples the arbitrariness and thus representativeness of sampling is assessed. Moreover, statistical information on the variability of the shape factor is yielded.

[8] In appendix [A] the applied sampling techniques have been discussed in detail.

3.3.3 Virtual 1-5+ inch grading

The 1-5 inch and 5+ inch gradings tested in Sløvag have been virtually combined into a virtual 1-5+ inch grading. Both gradings consist of rock produced in the same production process. These were obtained after the execution of two steps:

1. Sieving of the rock on a sieve with a mesh width of one inch and removal of the passing rock, and;
2. Sieving of the retained rock on a sieve with a mesh width of 5 inch.

The rock passing in step 2 yields the 1-5 inch grading. The ultimately retained rock yields the 5+ inch - or oversize - grading. Since the rock was produced in the same process, presumably only the coarseness of the gradings differs. Complications for the representativeness of rock shapes due to remixing of the 1-5+ inch grading are therefore not expected. This assumption is evaluated in paragraphs 4.2.1 and 4.2.2.

4 Test results

In this chapter the test results of the experiments are presented. The details of the value and variability of the shape factor are assessed in section 4.1. An overview of the rock shapes in terms of elongation, blockiness and roundness is given in section 4.2. The findings on the coarseness, width and density of the tested gradings are presented in sections 4.3, 4.4 and 4.5 respectively. The raw data can be found in appendix [C]. The calculation methods applied to process the raw data into the results presented in this chapter can be consulted in appendix [D].

4.1 The shape factor

The value and variability of the shape factor have been assessed in paragraph 4.1.1. Distributions of the found shape factor values are presented in paragraph 4.1.2. Furthermore, the uniformity of the value of the shape factor over a grading is assessed in paragraph 4.1.3.

4.1.1 The value and variability

In chapter 1 it has been shown that the shape factor F_s^* is defined by the ratio of d_{n50} and d_{50}. In order to assess the value of the shape factor, thus information is required on the value of both parameters. This has been achieved by the derivation of nominal diameter curves and sieve curves for each of the samples. The plots of all nominal diameter curves and sieve curves can be found in appendix [D]. By interpolation of those plots the median nominal diameter and median sieve diameter values have been determined. These values, as well as the ratios - the shape factor per sample - are listed per grading in Table 4-1 to Table 4-6.

Table 4-1 - shape factors for the samples extracted from the 22-90 mm grading

	A	B	C	D	E	A-E
d_{n50}	65.7	60.8	64.6	62.0	57.7	62.9
d_{50}	73.9	72.9	76.4	75.6	63.3	73.3
F_s^*	0.889	0.834	0.846	0.820	0.912	0.859

Table 4-2 - shape factors for the samples extracted from the 2-5 inch grading

	A	B	C	D	E	A-E
d_{n50}	62.8	72.7	69.5	62.1	72.6	67.6
d_{50}	72.6	82.6	76.3	73.2	83.7	77.7
F_s^*	0.865	0.881	0.911	0.848	0.867	0.869

Table 4-3 - shape factors for the samples extracted from the 2-8 inch grading

	A	B	C	D	E	A-E
d_{n50}	101.4	98.1	98.3	95.8	109.6	100.7
d_{50}	116.8	111.1	115.4	111.6	131.5	117.1
F_s^*	0.868	0.883	0.851	0.858	0.834	0.859

Table 4-4 - shape factors for the samples extracted from the 1-5 inch grading

	A	B	C	A-C
d_{n50}	78.1	57.1	45.6	60.7
d_{50}	87.5	65.0	53.3	68.7
F_s^*	0.892	0.878	0.856	0.884

Table 4-5 - shape factors for the samples extracted from the 5+ inch grading

	A	B	C	A-C
d_{n50}	113.0	111.3	105.3	110.3
d_{50}	133.2	128.1	125.3	129.5
F_s^*	0.848	0.869	0.840	0.852

Table 4-6 - shape factors for the samples extracted from the 1-5+ inch grading

	A	B	C	A-C
d_{n50}	108.2	100.6	98.2	102.6
d_{50}	128.0	114.8	113.0	119.2
F_s^*	0.846	0.876	0.869	0.861

It is concluded that for each of the gradings, significant fluctuation over the samples is observed in the values of both the median nominal diameter and median sieve diameter. The resulting shape factor value ranges from 0.82 to 0.91. A plausible explanation is the arbitrary character of sampling, as discussed in 3.3.2. In the A-E and A-C samples the arbitrariness is corrected for. Since these samples consist of the combined data of the separate samples[9] extremes are cancelled out and thus mediate values for the shape factor are yielded; the range of F_s^* diminishes to 0.85-0.88. It is concluded that 200-250 rocks are inadequate to assess the value of the shape factor sufficiently accurate. Generally, the accuracy and thus reliability of the found shape factor value increases for an increase of the sample size. It is however stressed that the rocks should be still extracted from different parts of the stockpile in accordance with NEN-EN 13383-2 (2013). The results based on a sample consisting of approximately 1000 rocks are considered sufficiently accurate.
Considering the value of the shape factor for the 21 samples, the value of 0.84 is exceeded eighteen times. As a logical result the shape factor has a value less than 0.84 three times. Moreover, for the combined A-E and A-C samples the value of the shape factor exceeds the value of 0.84 for each of the gradings. The samples of the 1-5+ inch grading were neglected in this analysis to prevent this data to be represented twice.

[9] Note that the results of the A-E and A-C samples are **not** the averages values of the separate samples.

4.1.2 The distribution of the shape factor

The distribution of the shape factor in both its commonly applied form as well as its primitive form is analysed in subparagraphs 4.1.2.1 and 4.1.2.2. Furthermore, in subparagraph 4.1.2.3 the distribution of the individual shape factor is presented.

4.1.2.1 The shape factor F_s^*, defined by d_{n50}/d_{50}.

The distribution of the shape factor values presented in 4.1.1 is examined in this paragraph. To prevent data from being represented twice, only the shape factor values of the 21 separate samples are considered. The combined sample A-E and A-C are thus omitted in this analysis. In Figure 4-1 the distribution of shape factor values is visualized by means of a histogram. Furthermore, the average and standard deviation of the shape factor have been calculated; 0.864 and 0.024 respectively. Based on these figures, a Gaussian distribution is also depicted in Figure 4-1 as an approximation of the distribution of the found shape factor values.

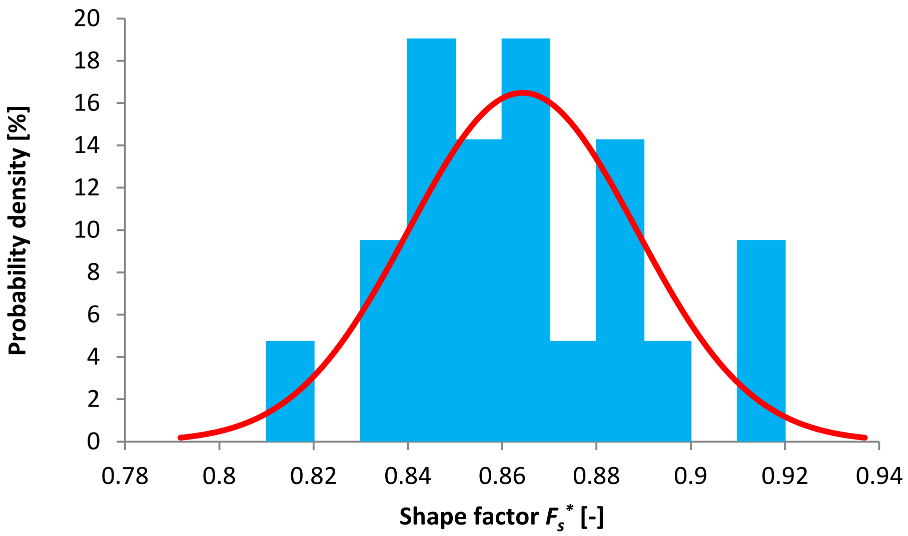

Figure 4-1 - distribution of the shape factor F_s^*, based on 21 samples

It is concluded that based on the individual samples the distribution of the value of the shape factor is reasonably well represented by means of a Gaussian distribution. The representation is analysed in more detail by examining the skewness and kurtosis of the dataset. The skewness of the dataset is 0.32. For positive skewness the right tail of the distribution is longer than for the Gaussian distribution. To a limited extent this is observed in Figure 4-1. The kurtosis is -0.35. Negative kurtosis means that the distribution is flatter than the normal distribution; the probability to find a shape factor value in one of the tails is larger compared to the Gaussian distribution. This findings is not clearly observed in Figure 4-1.

4.1.2.2 The shape factor in its primitive form F_s

The same analysis has been performed for the primitive shape factor; F_s. In Figure 4-2 the distribution of the primitive shape factor (based on 21 samples) has been depicted by a histogram. Also, the histogram has been approximated by means of a Gaussian distributions, based on an average value of 0.647 and a standard deviation of 0.055.

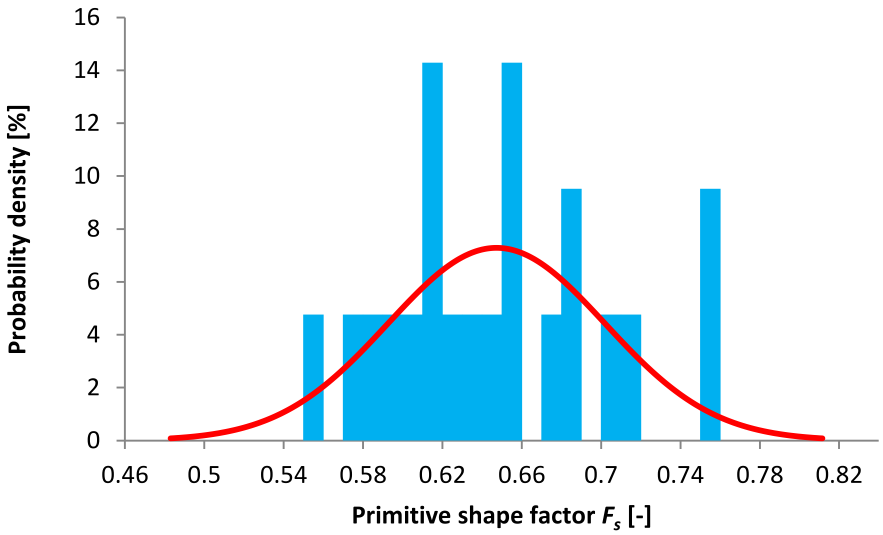

Figure 4-2 - distribution of the *primitive* shape factor F_s, based on 21 samples

It is concluded that based on the individual samples the distribution of the value of the primitive shape factor found is rather poorly represented by means of a Gaussian distribution. This findings is not surprising, since in subparagraph 4.1.2.1 it was already found that the distribution of the shape factor in its commonly applied form, is reasonably well represented by means of a Gaussian distribution. (Recall F_s=F_s^{*3}). The representation is analysed in more detail by examining the skewness and kurtosis of the dataset. The skewness of the dataset is 0.45. For positive skewness the right tail of the distribution is longer than for the Gaussian distribution. To a limited extent this is observed in Figure 4-2. The kurtosis is -0.25. This means the peakness of the distribution is comparable to that of the Gaussian distribution. This cannot be clearly observed in Figure 4-2. In contrary, four sparks are observed, of which three are located relatively close to the average value of the primitive shape factor: 0.647. The remaining shape factor values are rather uniformly distributed.

4.1.2.3 Individual shape factors

In section 2.2 the concept of individual has been discussed. For 969 rocks the required data to determine the value of the individual shape factor is available. In Figure 4-3 the distribution of the individual shape factor has been depicted by means of a histogram. Also a Gaussian distribution based on the average and standard deviation of the dataset, 0.844 and 0.083 respectively, has been included as an approximation.

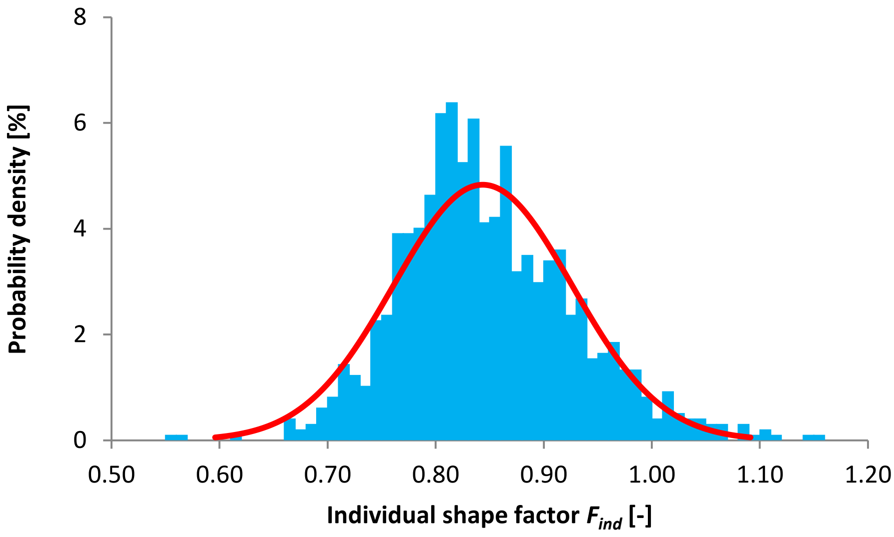

Figure 4-3 - distribution of the *individual* shape factor F_{ind}, based on 969 individual rocks

It is concluded that based on the individual rocks the distribution of the value of the individual shape factor is reasonably well represented by means of a Gaussian distribution[10]. The representation is analysed in more detail by examining the skewness and kurtosis of the dataset. The skewness value of the distribution is 0.62, which means the distribution is asymmetrical with a longer right tail. This is clearly observed in Figure 4-3. The kurtosis is 1.66, which means the distribution is rather peaked compared with the Gaussian distribution. This is also clearly observed in Figure 4-3.

[10] 71 percent of the of the individual shape factors has a value within one standard deviation of the average or expected value. 95 percent of the of the individual shape factors has a value within two standard deviations of the average or expected value. For the Gaussian distributions these percentages are 68 and 95 respectively.

4.1.2.4 Conclusion

According to the subparagraphs 4.1.2.1, 4.1.2.2 and 4.1.2.3 it has been found that the distribution of the shape factor F_s^* is represented reasonably well by means of a Gaussian distribution. The average, or expected value, variance, standard deviation, skewness and kurtosis of the per grading are listed in Table 4-7. It is however stressed that these figures are based on 5 samples only for the 22-90 mm, 2-5 inch and 2-8 inch gradings and on 3 samples only for the 1-5 inch, 5+ inch and 1-5+ inch gradings. The statistical meaning of the obtained values as a result is questionably low.

Table 4-7 - statistics of the shape factor per grading

	$[F_s^*]$				
Grading	E [ ]	Var [ ]	St dev [ ]	Skewness [ ]	Kurtosis [ ]
22-90 mm	0.860	0.00122	0.035	0.569	-1.886
2-5 inch	0.875	0.00045	0.021	0.960	1.383
2-8 inch	0.858	0.00026	0.016	-0.012	0.355
1-5 inch	0.876	0.00022	0.015	-0.542	-
5+ inch	0.852	0.00014	0.012	1.160	-
1-5+ inch	0.863	0.00017	0.013	-1.355	-
Together	0.864	0.00059	0.024	0.325	-0.345

It is concluded that for all gradings the expected value of the shape factor exceeds the value of 0.84. To be more precise, the expected value of the shape factor ranges from 0.85 to 0.88. Considering all 21 samples from the various gradings altogether, the expected value of the shape factor is 0.864 and has a standard deviation of 0.024. Taking into account one standard deviation, a lower limit of approximately 0.84 and an upper limit of approximately 0.89 are yielded.
The standard deviation of the shape factor ranges from 0.012 to 0.035 over the tested gradings, which is considered relatively limited. The largest values for the standard deviation are observed for the 22-90 mm, 2-5 inch and 2-8 inch gradings; the smallest for the 1-5 inch, 5+ inch and 1-5+ inch gradings. This observation can be explained by the fact that the standard deviations of the 22-90 mm, 2-5 inch and 2-8 inch gradings are based on 5 samples, in contrast to the standard deviation of the 1-5 inch, 5+ inch and 1-5+ inch gradings; these are based on 3 samples. The latter standard deviations are thus derived on basis of less information, which has as a result that the probability to contain extreme values is lower.
The skewness values fluctuate from approximately -1.4 to 1.2. It is concluded that both significant negative and positive skew is observed. For kurtosis comparable fluctuation is observed in the results. Note that the kurtosis values of the 1-5 inch, 5+ inch and 1-5+ inch were unable to be calculated due to insufficient information (only 3 samples).

Also, the value of the individual shape factor is represented rather well by means of a Gaussian distribution. Based on the 969 individual rocks in the A samples the individual shape factor has an average value and standard deviation of 0.844 and 0.083 respectively. Furthermore it has been concluded that the primitive shape factor F_s is poorly represented by means of a Gaussian distribution. This is a logical consequence of the fact that the shape factor F_s^* is represented reasonably well by means of a Gaussian distribution.

4.1.3 The uniformity within a grading

In hydraulic engineering practice the value of the shape factor is applied as a constant for an entire grading. In other words, the ratio of d_{n50} / d_{50} is assumed equal to the ratios of d_{n15} / d_{15}, d_{n90} / d_{90} or whichever other ratio of nominal diameter and sieve diameter at some specific cumulative mass exceedance percentage $d_{n\%}$ / $d_{\%}$. The value of the shape factor is however determined on basis of the **median** value of the nominal and **median** sieve diameter only.

Not that in paragraph 4.1.1 it has been concluded that the value of the shape factor is not a universal constant. As a consequence, the assumption of a constant shape factor value for rock gradings has become quite questionable. Therefore, in this paragraph the uniformity of the value of the shape factor within the tested gradings is examined. This has been done by calculation of the ratios of the nominal diameter and sieve diameter at several cumulative mass exceedance percentages, viz.: at 5, 15, 50, 90 and 98 percent for each of the samples. The results have been listed per grading in Table 4-8 to Table 4-13. Indexes have been added to indicate the cumulative mass exceedance percentage that 'particular shape factor' is associated with.

Table 4-8 - shape factor fluctuation within the 22-90 mm grading

	A	B	C	D	E	A-E
F_{s5}^*	0.885	0.864	0.840	0.881	0.855	0.867
F_{s15}^*	0.858	0.841	0.858	0.824	0.882	0.860
F_{s50}^*	0.889	0.834	0.846	0.820	0.912	0.859
F_{s90}^*	0.878	0.905	0.862	0.923	0.848	0.904
F_{s98}^*	0.729	0.876	0.667	0.790	0.820	0.762

Table 4-9 - shape factor fluctuation within the 2-5 inch grading

	A	B	C	D	E	A-E
F_{s5}^*	0.868	0.880	0.875	0.872	0.889	0.882
F_{s15}^*	0.859	0.875	0.848	0.900	0.863	0.866
F_{s50}^*	0.865	0.881	0.911	0.848	0.867	0.869
F_{s90}^*	0.711	0.736	0.734	0.708	0.911	0.767
F_{s98}^*	0.667	0.693	0.643	0.536	0.756	0.702

Table 4-10 - shape factor fluctuation within the 2-8 inch grading

	A	B	C	D	E	A-E
F_{s5}^*	0.895	0.913	0.896	0.867	0.897	0.889
F_{s15}^*	0.903	0.871	0.910	0.916	0.858	0.882
F_{s50}^*	0.868	0.883	0.851	0.858	0.834	0.859
F_{s90}^*	0.798	0.764	0.805	0.785	0.742	0.789
F_{s98}^*	0.728	0.768	0.726	0.737	0.685	0.752

Table 4-11 - shape factor fluctuation within the 1-5 inch grading

	A	B	C	A-C
F_{s5}^*	0.917	-[11]	-[11]	0.762
F_{s15}^*	0.893	0.851	0.819	0.856
F_{s50}^*	0.892	0.878	0.856	0.884
F_{s90}^*	0.785	0.818	0.928	0.802
F_{s98}^*	0.767	0.770	0.785	0.786

Table 4-12 - shape factor fluctuation within the 5+ inch grading

	A	B	C	A-C
F_{s5}^*	0.918	0.945	0.949	0.906
F_{s15}^*	0.938	0.907	0.905	0.919
F_{s50}^*	0.848	0.869	0.840	0.852
F_{s90}^*	0.819	0.820	0.789	0.823
F_{s98}^*	0.822	0.800	0.747	0.796

Table 4-13 - shape factor fluctuation within the 1-5+ inch grading

	A	B	C	A-C
F_{s5}^*	0.942	0.870	0.843	0.863
F_{s15}^*	0.901	0.884	0.845	0.895
F_{s50}^*	0.846	0.876	0.869	0.861
F_{s90}^*	0.802	0.836	0.776	0.834
F_{s98}^*	0.812	0.808	0.682	0.803

It is concluded that the value of the shape factor is not constant within the grading of any of the samples. In contrast, significant fluctuations are observed. In general the value of the shape factor decreases for an increase of rock size. This finding is most pronounced for the 22-90 mm, 2-5 inch and 2-8 inch gradings. A more limited relation is found for the samples of the 1-5 inch, 5+ inch and 1-5+ inch gradings[12]. For the majority of the samples, the largest value of the shape factor is observed for either F_5 or F_{15}. For all samples the smallest value of the shape factor is observed for either F_{90} or F_{98}. A plausible explanation is based on 'sieve density'.

- Intermezzo -

Sieve density is defined as the number of rocks that is found in a specific sieve fraction. In a grading usually a relatively small amount of large rocks occurs in comparison with small rocks. As a result the sieve density for the sieves with the largest mesh widths is usually low. The difficulty of low sieve density is that the sieve diameter of the rock in the associated sieve fractions is determined relatively inaccurate. Consider the two largest sieves applied in a sieve test have mesh widths of 180 and 250 mm. The few rocks retained on the 180 mm sieve are now assigned as passing the 250 mm sieve. It is however possible these few rocks would also have passed a 200 mm sieve.

[11] These values could not be calculated since for the fines (d_s < 25 mm) no **individual** rock masses were determined.

[12] Concerning the sieve tests of those gradings, more sieves were applied, especially in the upper tail of the grading. As a result the sieve density increases and the sieve diameters are determined more accurately.

As a result the mass associated with those rocks is plotted at an incorrect sieve diameter in the sieve curve. In such cases the upper right point in the sieve curve should actually be shifted to the left, closer to the nominal diameter curve. This will result in larger values of the shape factor. It is therefore recommended to determine the sieve diameters of the relatively large rock in more detail.

-

Based on the results of the 21 separate samples, presented in Table 4-8 to Table 4-13, the expected value, variance and standard deviation of the shape factor at the considered cumulative mass exceedance percentages have been calculated. The results have been listed in Table 4-14.

Table 4-14 - statistics of the shape factor fluctuation within the gradings

	$[F_s^*]$		
	E. [ ]	Var. [ ]	St. Dev. [ ]
F_{s5}^*	0.904	0.00190	0.044
F_{s15}^*	0.875	0.00045	0.021
F_{s50}^*	0.864	0.00051	0.023
F_{s90}^*	0.813	0.00226	0.048
F_{s98}^*	0.739	0.00281	0.053

Considering Table 4-14, it is once more concluded that the shape factor is not constant within the grading. The value decreases for an increase of the rock size. Furthermore, the standard deviation increases in both tails of the grading. In the upper tail this is explained by the low sieve density in this section of the grading. In the lower tail this is explained by measurement inaccuracies. The during submersion introduced small waves, cause a large relative error, especially in this part of a grading. More detailed information on the influence of density on the value of the shape factor can be found in section 5.3. In Figure 4-4 the expected value and variability of the shape factor within a grading have been plotted versus the cumulative mass exceedance percentages.

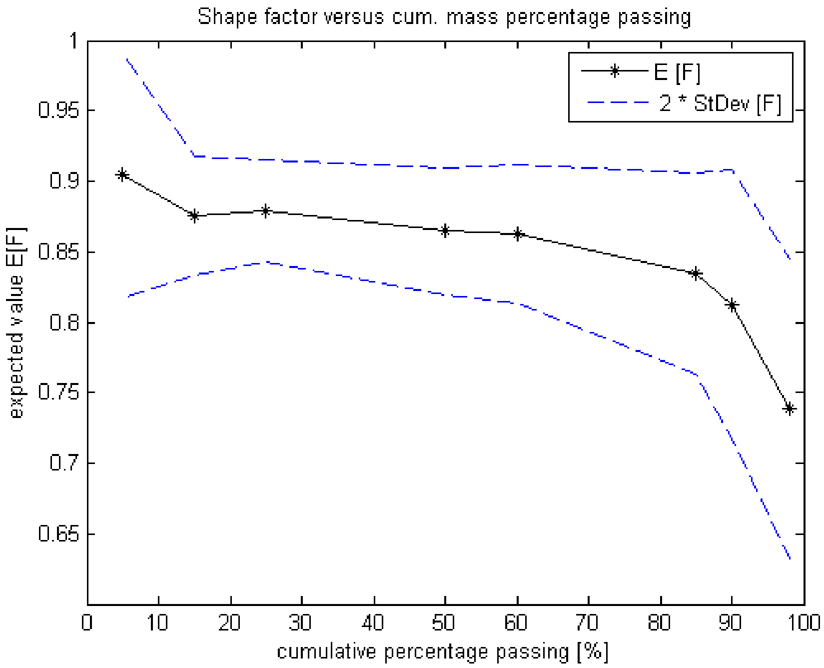

Figure 4-4 - expected value and variability for the shape factor within a grading

Considering Figure 4-4, it is concluded that in the middle part of the grading the relation is rather constant and limited. In the tails of the gradings the amplification of the relation is amplified as a consequence of the measurement inaccuracies discussed above. It is expected that in reality the relation in the tails of the grading will be comparable to the relation in the middle part of the grading. Therefore, the relation is approximated by means of the red line in Figure 4-5.

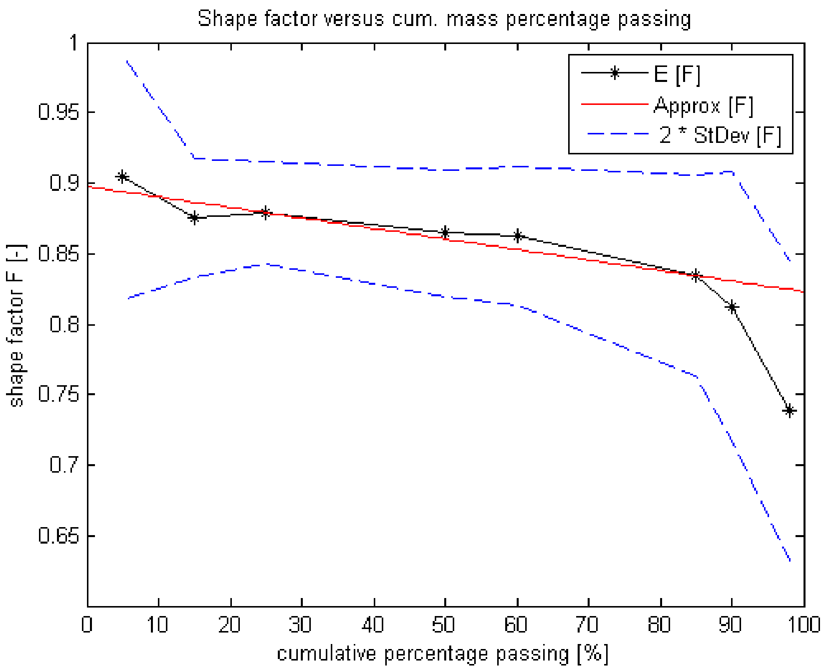

Figure 4-5 - approximation of F_s^* within a grading

The equation of the approximation is given by: F_s^*=-0.00075**CMP*+0.898. Where *CMP* denotes the cumulative mass percentage [%].

4.2 Shape

In paragraphs 4.2.1 and 4.2.2 statistical information is provided on elongation and blockiness respectively. Furthermore, the distributions of elongation and blockiness have been given by a histogram, and are approximated by means of theoretical distributions, viz.: a Gaussian and Lognormal distributions.

4.2.1 Elongation

Per grading the minimum, maximum and average value as well as the standard deviation, skewness and kurtosis of the elongation dataset are listed in Table 4-15. By the symbol #, the number of examined rocks is indicated. In appendix [D] detailed information can be found on the elongation per sieve fraction.

Table 4-15 - statistical information of elongation per grading

	Elongation *LT*						
Grading	# [-]	min. [-]	max. [-]	ave. [-]	st. dev. [-]	skew. [-]	kurt. [-]
22-90 mm	209	1.0	5.3	2.04	0.59	1.61	5.08
2-5 inch	304	1.0	5.5	2.36	0.67	1.30	2.53
2-8 inch	201	1.2	4.7	2.44	0.61	0.97	1.57
1-5 inch	148	1.4	7.1	2.76	1.02	1.45	2.81
5+ inch	107	1.4	7.0	2.55	0.80	2.01	8.45
1-5+ inch	255	1.4	7.1	2.68	0.94	1.67	4.30
Together[13]	969	1.0	7.1	2.40	0.74	1.73	5.40

It is concluded that the found elongation values do agree with values usually observed for regular gradings in hydraulic engineering practice. Compared to the 22-90 mm, 2-5 inch and 2-8 inch Gneiss gradings, slightly larger elongation values are found for the 1-5 inch, 5+ inch and 1-5+ inch Basalt - Gneiss/Granite mixture gradings. No distinct trends are observed in elongation over the sieve fractions for any of the gradings. In other words: elongation is not related to rock size, which is observed clearly in Figure 4-6.

Elongation has a minimum value of 1.0. This observation is explained by the definition of the parameter: L should always be larger than T. Furthermore, it is found that the majority of the rock has an elongation value of approximately 2.5. For some rocks however, relatively large elongation values are also found. The skewness and kurtosis values given in Table 4-15 are in line with these observations as they indicate an asymmetrical, peaked distribution. Based on these observations it is assumed that the distribution of elongation can be represented by means of lognormal distribution.

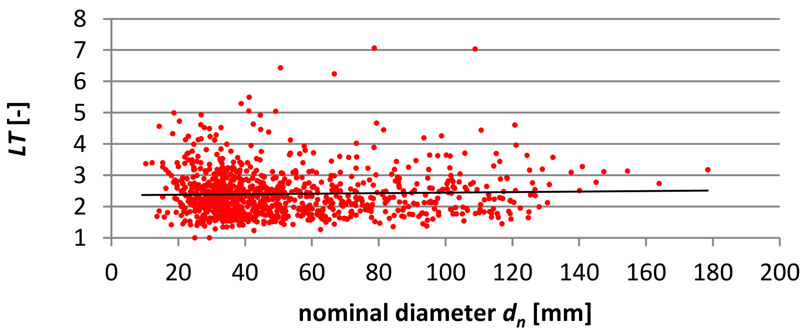

Figure 4-6 - rock size versus elongation

[13] These value are based on the complete dataset, not the average values of the individual gradings.

In Figure 4-7 the distribution of elongation for 969 individual rocks has been given by a histogram. By means of a Lognormal distribution (in black) the histogram has been approximated. For comparison, a Gaussian distribution (in red) based on the average value and standard deviation of 2.40 and 0.74 respectively is included.

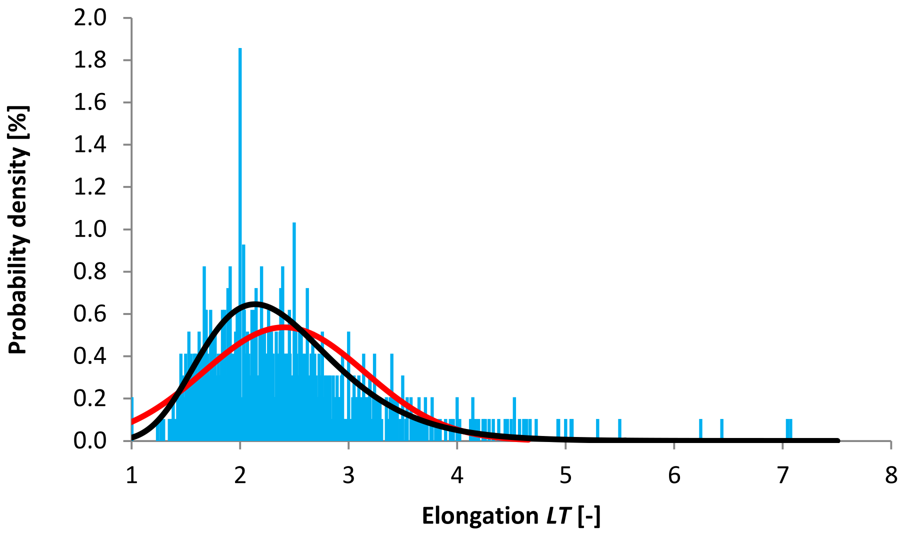

Figure 4-7 - distribution of elongation based on 969 individual rocks

It is concluded that the distribution of elongation is rather well represented by means of a Lognormal distribution. In contrary to the Gaussian distribution, the Lognormal distribution reasonably well fits the skewness (asymmetry) and kurtosis (peakedness) of the elongation dataset.

4.2.2 Blockiness

Per grading the minimum, maximum and average value as well as the standard deviation, skewness and kurtosis of the blockiness dataset are listed in Table 4-16. By the symbol #, the number of examined rocks is indicated. In appendix [D] detailed information can be found on the blockiness per sieve fraction.

Table 4-16 - statistical information of blockiness per grading

	Blockiness *BLC*						
Grading	# [-]	min. [%]	max. [%]	ave. [%]	st. dev. [-]	skew. [-]	kurt. [-]
22-90 mm	209	17	89	44.0	8.13	1.23	5.70
2-5 inch	304	26	65	45.8	7.10	0.07	-0.10
2-8 inch	201	30	97	47.3	8.92	2.11	9.03
1-5 inch	148	11	65	42.5	7.87	0.03	1.17
5+ inch	107	30	73	45.5	7.10	0.70	1.18
1-5+ inch	255	11	73	43.9	7.70	0.16	1.19
Together[14]	969	11	97	45.3	7.94	0.98	4.89

It is concluded that the found blockiness values do agree with values usually observed for regular gradings in hydraulic engineering practice. No distinct trends are observed in blockiness over the sieve fractions for any of the gradings. In other words: blockiness is not related to rock size, which is observed clearly in Figure 4-8.
According to the skewness values the distribution of blockiness is relatively symmetric for most of the gradings. This means that the percentage of rock that has a smaller than average blockiness value is more or less equal than the percentage of rock that has a larger than average blockiness value. (Near 50% logically). For two gradings however, some significant positive skewness is present. Considering the kurtosis values, the peakedness of the distribution differs significantly over the gradings; in five of the gradings the elongation is distributed more peaked than in a normal distribution, of which two are very peaked. It is noted that for these two gradings also the highest skewness values are observed. Also, according to the negative kurtosis in one of the gradings, the blockiness is distributed flatter in comparison to a Gaussian distribution.

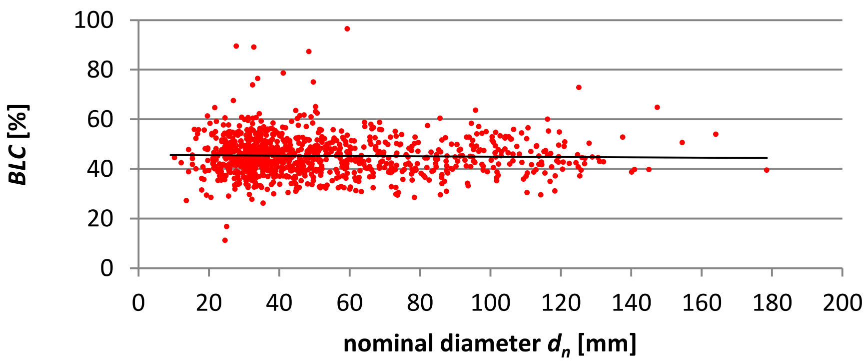

Figure 4-8 - rock size versus blockiness

[14] These value are based on the complete dataset, not the average values of the individual gradings.

In Figure 4-9 the distribution of blockiness for 969 individual rocks has been given by a histogram. The average value and standard deviation of the dataset are 45.3 and 7.94 respectively. Based on these figures, a Gaussian distribution is also depicted in Figure 4-9 as an approximation of the blockiness distribution.

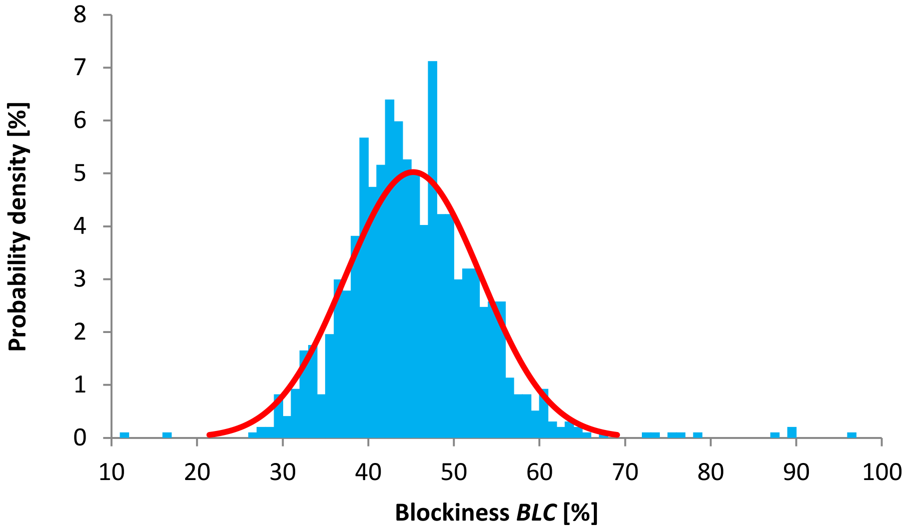

Figure 4-9 - distribution of blockiness based on 969 individual rocks

It is concluded that the distribution of blockiness is reasonably well represented by means of a Gaussian distribution. The representation is analysed in more detail by examining the skewness and kurtosis of the dataset. The skewness of the dataset is 0.98. For positive skewness the right tail of the distribution is longer than for the Gaussian distribution. This is clearly observed in Figure 4-9. The kurtosis is 4.89. Positive kurtosis means that the distribution is more peaked than the normal distribution. This finding is also clearly observed in Figure 4-9.

4.2.3 Roundness

For all gradings the roundness is considered predominantly tabular according to Latham *et. al.* (1988). According to Powers (1953) the rock is angular and has a low sphericity.

4.3 Coarseness

In Table 4-17 the coarseness, in terms of the value of the median nominal diameter for each of the tested samples, has been listed per grading. Furthermore, for each grading the average value of the coarseness of the samples has been given.

Table 4-17 - coarseness of the tested gradings

	Coarseness d_{n50} [mm]						
Grading	A	B	C	D	E	A-E	ave.
22-90 mm	66	61	65	62	58	63	62
2-5 inch	63	73	70	62	73	68	68
2-8 inch	101	98	98	96	110	101	101
1-5 inch	78	57	46	-	-	61	60
5+ inch	113	111	105	-	-	110	110
1-5+ inch	108	101	98	-	-	103	102

It is concluded that the calculated coarseness of the samples are not all in line with the expectations based on the gradings specifications or ‘commercial names’ given by the producers. Moreover, per grading the coarseness considerably varies over the samples.

4.4 Grading width

In Table 4-18 the grading width, in terms of the ratio of the sieve diameters associated with 85 percent cumulative mass and 15 percent cumulative mass; d_{85}/d_{15}, for each of the tested samples, has been listed per grading. Furthermore, for each grading the average value of the width of the samples has been given.

Table 4-18 - width of the tested gradings

	Width d_{85}/d_{15} [-]						
Grading	A	B	C	D	E	A-E	ave.
22-90 mm	2.4	2.5	2.5	2.4	2.7	2.5	2.5
2-5 inch	3.0	3.2	2.7	4.0	2.6	3.0	3.1
2-8 inch	2.8	3.1	2.7	3.1	3.1	2.9	2.9
1-5 inch	1.8	2.5	3.3	-	-	3.0	2.6
5+ inch	1.5	1.7	1.6	-	-	1.6	1.6
1-5+ inch	1.6	2.3	2.4	-	-	2.0	2.1

It is concluded that the calculated grading widths of the samples are not all in line with the expectations based on the gradings specifications or ‘commercial names’ given by the producers. Moreover, per grading the width varies over the samples, particularly for the 2-5 inch and 1-5 inch gradings. According to paragraph 2.3.2 the tested gradings are rather wide. This means the percentage of rather fine rock in the gradings is relatively high. An exception is the 5+ inch grading, which is, as explained in paragraph 3.3.3 obtained after separation from the finer 1-5 material.

4.5 Density

The expected and measured average density values for the tested grading are presented in paragraph 4.5.1. Furthermore, the sensitivity of the calculation of nominal diameters curves on relatively small variations in rock density is analysed in paragraph 4.5.2

4.5.1 Verification of rock densities

For each of the gradings the average rock densities as expected by the producer has been listed in section 3.2. By means of density tests these given values have been measured for verification. Both the expected and measured average densities are presented in Table 4-19.

Table 4-19 - expected and measured densities of the tested gradings

Grading	Rock type	Density ρ [kg/m³] Expected	Measured
22-90 mm	Gneiss	2650	2653
2-5 inch	Gneiss	2650	2616
2-8 inch	Gneiss	2650	2657
1-5 inch	Basalt(ic)[15]	± 3100	2948
	Gneiss/Granite	2650	2651
	Together	2950	2748
5+ inch	Basalt(ic)[15]	± 3100	2940
	Gneiss/Granite	2650	2659
	Together	2950	2736

It is concluded that the measured rock densities deviate from the grading specifications given by the producers. Particularly for the 1-5 inch and 5+ inch gradings large differences are observed. The reason is that the Gneiss/Granite fraction within these gradings was significantly larger than expected by the producer. Since the Gneiss/Granite material has a considerable lower average density than the Basalt material, (viz.: 2659 kg/m³ and 2940 kg/m³ respectively), the total average density of the grading logically decreases for an increase of the Gneiss/Granite fraction.

4.5.2 Sensitivity and nominal diameters

For each of the gradings on sample A density tests were performed. For each individual rock the density was determined based on the ratio of mass and volume, referred to as the rock specific density. Furthermore, the average density value of the rocks in the 63-90 mm and 90-125 mm sieve fractions has been calculated, referred to as the average sample density. For each of the tested samples the nominal diameter curves has been calculated for both the rock specific densities as well as the average sample density. An example of these curves has been given in Figure 4-10. Detailed information on the calculation of the nominal diameter curve can be found in appendix [D].

[15] No petrological details on this rock type were available. For the density however a value of approximately 3100 kg/m³ was expected by the producer.

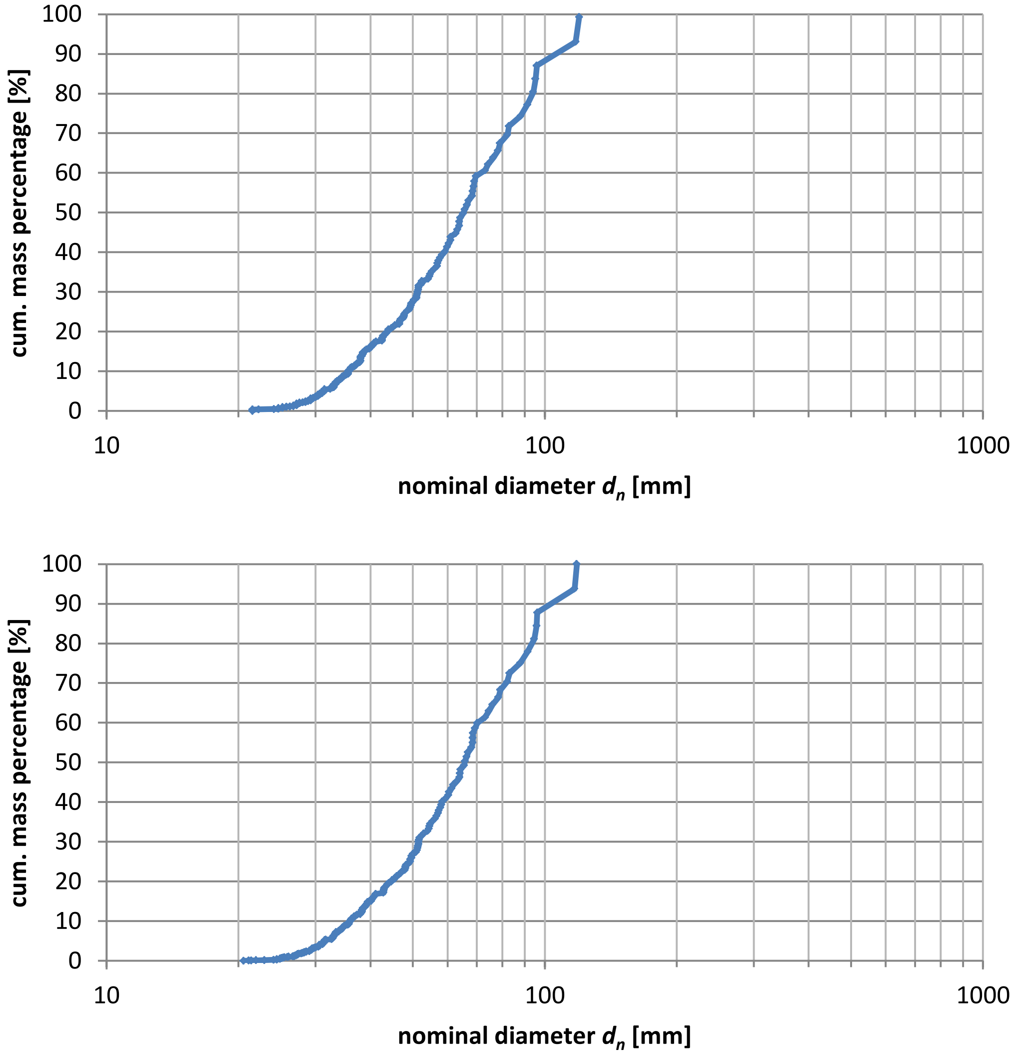

Figure 4-10 - nominal diameter curves, upper panel: based on rock specific densities, lower panel: based on average sample density

Comparing both nominal diameter curves it is concluded that the differences of either using the rock specific densities or the average sample density on the determination of nominal diameter curves and rather limited.

Since the average sample density is rather constant for samples extracted from a common parent grading, the application of the average density of sample A on the remaining samples in the grading does not significantly influence the calculation of the median nominal diameter.

5 Interpretation

In chapter 4 it has been concluded that the shape factor is not a universal constant. The value varies over rock samples. The dependency of the shape factor value on a certain set of parameters that describe rock is examined in the present chapter. The expected influence of elongation and blockiness on the value of the shape factor, elaborated upon in appendix [E], is examined in section 5.1 and 5.2 respectively. The possible influence of density is examined in section 5.3. The chapter is concluded with the examination of the possible influences of coarseness and grading width on the value of the shape factor in sections 5.4 and 0 respectively.

5.1 Shape factor versus elongation

The hypothesis for a relation between the value of the shape factor and elongation has been theoretically founded in appendix [E]. For an increase of elongation an increase of the shape factor value is expected. The influence of elongation on the value of the shape factor however is examined in this section.

5.1.1 Shape factor versus elongation for individual rocks

In subparagraph 4.1.2.3 the distribution of the individual shape factor has been presented for 969 individual rocks[16]. For each of those rocks also the value for elongation is available. In Figure 5-1 the individual shape factors have been plotted versus the associated elongation.

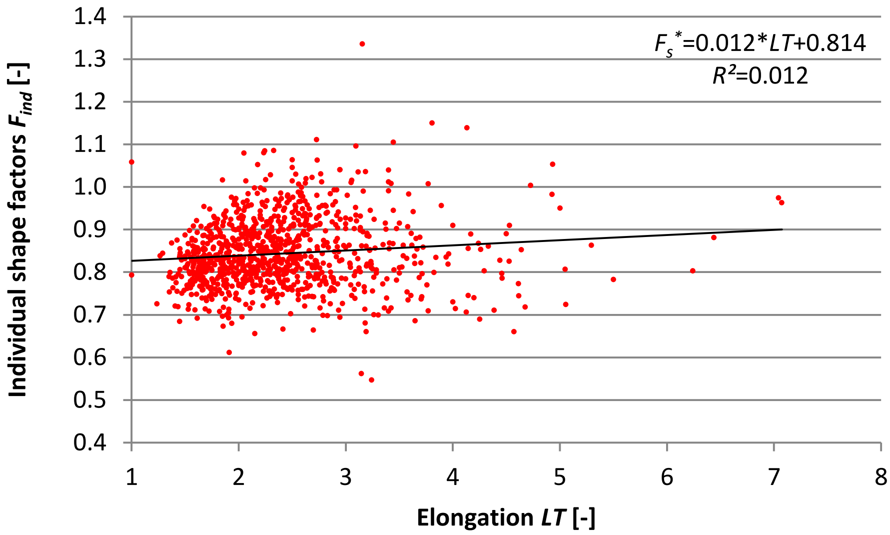

Figure 5-1 - individual shape factor versus elongation for 969 individual rocks

Recall that the average value of the individual shape factors is 0.844. The standard deviation is 0.083, which is considered relatively large compared to the average value (10%). The elongation ranges from 1.0 to 7.1. The average value and standard deviation are 2.4 and 0.7 respectively. The distribution of elongation was rather well represented by means of a lognormal distribution.

[16] Those are the rocks found in sample A of each of the tested gradings.

The cloud of data observed in Figure 5-1 is rather scattered. Considering the bandwidths of the scatter for the upper limit of the band width, the value of the shape factor increases for an increase of elongation. At an approximate elongation value of 2.0 the increase flattens. For the lower limit of the bandwidth the value of the individual shape factor is considered relatively constant over elongation at an approximate value of 0.65. As a result the data cloud widens for an increase of elongation. At first glance however, a relation between the value of the shape factor and elongation for individual rocks is not distinguished.

In Figure 5-1 also a regression line has been included. It shows an increase of the individual shape factor over elongation. The correlation coefficient, denoted R^2 is 0.012, which implies that the parameters are practically uncorrelated. The equation of the regression line is given by $F_s^*=0.012*LT+0.814$. For sample A of each grading a similar analysis has been performed, which can be consulted in appendix [F]. Each of those analyses shows an increase of the individual shape factor value for an increase of elongation, albeit like in Figure 5-1 very limited.

It is concluded that on macro-scale - considering all data points - a relatively weak relation is discerned between the value of the individual shape factor and elongation; *The value of the individual shape factor increases for an increase of elongation at an approximate rate of 0.010-0.015 to 1.0.* This finding is in line with the hypothesis developed in appendix [E]. On micro-scale - two subsequent data points - this relation does not hold and should therefore not be applied to individual rocks. The value of the individual shape factor fluctuates too extensively over elongation to determine the shape factor value for an individual rock.

5.1.2 Shape factor versus sample elongation

In paragraph 5.1.1 the relation between the shape factor and elongation has been examined for individual rocks. It has been concluded that only on a macro-scale a relation can be distinguished. On average the value of the shape factor slightly increases for an increase of elongation. This paragraph focusses on the influence of elongation on the shape factor of a rock grading. In order to do so, the dependency of the shape factor value on both the average elongation in the A samples, as well as the percentage of 'high elongated' rock in the A samples has been examined in subparagraphs 5.1.2.1 and 5.1.2.2 respectively.

5.1.2.1 Average elongation

Based on the five available samples the relation between the shape factor and the average elongation values is examined in this subparagraph. In Figure 5-2 the data has been plotted.

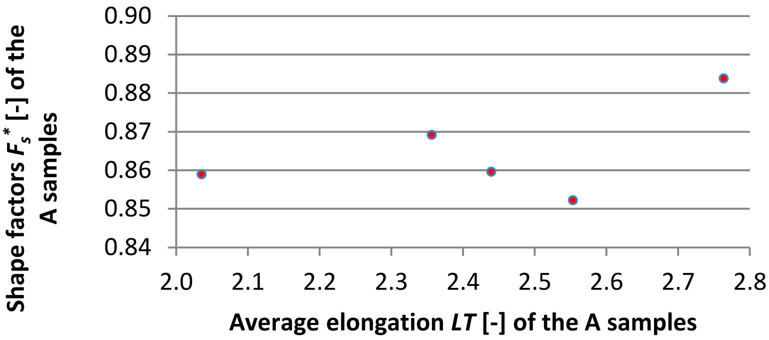

Figure 5-2 - average elongation versus the shape factor for the A samples

It is concluded that the value of the shape factor fluctuates over the average elongation values. For an increase of the average elongation within a sample either an increase or decrease of the value of the shape factor cannot be expected. As a result no clear relation can be discerned between the value of the shape factor and the average elongation value of a sample.

In paragraph 4.1.1 it has been found that, to assess a reliable value of the shape factor, a sample size of approximately 200-250 rocks is insufficient. Therefore the above analysis is repeated based on the shape factor values of the A-E and A-C samples, which consist of significantly more rocks. These values are plot versus the average elongation values of the A samples in Figure 5-3. As a result of this approach it has been implicitly assumed that the elongation distribution in sample A is representative for the remaining samples of the common parent grading[17].

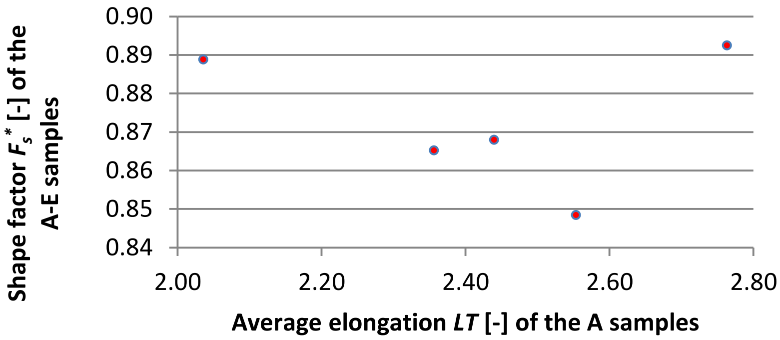

Figure 5-3 - average elongation of the A samples versus the shape factor of the A-E samples

Compared to Figure 5-2, in particular the value of the shape factor of the leftmost data point has changed in Figure 5-3; it has increased approximately 0.03. The value of the shape factor of the remaining four data points just changed slightly by less than 0.01. It is concluded that also based on the shape factor values of the A-E and A-C samples no relation can be distinguished between the value of the shape factor and the sample average elongation.

[17] This implied assumptions to some extent harms the analysis since the influence of elongation on the value of the shape factor is the subject of the analysis.

5.1.2.2 Percentage of high elongated rock

It has been found that on average the individual shape factor value increases for an increase of elongation in paragraph 5.1.1. No such relation has been observed for the value of the shape factor of a grading versus the sample average elongation in subparagraph 5.1.2.1. The relation between the value of the shape factor for gradings and the percentage of 'high elongated' rock is examined in this subparagraph. High elongated rock is referred to as the rock that has an elongation value equal or larger than 3.0. In Figure 5-4 the shape factor values of the A samples have been plotted versus the percentage of high-elongated rock.

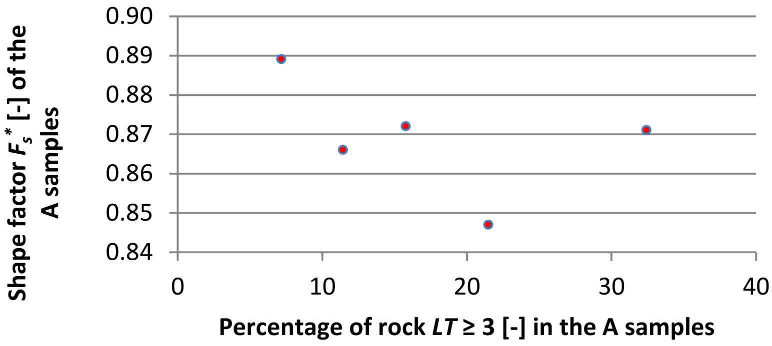

Figure 5-4 - percentage of high-elongated rock $LT \geq 3$ versus the shape factor for the A samples

From Figure 5-4 no relation is discerned between the value of the shape factor and the percentage of high elongated rock. In contrary, fluctuation is observed for the value of the shape factor over the percentage of high elongated rock. As a result the value of the shape factor cannot be estimated based on the percentage of high elongated rock within a sample.

Like in subparagraph 5.1.2.1, the above analysis is repeated based on the shape factor values of the A-E and A-C samples, which consist of significantly more rocks. These values are plot versus the percentage of high elongated rock in the A samples in Figure 5-5.

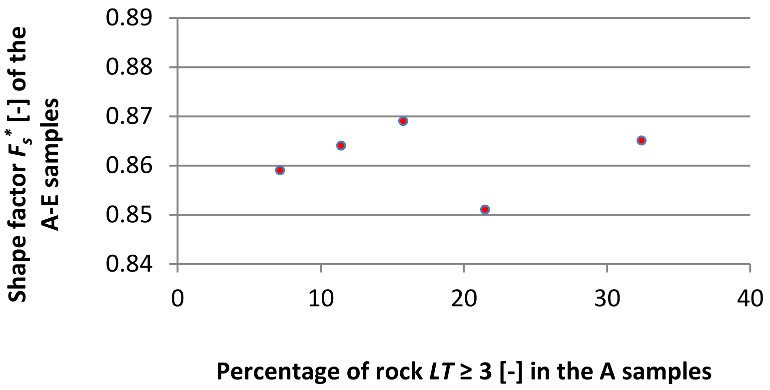

Figure 5-5 - percentage of high-elongated rock LT ≥ 3 in the A samples versus the shape factor of the A-E samples

Compared to Figure 5-4, in particular the value of the shape factor of the leftmost data point has changed in Figure 5-3; it has decreased approximately 0.03. The value of the shape factor of the remaining four data points just changed slightly by less than 0.01. It is concluded that also based on the shape factor values of the A-E and A-C samples no relation can be distinguished between the value of the shape factor and the percentage of high elongated rock in a sample.

5.2 Shape factor versus blockiness

The hypothesis for a relation between the value of the shape factor and blockiness has been theoretically founded in appendix [E]. For an increase of blockiness an increase of the shape factor value is expected. The influence of blockiness on the value of the shape factor however is examined in this section.

5.2.1 Shape factor versus blockiness for individual rocks

In subparagraph 4.1.2.3 the distribution of the individual shape factor has been presented for 969 individual rocks[18]. For each of those rocks also the value for blockiness is available. In Figure 5-6 the individual shape factors have been plotted versus the associated blockiness.

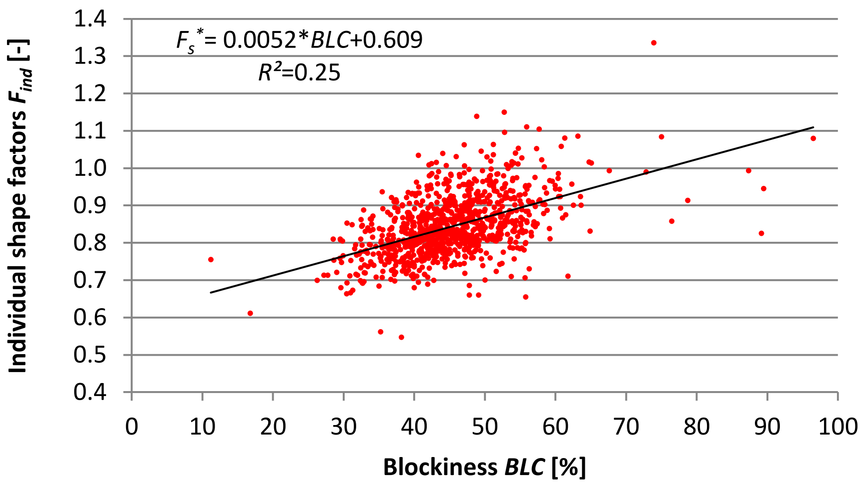

Figure 5-6 - individual shape factor versus blockiness for 969 individual rocks

Recall that the average value of the individual shape factors is 0.844. The standard deviation is 0.083, which is considered relatively large compared to the average value (10%). The blockiness ranges from 11.2% to 96.5%. The average value and standard deviation are 45.2%. and 7.9% respectively. The distribution of elongation was reasonably well represented by means of a Gaussian distribution.

The cloud of data observed in Figure 5-6 is rather scattered. Considering the bandwidths of the scatter, for the upper limit of the band width the value of the shape factor increases for an increase of blockiness. For the lower limit of the band width the value of the shape factor is considered relatively constant over blockiness at an approximate value of 0.65. As a result the data cloud widens for an increase of blockiness. At first glance however, a relation between the value of the shape factor and blockiness for individual rocks is not distinguished.

In Figure 5-6 also a regression line has been included. It shows an increase of the individual shape factor over blockiness. The correlation coefficient, denoted R^2 is 0.249, which implies that the parameters are slightly correlated. The equation of the regression line is given by F_s^*=0.0052*BLC+0.249. For sample A of each grading a similar analysis has been performed, which can be consulted in appendix [G]. Each of those analyses shows an increase of the individual shape factor value for an increase of blockiness, like in Figure 5-6.

[18] Those are the rocks found in sample A of each of the tested gradings.

It is concluded that on macro-scale - considering all data points - a relation is discerned between the value of the individual shape factor and blockiness: *The value of the individual shape factor increases for an increase of elongation at an approximate rate of 0.005 to 1.0.* This finding is in line with the hypothesis developed in appendix [E]. On micro-scale - two subsequent data points - this relation does not hold and should therefore not be applied to individual rocks. The value of the individual shape factor fluctuates too extensively over blockiness to determine the shape factor value for an individual rock.

5.2.2 Shape factor versus sample blockiness

In paragraph 5.2.1 the relation between the shape factor and blockiness has been examined for individual rocks. It has been concluded that only on a macro-scale a relation can be distinguished. On average the value of the shape factor slightly increases for an increase of blockiness. This paragraph focusses on the influence of blockiness on the shape factor of a rock grading. In order to do so, the dependency of the shape factor value on both the average blockiness in the A samples, as well as the percentage of 'high blocky' rock in the A samples has been examined in subparagraphs 5.2.2.1 and 5.2.2.2 respectively.

5.2.2.1 Average blockiness

Based on the five available samples the relation between the shape factor and the average blockiness values is examined in this subparagraph. In Figure 5-7 the data has been plotted.

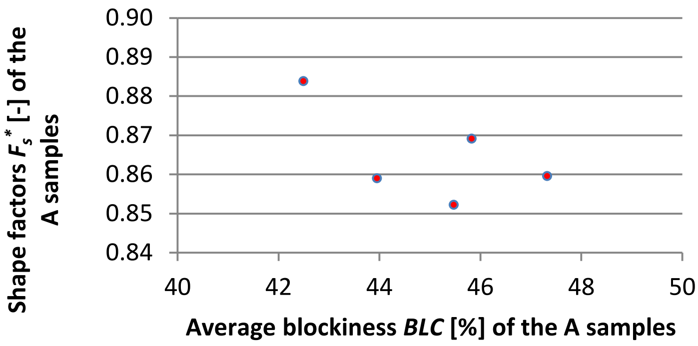

Figure 5-7 - average blockiness versus the shape factor for the A samples

It is concluded that the value of the shape factor fluctuates over the average blockiness values. For an increase of the average blockiness within a sample either an increase or decrease of the value of the shape factor cannot be expected. As a result no clear relation can be discerned between the value of the shape factor and the average blockiness value of a sample.

In paragraph 4.1.1 it has been found that, to assess a reliable value of the shape factor, a sample size of approximately 200-250 rocks is insufficient. Therefore the above analysis is repeated based on the shape factor values of the A-E and A-C samples, which consist of significantly more rocks. These values are plot versus the average blockiness values of the A samples in Figure 5-8. As a result of this approach it has been implicitly assumed that the blockiness distribution in sample A is representative for the remaining samples of the common parent grading[19].

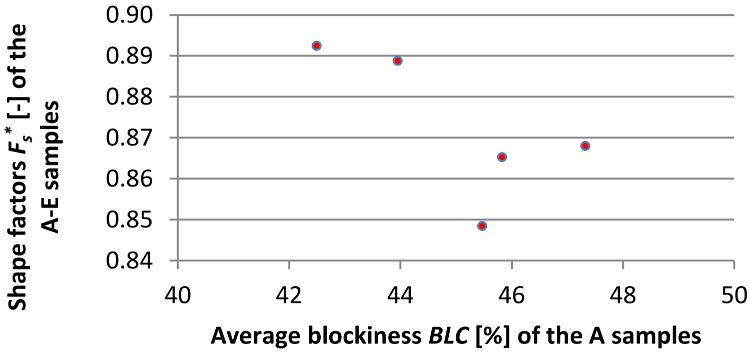

Figure 5-8 - average elongation of the A samples versus the shape factor of the A-E samples

Compared with Figure 5-7, in particular the value of the shape factor of the second left data point has changed in Figure 5-8; it has increased approximately 0.03. The value of the shape factor of the remaining four data points just changed slightly by less than 0.01. It is concluded that also based on the shape factor values of the A-E and A-C samples no relation can be distinguished between the value of the shape factor and the sample average blockiness value.

[19] This implied assumptions to some extent harms the analysis since the influence of elongation on the value of the shape factor is the subject of the analysis.

5.2.2.2 Percentage of rock 50% and 60% blockiness

It has been found that on average the individual shape factor value increases for an increase of blockiness in paragraph 5.1.1. No such relation has been observed for the value of the shape factor of a grading versus the sample average blockiness in subparagraph 5.2.2.1. The relations between the value of the shape factor for gradings and the percentage of rock that has a specific minimum blockiness value is examined in this subparagraph. For a blockiness values of equal or larger than 50% and 60% the results are presented in Figure 5-9 and Figure 5-10 respectively.

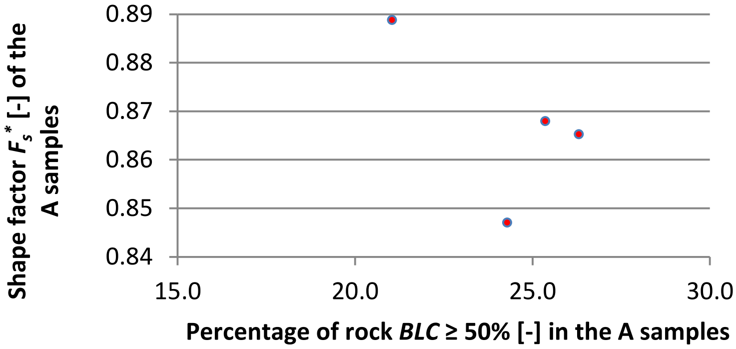

Figure 5-9 - percentage of rock *BLC* ≥ 50% versus the shape factor for the A samples

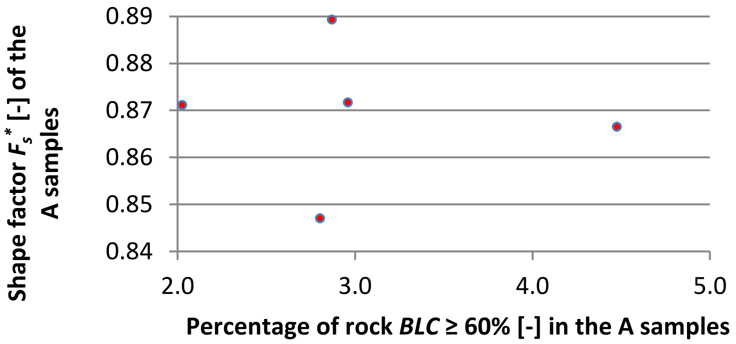

Figure 5-10 - percentage of rock *BLC* ≥ 60% versus the shape factor for the A samples

From neither Figure 5-9 nor Figure 5-10 a relation is discerned between the value of the shape factor and the percentage of rock with a blockiness value equal or larger than 50% and 60% respectively. In contrary, fluctuation is observed for the value of the shape factor over the percentage of the specific blockiness values. As a result the value of the shape factor cannot be estimated based on the percentage of rock in a sample that has specific blockiness.

Like in subparagraph 5.2.2.1, the above analysis is repeated based on the shape factor values of the A-E and A-C samples, which consist of significantly more rocks. These values are plot versus the percentage of high elongated rock in the A samples versus the percentage of rock that has a specific minimum blockiness value. For blockiness values equal or larger than 50% and 60% the results are presented in Figure 5-11 and Figure 5-12 respectively.

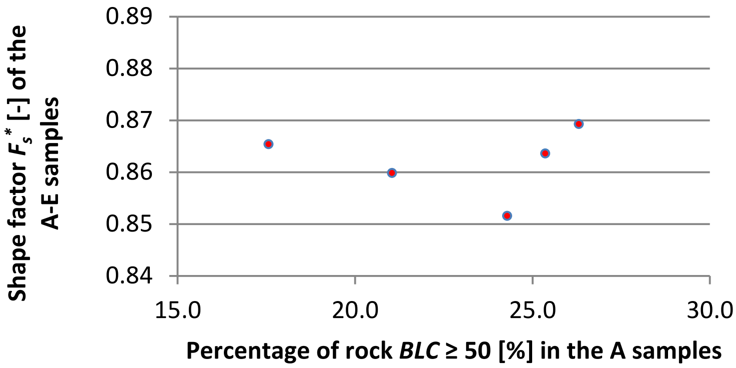

Figure 5-11 - percentage of rock *BLC* ≥ 50% in the A samples versus the shape factor of the A-E samples

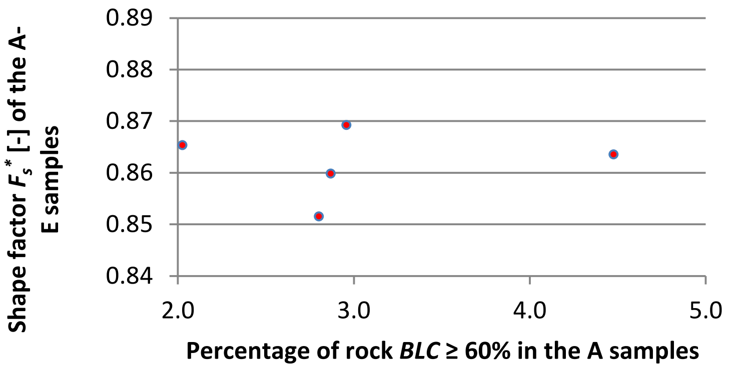

Figure 5-12 - percentage of rock *BLC* ≥ 60% in the A samples versus the shape factor of the A-E samples

From neither Figure 5-11 nor Figure 5-12 a relation is discerned between the value of the shape factor and the percentage of rock with a blockiness value equal or larger than 50% and 60% respectively. In contrary, fluctuation is observed for the value of the shape factor over the percentage of the specific blockiness values. As a result the value of the shape factor cannot be estimated based on the percentage of rock in a sample that has specific blockiness.

5.3 Shape factor versus average rock density

The influence of the average rock density on the value of shape factor is examined in the present section. In order to do so the average rock density of the tested gradings have been ranked in order of increasing value in Table 5-1. The top three gradings consisted of Gneiss rock. The density of these gradings is in the approximate range of 2600-2650 kg/m³. The bottom three gradings consisted of a mixture of Basalt(ic) and Gneiss/Granite rock. The density of these gradings is in the approximate range of 2700-2750 kg/m³. This observation is explained by the fact that Basalt(ic) rock is usually denser than Gneiss and Granite rock.

Table 5-1 - average grading density and expected shape factor

	Grading	Density ρ [kg/m³]	F_s^* [-][20]
↓ Denser	2-5 inch	2616	0.875
	22-90 mm	2653	0.860
	2-8 inch	2657	0.859
	5+ inch	2724	0.852
	1-5+ inch	2736	0.867
	1-5 inch	2748	0.876

It is concluded that the expected value of the shape factor fluctuates over rock density. Comparing the gradings in the range of 2600-2650 kg/m³ to the gradings in the range of 2700-2750 kg/m³ it is found that the minimum and maximum values for the shape factor are practically equal. This finding can be observed clearly also in Figure 5-13. As a result, the value of the shape factor is considered independent from rock density. The examined density range rather limited. A relation between average rock density and the value of shape factor cannot be ruled out completely for wider density ranges.

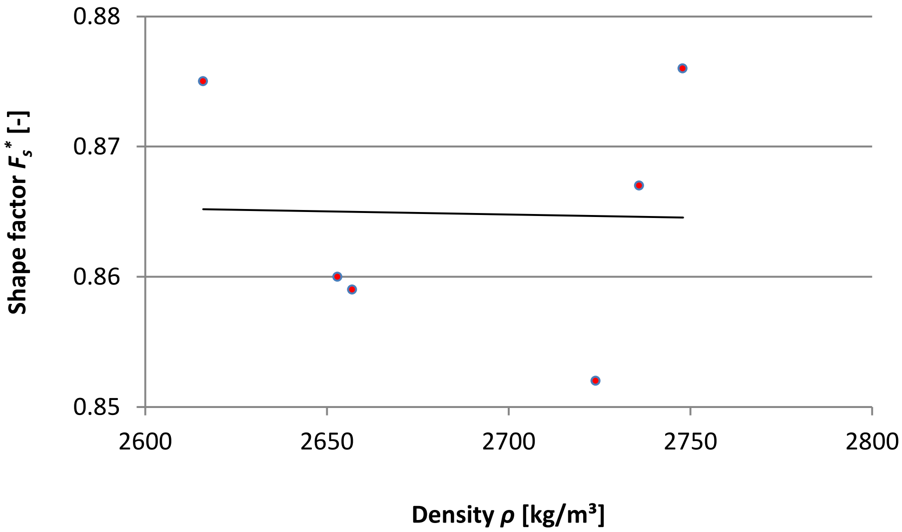

Figure 5-13 - grading average rock density versus the expected value of the shape factor

[20] The expected values have been presented as these are the most reliable shape factor values for the tested gradings.

5.4 Shape factor versus coarseness

The influence of coarseness on the value of the shape factor is examined in the present section. This has been done for individual rocks and gradings in paragraphs 5.4.1 and 5.4.2 respectively.

5.4.1 Individual rocks

For 969 rocks the nominal diameter is plotted versus the individual shape factor in Figure 5-14. The data is also approximated by means of linear regression.

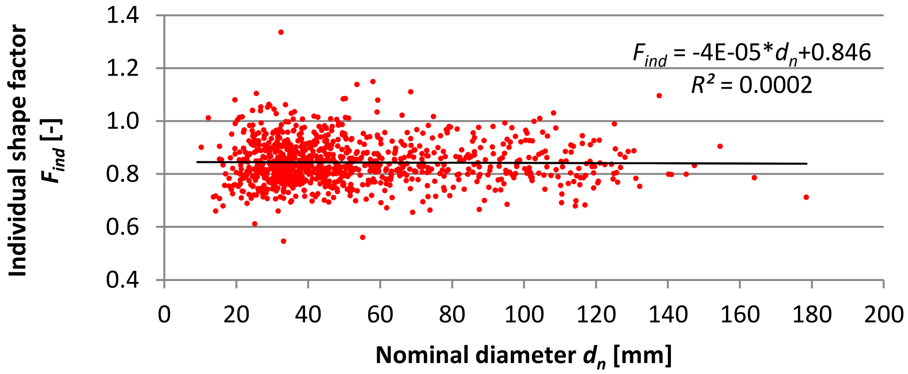

Figure 5-14 - nominal diameter versus individual shape factor

It is concluded that on average the individual shape factor is rather constant over coarseness at an approximate value of 0.84. Furthermore, it is found that the individual shape factor is uncorrelated with the nominal diameter.

5.4.2 Gradings

For 24 samples[21] the value of the shape factor is plotted versus the coarseness in Figure 5-15. The data is also approximated by means of linear regression.

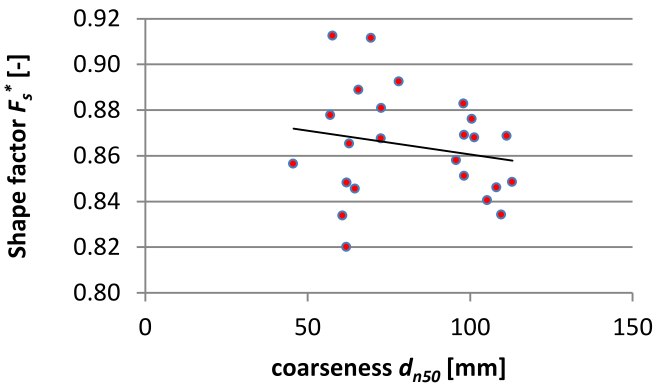

Figure 5-15 - coarseness versus the shape factor for all individual samples

It is concluded that on average the value of the shape factor slightly decreases for an increase of coarseness. The data cloud however is rather scattered. Furthermore, it is observed that for the coarser gradings (d_n>90) the value of the shape factor is converging to an approximate value of 0.86.

[21] This includes the samples A, B, C, D, and E of the 22-90 mm, 2-5 inch and 2-8 inch gradings and the samples A, B and C of the 1-5 inch, 5+ inch and 1-5+ inch gradings.

In sections 4.1 and 4.3 it has been concluded that per sample, both the shape factor as well coarseness considerably vary over the tested samples. The above analysis is repeated therefore based on the A-E and A-C samples, which consist of considerably more rocks, yielding more accurate and thus more reliable shape factor and coarseness values for the tested gradings. In Table 5-2 those values are listed per gradings in order of increasing coarseness.

Table 5-2 - coarseness and shape factor values of the A-E and A-C samples

	Grading	Coarseness d_{n50} [mm]	F_s^* [-]
↓ Coarser	1-5 inch	61	0.884
	22-90 mm	63	0.859
	2-5 inch	68	0.869
	2-8 inch	101	0.859
	1-5+ inch	103	0.861
	5+ inch	110	0.852

The smallest and largest shape factor value are found for the coarsest and finest gradings respectively. For the gradings of intermediate coarseness, the shape factor is relatively constant at an approximate value of 0.86. Note that the shape factor value of 0.859 is observed for both the 22-90 mm grading and the 2-8 inch grading. The coarseness of these gradings however significantly differs, viz.: 63 mm and 101 mm respectively. The shape factor values are plotted versus the coarseness in Figure 5-16. The data is also approximated by means of linear regression.

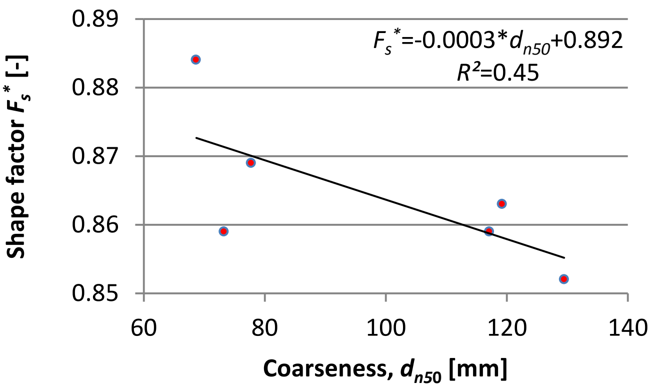

Figure 5-16 - coarseness versus shape factor for the combined gradings A-E and A-C

The equation for the regression line in Figure 5-16 is given by: F_s^*=-0.0003*d_{n50}+0.892, with d_{n50} in mm. However, fluctuations of the shape factor value over coarseness can be clearly observed. The formula therefore is not to be used to calculate the value of the shape factor for a specific given coarseness value.

It has been concluded that on average the value of the shape factor decreases for an increase of coarseness. The relation between both parameters however is rather weak and could not be represented by a clear formula.

5.5 Shape factor versus grading width

The influence of grading width on the value of the shape factor is examined in the present section. For 24 samples[22] the value of the shape factor is plotted versus the grading width in Figure 5-17. The data is also approximated by means of linear regression.

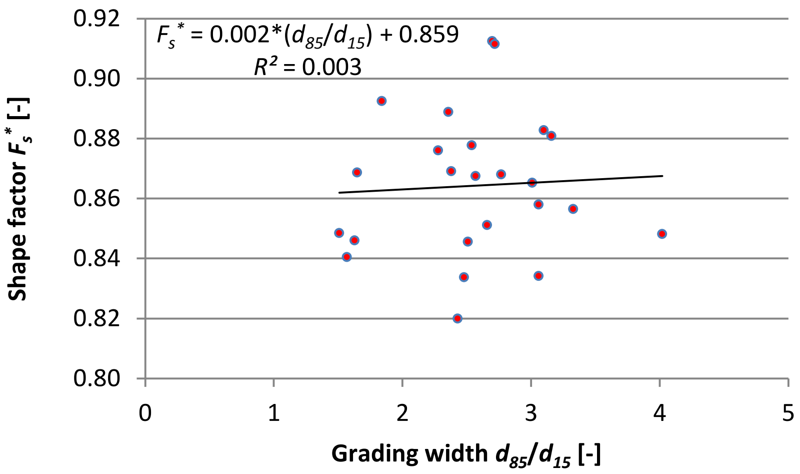

Figure 5-17 - grading width versus the shape factor for all individual samples

It is concluded that on average the value of the shape factor slightly increases for an increase of grading width. The data cloud however is rather scattered. In sections 4.1 and 4.4 it has been concluded that per sample, both the shape factor as well as grading width considerably vary over the tested samples. The above analysis is repeated therefore based on the A-E and A-C samples, which consist of considerably more rocks, yielding more accurate and thus more reliable shape factor and grading width values for the tested gradings. In Table 5-3 those values are listed per gradings in order of increasing grading width.

Table 5-3 - grading width and the shape factor values of the A-E and A-C samples

	Grading	Width d_{85}/d_{15} [-]	F_s^* [-]
← Wider	5+ inch	1.6	0.852
	1-5+ inch	2.0	0.863
	22-90 mm	2.5	0.859
	2-8 inch	2.9	0.859
	1-5 inch	3.0~~0~~	0.884
	2-5 inch	3.0~~4~~	0.869

The smallest value for the shape factor is observed for the narrowest grading. The largest value for the shape factor is observed for the second widest grading. The grading widths of the second widest and widest grading however are practically equal. Furthermore, for the intermediate wide gradings, the value of the shape factor is relatively constant. Note that the shape factor value of 0.859 is observed for both the 22-90 mm grading and 2-8 inch grading. The width of these gradings however of these gradings however differs, viz.: 2.5 and 2.9 respectively. The shape factor values are plotted versus the grading widths in Figure 5-18. The data is also approximated by means of linear regression.

[22] This includes the samples A, B, C, D, and E of the 22-90 mm, 2-5 inch and 2-8 inch gradings and the samples A, B and C of the 1-5 inch, 5+ inch and 1-5+ inch gradings.

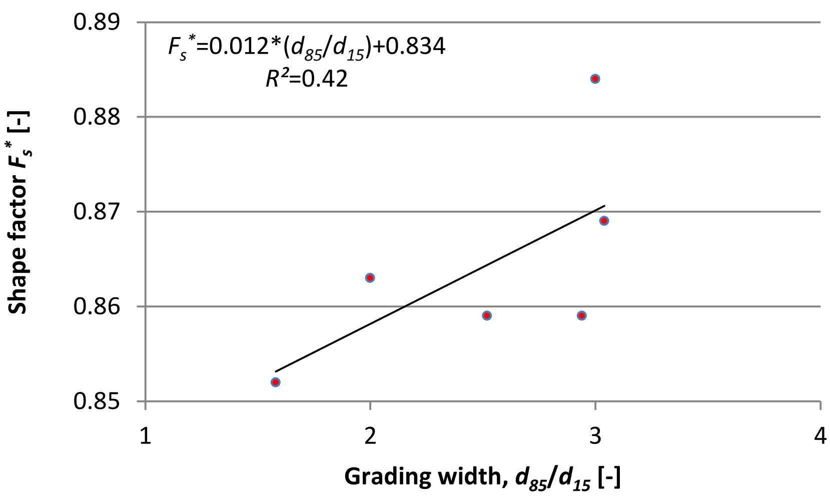

Figure 5-18 - grading width versus the shape factor for the combined gradings A-E and A-C

The equation for the regression line in Figure 5-18 is given by: F_s^*=-0.012*(d_{85}/d_{15})+0.892. However, fluctuations of the shape factor value over grading width can be clearly observed. The formula therefore is not to be used to calculate the value of the shape factor for a specific given grading width value.

It has been concluded that on average the value of the shape factor increases for an increase of grading width. The relation between both parameters however is rather weak and could not be represented by a clear formula.

6 Discussion

Throughout this research project many - sometimes contradicting - findings are observed. In the present chapter those findings are reconsidered and integrally explained.

6.1 The value of the shape factor

The reassessed value 0.86 for the shape factor deviates relatively little from the commonly applied value 0.84. To be more precise, the standard deviation of the reassessed value is 0.024. It is concluded that the commonly applied value of 0.84 is within one standard deviation of the newly derived value 0.86.
The implications of the use of either 0.84 or 0.86 in hydraulic engineering practice as a result will remain limited. However, the insight in the variability of the shape factor value as well as its dependency on parameters that describe quarry rock is enhanced by means of the present report. This has resulted in a solid justification for the value 0.86, which is lacking for the value 0.84. It is therefore recommended to apply the newly derived value **0.86** for the value of the shape factor.

6.2 Shape factor versus elongation and blockiness

The influence of rock shape on the value of the shape factor, in terms of both elongation and blockiness, has been analysed for both individual rocks and rock gradings. For individual rocks it has been found that on average, the shape factor value increases for an increase of both elongation as well as blockiness, which is in accordance with the hypothesis formulated in appendix [E]. However, the observed relation is rather weak and is moreover frustrated considerably as a consequence of extensive fluctuations of the individual shape factor, both over elongation and blockiness.

In contradiction to the findings for individual rocks, for rock gradings relations between the value of the shape factor and either elongation or blockiness have not been found. This observation can be explained by considering the determination method of the shape factor for rock gradings. Recall that the definition of the shape factor for rock gradings is given by the ratio of the median nominal diameter and the median sieve diameter. Both parameters are related to the fifty percent cumulative mass exceedance limit. This means that the median nominal diameter is calculated based on the particular rock that represents the median mass in the grading[23]. Note that the determination of the median nominal diameter as a result is not influenced by the shape of this particular rock.
Furthermore, the median sieve diameter is defined as the mesh width of the square sieve that should be applied to separate fifty percent of the mass of the grading. Since both elongation and blockiness are distributed uniformly over the sieve fractions (section 4.2), the median sieve diameter represents a median rock size and shape. It is concluded that for rock gradings, the influence of the shape on the value of the shape factor is less substantial both in terms of the median nominal diameter and median sieve diameter compared to the shape factor of individual rocks. As a consequence, the value of the shape factor for rock gradings converges to a median value.

[23] Recall that this rock accumulates fifty percent of the grading, provided that the rocks in the grading have been ranked in order of increasing mass.

For the tested gradings, dependency of the shape factor value on either the average value of elongation or the percentage of high elongated rock in a grading, has not been observed. The same holds for blockiness. For rock gradings consisting of a significantly higher percentage of relatively elongated and/or blocky rock compared to the tested grading however, an increase of the shape factor cannot be ruled out. As a result of the increase of the average elongation or blockiness, or the percentage of rather elongated and/or blocky rock, in general the mass of the individual rocks and thus the value of the (median) nominal diameters. Since the sieve diameters remain the same (sections 2.4 and 4.2), the ratio of both parameters; the shape factor, will increase value.

7 Conclusions

In the present chapter the most important conclusions of the research project are drawn. The findings on the value and variability of the shape factor are presented in section 7.1. The dependency of the shape factor value on elongation, blockiness, density, coarseness and grading width are discussed in sections 7.2 to 7.5.

7.1 The value of the shape factor

The value of the shape factor has been analysed both for gradings and individual rocks. For gradings it has been concluded that the value of the shape factor is not constant. Based on 21 samples the value roughly fluctuates between 0.82 and 0.91. The value of the shape factor is approximated reasonably well by means of a Gaussian distribution. The average value and standard deviation are 0.86 and 0.024 respectively.
For individual rocks the shape factor is even more variable. Based on 969 individual rocks the value fluctuates between 0.65 and 1.10. Also the value of the individual shape factor is approximated reasonably well by means of a Gaussian distribution. The average value and standard deviation are 0.844 and 0.083 respectively. It is furthermore concluded that the individual shape may exceed the value of 1.0, which means the nominal diameter exceeds the sieve diameter.

The value and variability of the shape factor has been assessed based on rock samples that consisted of 200-250 rocks. This sample size is prescribed for sieve tests in the euro code regulations NEN-EN 13383-2 (2013) and had been assumed applicable also for the determination of the shape factor value. In paragraph 4.1.1 however, it has been found that the value of the shape factor considerably varies over the rock samples.
In general, it holds that the accuracy and thus reliability of the determination of the shape factor value increases for an increase of sample size. Based on samples consisting of approximately 1000 rocks, sufficiently accurate and thus reliable shape factor values have been found. Note that still the rock should be extracted from various parts of the stockpile. The value of the shape factor has not been assessed based on rock samples of intermediate size. In possible subsequent research the sample size and sampling techniques could be further optimized.

7.2 Elongation and blockiness

From a theoretical point of view it has been expected that the value of the shape factor increases for both an increase of elongation as well as blockiness. For individual rocks this hypothesis is partially confirmed. On average a slight increase of the shape factor value is clearly observed for an increase of both elongation and blockiness. These relations are formulated by means of the equations $F_s^*=0.012*LT+0.814$ and $F_s^*=0.0052*BLC+0.609$ respectively. The value of the individual shape factor however considerably fluctuates over both elongation and blockiness. It is therefore recommended not to apply above formulae to calculate the value of the individual shape factor.
No influence of either elongation or blockiness is observed on the value of the shape factor for rock gradings. For rock gradings consisting of a relatively high percentage of rather elongated or blocky rock, an increase of the shape factor value cannot be ruled out.

7.3 Rock density

It has been concluded that the determination of the shape factor value is rather insensitive to small deviations of rock density. Moreover, it has been found that the shape factor is practically constant over rock density in the range of 2600-2750 kg/m³, at an approximate value of 0.86. It has been concluded that it is unlikely that the value of the shape factor has a significantly different value for rock densities outside the range of the tested gradings.

7.4 Coarseness

For individual rocks it has been concluded that the shape factor is independent from its coarseness, in terms of the nominal diameter. In the range of 20 to 150 mm the individual shape factor has an approximate value of 0.84. For rock gradings, the influence of coarseness, in terms of the median nominal diameter on the value of the shape factor has remained unclear. Findings have been observed that indicate either a decrease of the shape factor value for an increase of coarseness, or a rather constant shape factor value over coarseness. Nonetheless, it has been concluded that the fluctuations of the shape factor value remain rather limited over the tested coarseness range of 60 to 110 mm, viz.: 0.88 to 0.85.

It has been concluded that the shape factor is not constant within a grading. By means of examination of the ratio of the nominal diameter and sieve diameter for various cumulative mass percentages, it has been found that 'the' shape factor value decreases for an increase of coarseness. The observed relation can be approximated by means of the equation: $F_s^*=-0.00075*CMP+0.898$, Where *CMP* is the cumulative mass percentage [%].

7.5 Grading width

The dependency of the shape factor value on the gradings width, in terms of the ratio d_{85}/d_{15} has remained unclear. Findings have been observed that indicate either an increase of the shape factor value for an increase of grading width, or a rather constant shape factor value over grading width. Nonetheless, it has been concluded that the fluctuations of the shape factor value remain rather limited over the tested grading width range of 1.5 to 3.0, viz.: 0.85 to 0.88.

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Considering above findings integrally, it has been concluded that the influences on the shape factor remain rather limited. The representation of the shape factor by means of a Gaussian distribution, with an average value and standard deviation of 0.86 and 0.024 respectively, these influences are effectively accounted for.

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8 Recommendations

Recommendations for subsequent research to further enhance the knowledge on the value and variability of the shape factor are given in the present chapter.

8.1 Measurement errors

The basis of the present research project has been measurement data. Unfortunately, measurements will always contain errors. Various origins that have caused these errors can be distinguished. Firstly, the manual character of most measurements, in particular concerning the shape tests. The manual placement of the rocks in the calliper and blockiness-meter to some extent is arbitrary. The same holds for the manually fitting of the rocks in the sieves. Second, is the visual character of measuring. Except weighing, all measurements have been performed by analogously reading the measurement tools. Both the mesh width dimension of the square sieves as well as the calliper and blockiness-meter have been read by means of a ruler. Lastly, the measurement tools have been subject to wear and tear, in particular the blockiness-meter. The structure of the tool, consisting of wooden strips and screwed joints have encountered inflection as well as loosening.
It has been concluded that the blockiness-meter is the most important source of measurement errors. In order to enhance the accuracy of this tool, it is recommended to improve its structure. The wood is advised to be replaced by metal and the joints should be manufactured from integral studs. The resulting structure is significantly more rigid.

In case it is decided to perform subsequent research however, it is recommended to consider the potential of remote sensing techniques to three-dimensionally observe rock shapes. In combination with computational software the dimensions of the smallest enclosing orthogonal box, as well as the length and thickness of the rocks can be digitally recalculated. Moreover, various other parameters that describe the rock, such as the rock volume and the sieve diameter can be analysed integrally by means of this technique. It is expected that besides measurement accuracies, also the efficiency of the testing will be enhanced in terms of time consumption.

8.2 Untested gradings

The conclusions on the value of the shape factor drawn in this report, are based on six gradings only. The represented range of rock types, in terms of shape, density and grading specifications, therefore is relatively limited. According to the test results, significant changes in the value of the shape factor for slightly different gradings are not expected. For significantly different gradings however, the conclusions on the value of the shape factor presented in this report are expected less applicable.

It is recommended therefore, to perform subsequent research on gradings that differ significantly from the gradings analysed in this research project. The main interest includes very coarse gradings, in the heavy class (300+ kg), as defined in the Rock Manual (2007). In order to do so, despite nearly impracticable, the determination of the sieve diameter for very large rocks is inevitable. Furthermore, for gradings consisting of a significantly higher percentage of relatively elongated and/or blocky rock, compared to the tested gradings, a significant increase of the shape factor value can be expected. It is therefore recommended to examine the value of the shape factor for such gradings.
The interests in the shape factor value for both very coarse gradings, as well as gradings consisting of a relatively high percentage of rather elongated and/or blocky rock can be included in testing uncrushed rock. In general the crusher settings have a large effect on the eventual shape of the quarry rock. Besides the crushing process, the eventual shape of quarry rock is to a large dependent on the type of the rock in terms of its petrology. It is therefore recommended to examine the shape factor for quarry rock for rock of different origins, compositions and structures.

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List of symbols

Symbol	*Unit*	*Definition*
BLC	[%]	blockiness
CMP	[%]	cumulative mass percentage
d	[m]	sieve diameter
$d_{\%}$	[m]	sieve diameter at specific *CMP*
d_{50}	[m]	median sieve diameter
d_n	[m]	nominal diameter
$d_{n\%}$	[m]	nominal diameter at specific *CMP*
d_{n50}	[m]	median nominal diameter
d_s	[m]	sieve diameter
d_{sv}	[m]	virtual sieve diameter
F_{ind}	[-]	individual shape factor
F_s	[-]	primitive shape factor
$F_{s\%}^*$	[-]	shape factor at specific *CMP*
F_s^*	[-]	shape factor (for a grading)
l	[m]	length
L	[m]	maximum length of an individual rock
LT	[-]	elongation
m	[kg]	mass
R^2	[-]	correlation coefficient
T	[m]	thickness of an individual rock
V	[m³]	rock volume
X	[m]	largest dimension of smallest enclosing orthogonal box
Y	[m]	median dimension of smallest enclosing orthogonal box
Z	[m]	smallest dimension of smallest enclosing orthogonal box
ρ	[kg/m³]	rock density
#	[-]	number of rocks

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A. Measurement reports

A.1 IJmuiden

Rock measuring campaign 1

IJmuiden, the Netherlands 29/7 – 14/8

A.1.1 Introduction - scope

The present document includes the report on tests performed at the rock transhipment quay 'De Branding' in IJmuiden, the Netherlands from 29th July until August 14th. The tests are of interest for the graduation project 'Influences on the shape factor'.

The IJmuiden testing campaign was first in a series of in total three measurement campaigns. The second campaign will be held in Slovag, Norway and the third in Zuilichem, the Netherlands. The testing for this project generally consists of sieve and shape tests.

A.1.2 Test report

Tests have been performed on three rock gradings (22-90 mm, 2-5 inch and 2-8 inch) from three different stockpiles. The tests for these grading for the greatest part were performed conform the same procedure. Therefore this section treats the tests per test phase and not per tested grading.

A.1.2.1 Sampling

According to the European Standard, NEN EN 13383 rock is extracted from six different locations with a wheel loader from each stockpile. The rock was dumped on concrete paved spots at the quay terrain to actually create three new 'sample stockpiles'. With a spade the tip of the those small stockpiles was removed to be able to extract the rock required for the sample from the core. Also a small quantity of rocks is selected from the sides of the stockpile to add some larger rocks. In this way well-mixed samples are created that is representative for the grading of the base stockpiles.

In Figure A.1-1 an example is of sampling stockpile, the absence of the tip of the pile is clearly visible. In the background several stockpiles can be distinguished.

Figure A.1-1 - stockpile (back) and sampling stockpile (front)

For each of the three examined gradings 5 samples were taken, each containing at least 200 rocks to obtain reliable sieve curves (in accordance with the NEN-code). 4 of the 5 samples can be regarded as control samples. These are intended to examine the variability on the results introduced by the sampling itself. As three different gradings have been tested, ultimately 15 samples were examined.

A.1.2.2 Sieving

Each of the 15 samples has been sieved by application of so-called steel-rod sieves, depicted in Figure A.1-4. After sieving the rocks of each sample were washed to remove attached dirt. The first sample of each of the three different gradings was numbered for identification as for these rocks also shape tests were performed. Numbers increase with decreasing sieve size fraction.

A.1.2.3 Weighing

Each rock of each of the 15 samples was individually weighed. Also, for all numbered rocks the submerged weight is to be determined. For this reason a bucket filled with water was put on a balance and weighed with and without submerged rock. Via the Archimedes principle one is able to recalculate the submerged weight of the rocks and ultimately the volume of the rock. As water is attached to the surface of each submerged rock, the quantity of water in the bucket decreases after removal of each rock from the bucket. Therefore the weight of the bucket filled with water without submerged rock is recorded before submersion of each rock. For submersion three wire 'containers' of different sizes were constructed. One has to correct for these containers, the submerged weight of these containers is therefore also determined. In Figure A.1-2 the submersion of a rock is depicted.

Figure A.1-2 submersion of a rock

A.1.2.4 Shape measuring

On all numbered rocks shape tests have been performed. The length, thickness and smallest enclosing dimensions width X, depth Y and height Z were measured and recorded. In order to do so a calliper and so-called 'blockiness-meter' were applied, see Figure A.1-6.

Figure A.1-3 measuring the smallest enclosing rectanguloid of a rock

A.1.3 Equipment

A.1.3.1 Sieves

In Figure A.1-4 the sieve sizes applied are depicted. From bottom to top the sieve sizes are: 31.5, 45, 63, 90, 125, 180 and 250 mm.

Figure A.1-4 sieving setup

A.1.3.2 Submerging container

For submersion three containers of different sizes have been applied, the smallest and the biggest one are depicted in Figure A.1-5.

Figure A.1-5 submersion containers

A.1.3.3 Shape measuring tools


Figure A.1-6 left: caliper, right: blockiness-meter

A.1.3.4 Balance

The balance used in all experiments is depicted in Figure A.1-7. The apparatus measured the in grams accurate and has an capacity of 25 kg. The error of the balance was checked by comparison with reference weights and amounted maximally 1 gram.

Figure A.1-7 balance

A.2 Slovag

Rock measuring campaign 2

Slovag, Norway 19/8 – 27/8

A.2.1 Introduction - scope

The present document includes the report on tests performed in the Yeoman Halsvik quarry in Slovag, Norway from August 19th until August 27th. The tests are of interest for both the graduation project 'Influences on the shape factor' and the EPC offshore windmill project 'Gemini'. The tests were performed in collaboration with Rutger Lieverse, trainee at Van Oord Offshore.

In respect to the graduation study the Slovag testing campaign was second in a series of in total three measurement campaigns. The first campaign in this series was performed in IJmuiden, the Netherlands, and the third will be held in Zuilichem, the Netherlands. The testing for this project generally consists of sieve and shape tests. Those tests are also of interest for the Gemini project. Besides, specific density tests and the mixing process of gradings was of interest for this project specifically. Thanks to the large overlap of interests of both projects it was decided to combine the tests into one single measurement campaign. Although, in order to improve overview, in this document the specific Gemini tests are reported separately from the tests relevant for the graduation project.

A.2.2 Test report

A.2.2.1 Test 1

Sampling

According to a report by Harro Vaags, for the Gemini grading a minimum of 400 kg of rock is required to obtain reliable test results. The Gemini grading can be considered as a special since it is a mixture of a 1-5 inch material stockpile and a 5+ inch stockpile in a ratio of 1 to 4. Obviously this ratio is also applied also for the sample which yields 80 kg 1-5 and 320 kg 5+material is required per test. Nonetheless, the sample portions of both gradings were kept separate to be able to investigate the mixing process, see paragraph 0.

A wheel loader provided us with 1-5 rock which was put into buckets and weighed on a balance in the laboratory immediately. The total weight of the rock from the wheel loader amounted 229 kg. Since only 80 kg of this material was required for the test sample, the total weight was reduced in accordance to NEN EN 13383. In order to do so the rock was put on a canvas in a dike shape and 65 per cent was removed. Also the wheel loader provided us with 743 kg of 5+ material, which in the same was reduced to a quantity of 320 kg. The surplus of rock was directly returned to the stockpile by the wheel loader. In Figure A.2-1 the sample reduction method is depicted, please note these are photos of test 2-3.

Figure A.2-1 sample reduction on 5+ material (test 2-3)

Sieving and weighing

The next step consisted of performing a sieve analysis on both the 1-5 and 5+ material. An example of the resulting fractions is depicted in Figure A.2-2 After sieving the rocks were washed to remove possible attached dirt. Each individual rock was given a unique number for identification, to assure all measured data is dedicated to the right rocks. The rock numbers increase with decreasing sieve sizes. Each individual rock was then weighed in surface dry condition. Furthermore also the submerged weight of the rocks was determined. The data obtained will be used to calculate the apparent density and volume of each individual rock.

Figure A.2-2 sieve fractions

Shape tests

Finally the shape of each rock was investigated by measuring of its length L, thickness T, and smallest enclosing rectangular dimensions width X, depth Y and height Z. This has been done by application of a calliper and a blockiness-meter for which is referred to chapter A.2.3.

A.2.2.2 Test 2 and 3

In general tests 2 and 3 are performed in a similar procedure to test 1. The most important differences are discussed given in this section.

Sampling

The 1-5 material required for test 2 and 3 was taken from just 1 trip with the wheel loader. The same holds for the 5+ material for test 2 and 3. Note that the same stockpiles as in test 1 were used! Those trips provided 531 kg 1-5 and 723 kg 5+ material. After sample reduction 160 kg of 1-5 and 640 kg of 5+ material was reserved for test 2 and 3. The eventual samples were then created simply by halving those quantities.

During sieving it already appeared the samples for test 2 and 3 consisted of a significantly larger fraction of fines. As a result significantly more rocks were expected to occur in the samples of test 2 and 3. Therefore it was decided to apply a 25 mm. sieve in addition compared to the test 1. In this way the finest material was caught apart to save time. The 25 passing fraction has been treated as 'rest'.

Shape tests

In test 2 and 3 no shape tests were performed. In the IJmuiden measuring campaign and during Slovag test 1 it was learned these tests take a considerable amount of time; approximately 20 man hours for 200 rocks (LT and Blockiness). It is assumed the shape tests in test 1 are sufficient to well enough represent the variety of rock shapes occurring in the stockpile. Since no shape tests were performed, identification of the rocks was not necessary and therefore also not performed in these tests.

A.2.2.3 Additional Gemini tests

In brief the tests performed for the Gemini project specifically are discussed in this section. The Gemini project requires rock that have an average specific density of 2950 kg per cubic metre.

Categories

The highest interest of the testing was to investigate whether or not the Yeoman Halsvik quarry is able to provide rock with an average specific density of 2950 kg/m³. The quarry claims they can achieve this goal by a delivery of special rock type, referred to as 'Black Rock'. However the rock face containing the black rock material also contains different, less heavy types of rock. It is therefore important to get insight in the rate of occurrence of the different types of rock. This has been done by setting up a category system and visual classification of the rock. All individual rocks were dedicated to one of the categories in the list beneath. Or in case of inhomogeneous material in multiple categories.

- Black Rock
- Grey Pink 'Shaded'
- Pink Whitish 'Layered'
- Black Pinkish 'Layered'
- Black and White, 'Dotted'
- White with Black 'Stripes'
- Complete White 'Cristal'

The classification of the rock has been performed by visual comparison with the rocks depicted in Figure A.2-3.

Figure A.2-3 rock categories

Specific densities

By determination of the specific density of all the above categories on is able to calculate the average density of the entire sample. Moreover one is able to randomly pick 10 rocks (by computer) and recalculate the specific density of such a sample numerous times. In addition, for all rocks that passed the 90 mm sieve and were kept on the 45 mm sieve also the specific density was calculated. In this way the specific densities of the categories were determined by taking the average of the rocks available in those categories.

For determination of the specific density of rocks the European Standard NEN EN 13383, clause 8 is applied. In addition to the experiments discussed in section A.2.2.1 and A.2.2.2 also the oven-dried mass of the rocks concerned was determined. The rocks were kept in the oven for a minimum duration of 2 hours at a constant temperature of 120 degrees Celsius.

Mixing of gradings

The black rock contemplated for the Gemini project is produced in standardly in a 1-5 and 5+ grading. The grading envelope for the Gemini project however requires mixing of rock from those different stockpiles. The quarry claims, via a computer tool, they can answer the required envelop properties by mixing of the rock from both stockpiles in a ratio of 1 to 4. To investigate this mixing process during this test campaign samples were taking in this ratio also. In this way one is now able to check 'by hand' whether the determination of the mixing ratio by computer tool indeed yields the required envelope.

Shape tests

For the FFPV (Flexible Fall Pipe Vessels) of Van Oord Offshore it is of high concern what rock sizes could occur in the grading. Too large rocks fed into the bucket system of the fall pipes they can cause blocking, clogging and ultimately damage. It is therefore important to get insight in the shape of the larger rocks in detail. In order to do so the largest available rocks were collected from the coarsest stockpile at the quarry by visual selection. The length, thickness and smallest enclosing boxes dimensions of these rocks was recorded in a separate data sheet.

A.2.3 Equipment

A.2.3.1 Sieves

In all tests drum sieves of sizes 31.5, 45, 63, 90 and 125 mm were applied for sieving the 1-5 samples. In test 3 also the drum sieve of size 25 mm was used to take out the fines and be able to treat them as rest fraction. For the 5+ samples of all three tests steel plate sieves of sizes 63, 90, 125, 150, 180, 200, 250 and 300 mm were applied. In this range the 150 and 200 mm sieves are no standard ones. These are added for the Gemini project grading envelope requirements. In Figure A.2-4 a drum sieve setup is depicted in the left panel and the steel plate sieves are depicted in the right panel.


Figure A.2-4 left: drum sieve setup, right: steel plate sieves

A.2.3.2 Shape measuring tools

In order to determine the length and thickness of the rocks simply a calliper, depicted in Figure A.2-5 (left panel) is applied. For the determination of the width, depth and height of the rocks a so-called blockiness-meter was constructed. It consists of a framework of laths that can be slid across each other to be fit around the rock examined. The blockiness-meter is depicted in Figure A.2-5 (right panel).


Figure A.2-5 left: calliper, right: blockiness-meter

A.2.3.3 Balances

To weigh the rocks, two different balances were applied, see Figure A.2-6. The balance depicted in the left panel was applied for the determination of the individual rock masses, oven dried masses and submerged weights. This balance displayed the mass in grams accurate and had a capacity of 20 kg.
The balance depicted in the right panel was applied for weighing of the total volume of rock delivered by the wheel loader. Furthermore this balance was used for the rocks that were having a mass beyond the capacity of the smaller balance or required a larger (and thus heavier) bucket of water for the submersion experiment. This balance displayed the mass in 5-hundreds of kilos accurate and had a capacity of over 100 kg.

Figure A.2-6 left: low capacity balance, right: high capacity balance

B. Photos

B.1 IJmuiden

B.1.1 Gradings

Figure B-1 - grading 22-90 mm

Figure B-2 - grading 2-5 inch

Figure B-3 - grading 2-8 inch

B.1.2 Example of sieve fractions

Figure B-4 - ≤ 31.5 mm, sample E, grading 2-8 inch

Figure B-5 - 31.5-45 mm, sample E, grading 2-8 inch

Figure B-6 - 45-63 mm, sample E, grading 2-8 inch

Figure B-7 - 63-90 mm, sample E, grading 2-8 inch

Figure B-8 - 90-125 mm, sample E, grading 2-8 inch

Figure B-9 - 125-180 mm, sample E, grading 2-8 inch

Figure B-10 - 180-250 mm sample E, grading 2-8 inch

B.1.3 Applied equipment

Figure B-11 - steel rod sieves

Figure B-12 - container to submerge rocks

Figure B-13 - calliper

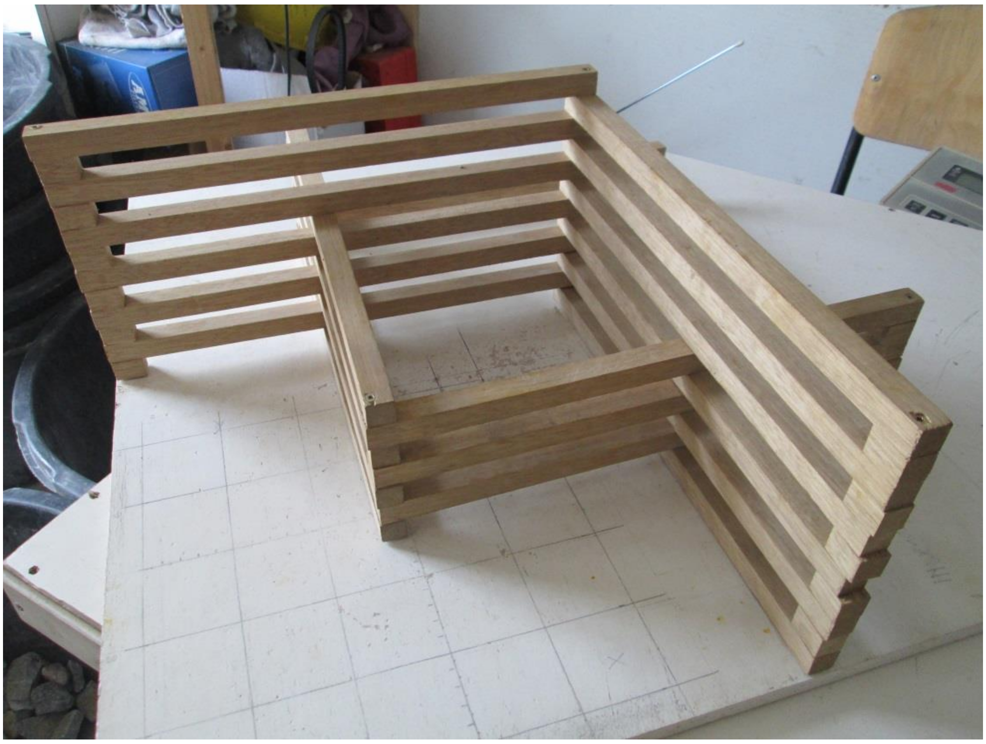


Figure B-14 - blockiness-meter

Figure B-15 - blockiness-meter top view

Figure B-16 - blockiness-meter side view

B.2 Slovag

B.2.1 Gradings

Figure B-17 - 1-5 inch

Figure B-18 - 5+ inch

B.2.2 Example of sieve fractions

Figure B-19 - 45-63 mm, sample C, grading 5+ inch

Figure B-20 - 63-90 mm, sample C, grading 5+ inch

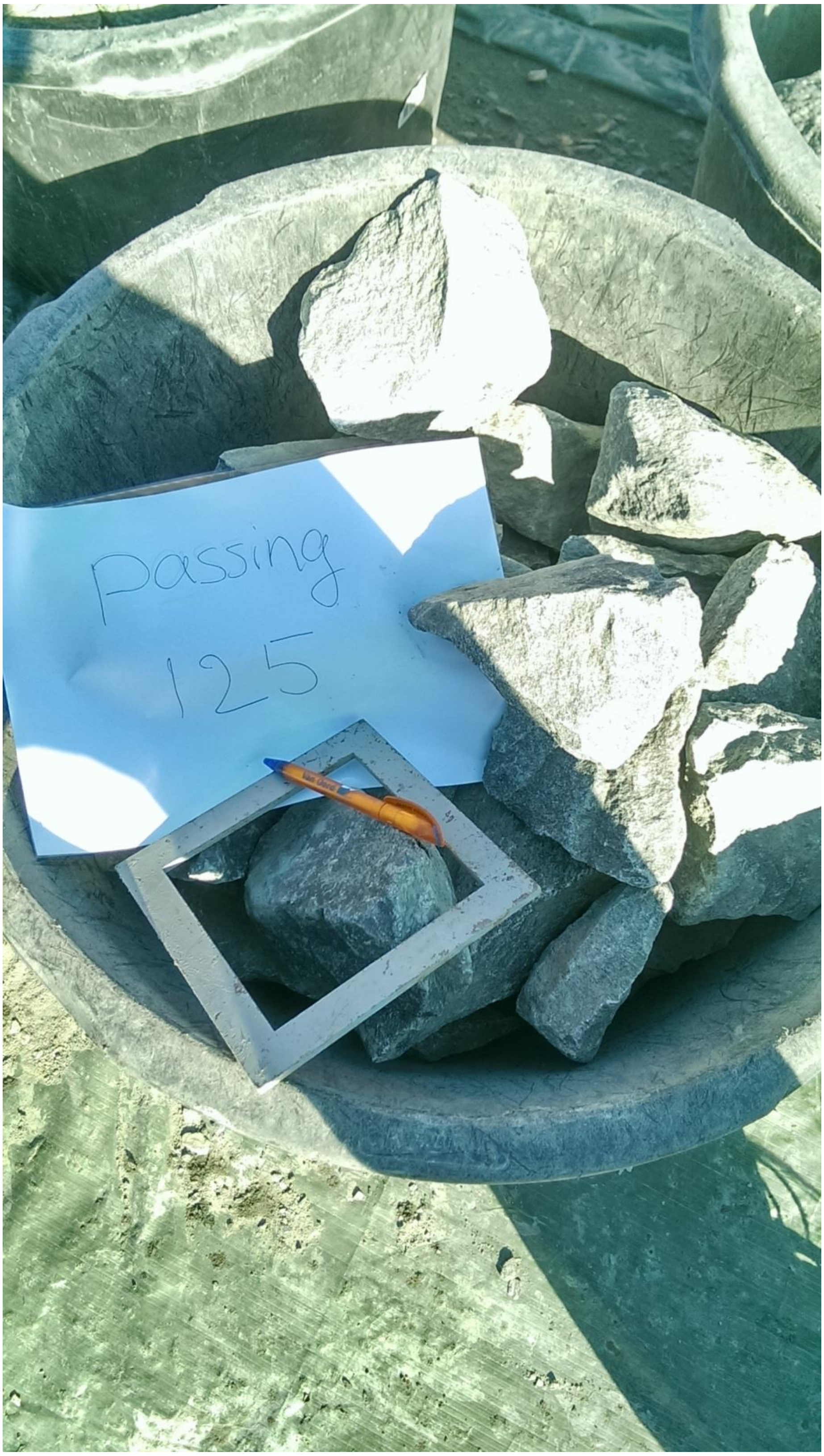


Figure B-21 - 90-125 mm, sample C, grading 5+ inch

Figure B-22 - 125-150 mm, sample C, grading 5+ inch

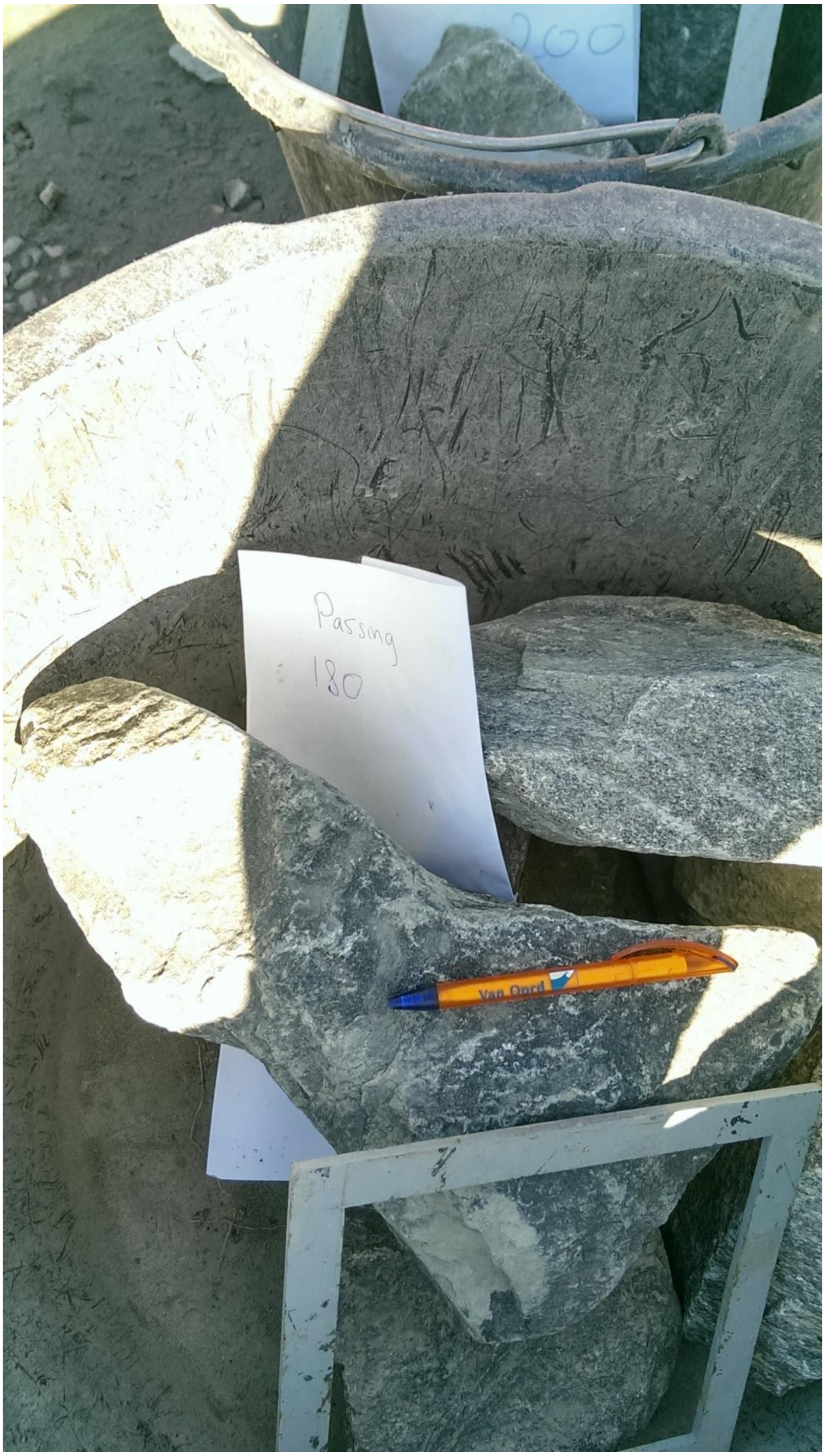


Figure B-23 - 150-180 mm, sample C, grading 5+ inch

Figure B-24 - 180-200 mm, sample C, grading 5+ inch

B.2.3 Applied equipment

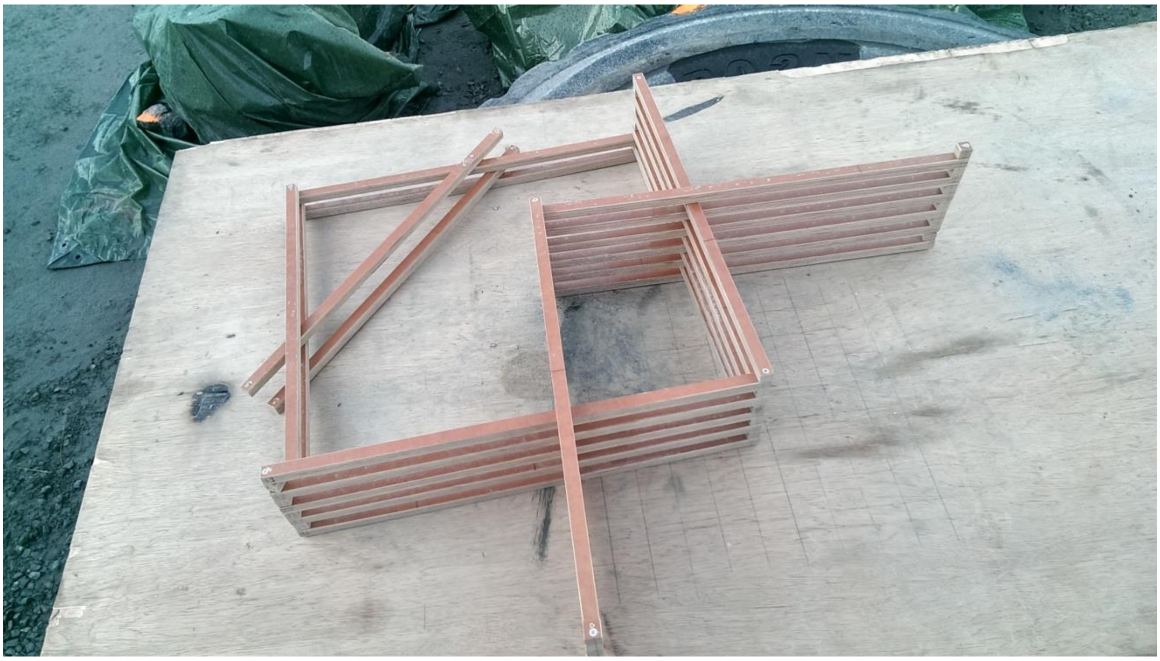


Figure B-25 - blockiness-meter

Figure B-26 - blockiness-meter

Figure B-27 - drum sieve

Figure B-28 - steel plate sieves

C. Data

C.1 Symbols

Symbol	*Unit*	*Definition*
Masses		
M_1	[kg]	dry mass
$M_{2,1}$	[kg]	mass tank filled with water
$M_{2,2}$	[kg]	mass tank with submerged rock
M_3	[kg]	oven dried mass
Elongation		
L	[m]	maximum length
T	[m]	maximum thickness
Blockiness		
X	[m]	largest dimension of smallest enclosing orthogonal box
Y	[m]	median dimension of smallest enclosing orthogonal box
Z	[m]	smallest dimension of smallest enclosing orthogonal box

C.2 **IJmuiden**

C.2.1 22-90

C.2.1.1 Sample A

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
31.5	11	75		6169	6200	70	28	68	30	28
31.5	25	42		6167	6186	51	21	48	31	21
31.5	34	28		6166	6180	43	12	45	38	15
31.5	42	39		6165	6183	56	21	53	37	21
31.5	43	65		6164	6192	65	26	66	29	25
31.5	57	44		6163	6183	50	22	41	34	24
31.5	61	47		6163	6183	54	20	48	39	20
31.5	69	26		6162	6175	41	15	41	32	16
31.5	96	39		6161	6179	53	18	52	26	20
31.5	104	23		6160	6173	40	15	36	32	18
31.5	105	25		6159	6172	40	20	34	30	21
31.5	107	41		6158	6177	49	22	42	41	24
31.5	110	32		6157	6170	52	14	45	36	16
45	1	160		6155	6215	75	43	72	47	40
45	2	145		6152	6209	81	33	72	57	35
45	3	172		6151	6217	95	39	94	51	40
45	4	103		6148	6190	68	27	40	47	27
45	5	59		6147	6171	63	20	62	40	20
45	6	62		6145	6171	51	28	49	48	28
45	7	76		6144	6176	59	24	51	42	38
45	8	83		6143	6177	62	22	63	40	23
45	9	82		6141	6175	60	29	58	39	29
45	10	67		6140	6168	64	20	62	38	25
45	12	67		6138	6166	57	29	56	39	25
45	13	109		6137	6180	60	38	46	43	40
45	14	71		6135	6165	59	29	54	45	30
45	15	159		6134	6196	88	35	89	46	39
45	16	110		6132	6176	65	35	55	39	36
45	17	50		6131	6153	48	23	49	38	24
45	18	95		6129	6168	51	32	52	39	36
45	19	126		6128	6178	86	27	82	39	29
45	20	113		6126	6171	68	36	64	41	39
45	21	57		6125	6147	50	31	44	38	31
45	22	103		6124	6165	60	27	54	46	29
45	23	130		6122	6173	68	40	62	41	40
45	24	121		6123	6171	65	27	64	60	26
45	26	84		6120	6153	75	31	61	36	30
45	27	182		6117	6188	84	34	82	59	33
45	28	175		6115	6128	92	32	91	52	31
45	29	135		6113	6166	70	38	67	52	37
45	30	121		6112	6160	76	32	73	47	31
45	31	67		6111	6139	67	20	67	41	22
45	32	105		6109	6151	69	26	70	53	25
45	33	37		6107	6124	44	17	45	39	19
45	35	82		6106	6140	61	30	59	38	28
45	36	122		6105	6154	62	39	58	48	41
45	37	41		6104	6122	48	15	50	38	17
45	38	52		6103	6126	47	21	42	30	23
45	39	161		6101	6164	64	40	63	50	41
45	40	42		6100	6145	65	34	58	44	37
45	41	70		6099	6128	66	30	66	34	29
45	44	121		6098	6146	62	40	56	50	40
45	45	99		6096	6137	58	38	58	49	36
45	46	109		6095	6139	65	32	66	47	30
45	47	76		6094	6125	52	26	48	41	30
45	48	148		6093	6151	90	38	80	48	37
45	49	54		6091	6115	49	23	47	45	25
45	50	72		6090	6120	61	23	52	48	28
45	51	149		6089	6148	77	25	71	52	26
45	52	94		6087	6126	72	34	71	36	32
45	53	96		6086	6125	61	26	55	48	29
45	54	179		6085	6154	78	39	76	53	39
45	55	99		6084	6124	59	32	52	42	35

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
45	56	97		6082	6121	62	36	49	49	44
45	58	98		6080	6120	60	30	50	47	29
45	59	68		6079	6107	49	30	45	41	28
45	60	75		6077	6108	55	26	55	42	26
45	62	123		6072	6120	76	31	74	41	32
45	63	53		6070	6093	49	24	43	38	26
45	64	60		6068	6094	55	26	45	38	31
45	65	107		6067	6111	62	40	54	44	46
45	66	75		6067	6097	58	24	49	48	25
45	67	80		6066	6098	63	36	53	46	37
45	68	80		6064	6096	65	24	49	49	23
45	70	54		6062	6085	52	31	60	35	29
45	71	94		6061	6100	86	19	41	51	19
45	72	54		6059	6082	55	21	48	39	22
45	73	80		6058	6091	40	31	76	42	29
45	74	185		6056	6127	80	37	45	48	41
45	75	62		6054	6081	51	25	48	43	26
45	76	55		6053	6077	45	31	45	34	31
45	77	53		6052	6075	45	30	42	36	30
45	78	76		6051	6082	64	28	44	45	27
45	79	119		6050	6097	61	37	57	49	43
45	80	95		6048	6087	66	36	55	42	41
45	81	58		6047	6072	42	25	40	40	25
45	82	46		6046	6067	39	26	35	34	27
45	83	66		6045	6073	47	31	43	42	32
45	84	68		6044	6073	53	24	47	46	24
45	85	43		6043	6062	48	20	46	39	22
45	86	42		6042	6060	46	19	41	38	21
45	87	112		6041	6084	59	30	55	45	32
45	88	39		6040	6080	53	18	52	26	20
45	89	92		6038	6075	78	29	68	36	36
45	90	124		6037	6085	60	38	54	46	40
45	91	93		6036	6073	65	30	59	46	35
45	92	98		6034	6074	67	23	58	49	24
45	93	51		6033	6056	60	13	52	47	15
45	94	127		6032	6082	58	37	51	48	46
45	95	41		6031	6050	51	51	50	39	18
45	97	80		6030	6063	62	26	57	45	25
45	98	51		6029	6051	48	24	42	36	27
45	99	82		6029	6063	67	34	66	33	37
45	100	97		6028	6068	52	33	53	37	36
45	101	94		6026	6064	67	28	62	39	32
45	102	83		6025	6059	73	26	70	38	25
45	103	125		6024	6074	66	31	60	51	31
45	106	65		6023	6050	55	23	53	45	25
45	108	82		6022	6055	56	29	56	45	29
45	109	60		6021	6047	52	22	52	47	25
63	1	349		10697	10827	79	53	73	64	57
63	2	293		10694	10805	105	41	104	49	46
63	3	437		10692	10857	108	49	98	73	49
63	4	326		10689	10814	102	51	97	69	52
63	5	370		10685	10825	108	44	100	75	43
63	6	418		10682	10740	109	44	97	79	45
63	7	219		10678	10764	80	42	80	61	43
63	8	527		10676	10672	109	47	99	77	50
63	9	172		10673	10740	79	33	65	55	34
63	10	319		10672	10796	103	50	100	61	47
63	11	394		10669	10816	86	51	80	73	52
63	12	209		10666	10746	75	46	66	60	46
63	13	249		10664	10759	82	43	78	59	43
63	14	209		10661	10741	75	48	74	56	46
63	15	325		10659	10781	110	44	95	78	45
63	16	151		10656	10715	78	27	62	60	32
63	17	222		10654	10739	87	37	80	59	39
63	18	210		10652	10733	66	42	63	52	47
63	19	149		10651	10709	66	35	67	48	38
63	20	211		10650	10730	86	35	83	46	41
63	21	358		10648	10784	90	47	83	80	51
63	22	236		10645	10733	93	43	83	67	44
63	23	363		10642	10780	99	52	90	67	53
63	24	146		10637	10692	74	28	71	56	30
63	25	267		10635	10739	91	41	88	50	46
63	26	184		10632	10705	82	29	75	73	34

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
63	27	298		10630	10744	109	46	110	56	46
63	28	239		10627	10719	84	41	78	50	44
63	29	274		10626	10730	90	46	88	55	52
63	30	132		10625	10678	68	28	58	57	27
63	31	280		10623	10729	82	55	73	67	56
63	32	108		10621	10670	61	35	53	51	36
63	33	363		10620	10759	78	49	71	65	53
63	34	252		10617	10722	80	52	74	60	53
63	35	163		10615	10676	68	48	55	50	52
63	36	176		10614	10683	68	29	66	54	35
63	37	131		10612	10667	74	25	68	57	29
63	38	163		10610	10677	77	30	67	55	34
63	39	215		10609	10692	81	43	77	67	40
63	40	155		10607	10667	66	35	65	52	38
63	41	319		10605	10728	105	50	102	70	50
63	42	295		10604	10716	89	44	80	64	48
63	43	332		10601	10729	82	49	81	68	49
63	44	151		10599	10656	65	39	60	51	40
63	45	431		10598	10760	101	51	92	72	51
63	46	138		10594	10648	67	40	52	46	51
63	47	228		10592	10680	88	44	65	53	55
63	48	355		10589	10725	103	41	81	70	50
63	49	296		10585	10697	84	42	74	79	43
63	50	359		10582	10719	107	35	94	84	43
63	51	258		10579	10676	103	50	100	54	47
63	52	313		10577	10694	78	51	62	60	52
63	53	500		10574	10761	101	58	97	77	57
63	54	156		10572	10632	90	17	82	55	28
63	55	115		10570	10616	60	36	54	53	36
63	56	212		10569	10650	85	42	79	51	45
63	57	149		10567	10625	65	37	62	50	40
90	1	664		21202	21457	121	74	105	82	74
90	2	1037		21198	21591	161	79	159	84	98
90	3	917		21192	21532	133	64	131	65	80
90	4	754		21185	21471	147	49	148	92	51
90	5	580		21176	21405	121	75	91	93	79
90	6	1098		21171	21583	138	74	131	80	79
90	7	627		21163	21411	128	69	93	99	82
90	8	482		21158	21344	104	43	93	90	47
90	9	494		21148	21338	118	56	111	60	76
90	10	791		21147	21450	107	62	105	82	61
90	11	1168		21144	21591	142	71	139	90	77
90	12	855		21135	21458	153	61	151	84	63
90	13	697		21128	21394	103	61	99	64	85
90	14	512		21122	21323	108	57	91	86	58
90	15	2027		21117	21879	202	74	198	82	104
90	16	1278		21106	21587	154	68	146	81	81
90	17	694		21099	21362	120	56	116	61	86
90	18	427		21091	21258	92	64	89	63	74
90	19	1468		21087	21643	149	81	138	95	95
90	20	1318		21072	21568	196	65	192	89	69
90	21	851		21064	21392	139	61	134	66	88
90	22	521		14401	14596	109	55	107	85	58
90	23	611		14396	14625	117	56	111	57	71
90	24	451		14390	14561	111	38	110	77	39
90	25	588		14382	14605	134	36	131	89	37
90	26	837		14372	14693	120	66	112	77	80
90	27	382		14379	14526	113	48	106	84	49
90	28	776		14371	14667	113	59	110	83	57
90	29	885		14366	14698	138	64	136	86	66
90	30	703		14359	14621	99	66	87	75	69
90	31	745		14353	14631	143	50	132	99	53
90	32	366		14348	14488	86	60	81	66	78
90	33	555		14344	14554	114	66	110	71	70
90	34	469		14341	14519	101	53	77	90	64
90	35	854		14337	14554	130	42	131	89	47
125	1	2246		21333	22170	155	99	127	112	102
125	2	4397		21289	23008	308	105	296	156	115
125	3	1526		21274	21845	143	88	131	102	92
125	4	2334		21267	22132	172	81	136	121	84
125	5	1803		21246	21932	199	93	185	93	103
125	6	2361		21234	22117	159	99	154	110	97
180	1	4243		14429	16056	216	149	165	187	148

C.2.1.2 Sample B

Sieve Passing	Rock ID	Mass M1
31.5	1	13
31.5	2	32
31.5	3	17
31.5	4	17
31.5	5	39
31.5	6	52
31.5	7	23
31.5	8	35
31.5	9	44
31.5	10	9
31.5	11	14
31.5	12	12
31.5	13	25
31.5	14	39
31.5	15	22
31.5	16	24
31.5	17	24
31.5	18	21
31.5	19	7
31.5	20	14
31.5	21	9
31.5	22	12
31.5	23	19
31.5	24	18
31.5	25	16
31.5	26	24
31.5	27	57
31.5	28	24
31.5	29	33
31.5	30	23
31.5	31	49
31.5	32	24
31.5	33	17
31.5	34	54
31.5	35	48
31.5	36	19
31.5	37	15
45	1	67
45	2	102
45	3	93
45	4	124
45	5	95
45	6	189
45	7	79
45	8	153
45	9	95
45	10	55
45	11	73
45	12	179
45	13	51
45	14	50
45	15	80
45	16	80
45	17	77
45	18	115
45	19	189
45	20	113
45	21	93
45	22	115
45	23	74
45	24	49
45	25	98
45	26	50
45	27	85
45	28	55
45	29	79
45	30	109
45	31	167
45	32	60
45	33	150

Sieve Passing	Rock ID	Mass M1
45	34	62
45	35	90
45	36	57
45	37	80
45	38	91
45	39	68
45	40	86
45	41	46
45	42	98
45	43	72
45	44	73
45	45	84
45	46	69
45	47	41
45	48	117
45	49	103
45	50	85
45	51	63
45	52	132
45	53	54
45	54	72
45	55	113
45	56	108
45	57	61
45	58	83
45	59	66
45	60	50
45	61	55
45	62	183
45	63	69
45	64	96
45	65	101
45	66	103
45	67	100
45	68	53
45	69	110
45	70	86
45	71	101
45	72	90
45	73	59
45	74	94
45	75	62
45	76	116
45	77	123
45	78	85
45	79	70
45	80	58
45	81	81
45	82	93
45	83	60
45	84	103
45	85	81
45	86	67
45	87	111
45	88	80
45	89	98
45	90	53
45	91	59
45	92	61
45	93	96
45	94	65
45	95	86
45	96	52
45	97	62
45	98	74
45	99	68
45	100	115
45	101	122
45	102	89
45	103	81

Sieve Passing	Rock ID	Mass M1
45	104	55
45	105	107
45	106	56
45	107	73
45	108	88
45	109	70
45	110	89
45	111	167
45	112	159
45	113	82
63	1	248
63	2	545
63	3	550
63	4	457
63	5	162
63	6	204
63	7	265
63	8	203
63	9	262
63	10	186
63	11	172
63	12	526
63	13	325
63	14	353
63	15	155
63	16	153
63	17	248
63	18	260
63	19	364
63	20	371
63	21	359
63	22	351
63	23	261
63	24	321
63	25	191
63	26	196
63	27	144
63	28	395
63	29	341
63	30	182
63	31	210
63	32	185
63	33	141
63	34	331
63	35	196
63	36	112
63	37	394
63	38	156
63	39	141
63	40	143
63	41	217
63	42	175
63	43	295
63	44	141
90	1	910
90	2	585
90	3	1712
90	4	840
90	5	779
90	6	560
90	7	921
90	8	741
90	9	907
90	10	1311
90	11	630
90	12	450
90	13	459
90	14	646
90	15	831
90	16	501
90	17	458
90	18	562
90	19	497

Sieve Passing	Rock ID	Mass M1
90	20	467
90	21	647
90	22	591
90	23	598
90	24	380
90	25	560
90	26	1017
90	27	812
90	28	485
90	29	593
90	30	877
90	31	578
125	1	3503
125	2	2764
125	3	2881
125	4	1924
125	5	1646
125	6	2358
125	7	1599

C.2.1.3 Sample C

Sieve Passing	Rock ID	Mass M1
31.5	1	25
31.5	2	12
31.5	3	21
31.5	4	30
31.5	5	42
31.5	6	31
31.5	7	46
31.5	8	32
31.5	9	24
31.5	19	26
31.5	20	25
31.5	21	22
31.5	10	8
31.5	11	10
31.5	12	14
31.5	13	19
31.5	14	23
31.5	15	9
31.5	16	9
31.5	17	11
31.5	18	12
45	1	124
45	2	56
45	3	78
45	4	102
45	5	34
45	6	41
45	7	76
45	8	81
45	9	101
45	10	68
45	11	139
45	12	102
45	13	111
45	14	95
45	15	140
45	16	104
45	17	53
45	18	50
45	19	66
45	20	143
45	21	178
45	22	84
45	23	142
45	24	128
45	25	42
45	26	100
45	27	56
45	28	90
45	29	92
45	30	62
45	31	55
45	32	72
45	33	65
45	34	80
45	35	70
45	36	62
45	37	91
45	38	93
45	39	106
45	40	50
45	41	57
45	42	94
45	43	83
45	44	71
45	45	56
45	46	46
45	47	43
45	48	111
45	49	72

Sieve Passing	Rock ID	Mass M1
45	50	44
45	51	28
45	52	37
45	53	61
45	54	60
45	55	54
45	56	33
45	57	48
45	58	62
45	59	119
45	60	92
45	61	73
45	62	116
45	63	90
45	64	88
45	65	100
45	66	102
45	67	54
45	68	162
45	69	73
45	70	65
45	71	96
45	72	81
45	73	53
45	74	83
45	75	86
45	76	81
45	77	70
45	78	76
45	79	59
45	80	75
45	81	75
45	82	54
45	83	59
45	84	86
45	85	69
45	86	67
45	87	121
45	88	96
45	89	74
45	90	55
45	91	129
45	92	71
45	93	105
45	94	80
45	95	123
45	96	100
45	97	71
45	98	96
45	99	81
45	100	53
45	101	83
45	102	44
45	103	62
45	104	51
45	105	59
45	106	28
45	107	172
63	1	446
63	2	510
63	3	169
63	4	140
63	5	191
63	6	576
63	7	210
63	8	219
63	9	234
63	10	705
63	11	407
63	12	336

Sieve Passing	Rock ID	Mass M1
63	13	240
63	14	288
63	15	265
63	16	197
63	17	295
63	18	207
63	19	269
63	20	213
63	21	171
63	22	319
63	23	109
63	24	114
63	25	138
63	26	249
63	27	315
63	28	485
63	29	231
63	30	402
63	31	239
63	32	132
63	33	178
63	34	223
63	35	160
63	36	173
63	37	225
63	38	228
63	39	212
63	40	371
63	41	266
63	42	136
63	43	372
63	44	249
90	1	648
90	2	1297
90	3	533
90	4	905
90	5	1265
90	6	530
90	7	465
90	8	1245
90	9	373
90	10	456
90	11	1245
90	12	373
90	13	456
90	14	678
90	15	538
90	16	672
90	17	666
90	18	723
90	19	664
90	20	586
90	21	663
90	22	470
90	23	594
90	24	1483
90	25	690
90	26	453
90	27	839
90	28	836
90	29	851
90	30	306
90	31	872
90	32	628
90	33	561
90	34	618
90	35	727
90	36	440
90	37	998
90	38	795
125	1	2387
125	2	3856
125	3	2506

Sieve Passing	Rock ID	Mass M1
125	4	1748
125	5	1438
125	6	1224
180	1	3687
180	2	3862

C.2.1.4 Sample D

Sieve Passing	Rock ID	Mass M1
31.5	1	42
31.5	2	28
31.5	3	25
31.5	4	35
31.5	5	84
31.5	6	17
31.5	7	27
31.5	8	43
31.5	9	43
31.5	10	11
31.5	11	43
31.5	12	21
31.5	13	98
31.5	14	23
31.5	15	32
31.5	16	32
31.5	17	25
31.5	18	34
31.5	19	70
31.5	20	45
31.5	21	13
31.5	22	16
31.5	23	31
31.5	24	21
31.5	25	38
31.5	26	43
31.5	27	51
31.5	28	18
31.5	29	49
31.5	30	23
31.5	31	35
31.5	32	11
31.5	33	20
31.5	34	13
31.5	35	21
31.5	36	17
31.5	37	16
45	1	105
45	2	49
45	3	103
45	4	83
45	5	84
45	6	102
45	7	118
45	8	123
45	9	86
45	10	141
45	11	87
45	12	121
45	13	143
45	14	76
45	15	42
45	16	66
45	17	55
45	18	65
45	19	90
45	20	54
45	21	95
45	22	62
45	23	76
45	24	81
45	25	79
45	26	123
45	27	72
45	28	85
45	29	122
45	30	85
45	31	137
45	32	85
45	33	112

Sieve Passing	Rock ID	Mass M1
45	34	150
45	35	106
45	36	146
45	37	111
45	38	54
45	39	103
45	40	101
45	41	66
45	42	170
45	43	99
45	44	198
45	45	60
45	46	51
45	47	105
45	48	51
45	49	63
45	50	46
45	51	58
45	52	66
45	53	92
45	54	82
45	55	93
45	56	109
45	57	126
45	58	120
45	59	123
45	60	53
45	61	128
45	62	96
45	63	133
45	64	129
45	65	88
45	66	69
45	67	119
45	68	131
45	69	43
45	70	64
45	71	70
45	72	68
45	73	61
45	74	57
45	75	47
45	76	109
45	77	65
45	78	75
45	79	55
45	80	62
45	81	65
45	82	124
45	83	91
45	84	79
45	85	77
45	86	133
45	87	56
45	88	111
45	89	140
45	90	139
45	91	135
45	92	147
45	93	84
45	94	131
45	95	120
45	96	74
45	97	106
45	98	89
45	99	115
45	100	54
45	101	95
45	102	65
45	103	34

Sieve Passing	Rock ID	Mass M1
45	104	127
45	105	55
45	106	56
45	107	55
45	108	92
45	109	50
45	110	70
45	111	75
45	112	55
45	113	69
45	114	44
63	1	609
63	2	316
63	3	374
63	4	330
63	5	208
63	6	177
63	7	388
63	8	328
63	9	268
63	10	375
63	11	367
63	12	267
63	13	128
63	14	422
63	15	319
63	16	133
63	17	138
63	18	191
63	19	399
63	20	292
63	21	365
63	22	137
63	23	221
63	24	127
63	25	268
63	26	296
63	27	198
63	28	430
63	29	336
63	30	321
63	31	202
63	32	232
63	33	161
63	34	147
63	35	210
63	36	270
63	37	459
63	38	399
63	39	361
63	40	457
63	41	442
63	42	277
63	43	149
63	44	140
63	45	198
63	46	301
63	47	159
63	48	160
63	49	155
63	50	88
63	51	210
63	52	139
63	53	180
63	54	393
63	55	141
63	56	189
63	57	147
63	58	133
63	59	306
63	60	158
63	61	134
63	62	131

Sieve Passing	Rock ID	Mass M1
90	1	612
90	2	550
90	3	525
90	4	851
90	5	1564
90	6	474
90	7	869
90	8	633
90	9	753
90	10	607
90	11	968
90	12	592
90	13	973
90	14	640
90	15	915
90	16	508
90	17	499
90	18	664
90	19	675
90	20	377
90	21	1003
90	22	708
90	23	630
90	24	1032
90	25	834
90	26	528
90	27	631
90	28	441
90	29	486
90	30	437
90	31	502
90	32	528
90	33	631
90	34	441
90	35	486
90	36	437
90	37	502
90	38	528
90	39	940
90	40	410
90	41	624
90	42	463
125	1	4326
125	2	3107
125	3	2368
125	4	1268
125	5	1457
125	6	1735
125	7	4677
125	8	2283
125	9	1212
180	1	3124

C.2.1.5 Sample E

Sieve Passing	Rock ID	Mass M1
31.5	1	49
31.5	2	45
31.5	3	37
31.5	4	25
31.5	5	45
31.5	6	34
31.5	7	47
31.5	8	42
31.5	9	28
31.5	10	52
31.5	11	20
31.5	12	68
31.5	13	45
31.5	14	42
31.5	15	18
31.5	16	34
31.5	17	25
31.5	18	47
31.5	19	44
31.5	20	31
31.5	21	29
31.5	22	21
31.5	23	45
31.5	24	43
31.5	25	54
31.5	26	74
31.5	27	40
31.5	28	36
31.5	29	29
31.5	30	30
31.5	31	24
31.5	32	39
31.5	33	18
31.5	34	15
31.5	35	9
31.5	36	23
31.5	37	15
31.5	38	27
31.5	39	19
31.5	40	29
31.5	41	18
31.5	42	19
31.5	43	18
31.5	44	13
31.5	45	9
31.5	46	31
31.5	47	30
31.5	48	25
31.5	49	18
31.5	50	24
31.5	51	12
31.5	52	29
31.5	53	22
31.5	54	13
31.5	55	20
31.5	56	18
31.5	57	16
31.5	58	17
31.5	59	20
31.5	60	8
31.5	61	9
31.5	62	12
31.5	63	13
31.5	64	11
31.5	65	15
31.5	66	8
31.5	67	19
31.5	68	6
31.5	69	10
31.5	70	9

Sieve Passing	Rock ID	Mass M1
31.5	71	8
31.5	72	14
45	1	93
45	2	1333
45	3	92
45	4	49
45	5	115
45	6	95
45	7	59
45	8	100
45	9	129
45	10	78
45	11	123
45	12	88
45	13	80
45	14	95
45	15	101
45	16	94
45	17	82
45	18	110
45	19	69
45	20	54
45	21	87
45	22	46
45	23	108
45	24	57
45	25	79
45	26	82
45	27	112
45	28	83
45	29	92
45	30	116
45	31	39
45	32	77
45	33	109
45	34	110
45	35	90
45	36	97
45	37	64
45	38	109
45	39	49
45	40	70
45	41	62
45	42	68
45	43	65
45	44	102
45	45	88
45	46	107
45	47	85
45	48	57
45	49	84
45	50	107
45	51	39
45	52	59
45	53	70
45	54	103
45	55	123
45	56	92
45	57	38
45	58	62
45	59	66
45	60	210
45	61	107
45	62	126
45	63	87
45	64	148
45	65	117
45	66	66
45	67	70
45	68	61

Sieve Passing	Rock ID	Mass M1
45	69	138
45	70	763
45	71	100
45	72	58
45	73	83
45	74	63
45	75	69
45	76	55
45	77	56
45	78	126
45	79	105
45	80	179
45	81	126
45	82	70
45	83	193
45	84	94
45	85	54
45	86	55
45	87	74
45	88	118
45	89	86
45	90	91
45	91	105
45	92	114
45	93	69
45	94	99
45	95	58
45	96	138
45	97	47
45	98	133
45	99	56
45	100	96
45	101	81
45	102	69
45	103	112
45	104	115
45	105	119
45	106	75
45	107	90
45	108	53
45	109	118
45	110	67
45	111	75
45	112	160
45	113	69
45	114	104
45	115	55
45	116	69
45	117	48
45	118	79
45	119	105
45	120	69
45	121	65
45	122	110
45	123	65
45	124	72
45	125	35
45	126	90
45	127	80
45	128	135
45	129	60
45	130	101
45	131	43
45	132	61
45	133	55
45	134	242
45	135	68
45	136	57
45	137	65
45	138	83
45	139	53
45	140	54
45	141	56
45	142	63
45	143	54
63	1	155
63	2	573
63	3	165
63	4	320
63	5	182
63	6	175
63	7	441
63	8	453
63	9	248
63	10	256
63	11	268
63	12	248
63	13	145
63	14	170
63	15	184
63	16	221
63	17	147
63	18	214
63	19	87
63	20	149
63	21	282
63	22	233
63	23	157
63	24	132
63	25	192
63	26	167
63	27	223
63	28	168
63	29	436
63	30	330
63	31	506
63	32	157
63	33	223
63	34	403
63	35	330
63	36	475
63	37	199
63	38	178
63	39	144
63	40	192
63	41	281
63	42	141
63	43	357
63	44	264
63	45	108
63	46	154
63	47	269
63	48	228
63	49	140
63	50	115
63	51	173
63	52	161
63	53	117
63	54	132
63	55	293
63	56	179
63	57	118
63	58	185
63	59	194
90	1	747
90	2	1103
90	3	1144
90	4	754
90	5	731
90	6	1262
90	7	420
90	8	1092
90	9	452
90	10	754
90	11	559
90	12	501

Sieve Passing	Rock ID	Mass M1
90	13	667
90	14	539
90	15	480
90	16	553
90	17	564
90	18	576
90	19	870
90	20	479
90	21	591
90	22	422
90	23	569
125	1	1743
125	2	1766
125	3	2641
125	4	2681
125	5	2128
125	6	2187
125	7	1141

C.2.2 2-5

C.2.2.1 Sample A

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
31.5	1	24	NVT	6846	6858	36	21	31	25	22
31.5	2	44	NVT	6844	6862	45	32	46	36	35
31.5	3	56	NVT	6843	6868	64	24	63	31	28
31.5	4	37	NVT	6841	6857	64	19	60	30	21
31.5	5	32	NVT	6840	6854	56	16	52	35	17
31.5	6	48	NVT	6838	6858	55	21	52	34	21
31.5	7	28	NVT	6837	6849	43	18	43	30	19
31.5	8	50	NVT	6836	6857	68	20	67	27	24
31.5	9	47	NVT	6835	6854	53	23	51	30	26
31.5	10	40	NVT	6833	6852	55	20	55	30	20
31.5	11	44	NVT	6833	6851	62	18	59	26	19
31.5	12	47	NVT	6832	6849	52	22	52	31	22
31.5	13	22	NVT	6831	6841	52	11	48	25	12
31.5	14	41	NVT	6830	6846	49	24	46	29	24
31.5	15	44	NVT	6829	6845	56	22	52	37	22
31.5	16	35	NVT	6828	6843	48	23	45	25	23
31.5	17	44	NVT	6827	6843	51	17	50	34	18
31.5	18	35	NVT	6826	6841	47	19	46	32	19
31.5	19	29	NVT	6825	6837	47	20	42	33	20
31.5	20	35	NVT	6823	6839	37	26	36	28	26
31.5	21	39	NVT	6823	6841	46	19	46	30	22
31.5	22	39	NVT	6822	6840	50	23	46	25	25
31.5	23	30	NVT	6821	6835	43	24	39	25	26
31.5	24	34	NVT	6821	6836	43	28	36	35	29
31.5	25	28	NVT	6820	6833	37	24	34	25	24
31.5	26	33	NVT	6819	6833	49	22	46	28	25
31.5	27	25	NVT	6818	6828	43	21	39	29	20
31.5	28	18	NVT	6817	6826	40	14	38	33	14
31.5	29	23	NVT	6817	6828	49	23	48	32	20
31.5	30	18	NVT	6816	6822	34	15	34	28	15
31.5	31	19	NVT	6816	6825	40	22	40	28	22
31.5	32	38	NVT	6814	6829	47	23	46	27	23
31.5	33	17	NVT	6813	6821	39	14	39	31	15
31.5	34	33	NVT	6812	6826	45	20	44	30	24
31.5	35	21	NVT	6811	6820	46	14	47	31	14
31.5	36	32	NVT	6811	6825	48	22	47	28	25
31.5	37	20	NVT	6810	6817	40	15	39	27	15
31.5	38	34	NVT	6809	6821	48	21	42	36	21
31.5	39	44	NVT	6808	6826	42	25	39	31	26
31.5	40	34	NVT	6808	6821	46	25	43	31	25
31.5	41	25	NVT	6807	6816	39	19	38	31	19
31.5	42	20	NVT	6806	6815	51	15	51	23	15
31.5	43	28	NVT	6805	6817	43	22	42	23	23
31.5	44	13	NVT	6805	6812	34	11	30	27	11
31.5	45	39	NVT	6804	6820	44	20	41	30	20
31.5		13								
31.5		14								
31.5		24								
31.5		15								
31.5		6								
31.5		5								
31.5		14								
31.5		12								
31.5		11								
31.5		5								
31.5		5								
31.5		5								
31.5		2								
31.5		3								
31.5		14								
31.5		9								
31.5		15								
31.5		18								
31.5		16								
31.5		4								
31.5		4								
31.5		5								

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
31.5		8								
31.5		9								
31.5		10								
31.5		9								
31.5		14								
31.5		9								
31.5		16								
31.5		14								
31.5		23								
31.5		7								
31.5		9								
31.5		5								
31.5		11								
31.5		10								
31.5		9								
31.5		5								
31.5		6								
31.5		3								
31.5		8								
31.5		6								
31.5		7								
31.5		5								
31.5		7								
31.5		7								
31.5		5								
31.5		5								
31.5		2								
31.5		4								
31.5		5								
31.5	rest	34								
45	1	154	NVT	7067	7126	87	26	78	63	28
45	2	81	NVT	7063	7096	73	17	67	50	19
45	3	129	NVT	7061	7110	80	28	80	39	35
45	4	118	NVT	7058	7105	82	30	80	50	27
45	5	97	NVT	7057	7094	65	20	63	52	22
45	6	144	NVT	7055	7111	68	41	62	45	46
45	7	112	NVT	7054	7098	78	34	75	50	35
45	8	101	NVT	7053	7092	73	34	68	36	31
45	9	195	NVT	7051	7126	99	43	98	47	44
45	10	122	NVT	7049	7097	70	29	62	49	35
45	11	122	NVT	7048	7097	76	32	70	39	35
45	12	106	NVT	7047	7088	66	25	63	43	24
45	13	99	NVT	7045	7082	64	27	64	43	26
45	14	147	NVT	7044	7100	76	32	73	53	42
45	15	109	NVT	7042	7084	66	27	54	51	29
45	16	102	NVT	7041	7079	74	24	75	49	25
45	17	71	NVT	7039	7066	67	28	64	37	28
45	18	87	NVT	7037	7071	68	29	63	32	34
45	19	189	NVT	7036	7108	92	35	87	43	38
45	20	120	NVT	7035	7083	98	26	93	41	27
45	21	98	NVT	7033	7072	70	23	61	44	23
45	22	79	NVT	7032	7065	61	21	58	38	23
45	23	134	NVT	7030	7083	75	35	67	41	39
45	24	259	NVT	7029	7126	118	45	114	48	43
45	25	100	NVT	7026	7065	61	37	58	38	36
45	26	141	NVT	7025	7080	84	36	82	41	40
45	27	91	NVT	7023	7061	66	19	61	54	19
45	28	88	NVT	7021	7057	63	33	60	47	43
45	29	86	NVT	7020	7056	61	23	58	42	24
45	30	122	NVT	7018	7067	62	34	60	46	35
45	31	63	NVT	7017	7044	58	24	58	35	28
45	32	97	NVT	7016	7056	50	37	49	48	39
45	33	96	NVT	7015	7054	61	32	52	42	37
45	34	127	NVT	7014	7065	68	39	62	50	38
45	35	53	NVT	7012	7035	51	25	50	35	32
45	36	93	NVT	7012	7049	67	29	61	45	29
45	37	45	NVT	7010	7030	52	25	47	37	25
45	38	82	NVT	7009	7043	62	29	62	44	31
45	39	96	NVT	7007	7042			53	40	29
45	40	67	NVT	7006	7035	59	25	58	40	27
45	41	47	NVT	7005	7025	45	24	42	41	27
45	42	110	NVT	7004	7042	62	27	59	52	28
45	43	49	NVT	7001	7020	49	22	50	37	24

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
45	44	84	NVT	7000	7035	60	28	51	47	28
45	45	60	NVT	6999	7024	54	26	44	41	27
45	46	72	NVT	6998	7026	52	32	51	38	34
45	47	73	NVT	6996	7023	59	22	55	44	26
45	48	91	NVT	6995	7031	67	27	61	49	33
45	49	106	NVT	6992	7035	69	22	69	54	23
45	50	87	NVT	6991	7025	64	21	59	51	26
45	51	59	NVT	6989	7011	56	30	53	36	35
45	52	59	NVT	6988	7012	51	25	41	41	25
45	53	88	NVT	6987	7022	59	29	57	41	30
45	54	89	NVT	6985	7021	61	33	55	42	36
45	55	60	NVT	6984	7009	65	17	60	43	23
45	56	110	NVT	6983	7025	64	31	62	43	33
45	57	104	NVT	6982	7023	57	36	52	45	37
45	58	203	NVT	6981	7059	107	35	102	42	42
45	59	125	NVT	6978	7025	70	31	60	44	40
45	60	37	NVT	6977	6992	49	13	45	45	13
45	61	95	NVT	6976	7012	68	26	58	54	29
45	62	54	NVT	6974	6995	52	34	45	41	35
45	63	200	NVT	6972	7049	86	40	85	51	39
45	64	65	NVT	6971	6995	54	22	48	38	25
45	65	62	NVT	6970	6995	63	27	62	40	28
45	66	140	NVT	6968	7023	61	39	53	46	39
45	67	95	NVT	6967	7003	67	24	63	57	24
45	68	81	NVT	6965	6999	64	30	54	35	35
45	69	79	NVT	6963	6995	62	27	61	32	28
45	70	130	NVT	6962	7011	76	32	72	55	34
45	71	93	NVT	6960	6996	64	31	64	40	31
45	72	170	NVT	6959	7027	71	42	59	52	48
45	73	88	NVT	6958	6993	82	32	60	40	34
45	74	56	NVT	6956	6979	55	19	47	46	20
45	75	79	NVT	6955	6987	56	25	47	44	27
45	76	154	NVT	6953	7014	78	30	88	45	32
45	77		NVT	6950	7000	83	29	81	48	29
45	78	98	NVT	6948	6988	74	29	71	50	32
45	79	100	NVT	6947	6986	82	30	82	33	30
45	80	92	NVT	6945	6983	73	19	66	49	22
45	81	138	NVT	6943	6997	78	31	71	54	32
45	82	77	NVT	6941	6972	63	27	60	39	29
45	83	62	NVT	6940	6966	61	28	57	25	29
45	84	114	NVT	6940	6984	65	39	54	48	40
45	85	105	NVT	6939	6973	60	32	55	34	39
45	86	75	NVT	6936	6966	60	24	56	44	25
45	87	107	NVT	6935	6976	75	34	72	34	35
45	88	81	NVT	6934	6965	52	33	46	40	33
45	89	95	NVT	6933	6971	65	32	59	39	33
45	90	89	NVT	6932	6964	67	24	63	42	31
45	91	118	NVT	6930	6976	63	39	46	42	41
45	92	118	NVT	6929	6973	76	25	71	54	25
45	93	45	NVT	6927	6946	50	25	45	35	26
45	94	145	NVT	6926	6983	77	38	71	43	38
45	95	102	NVT	6924	6964	58	37	49	41	45
45	96	97	NVT	6923	6962	62	22	57	54	24
45	97	163	NVT	6922	6984	73	34	67	54	38
45	98	144	NVT	6920	6971	62	37	63	42	37
45	99	61	NVT	6918	6942	56	21	53	38	21
45	100	72	NVT	6917	6945	54	24	51	36	25
45	101	90	NVT	6915	6950	62	24	57	37	27
45	102	65	NVT	6914	6940	47	29	44	37	31
45	103	87	NVT	6912	6948	60	28	58	38	32
45	104	76	NVT	6911	6942	63	31	63	35	32
45	105	65	NVT	6910	6937	55	23	55	40	22
45	106	61	NVT	6909	6934	50	24	50	34	29
45	107	82	NVT	6908	6941	65	28	58	42	28
45	108	108	NVT	6907	6947	66	33	56	52	34
45	109	90	NVT	6905	6940	67	19	65	51	20
45	110	65	NVT	6904	6930	51	27	46	45	26
45	111	62	NVT	6903	6928	54	20	52	49	20
45	112	74	NVT	6902	6932	54	24	51	49	24
45	113	45	NVT	6900	6921	44	30	42	34	31
45	114	79	NVT	6899	6931	67	26	62	45	25
45	115	124	NVT	6898	6942	55	40	50	43	40
45	116	87	NVT	6896	6931	65	30	63	47	30

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
45	117	91	NVT	6894	6929	60	25	53	46	30
45	118	91	NVT	6893	6930	61	28	51	44	28
45	119	59	NVT	6891	6915	68	22	69	34	23
45	120	44	NVT	6890	6908	43	21	43	37	23
45	121	91	NVT	6889	6925	64	30	52	50	30
45	122	55	NVT	6888	6910	51	26	48	29	28
45	123	54	NVT	6886	6909	51	24	49	39	26
45	124	77	NVT	6885	6916	59	28	59	41	25
45	125	100	NVT	6883	6922	59	35	50	48	36
45	126	45	NVT	6882	6902	50	19	49	33	20
45	127	66	NVT	6880	6908	27	27	55	29	26
45	128	32	NVT	6879	6893	51	12	51	44	13
45	129	52	NVT	6878	6897	44	30	40	34	31
45	130	53	NVT	6876	6896	55	22	55	42	20
45	131	46	NVT	6874	6894	58	14	55	45	16
45	132	46	NVT	6873	6890	44	23	38	35	24
45	133	83	NVT	6872	6903	63	31	59	40	33
45	134	79	NVT	6870	6900	50	31	42	37	32
45	135	56	NVT	6868	6900	54	31	48	41	32
45	136	54	NVT	6867	6889	41	24	45	36	25
45	137	35	NVT	6865	6879	43	20	41	35	20
45	138	37	NVT	6863	6878	49	14	45	32	17
45	139	51	NVT	6861	6882	47	29	46	34	30
45	140	57	NVT	6860	6883	47	34	39	36	35
45	141		NVT	6858	6876	44	25	46	40	25
63	1	259	NVT	6803	6905	93	47	84	71	47
63	2	299	NVT	6800	6914	91	40	75	72	41
63	3	215	NVT	6798	6882	92	26	81	66	26
63	4	241	NVT	6793	6884	85	43	80	64	43
63	5	330	NVT	6791	6918	100	42	78	73	45
63	6	318	NVT	6787	6908	100	42	97	54	49
63	7	371	NVT	6784	6926	93	50	87	58	53
63	8	311	NVT	6781	6901	101	20	105	73	41
63	9	394	NVT	6778	6928	131	47	110	94	45
63	10	324	NVT	6776	6903	96	49	84	69	54
63	11	153	NVT	6773	6836	77	34	71	63	35
63	12	363	NVT	6772	6911	106	46	89	80	52
63	13	372	NVT	6768	6894	108	46	101	69	51
63	14	199	NVT	6765	6843	72	45	58	55	53
63	15	317	NVT	6764	6886	110	43	103	51	49
63	16	238	NVT	6761	6852	99	36	92	60	52
63	17	246	NVT	6759	6852	91	33	79	59	35
63	18	361	NVT	6756	6894	102	60	95	80	56
63	19	173	NVT	6754	6822	91	29	89	54	30
63	20	351	NVT	6753	6885	111	40	105	57	41
63	21	275	NVT	6749	6856	79	43	67	64	48
63	22	116	NVT	6748	6792	68	36	68	54	46
63	23	271	NVT	6746	6852	93	38	86	70	40
63	24	128	NVT	6744	6795	77	29	71	56	29
63	25	111	NVT	6743	6789	68	21	62	55	21
63	26	234	NVT	6741	6831	91	43	85	64	53
63	27	248	NVT	6738	6833	89	39	87	73	39
63	28	215	NVT	6736	6821	98	31	96	59	31
63	29	185	NVT	6734	6806	84	48	68	54	48
63	30	178	NVT	6732	6802	83	46			
63	31	318	NVT	6730	6854	90	52	77	54	50
63	32	160	NVT	6727	6788	82	36	77	57	34
63	33	131	NVT	6725	6777	68	33	55	53	37
63	34	251	NVT	6723	6821	73	48	69	67	50
63	35	205	NVT	6721	6802	76	41	66	59	42
63	36	486	NVT	6719	6906	129	44	125	71	44
63	37	285	NVT	6716	6824	85	50	72	66	50
63	38	183	NVT	6714	6784	99	18	91	68	24
63	39	128	NVT	6711	6763	73	42	57	53	41
63	40	178	NVT	6710	6780	78	33	77	61	34
63	41	208	NVT	6708	6791	75	41	63	62	42
63	42	148	NVT	6706	6765	80	36	80	51	36
63	43	170	NVT	6705	6771	81	46	75	52	45
63	44	366	NVT	6703	6843	90	46	81	74	45
63	45	248	NVT	6700	6795	77	53	59	57	56
63	46	197	NVT	6696	6775	70	42	63	52	44
63	47	185	NVT	6695	6760	75	45	75	48	45
63	48	244	NVT	6694	6788	77	35	73	66	37

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
63	49	156	NVT	6692	6752	84	25	79	70	26
63	50	95	NVT	6690	6721	71	21	63	58	20
63	51	404	NVT	6687	6842	104	46	96	70	46
63	52	278	NVT	6685	6792	80	43	77	65	57
63	53	180	NVT	6682	6750	85	35	64	59	38
63	54	162	NVT	6679	6742	79	31	70	56	29
63	55	229	NVT	6677	6766	81	39	76	50	50
63	56	253	NVT	6675	6773	80	46	60	57	46
63	57	136	NVT	6672	6725	75	24	71	57	27
63	58	180	NVT	6670	6742	64	42	56	54	40
63	59	171	NVT	6669	6736	65	41	63	52	42
63	60	192	NVT	6668	6743	85	33	84	54	33
63	61	298	NVT	6666	6781	83	50	73	68	48
63	62	175	NVT	6664	6732	68	41	66	59	44
63	63	126	NVT	6663	6712	75	23	62	58	25
63	64	191	NVT	6661	6734	91	23	85	66	23
63	65	222	NVT	6659	6746	87	48	76	57	54
63	66	137	NVT	6657	6712	67	31	59	55	32
63	67	230	NVT	6656	6745	98	28	96	67	37
63	68	142	NVT	6653	6710	66	42	65	51	42
63	69	142	NVT	6652	6708	71	28	65	57	30
63	70	333	NVT	6651	6780	93	45	82	53	45
63	71	343	NVT	6648	6771	84	43	75	65	43
63	72	189	NVT	6645	6719	89	40	88	46	40
63	73	259	NVT	6643	6744	83	48	80	55	47
63	74	278	NVT	6642	6747	86	49	77	63	50
63	75	155	NVT	6640	6700	70	45	63	49	44
63	76	160	NVT	6638	6700	75	45	51	50	47
63	77	144	NVT	6637	6694	79	27	77	51	27
63	78	155	NVT	6634	6695	71	36	64	62	38
63	79	140	NVT	6633	6687	66	37	59	57	38
63	80	121	NVT	6632	6678	77	27	75	60	25
63	81	111	NVT	6630	6674	71	22	67	51	23
90	1	1272	NVT	21545	22022	179	46	177	100	52
90	2	1249	NVT	21528	22008	153	74	153	95	84
90	3	492	NVT	21520	21711	126	37	120	83	39
90	4	473	NVT	21518	21704	112	48	95	85	58
90	5	688	NVT	21512	21781	136	64	122	78	66
90	6	733	NVT	21506	21791	117	59	101	91	70
90	7	492	NVT	21496	21692	102	55	91	80	56
90	8	755	NVT	21490	21778	137	51	131	73	52
90	9	479	NVT	21484	21671	109	64	110	799	65
90	10	895	NVT	21477	21812	124	76	120	95	74
90	11	1183	NVT	21469	21911	184	57	182	93	63
90	12	1207	NVT	21462	21925	168	59	169	117	56
90	13	529	NVT	21455	21659	115	49	114	82	54
90	14	918	NVT	21445	21800	121	76	110	101	75
90	15	533	NVT	21442	21651	98	62	84	71	67
90	16	746	NVT	21437	21726	138	40	130	104	41
90	17	745	NVT	21431	21720	125	59	123	97	59
90	18	1188	NVT	21425	21880	129	68	127	100	74
90	19	603	NVT	21418	21652	145	47	121	103	48
90	20	1016	NVT	21413	21802	139	66	112	91	69
90	21	568	NVT	21408	21631	124	64	121	88	64
90	22	632	NVT	21400	21648	117	63	114	74	66
90	23	522	NVT	21395	21597	108	59	106	77	57
90	24	704	NVT	21390	21661	120	55	120	91	61
90	25	545	NVT	21380	21599	112	56	107	71	63
90	26	651	NVT	21375	21631	139	50	125	100	47
90	27	372	NVT	21368	21521	97	46	87	70	46
90	28	508	NVT	21364	21562	128	47	117	83	49
90	29	854	NVT	21360	21698	129	62	107	99	72
90	30	554	NVT	21354	21570	96	61	87	76	70
125	1	1753	NVT	21632	22290	170	87	151	124	91
125	2	2172	NVT	21620	22437	180	76	158	129	77
125	3	1607	NVT	21606	22199	195	69	181	117	66
125	4	2473	NVT	21596	22512	201	81	183	138	79
125	5	2005	NVT	21582	22316	170	82	164	119	82
125	6	1939	NVT	21570	22311	164	78	149	133	75
125	7	1903	NVT	21557	22275	176	72	158	135	76
180	1	4602	NVT	21710	23458	323	70	280	201	73
180	2	2262	NVT	21681	22548	208	57	183	183	54
180	3	2952	NVT	21657	22648	183	80	180	157	83

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
180	4	3098	NVT	21644	22820	230	62	190	184	65

C.2.2.2 Sample B

Sieve Passing	Rock ID	Mass M1
31.5	1	41
31.5	2	53
31.5	3	36
31.5	4	56
31.5	5	44
31.5	6	44
31.5	7	24
31.5	8	29
31.5	9	31
31.5	10	53
31.5	11	43
31.5	12	19
31.5	13	27
31.5	14	48
31.5	15	47
31.5	16	29
31.5	17	30
31.5	18	34
31.5	19	35
31.5	20	37
31.5	21	33
31.5	22	23
31.5	23	44
31.5	24	36
31.5	25	19
31.5	26	18
31.5	27	21
31.5	28	21
31.5	29	38
31.5	30	24
31.5	31	23
31.5	32	8
31.5	33	9
31.5	34	9
31.5	35	12
31.5	36	11
31.5	37	9
31.5	38	12
31.5	39	6
31.5	40	5
31.5	41	4
31.5	42	4
31.5	43	4
31.5	44	3
31.5	45	3
45	1	164
45	2	122
45	3	80
45	4	101
45	5	112
45	6	163
45	7	161
45	8	131
45	9	132
45	10	94
45	11	155
45	12	156
45	13	84
45	14	146
45	15	97
45	16	146
45	17	94
45	18	90
45	19	112
45	20	152
45	21	101
45	22	73
45	23	84
45	24	57
45	25	61

Sieve Passing	Rock ID	Mass M1
45	26	52
45	27	105
45	28	144
45	29	121
45	30	130
45	31	45
45	32	70
45	33	94
45	34	91
45	35	53
45	36	58
45	37	121
45	38	130
45	39	45
45	40	70
45	41	94
45	42	91
45	43	53
45	44	58
45	45	121
45	46	128
45	47	41
45	48	82
45	49	174
45	50	119
45	51	98
45	52	113
45	53	58
45	54	75
45	55	96
45	56	91
45	57	51
45	58	78
45	59	76
45	60	148
45	61	107
45	62	71
45	63	62
45	64	164
45	65	121
45	66	71
45	67	50
45	68	71
45	69	48
45	70	58
45	71	73
45	72	45
45	73	73
45	74	75
45	75	74
45	76	73
45	77	90
45	78	162
45	79	73
45	80	80
45	81	85
45	82	86
45	83	108
45	84	102
45	85	129
45	86	170
45	87	139
45	88	120
45	89	91
45	90	120
45	91	137
45	92	175
45	93	83
45	94	84
45	95	77

Sieve Passing	Rock ID	Mass M1
45	96	45
45	97	93
45	98	45
45	99	154
45	100	45
45	101	72
45	102	58
45	103	69
45	104	31
45	105	58
45	106	38
45	107	66
45	108	61
45	109	91
45	110	64
45	111	124
45	112	54
45	113	92
45	114	38
45	115	72
45	116	105
63	1	380
63	2	429
63	3	134
63	4	234
63	5	252
63	6	273
63	7	330
63	8	283
63	9	322
63	10	289
63	11	261
63	12	221
63	13	227
63	14	160
63	15	208
63	16	181
63	17	260
63	18	194
63	19	275
63	20	241
63	21	267
63	22	255
63	23	135
63	24	153
63	25	128
63	26	286
63	27	139
63	28	179
63	29	580
63	30	167
63	31	100
63	32	378
63	33	570
63	34	138
63	35	345
63	36	322
63	37	224
63	38	173
63	39	166
63	40	177
63	41	123
63	42	168
63	43	180
63	44	163
63	45	172
63	46	279
63	47	221
63	48	161
63	49	126
63	50	196
63	51	145
63	52	215

Sieve Passing	Rock ID	Mass M1
63	53	337
63	54	227
63	55	164
63	56	249
63	57	205
90	1	753
90	2	1223
90	3	1039
90	4	955
90	5	1014
90	6	1109
90	7	671
90	8	478
90	9	591
90	10	430
90	11	995
90	12	429
90	13	593
90	14	1060
90	15	401
90	16	402
90	17	453
90	18	567
90	19	628
90	20	498
90	21	607
90	22	699
90	23	272
90	24	528
90	25	797
90	26	423
125	1	1363
125	2	2992
125	3	1241
125	4	2310
125	5	2084
125	6	1572
125	7	2482
125	8	2339
125	9	1204
180	1	4171
180	2	3148
180	3	3552
180	4	4853

C.2.2.3 Sample C

Sieve Passing	Rock ID	Mass M1
31.5	1	36
31.5	2	45
31.5	3	37
31.5	4	28
31.5	5	40
31.5	6	40
31.5	7	23
31.5	8	28
31.5	9	30
31.5	10	25
31.5	11	19
31.5	12	34
31.5	13	70
31.5	14	45
31.5	15	28
31.5	16	22
31.5	17	28
31.5	18	48
31.5	19	38
31.5	20	39
31.5	21	39
31.5	22	29
31.5	23	38
31.5	24	23
31.5	25	23
31.5	26	23
31.5	27	18
31.5	28	24
31.5	29	27
31.5	30	22
31.5	31	24
31.5	32	23
31.5	33	25
31.5	34	19
31.5	35	30
31.5	36	21
31.5	37	15
31.5	38	6
31.5	39	9
31.5	40	4
31.5	41	12
45	1	45
45	2	150
45	3	74
45	4	98
45	5	53
45	6	107
45	7	68
45	8	59
45	9	105
45	10	66
45	11	81
45	12	72
45	13	90
45	14	110
45	15	140
45	16	54
45	17	96
45	18	58
45	19	45
45	20	89
45	21	57
45	22	164
45	23	119
45	24	40
45	25	83
45	26	82
45	27	82
45	28	54
45	29	49

Sieve Passing	Rock ID	Mass M1
45	30	44
45	31	87
45	32	84
45	33	46
45	34	77
45	35	34
45	36	69
45	37	65
45	38	47
45	39	51
45	40	84
45	41	94
45	42	36
45	43	73
45	44	82
45	45	88
45	46	112
45	47	68
45	48	52
45	49	55
45	50	200
45	51	126
45	52	109
45	53	138
45	54	114
45	55	201
45	56	136
45	57	173
45	58	101
45	59	98
45	60	158
45	61	182
45	62	113
45	63	152
45	64	116
45	65	118
45	66	97
45	67	114
45	68	137
45	69	61
45	70	92
45	71	90
45	72	61
45	73	68
45	74	76
45	75	80
45	76	146
45	77	100
45	78	83
45	79	55
45	80	72
45	81	148
45	82	83
45	83	70
45	84	118
45	85	49
45	86	70
45	87	84
45	88	77
45	89	123
45	90	70
45	91	180
45	92	68
45	93	116
45	94	114
45	95	78
45	96	57
45	97	70
45	98	58
45	99	57

Sieve Passing	Rock ID	Mass M1
45	100	135
63	1	148
63	2	225
63	3	247
63	4	422
63	5	212
63	6	348
63	7	309
63	8	287
63	9	291
63	10	340
63	11	346
63	12	455
63	13	457
63	14	493
63	15	290
63	16	278
63	17	134
63	18	211
63	19	207
63	20	429
63	21	256
63	22	251
63	23	201
63	24	429
63	25	138
63	26	248
63	27	234
63	28	290
63	29	259
63	30	354
63	31	130
63	32	223
63	33	118
63	34	245
63	35	203
63	36	196
63	37	289
63	38	131
63	39	102
63	40	180
63	41	172
63	42	148
63	43	206
63	44	216
63	45	459
63	46	226
63	47	139
63	48	353
63	49	274
63	50	165
63	51	268
63	52	158
63	53	184
63	54	295
63	55	212
63	56	168
63	57	240
63	58	452
63	59	111
63	60	186
63	61	118
63	62	189
63	63	139
63	64	166
63	65	236
63	66	267
63	67	400
63	68	117
63	69	160
63	70	118
63	71	140
63	72	130

Sieve Passing	Rock ID	Mass M1
90	1	1011
90	2	2033
90	3	1486
90	4	571
90	5	914
90	6	660
90	7	463
90	8	925
90	9	1167
90	10	896
90	11	435
90	12	759
90	13	777
90	14	795
90	15	402
90	16	364
90	17	597
90	18	419
90	19	430
125	1	2683
125	2	2844
125	3	1474
125	4	2522
125	5	2538
125	6	2586
125	7	1677
125	8	1435
180	1	2747
180	2	3798
180	3	3128

C.2.2.4 Sample D

Sieve Passing	Rock ID	Mass M1
31.5	1	76
31.5	2	48
31.5	3	49
31.5	4	34
31.5	5	44
31.5	6	31
31.5	7	72
31.5	8	50
31.5	9	26
31.5	10	32
31.5	11	13
31.5	12	36
31.5	13	31
31.5	14	12
31.5	15	29
31.5	16	33
31.5	17	48
31.5	18	22
31.5	19	41
31.5	20	15
31.5	21	50
31.5	22	15
31.5	23	36
31.5	24	23
31.5	25	21
31.5	26	40
31.5	27	30
31.5	28	28
31.5	29	15
31.5	30	10
31.5	31	30
31.5	32	22
31.5	33	11
31.5	34	22
31.5	35	12
31.5	36	13
31.5	37	17
31.5	38	18
31.5	39	22
31.5	40	28
31.5	41	13
31.5	42	18
31.5	43	29
31.5	44	6
31.5	45	15
31.5	46	15
31.5	47	4
31.5	48	9
31.5	49	17
31.5	50	11
31.5	51	14
31.5	52	7
31.5	53	4
31.5	54	8
45	1	124
45	2	59
45	3	154
45	4	120
45	5	151
45	6	169
45	7	124
45	8	180
45	9	111
45	10	103
45	11	183
45	12	102
45	13	139
45	14	60
45	15	83
45	16	78
45	17	133
45	18	98
45	19	109
45	20	85
45	21	103
45	22	234
45	23	133
45	24	128
45	25	70
45	26	98
45	27	87
45	28	63
45	29	116
45	30	88
45	31	153
45	32	106
45	33	146
45	34	103
45	35	152
45	36	143
45	37	70
45	38	94
45	39	117
45	40	120
45	41	117
45	42	74
45	43	59
45	44	80
45	45	67
45	46	100
45	47	97
45	48	66
45	49	89
45	50	61
45	51	54
45	52	67
45	53	36
45	54	105
45	55	95
45	56	45
45	57	85
45	58	36
45	59	189
45	60	61
45	61	140
45	62	145
45	63	70
45	64	65
45	65	64
45	66	57
45	67	72
45	68	49
45	69	120
45	70	138
45	71	88
45	72	62
45	73	102
45	74	108
45	75	65
45	76	71
45	77	52
45	78	54
45	79	150
45	80	117
45	81	71
45	82	139
45	83	48
45	84	115
45	85	44
45	86	59

Sieve Passing	Rock ID	Mass M1
45	87	64
45	88	68
45	89	158
45	90	43
45	91	77
45	92	161
45	93	81
45	94	78
45	95	142
45	96	167
45	97	73
45	98	65
45	99	62
45	100	79
45	101	82
45	102	28
45	103	90
45	104	78
45	105	37
45	106	126
45	107	63
45	108	64
45	109	63
45	110	116
45	111	67
45	112	84
45	113	54
45	114	47
45	115	43
45	116	73
63	1	348
63	2	139
63	3	265
63	4	522
63	5	236
63	6	360
63	7	424
63	8	413
63	9	206
63	10	310
63	11	247
63	12	370
63	13	229
63	14	297
63	15	175
63	16	337
63	17	469
63	18	125
63	19	290
63	20	185
63	21	217
63	22	194
63	23	155
63	24	151
63	25	136
63	26	329
63	27	235
63	28	207
63	29	287
63	30	313
63	31	207
63	32	210
63	33	310
63	34	233
63	35	163
63	36	177
63	37	252
63	38	342
63	39	189
63	40	317
63	41	253
63	42	233
63	43	252

Sieve Passing	Rock ID	Mass M1
63	44	252
63	45	242
63	46	160
63	47	257
63	48	308
63	49	245
63	50	355
63	51	457
90	1	530
90	2	983
90	3	1166
90	4	621
90	5	431
90	6	643
90	7	518
90	8	779
90	9	1078
90	10	509
90	11	931
90	12	766
90	13	521
90	14	506
125	1	1200
125	2	1393
125	3	2006
180	1	3865
180	2	5092
180	3	5071
250	1	4847

C.2.2.5 Sample E

Sieve Passing	Rock ID	Mass M1
31.5	1	58
31.5	2	46
31.5	3	47
31.5	4	32
31.5	5	23
31.5	6	40
31.5	7	39
31.5	8	27
31.5	9	39
31.5	10	24
31.5	11	79
31.5	12	57
31.5	13	9
31.5	14	38
31.5	15	35
31.5	16	17
31.5	17	31
31.5	18	55
31.5	19	32
31.5	20	9
31.5	21	33
31.5	22	11
31.5	23	32
31.5	24	54
31.5	25	15
31.5	26	32
31.5	27	39
31.5	28	11
31.5	29	13
31.5	30	23
31.5	31	18
31.5	32	21
31.5	33	20
31.5	34	28
31.5	35	22
31.5	36	33
31.5	37	40
31.5	38	13
31.5	39	10
31.5	40	45
31.5	41	42
31.5	42	22
31.5	43	20
31.5	44	18
31.5	45	23
31.5	46	17
31.5	47	18
31.5	48	17
31.5	49	18
31.5	50	10
31.5	51	13
31.5	52	18
31.5	53	37
31.5	54	5
31.5	55	15
31.5	56	14
31.5	57	9
31.5	58	6
31.5	59	10
31.5	60	6
31.5	61	4
45	1	48
45	2	175
45	3	80
45	4	91
45	5	80
45	6	180
45	7	119
45	8	137
45	9	74

Sieve Passing	Rock ID	Mass M1
45	10	133
45	11	173
45	12	113
45	13	131
45	14	136
45	15	81
45	16	80
45	17	79
45	18	135
45	19	64
45	20	111
45	21	113
45	22	130
45	23	105
45	24	78
45	25	92
45	26	86
45	27	124
45	28	77
45	29	137
45	30	61
45	31	62
45	32	86
45	33	126
45	34	105
45	35	130
45	36	114
45	37	149
45	38	181
45	39	83
45	40	62
45	41	71
45	42	93
45	43	79
45	44	66
45	45	129
45	46	98
45	47	68
45	48	98
45	49	229
45	50	64
45	51	128
45	52	141
45	53	93
45	54	71
45	55	68
45	56	80
45	57	56
45	58	73
45	59	58
45	60	104
45	61	112
45	62	77
45	63	74
45	64	61
45	65	109
45	66	54
45	67	93
45	68	55
45	69	62
45	70	122
45	71	90
45	72	55
45	73	49
45	74	152
45	75	105
45	76	75
45	77	83
45	78	55
45	79	60

Sieve Passing	Rock ID	Mass M1
45	80	80
45	81	65
45	82	97
45	83	60
45	84	144
45	85	55
45	86	60
45	87	57
45	88	65
45	89	79
45	90	112
45	91	79
45	92	50
45	93	60
45	94	107
45	95	83
45	96	55
45	97	86
45	98	61
63	1	598
63	2	298
63	3	267
63	4	390
63	5	300
63	6	259
63	7	231
63	8	396
63	9	176
63	10	550
63	11	398
63	12	307
63	13	196
63	14	168
63	15	213
63	16	314
63	17	357
63	18	216
63	19	246
63	20	307
63	21	279
63	22	403
63	23	268
63	24	134
63	25	269
63	26	172
63	27	155
63	28	214
63	29	446
63	30	346
63	31	203
63	32	290
63	33	184
63	34	228
63	35	273
63	36	215
63	37	158
63	38	174
63	39	188
63	40	232
63	41	230
63	42	130
63	43	276
63	44	140
63	45	176
63	46	125
63	47	242
63	48	126
63	49	147
63	50	213
63	51	317
63	52	160
63	53	265
63	54	190

Sieve Passing	Rock ID	Mass M1
63	55	237
63	56	123
63	57	150
63	58	212
63	59	230
63	60	169
90	1	640
90	2	1833
90	3	528
90	4	975
90	5	1009
90	6	591
90	7	601
90	8	611
90	9	997
90	10	378
90	11	533
90	12	1313
90	13	727
90	14	596
90	15	514
90	16	834
90	17	807
90	18	340
90	19	420
90	20	470
90	21	512
90	22	525
90	23	396
125	1	1781
125	2	4148
125	3	2666
125	4	1525
125	5	2210
125	6	2924
125	7	2586
125	8	3180
125	9	2252
125	10	2655
125	11	1356
125	12	1571
180	1	5429

C.2.3 2-8

C.2.3.1 Sample A

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
31.5	1	59	NVT	8384	8408	57	25	55	35	26
31.5	2	47	NVT	8383	8404	57	25	56	34	19
31.5	3	57	NVT	8381	8394	43	17	37	36	18
31.5	4	26	NVT	8380	8392	32	22	29	27	23
31.5	5	20	NVT	8379	8390	38	17	38	19	17
31.5	6	20	NVT	8378	8389	45	16	37	25	17
45	1	106	NVT	8377	8420	64	35	59	40	36
45	2	67	NVT	8376	8403	51	34	50	35	35
45	3	148	NVT	8375	8435	73	37	68	41	37
45	4	181	NVT	8373	8444	79	32	75	54	31
45	5	152	NVT	8370	8429	69	25	91	52	25
45	6	116	NVT	8369	8414	66	38	59	40	37
45	7	149	NVT	8366	8427	65	46	57	49	48
45	8	121	NVT	8365	8412	66	40	53	47	42
45	9	109	NVT	8364	8409	54	40	50	45	42
45	10	100	NVT	8362	8402	68	25	65	43	27
45	11	91	NVT	8362	8399	82	26	81	26	22
45	12	201	NVT	8360	8432	102	35	102	52	35
45	13	65	NVT	8358	8486	52	23	53	37	23
45	14	84	NVT	8356	8392	60	29	52	45	34
45	15	79	NVT	8355	8388	53	34	49	47	33
45	16	91	NVT	8353	8391	60	30	49	40	30
45	17	152	NVT	8352	8413	94	37	83	47	40
45	18	105	NVT	8351	8392	57	36	47	47	37
45	19	152	NVT	8349	8407	91	35	85	47	38
45	20	151	NVT	8346	8407	89	26	87	45	27
45	21	87	NVT	8345	8381	59	35	55	43	31
45	22	78	NVT	8343	8376	58	23	46	44	26
45	23	130	NVT	8342	8395	68	36	63	48	38
45	24	90	NVT	8341	8378	57	34	54	42	35
45	25	46	NVT	8339	8361	65	18	65	35	19
45	26	113	NVT	8338	8383	64	25	60	47	27
45	27	74	NVT	8336	8367	72	25	70	36	25
45	28	82	NVT	8335	8368	60	31	53	37	31
45	29	100	NVT	8333	8375	60	35	50	49	36
45	30	191	NVT	8331	8407	98	30	98	54	30
45	31	80	NVT	8329	8362	66	30	52	43	37
45	32	117	NVT	8328	8375	76	30	76	36	32
45	33	67	NVT	8327	8354	90	20	60	40	21
45	34	62	NVT	8324	8351	57	21	57	43	22
45	35	73	NVT	8323	8353	55	25	52	45	28
45	36	141	NVT	8322	8379	77	35	75	49	37
45	37	112	NVT	8320	8366	69	38	61	40	37
45	38	143	NVT	8319	8403	100	28	100	55	29
45	39	185	NVT	8316	8387	82	39	77	52	41
45	40	112	NVT	8313	8360	78	37	77	46	36
63	1	272	NVT	8257	8359	97	41	79	74	44
63	2	302	NVT	8253	8324	81	28	79	61	27
63	3	315	NVT	8250	8368	100	34	101	73	36
63	4	220	NVT	8245	8331	74	49	73	58	48
63	5	403	NVT	8242	8397	128	35	123	74	38
63	6	162	NVT	8240	8303	88	31	82	50	40
63	7	330	NVT	8237	8464	95	36	89	82	36
63	8	218	NVT	8233	8317	97	38	91	55	48
63	9	457	NVT	8230	8403	108	43	106	72	43
63	10	393	NVT	8226	8376	104	38	98	76	38
63	11	213	NVT	8220	8303	77	46	65	54	46
63	12	161	NVT	8217	8282	74	31	62	61	33
63	13	242	NVT	8213	8308	105	35	104	59	35
63	14	214	NVT	8210	8294	79	51	66	53	50
63	15	222	NVT	8208	8296	98	38	92	47	43
63	16	371	NVT	8204	8349	101	55	91	70	57
63	17	240	NVT	8201	8295	124	33	120	73	32
63	18	233	NVT	8197	8288	106	38	99	64	38
63	19	364	NVT	8194	8334	95	49	92	74	46
63	20	259	NVT	8190	8291	94	43	94	61	44
63	21	341	NVT	8189	8321	105	41	103	62	41

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
63	22	200	NVT	8183	8261	93	35	90	49	38
63	23	130	NVT	8180	8256	89	26	86	64	28
63	24	351	NVT	8177	8310	114	37	98	79	39
63	25	426	NVT	8174	8336	124	40	115	71	39
63	26	310	NVT	8170	8288	95	41	92	76	41
63	27	288	NVT	8166	8277	81	45	73	65	44
63	28	554	NVT	8161	8266	86	42	77	61	46
63	29	267	NVT	8158	8262	102	41	101	59	39
63	30	237	NVT	8155	8248	116	26	114	73	27
63	31	300	NVT	8151	8265	84	55	64	62	55
63	32	324	NVT	8149	8272	95	51	88	62	51
63	33	376	NVT	8146	8288	86	53	86	70	57
63	34	275	NVT	8143	8249	98	39	96	65	38
63	35	854	NVT	8139	8426	161	59	152	63	60
63	36	207	NVT	8134	8213	78	40	71	61	42
63	37	301	NVT	8131	8244	110	46	111	50	48
63	38	553	NVT	8125	8332	131	56	129	66	58
63	39	275	NVT	8120	8224	102	46	96	55	45
63	40	403	NVT	8117	8271	103	46	93	70	51
63	41	206	NVT	8113	8195	86	40	73	62	39
63	42	373	NVT	8110	8251	92	52	82	58	53
63	43	343	NVT	8106	8237	121	44	121	61	44
63	44	298	NVT	8103	8220	96	43	95	60	43
63	45	244	NVT	8101	8175	84	35	77	52	38
63	46	298	NVT	8099	8211	106	34	89	78	35
63	47	244	NVT	8095	8181	78	44	77	52	44
63	48	361	NVT	8092	8231	132	50	132	64	49
63	49	251	NVT	8084	8184	96	37	85	54	39
63	50	253	NVT	8085	8183	95	32	87	79	34
63	51	201	NVT	8079	8158	81	43	63	63	40
63	52	270	NVT	8076	8176	98	38	94	54	38
63	53	218	NVT	8074	8160	84	36	80	58	38
63	54	163	NVT	8072	8134	79	44	75	44	42
63	55	450	NVT	8070	8242	114	45	103	67	44
63	56	327	NVT	8065	8188	101	45	82	50	40
63	57	273	NVT	8062	8167	82	43	79	72	47
63	58	153	NVT	8060	8122	75	26	73	62	27
63	59	121	NVT	8056	8105	79	26	78	54	25
63	60	132	NVT	8055	8110	74	23	74	52	23
63	61	158	NVT	8052	8112	69	35	65	48	42
63	62	255	NVT	8050	8149	92	40	80	64	42
63	63	207	NVT	8046	8125	73	59	62	61	56
63	64	255	NVT	8044	8146	101	38	95	59	38
63	65	253	NVT	8042	8142	81	37	80	61	49
63	66	289	NVT	8039	8149	78	51	61	60	52
63	67	222	NVT	8037	8122	77	44	74	64	43
63	68	156	NVT	8034	8097	76	28	62	57	30
63	69	143	NVT	8030	8088	68	34	65	55	35
63	70	162	NVT	8029	8092	75	40	65	53	42
63	71	237	NVT	8027	8115	74	41	65	54	40
63	72	132	NVT	8023	8077	61	36	61	46	45
63	73	117	NVT	8021	8069	57	37	58	51	38
63	74	234	NVT	8019	8114	87	35	81	78	38
90	1	581	NVT	17850	18069	131	50	117	75	52
90	2	667	NVT	17845	18100	114	62	102	92	61
90	3	670	NVT	17835	18097	105	61	104	89	61
90	4	809	NVT	17829	18135	126	48	113	109	47
90	5	1434	NVT	17818	18357	188	76	187	94	69
90	6	1461	NVT	17804	18356	167	79	138	113	87
90	7	1702	NVT	17794	18428	178	68	167	106	70
90	8	1045	NVT	17779	18159	121	70	105	102	69
90	9	977	NVT	17769	18143	114	68	107	93	70
90	10	497	NVT	17758	17955	104	54	88	82	52
90	11	625	NVT	17755	17999	106	57	103	94	55
90	12	1047	NVT	17750	18147	153	62	133	100	59
90	13	461	NVT	17739	17921	100	58	87	75	55
90	14	895	NVT	17733	18075	109	67	103	90	80
90	15	758	NVT	17726	18011	122	60	114	79	60
90	16	1033	NVT	17718	18102	153	61	151	94	69
90	17	885	NVT	17709	18044	131	65	124	91	64
90	18	1338	NVT	17695	18205	167	68	163	91	67
90	19	475	NVT	17680	17861	115	46	113	70	44
90	20	977	NVT	17672	18025	159	62	151	91	68

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
90	21	773	NVT	17663	17960	129	61	126	91	64
90	22	708	NVT	17655	17930	127	55	104	83	54
90	23	899	NVT	17647	17991	125	60	121	82	73
90	24	814	NVT	17638	17950	130	52	124	97	52
90	25	980	NVT	17624	18002	139	76	133	100	72
90	26	811	NVT	17616	17928	124	53	116	103	53
90	27	578	NVT	17606	17835	138	44	136	78	42
90	28	552	NVT	17595	17814	123	52	102	82	53
90	29	620	NVT	17587	17827	120	47	106	91	50
90	30	676	NVT	17579	17842	121	76	107	95	81
90	31	544	NVT	17574	17761	102	54	95	80	54
90	32	818	NVT	17568	17875	144	57	141	79	58
90	33	402	NVT	17563	17723	95	43	92	77	45
90	34	531	NVT	17555	17765	125	51	129	81	59
90	35	573	NVT	17551	17770	114	49	110	79	55
90	36	651	NVT	17545	17794	124	98	126	76	73
90	37	620	NVT	17536	17770	114	65	112	88	65
90	38	986	NVT	17529	17900	160	54	147	103	60
90	39	572	NVT	17515	17739	110	63	95	78	63
90	40	555	NVT	17510	17705	107	54	105	70	53
90	41	342	NVT	17503	17641	98	41	88	74	40
90	42	370	NVT	17499	17647	101	35	93	86	36
90	43	349	NVT	17488	17612	94	35	90	86	37
90	44	733	NVT	17482	17761	117	74	112	85	72
90	45	843	NVT	17477	17800	127	77	94	90	74
90	46	329	NVT	17469	17601	97	38	97	83	35
90	47	767	NVT	17462	17755	129	51	119	95	51
90	48	590	NVT	17452	17682	122	46	119	95	45
90	49	510	NVT	17443	17643	126	32	122	89	32
125	1	3435	NVT	17426	18705	190	107	175	141	123
125	2	2319	NVT	17391	18273	180	83	174	140	84
125	3	2297	NVT	17373	18233	213	82	210	115	83
125	4	2353	NVT	17355	18243	189	73	175	147	70
125	5	988	NVT	17326	17697	135	73	127	122	73
125	6	2777	NVT	17310	18347	197	103	167	138	101
125	7	1983	NVT	17293	18046	184	73	182	132	72
125	8	2725	NVT	17270	18292	204	83	198	150	85
125	9	5111	NVT	21663	23588	295	81	291	185	84
125	10	1786	NVT	17244	17919	164	98	157	118	88
125	11	1248	NVT	17229	17703	141	72	115	114	73
125	12	2283	NVT	17218	18061	177	83	165	140	83
125	13	945	NVT	17191	17552	131	56	126	103	55
125	14	1677	NVT	17181	17804	192	102	190	108	104
125	15	1672	NVT	17167	17692	168	57	163	114	56
125	16	1611	NVT	17157	17771	151	88	148	114	88
125	17	1070	NVT	17145	17552	151	56	138	135	71
125	18	1088	NVT	17132	17551	132	58	129	110	58
125	19	1330	NVT	17120	17619	187	40	173	146	42
180	1	9796	NVT	21623	24339	342	109	332	209	105
180	2	6136	NVT	21561	23864	318	89	285	225	84
180	3	4521	NVT	21531	23226	229	105	218	179	97
180	4	5185	NVT	21505	23454	221	121	201	164	145
180	5	4273	NVT	21481	23139	208	92	185	171	110
180	6	3575	NVT	21428	23779	221	116	213	190	109
180	7	5163	NVT	x	x	222	135	181	179	131
180	8	3849	NVT	x	x	204	111	189	140	111
180	9	5410	NVT	21350	23368	275	108	251	163	118
180	10	4721	NVT	21288	23006	305	77	265	183	72
180	11	3199	NVT	21267	23457	210	83	201	155	84
250	1	11722	NVT	x	x	315	115	280	263	111
250	2	15111	NVT	x	x	448	141	334	314	137

C.2.3.2 Sample B

Sieve Passing	Rock ID	Mass M1
31.5	1	49
31.5	2	48
31.5	3	41
31.5	4	38
31.5	5	63
31.5	6	39
31.5	7	16
31.5	8	27
31.5	9	28
31.5	10	26
31.5	11	37
31.5	12	24
31.5	13	13
31.5	14	41
31.5	15	32
31.5	16	22
31.5	17	30
31.5	18	28
31.5	19	18
31.5	20	35
31.5	21	38
31.5	22	23
31.5	23	35
31.5	24	31
31.5	25	17
31.5	26	14
31.5	27	18
31.5	28	18
31.5	29	12
31.5	30	10
31.5	31	7
31.5	32	2
31.5	33	4
31.5	34	6
31.5	35	17
31.5	36	9
31.5	37	7
31.5	38	9
31.5	39	17
45	1	58
45	2	122
45	3	128
45	4	131
45	5	107
45	6	88
45	7	59
45	8	77
45	9	141
45	10	131
45	11	232
45	12	223
45	13	170
45	14	68
45	15	84
45	16	103
45	17	78
45	18	232
45	19	85
45	20	135
45	21	68
45	22	158
45	23	116
45	24	131
45	25	194
45	26	93
45	27	72
45	28	85
45	29	90
45	30	47
45	31	154

Sieve Passing	Rock ID	Mass M1
45	32	61
45	33	78
45	34	103
45	35	116
45	36	70
45	37	51
45	38	101
45	39	43
45	40	76
45	41	52
45	42	43
45	43	34
45	44	59
45	45	67
45	46	51
45	47	49
45	48	53
63	1	440
63	2	422
63	3	192
63	4	293
63	5	273
63	6	263
63	7	309
63	8	255
63	9	375
63	10	268
63	11	394
63	12	152
63	13	188
63	14	372
63	15	145
63	16	365
63	17	424
63	18	302
63	19	324
63	20	416
63	21	211
63	22	255
63	23	477
63	24	204
63	25	260
63	26	203
63	27	220
63	28	328
63	29	337
63	30	308
63	31	419
63	32	525
63	33	248
63	34	264
63	35	322
63	36	163
63	37	306
63	38	283
63	39	262
63	40	229
63	41	357
63	42	226
63	43	320
63	44	211
63	45	156
63	46	373
63	47	212
63	48	231
63	49	266
63	50	231
63	51	374
63	52	287
63	53	197

Sieve Passing	Rock ID	Mass M1
63	54	267
63	55	235
63	56	286
63	57	141
63	58	383
63	59	178
63	60	283
63	61	163
63	62	205
63	63	233
63	64	253
63	65	195
63	66	414
63	67	264
63	68	186
63	69	232
90	1	732
90	2	785
90	3	951
90	4	1383
90	5	617
90	6	870
90	7	1377
90	8	504
90	9	420
90	10	578
90	11	1553
90	12	932
90	13	568
90	14	960
90	15	1105
90	16	543
90	17	310
90	18	734
90	19	440
90	20	464
90	21	747
90	22	950
90	23	594
90	24	613
90	25	1238
90	26	493
90	27	690
90	28	1072
90	29	677
90	30	604
90	31	1074
90	32	443
90	33	678
90	34	768
90	35	985
90	36	548
90	37	564
90	38	1216
90	39	915
90	40	475
90	41	599
90	42	895
90	43	328
90	44	377
90	45	635
90	46	561
90	47	605
90	48	588
90	49	656
90	50	409
90	51	911
90	52	950
90	53	518
90	54	653
125	1	2114
125	2	1411
125	3	2808

Sieve Passing	Rock ID	Mass M1
125	4	2776
125	5	1605
125	6	1113
125	7	1133
125	8	1621
125	9	1403
125	10	2071
125	11	2530
125	12	4072
180	1	3241
180	2	3671
180	3	4844
180	4	9543
180	5	4691
180	6	5867
180	7	4392
180	8	4803
250	1	10096
250	2	18835

C.2.3.3 Sample C

Sieve Passing	Rock ID	Mass M1
31.5	1	44
31.5	2	36
31.5	3	23
31.5	4	20
31.5	5	58
31.5	6	54
31.5	7	24
31.5	8	50
31.5	9	34
31.5	10	27
31.5	11	23
31.5	12	53
31.5	13	12
31.5	14	29
31.5	15	47
31.5	16	23
31.5	17	50
31.5	18	20
31.5	19	18
31.5	20	15
31.5	21	24
31.5	22	27
31.5	23	43
31.5	24	33
31.5	25	34
31.5	26	38
31.5	27	34
31.5	28	23
31.5	29	35
31.5	30	22
31.5	31	17
31.5	32	47
31.5	33	35
31.5	34	28
31.5	35	33
31.5	36	43
31.5	37	24
31.5	38	38
31.5	39	32
31.5	40	16
31.5	41	34
31.5	42	44
31.5	43	26
31.5	44	39
31.5	45	16
31.5	46	17
31.5	47	11
31.5	48	33
31.5	49	17
31.5	50	26
31.5	51	23
31.5	52	27
31.5	53	16
31.5	54	10
31.5	55	8
31.5	56	31
31.5	57	19
31.5	58	30
31.5	59	12
31.5	60	27
31.5	61	25
31.5	62	7
31.5	63	16
31.5	64	24
31.5	65	15
31.5	66	8
31.5	67	14
31.5	68	17
31.5	69	11
31.5	70	15
31.5	71	12
31.5	72	8
31.5	73	9
31.5	74	7
31.5	75	17
31.5	76	8
31.5	77	11
31.5	78	10
31.5	79	9
31.5	80	12
31.5	81	14
31.5	82	12
31.5	83	15
31.5	84	18
45	1	69
45	2	123
45	3	213
45	4	147
45	5	148
45	6	50
45	7	106
45	8	213
45	9	146
45	10	136
45	11	100
45	12	123
45	13	131
45	14	90
45	15	227
45	16	112
45	17	75
45	18	109
45	19	79
45	20	21
45	21	151
45	22	138
45	23	123
45	24	244
45	25	73
45	26	139
45	27	124
45	28	195
45	29	124
45	30	44
45	31	113
45	32	104
45	33	71
45	34	110
45	35	50
45	36	164
45	37	112
45	38	158
45	39	150
45	40	55
45	41	114
45	42	60
45	43	173
45	44	92
45	45	101
45	46	123
45	47	107
45	48	84
45	49	51
45	50	57
45	51	72
45	52	51
45	53	49
45	54	34
45	55	35
45	56	65

Sieve Passing	Rock ID	Mass M1
45	57	49
45	58	87
45	59	121
45	60	146
45	61	63
45	62	70
45	63	62
45	64	179
45	65	52
45	66	132
45	67	110
45	68	78
45	69	61
45	70	56
45	71	114
45	72	142
45	73	88
45	74	113
45	75	81
45	76	83
45	77	139
45	78	124
45	79	84
45	80	57
45	81	110
45	82	40
45	83	41
45	84	41
45	85	32
45	86	51
45	87	39
45	88	32
45	89	84
45	90	62
45	91	102
45	92	96
45	93	60
45	94	50
45	95	197
45	96	33
45	97	79
45	98	51
45	99	71
63	1	440
63	2	420
63	3	239
63	4	374
63	5	178
63	6	182
63	7	280
63	8	197
63	9	428
63	10	184
63	11	278
63	12	297
63	13	390
63	14	192
63	15	165
63	16	218
63	17	301
63	18	732
63	19	330
63	20	337
63	21	440
63	22	318
63	23	311
63	24	276
63	25	525
63	26	239
63	27	278
63	28	341
63	29	160
63	30	168

Sieve Passing	Rock ID	Mass M1
63	31	259
63	32	367
63	33	225
63	34	279
63	35	173
63	36	240
63	37	352
63	38	214
63	39	211
63	40	406
63	41	296
63	42	231
63	43	191
63	44	160
63	45	191
63	46	190
63	47	346
63	48	154
63	49	189
63	50	218
63	51	318
63	52	159
63	53	229
63	54	161
63	55	227
63	56	161
63	57	166
63	58	183
63	59	175
63	60	252
63	61	171
63	62	80
63	63	234
90	1	1091
90	2	875
90	3	1293
90	4	953
90	5	2002
90	6	1342
90	7	1098
90	8	942
90	9	1094
90	10	1287
90	11	662
90	12	1496
90	13	1004
90	14	683
90	15	734
90	16	1344
90	17	719
90	18	962
90	19	546
90	20	563
90	21	966
90	22	623
90	23	439
90	24	396
90	25	926
90	26	566
90	27	1108
90	28	853
90	29	1021
90	30	606
90	31	443
90	32	1164
90	33	851
90	34	1128
90	35	451
90	36	919
90	37	696
90	38	763
90	39	974
90	40	560

Sieve Passing	Rock ID	Mass M1
90	41	678
90	42	632
90	43	1042
90	44	721
90	45	688
90	46	349
90	47	296
90	48	397
90	49	672
125	1	3150
125	2	878
125	3	1816
125	4	2515
125	5	1534
125	6	2637
125	7	1298
125	8	1345
125	9	1621
125	10	1936
125	11	1360
125	12	1846
125	13	3201
125	14	2356
125	15	1264
125	16	1489
125	17	3120
125	18	2458
125	19	2457
125	20	1591
125	21	2325
125	22	1724
125	23	2717
125	24	1554
125	25	1567
125	26	1978
125	27	2128
180	1	6772
180	2	4094
180	3	4334
180	4	5636
180	5	4894
180	6	8436
180	7	8264
180	8	6479
180	9	5778
180	10	5418
180	11	7301
250	1	14314
250	2	12716

C.2.3.4 Sample D

Sieve Passing	Rock ID	Mass M1
31.5	1	26
31.5	2	43
31.5	3	24
31.5	4	35
31.5	5	18
31.5	6	85
31.5	7	36
31.5	8	33
31.5	9	41
31.5	10	24
31.5	11	25
31.5	12	35
31.5	13	15
31.5	14	24
31.5	15	10
31.5	16	18
31.5	17	22
31.5	18	11
31.5	19	13
31.5	20	27
31.5	21	13
31.5	22	12
31.5	23	11
31.5	24	16
31.5	25	23
31.5	26	9
31.5	27	16
31.5	28	27
31.5	29	13
31.5	30	36
31.5	31	23
31.5	32	20
31.5	33	26
31.5	34	22
31.5	35	27
31.5	36	15
31.5	37	18
31.5	38	14
31.5	39	25
31.5	40	34
31.5	41	17
31.5	42	20
31.5	43	12
31.5	44	21
31.5	45	8
31.5	46	13
31.5	47	18
31.5	48	15
31.5	49	19
31.5	50	14
31.5	51	7
31.5	52	7
31.5	53	12
31.5	54	10
31.5	55	7
31.5	56	15
31.5	57	4
31.5	58	6
31.5	59	7
31.5	60	16
31.5	61	11
31.5	62	9
31.5	63	4
31.5	64	18
31.5	65	4
31.5	66	9
31.5	67	7
31.5	rest	72
45	1	255
45	2	84

Sieve Passing	Rock ID	Mass M1
45	3	102
45	4	130
45	5	162
45	6	80
45	7	115
45	8	41
45	9	109
45	10	138
45	11	85
45	12	127
45	13	96
45	14	106
45	15	107
45	16	168
45	17	95
45	18	80
45	19	98
45	20	122
45	21	87
45	22	156
45	23	73
45	24	62
45	25	88
45	26	125
45	27	101
45	28	76
45	29	93
45	30	132
45	31	55
45	32	64
45	33	105
45	34	79
45	35	76
45	36	77
45	37	128
45	38	103
45	39	169
45	40	135
45	41	128
45	42	103
45	43	147
45	44	63
45	45	46
45	46	63
45	47	83
45	48	86
45	49	96
45	50	56
45	51	126
45	52	46
45	53	122
45	54	114
45	55	60
45	56	45
45	57	65
45	58	53
45	59	55
45	60	46
45	61	48
45	62	61
45	63	55
45	64	44
45	65	80
63	1	253
63	2	455
63	3	453
63	4	504
63	5	258
63	6	505
63	7	476

Sieve Passing	Rock ID	Mass M1
63	8	272
63	9	318
63	10	374
63	11	296
63	12	502
63	13	568
63	14	528
63	15	456
63	16	414
63	17	200
63	18	400
63	19	578
63	20	611
63	21	400
63	22	264
63	23	392
63	24	477
63	25	189
63	26	375
63	27	226
63	28	231
63	29	173
63	30	237
63	31	289
63	32	395
63	33	242
63	34	174
63	35	149
63	36	138
63	37	267
63	38	263
63	39	354
63	40	233
63	41	178
63	42	266
63	43	241
63	44	255
63	45	219
63	46	199
63	47	182
63	48	217
63	49	99
63	50	346
63	51	178
63	52	149
63	53	237
63	54	161
63	55	288
63	56	357
63	57	375
63	58	156
63	59	411
63	60	396
63	61	414
63	62	376
63	63	191
63	64	202
63	65	296
63	66	224
63	67	426
63	68	118
63	69	461
63	70	193
63	71	118
63	72	204
63	73	165
63	74	379
63	75	133
63	76	174
63	77	302
63	78	234
63	79	371
63	80	186

Sieve Passing	Rock ID	Mass M1
63	81	137
90	1	532
90	2	1383
90	3	499
90	4	564
90	5	401
90	6	694
90	7	616
90	8	918
90	9	1576
90	10	1233
90	11	453
90	12	1080
90	13	570
90	14	144
90	15	914
90	16	437
90	17	946
90	18	911
90	19	664
90	20	624
90	21	661
90	22	369
90	23	378
90	24	606
90	25	541
90	26	439
90	27	552
90	28	1077
90	29	731
90	30	742
90	31	988
90	32	604
90	33	935
90	34	723
90	35	717
90	36	620
90	37	373
90	38	619
90	39	523
90	40	447
90	41	507
90	42	716
90	43	792
90	44	648
90	45	509
125	1	1277
125	2	1757
125	3	2701
125	4	1550
125	5	2683
125	6	2315
125	7	2941
125	8	1188
125	9	1562
125	10	2707
125	11	1329
125	12	1159
125	13	1958
125	14	2844
125	15	1731
125	16	1070
125	17	1914
125	18	2087
125	19	1348
125	20	1256
125	21	2736
125	22	1561
125	23	1461
180	1	3961
180	2	6808
180	3	3241
180	4	3571

Sieve Passing	Rock ID	Mass M1
180	5	8641
180	6	4861
180	7	4342
180	8	3081
180	9	3526
180	10	3327
250	1	15940
250	2	11519

C.2.3.5 Sample E

Sieve Passing	Rock ID	Mass M1
31.5	1	57
31.5	2	38
31.5	3	29
31.5	4	19
31.5	5	22
31.5	6	34
31.5	7	17
31.5	8	23
31.5	9	39
31.5	10	54
31.5	11	39
31.5	12	18
31.5	13	23
31.5	14	21
31.5	15	28
31.5	16	27
31.5	17	12
31.5	18	13
31.5	19	18
31.5	20	6
31.5	21	23
31.5	22	45
31.5	23	7
31.5	24	8
31.5	25	15
31.5	26	12
31.5	27	8
31.5	28	10
31.5	29	12
31.5	30	6
31.5	31	9
31.5	32	12
31.5	33	6
31.5	34	7
31.5	35	13
31.5	rest	117
45	1	214
45	2	242
45	3	150
45	4	142
45	5	96
45	6	116
45	7	134
45	8	133
45	9	75
45	10	61
45	11	139
45	12	107
45	13	85
45	14	141
45	15	120
45	16	64
45	17	97
45	18	132
45	19	44
45	20	120
45	21	98
45	22	50
45	23	133
45	24	65
45	25	91
45	26	55
45	27	149
45	28	37
45	29	95
45	30	88
45	31	104
45	32	88
45	33	76
45	34	127
45	35	113
45	36	90
45	37	46
45	38	51
45	39	46
45	40	74
45	41	87
45	42	64
45	43	63
45	44	51
45	45	131
45	46	120
45	47	101
45	48	143
45	49	74
45	50	91
45	51	63
45	52	124
45	53	49
45	54	53
63	1	166
63	2	204
63	3	218
63	4	506
63	5	345
63	6	269
63	7	281
63	8	283
63	9	310
63	10	153
63	11	342
63	12	428
63	13	185
63	14	421
63	15	289
63	16	256
63	17	244
63	18	155
63	19	530
63	20	397
63	21	301
63	22	459
63	23	481
63	24	366
63	25	395
63	26	306
63	27	294
63	28	225
63	29	317
63	30	248
63	31	192
63	32	356
63	33	133
63	34	309
63	35	282
63	36	274
63	37	350
63	38	175
63	39	161
63	40	391
63	41	226
63	42	302
63	43	354
63	44	348
63	45	409
63	46	330
63	47	163
63	48	133
63	49	223
63	50	107

Sieve Passing	Rock ID	Mass M1
63	51	210
63	52	229
63	53	154
63	54	237
63	55	170
63	56	147
63	57	163
63	58	189
63	59	134
63	60	156
63	61	427
90	1	868
90	2	1377
90	3	668
90	4	1277
90	5	595
90	6	465
90	7	636
90	8	766
90	9	1068
90	10	703
90	11	1144
90	12	940
90	13	922
90	14	488
90	15	485
90	16	697
90	17	575
90	18	444
90	19	826
90	20	489
90	21	714
90	22	526
90	23	1238
90	24	987
90	25	432
90	26	680
90	27	408
90	28	1230
90	29	418
90	30	609
90	31	445
90	32	486
90	33	611
90	34	718
90	35	1153
90	36	886
90	37	981
90	38	536
90	39	753
90	40	640
90	41	555
90	42	348
90	43	324
90	44	297
125	1	2027
125	2	2661
125	3	1505
125	4	1835
125	5	1352
125	6	1997
125	7	1950
125	8	1966
125	9	1416
125	10	1774
125	11	2520
125	12	1921
125	13	1233
125	14	2537
125	15	1946
125	16	1078
125	17	1071
125	18	1575

Sieve Passing	Rock ID	Mass M1
125	19	1063
180	1	4196
180	2	7895
180	3	4579
180	4	3145
180	5	6166
180	6	3532
180	7	7002
180	8	7463
180	9	6818
180	10	3832
250	1	12743
250	2	11653
250	3	11843
250	4	9742

C.3 **Slovag**

C.3.1 1-5

C.3.1.1 Sample A

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
31.5	108	41	NVT	14,404	14,423	58	26	146	38	24
31.5	109	41	NVT	14,394	14,415	52	16	53	42	15
31.5	110	101	NVT	14,377	14,411	99	28	96	47	24
31.5	111	32	NVT	14,366	14,379	55	19	52	32	18
31.5	112	45	NVT	14,355	14,377	51	21	65	31	20
31.5	113	32	NVT	14,348	14,363	59	16	57	36	16
31.5	114	71	NVT	14,336	14,369	89	21	87	43	18
31.5	115	53	NVT	14,321	14,348	74	15	71	31	16
31.5	116	43	NVT	14,309	14,329	48	22	46	33	21
31.5	117	36	NVT	14,301	14,315	60	22	56	31	16
31.5	118	21	NVT	14,293	14,303	39	15	37	33	13
31.5	119	12	NVT	14,280	14,285	35	11	32	31	11
31.5	120	59	NVT	14,266	14,285	77	17	77	39	15
31.5	121	26	NVT	14,240	14,249	43	15	34	33	19
31.5	122	16	NVT	14,231	14,237	37	26	37	29	15
31.5	123	28	NVT	14,227	14,238	37	20	36	23	19
31.5	124	41	NVT	14,220	14,239	68	17	66	32	19
31.5	125	25	NVT	14,206	14,220	40	20	34	29	17
31.5	126	26	NVT	14,198	14,210	45	16	44	34	15
31.5	127	27	NVT	14,189	14,207	44	15	40	38	16
31.5	128	30	NVT	14,213	14,228	58	14	56	33	13
31.5	129	18	NVT	14,178	14,181	50	10	47	25	10
31.5	130	43	NVT	14,176	14,196	50	27	45	30	24
31.5	131	28	NVT	14,168	14,184	46	18	43	37	16
31.5	132	29	NVT	14,160	14,173	44	13	41	36	13
31.5	133	30	NVT	14,156	14,170	55	21	53	29	12
31.5	134	16	NVT	14,149	14,163	39	13	53	29	12
31.5	135	53	NVT	14,143	14,174	75	18	67	38	16
31.5	136	25	NVT	14,129	14,138	45	18	43	23	17
31.5	137	10	NVT	14,127	14,131	30	13	30	19	14
31.5	138	10	NVT	14,124	14,130	34	10	31	28	10
31.5	139	12	NVT	14,123	14,132	31	12	29	24	12
31.5	140	8	NVT	14,119	14,122	32	7	30	29	7
31.5	141	5	NVT	14,118	14,120	34	10	34	14	9
31.5	142	10	NVT	14,118	14,122	36	11	34	22	11
31.5	143	3	NVT	14,117	14,120	27	8	25	14	7
31.5	144	11	NVT	14,115	14,120	25	15	25	22	13
31.5	145	8	NVT	14,112	14,116	26	14	24	24	13
31.5	146	7	NVT	14,111	14,114	27	16	26	20	18
31.5	147	13	NVT	14,109	14,116	29	16	21	26	16
31.5	148	17	NVT	14,105	14,118	52	12	51	27	11
45	80	243	243	15,671	15,767	133	27	131	55	29
45	81	79	79	15,655	15,688	59	32	52	43	38
45	82	98	98	15,646	15,690	76	31	74	41	36
45	83	88	88	15,632	15,669	66	27	51	44	27
45	84	121	121	15,623	15,670	75	30	68	47	36
45	85	78	77	15,618	15,650	52	22	48	39	38
45	86	86	85	15,606	15,644	77	21	69	45	23
45	87	81	81	15,593	15,634	66	16	57	58	16
45	88	100	99	15,577	15,616	81	25	38	76	33
45	89	145	145	15,569	15,629	78	39	66	40	39
45	90	60	60	15,557	15,585	59	26	54	26	36
45	91	91	91	15,547	15,578	84	32	81	36	32
45	92	68	68	15,543	15,568	64	23	58	41	24
45	93	87	87	15,533	15,568	67	21	44	61	24
45	94	86	85	15,524	15,560	69	27	64	47	35
45	95	78	78	15,510	15,545	65	28	56	48	29
45	96	113	112	15,500	15,542	72	18	62	62	19
45	97	186	186	15,489	15,559	92	27	89	55	34
45	98	127	126	15,479	15,526	73	28	66	47	29
45	99	80	79	15,469	15,502	67	22	54	47	22
45	100	351	349	15,462	15,588	100	43	94	43	50
45	101	67	67	15,443	15,470	53	26	48	45	25

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
45	102	83	83	15,433	15,466	56	30	50	48	28
45	103	113	112	15,425	15,470	79	27	69	51	35
45	104	41	41	15,414	15,429	54	17	45	40	20
45	105	50	50	15,408	15,424	43	23	41	38	24
45	106	56	55	15,390	15,414	45	28	40	42	28
45	107	52	52	15,384	15,405	58	18	57	38	20
63	55	356	356	14,093	14,232	161	25	156	73	29
63	56	570	569	14,058	14,275	162	52	161	61	52
63	57	211	210	14,031	14,114	116	25	106	54	44
63	58	265	265	14,013	14,114	82	41	70	68	46
63	59	537	536	13,994	14,175	156	41	153	55	44
63	60	492	491	13,978	14,151	144	39	139	74	48
63	61	241	241	13,949	14,043	88	35	89	67	43
63	62	368	367	13,935	14,065	88	48	72	72	53
63	63	192	191	13,909	13,982	91	18	82	75	22
63	64	228	227	13,890	13,989	99	35	94	52	38
63	65	346	344	13,869	13,996	101	49	98	56	48
63	66	246	245	13,848	13,944	101	38	98	56	48
63	67	422	421	13,835	13,976	157	38	156	53	38
63	68	204	204	13,826	13,908	80	38	63	66	48
63	69	552	551	13,812	14,028	110	61	88	81	69
63	70	322	321	13,792	13,907	90	37	79	76	40
63	71	305	304	13,785	13,906	95	55	86	73	52
63	72	251	251	13,767	13,862	96	40	94	60	38
63	73	162	161	13,748	13,816	89	38	76	50	39
63	74	360	358	13,729	13,875	102	40	91	68	41
63	75	119	118	13,708	13,758	65	32	53	61	33
63	76	337	336	13,701	13,837	90	55	82	69	59
63	77	329	329	13,687	13,823	111	38	107	68	40
63	78	230	229	13,679	13,760	85	37	77	53	43
63	79	156	155	13,650	13,721	92	29	86	58	38
90	21	1338	1,334	15,186	15,688	290	41	283	104	41
90	22	1653	1,650	15,119	15,680	182	79	155	106	83
90	23	693	692	15,148	15,407	117	73	95	83	74
90	24	879	878	15,082	15,419	148	41	122	116	48
90	25	779	777	15,286	15,564	140	63	136	87	65
90	26	817	816	15,050	15,366	206	33	207	108	36
90	27	490	489	15,020	15,202	107	55	100	69	57
90	28	286	284	15,262	15,377	114	26	104	90	18
90	29	1761	1,758	14,998	15,668	215	74	212	112	79
90	30	677	675	14,967	15,200	108	65	106	92	69
90	31	987	984	14,942	15,296	148	68	129	91	79
90	32	1160	1,185	14,892	15,287	155	71	157	93	74
90	33	699	697	15,310	15,549	129	67	119	69	68
90	34	1166	1,163	14,870	15,310	156	76	143	112	74
90	35	1096	1,093	14,834	15,250	174	78	176	101	76
90	36	648	647	14,798	15,047	127	57	131	86	59
90	37	424	423	14,773	14,945	126	34	132	92	38
90	38	564	562	14,750	14,967	126	53	123	85	54
90	39	817	815	15,376	15,685	170	57	167	87	63
90	40	526	524	15,234	15,416	123	47	121	98	49
90	41	815	814	15,349	15,665	55	38	141	93	59
90	42	1763	1,758	14,735	15,333	187	87	179	98	97
90	43	985	981	14,713	15,086	179	50	175	96	48
90	44	578	575	14,684	14,903	115	47	118	81	47
90	45	1551	1,548	14,671	15,248	191	87	188	97	87
90	46	1327	1,324	14,614	15,102	207	77	207	112	73
90	47	1020	1,018	14,582	14,969	161	77	156	77	73
90	48	1207	1,204	15,558	16,010	150	79	134	99	79
90	49	1027	1,024	15,221	15,608	141	79	130	83	89
90	50	460	458	14,525	14,702	129	41	85	127	44
90	51	904	902	15,247	15,582	129	60	75	131	60
90	52	462	461	14,504	14,685	117	38	91	91	40
90	53	569	567	14,482	14,672	113	41	115	88	48
90	54	680	680	14,464	14,732	117	65	96	87	70
125	2	1296	NVT	13,629	14,121	141	85	112	114	93
125	3	1076	NVT	13,592	14,003	158	69	147	112	73
125	4	1084	NVT	13,569	13,914	169	42	150	132	48
125	5	1955	NVT	13,555	14,234	178	101	169	112	94
125	6	2313	NVT	13,524	14,325	162	117	136	128	118
125	7	1671	NVT	13,484	14,108	201	63	191	122	57
125	8	1595	NVT	13,454	14,052	165	72	152	136	72
125	9	1507	NVT	13,435	13,952	159	70	139	126	70

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
125	10	2352	NVT	13,406	14,192	198	62	182	147	62
125	11	1426	NVT	13,393	13,876	147	100	120	111	102
125	12	1845	NVT	13,358	13,856	193	80	148	154	95
125	13	1286	NVT	13,341	14,046	158	80	134	121	76
125	14	2144	NVT	13,309	14,048	169	100	133	147	88
125	15	1936	NVT	13,289	13,950	186	57	148	164	58
125	16	2260	NVT	13,280	14,130	189	89	182	132	103
125	17	2017	NVT	13,244	14,003	173	99	135	135	98
125	18	1237	NVT	13,229	13,700	142	69	130	112	69
125	19	1351	NVT	13,200	13,716	143	94	137	103	88
125	20	2936	NVT	13,181	14,240	189	107	183	150	104
150	1	3694	NVT	14433	15653	185	97	169	148	103

C.3.1.2 Sample B

Sieve Passing	Rock ID	Mass M1
31.5	349	59
31.5	350	31
31.5	351	58
31.5	352	87
31.5	353	38
31.5	354	62
31.5	355	21
31.5	356	66
31.5	357	54
31.5	358	53
31.5	359	49
31.5	360	71
31.5	361	57
31.5	362	57
31.5	363	53
31.5	364	16
31.5	365	11
31.5	366	31
31.5	367	54
31.5	368	40
31.5	369	45
31.5	370	37
31.5	371	27
31.5	372	28
31.5	373	26
31.5	374	27
31.5	375	37
31.5	376	49
31.5	377	45
31.5	378	107
31.5	379	26
31.5	380	5
31.5	381	33
31.5	382	39
31.5	383	34
31.5	384	31
31.5	385	46
31.5	386	59
31.5	387	18
31.5	388	64
31.5	389	42
31.5	390	60
31.5	391	24
31.5	392	41
31.5	393	28
31.5	394	34
31.5	395	29
31.5	396	24
31.5	397	37
31.5	398	46
31.5	399	45
31.5	400	66
31.5	401	46
31.5	402	35
31.5	403	25
31.5	404	54
31.5	405	49
31.5	406	42
31.5	407	23
31.5	408	56
31.5	409	38
31.5	410	45
31.5	411	39
31.5	412	26
31.5	413	23
31.5	414	12
31.5	415	33
31.5	416	44
31.5	417	18
31.5	418	31
31.5	419	27
31.5	420	63
31.5	421	40
31.5	422	32
31.5	423	32
31.5	424	49
31.5	425	33
31.5	426	8
31.5	427	20
31.5	428	64
31.5	429	50
31.5	430	72
31.5	431	62
31.5	432	61
31.5	433	45
31.5	434	37
31.5	435	22
31.5	436	58
31.5	437	20
31.5	438	33
31.5	439	17
31.5	440	17
31.5	441	27
31.5	442	21
31.5	443	24
31.5	444	40
31.5	445	42
31.5	446	60
31.5	447	15
31.5	448	14
31.5	449	24
31.5	450	19
31.5	451	26
31.5	452	41
31.5	453	41
31.5	454	30
31.5	455	33
31.5	456	60
31.5	457	39
31.5	458	47
31.5	459	39
31.5	460	14
31.5	461	42
31.5	462	36
31.5	463	40
31.5	464	25
31.5	465	9
31.5	466	52
31.5	467	36
31.5	468	43
31.5	469	20
31.5	470	15
31.5	471	16
31.5	472	26
31.5	473	37
31.5	474	50
31.5	475	42
31.5	476	27
31.5	477	25
31.5	478	26
31.5	479	28
31.5	480	35
31.5	481	34
31.5	482	21
31.5	483	25
31.5	484	29
31.5	485	46
31.5	486	83
31.5	487	52
31.5	488	19

Sieve Passing	Rock ID	Mass M1
31.5	489	54
31.5	490	54
31.5	491	42
31.5	492	25
31.5	493	36
31.5	494	46
31.5	495	26
31.5	496	15
31.5	497	29
31.5	498	25
31.5	499	42
31.5	500	28
31.5	501	24
31.5	502	25
31.5	503	13
31.5	504	33
31.5	505	31
31.5	506	22
31.5	507	23
31.5	508	40
31.5	509	25
31.5	510	23
31.5	511	22
31.5	512	40
31.5	513	21
31.5	514	47
31.5	515	41
31.5	516	72
31.5	517	36
31.5	518	28
31.5	519	22
31.5	520	22
31.5	521	17
31.5	522	45
31.5	523	17
31.5	524	33
31.5	525	28
31.5	526	31
31.5	527	25
31.5	528	15
31.5	529	42
31.5	530	25
31.5	531	27
31.5	532	26
31.5	533	43
31.5	534	13
31.5	535	40
31.5	536	37
31.5	537	23
31.5	538	24
45	144	252
45	145	185
45	146	65
45	147	70
45	148	60
45	149	72
45	150	92
45	151	45
45	152	70
45	153	1716
45	154	85
45	155	83
45	156	68
45	157	135
45	158	167
45	159	107
45	160	132
45	161	188
45	162	146
45	163	86
45	164	73
45	165	121
45	166	39

Sieve Passing	Rock ID	Mass M1
45	167	83
45	168	54
45	169	123
45	170	104
45	171	60
45	172	58
45	173	43
45	174	67
45	175	39
45	176	60
45	177	64
45	178	58
45	179	68
45	180	66
45	181	102
45	182	82
45	183	61
45	184	129
45	185	161
45	186	96
45	187	73
45	188	63
45	189	83
45	190	59
45	191	51
45	192	103
45	193	130
45	194	106
45	195	113
45	196	102
45	197	82
45	198	183
45	199	92
45	200	70
45	201	122
45	202	75
45	203	160
45	204	114
45	205	69
45	206	77
45	207	71
45	208	48
45	209	68
45	210	49
45	211	52
45	212	165
45	213	81
45	214	185
45	215	106
45	216	113
45	217	126
45	218	104
45	219	186
45	220	110
45	221	92
45	222	96
45	223	78
45	224	49
45	225	120
45	226	55
45	227	63
45	228	168
45	229	49
45	230	80
45	231	68
45	232	96
45	233	69
45	234	69
45	235	50
45	236	54
45	237	124
45	238	67
45	239	74

Sieve Passing	Rock ID	Mass M1
45	240	59
45	241	112
45	242	70
45	243	156
45	244	113
45	245	65
45	246	169
45	247	56
45	248	162
45	249	83
45	250	74
45	251	61
45	252	74
45	253	61
45	254	74
45	255	83
45	256	81
45	257	151
45	258	93
45	259	88
45	260	53
45	261	86
45	262	49
45	263	114
45	264	64
45	265	66
45	266	89
45	267	62
45	268	53
45	269	73
45	270	71
45	271	93
45	272	62
45	273	83
45	274	55
45	275	63
45	276	75
45	277	148
45	278	130
45	279	51
45	280	61
45	281	75
45	282	144
45	283	89
45	284	86
45	285	32
45	286	149
45	287	42
45	288	69
45	289	83
45	290	62
45	291	59
45	292	48
45	293	40
45	294	59
45	295	54
45	296	45
45	297	65
45	298	43
45	299	91
45	300	109
45	301	54
45	302	65
45	303	142
45	304	109
45	305	169
45	310	71
45	311	106
45	312	126
45	313	149
45	314	73
45	315	106
45	316	116

Sieve Passing	Rock ID	Mass M1
45	317	99
45	318	189
45	319	51
45	320	62
45	321	129
45	322	52
45	323	69
45	324	47
45	325	111
45	326	137
45	327	192
45	328	68
45	329	56
45	330	69
45	331	70
45	332	136
45	333	39
45	334	94
45	335	149
45	336	51
45	337	71
45	338	52
45	339	73
45	340	69
45	341	63
45	342	52
45	343	65
45	344	51
45	345	88
45	346	81
45	347	47
45	348	56
63	63	111
63	64	107
63	65	184
63	66	355
63	67	224
63	68	433
63	69	303
63	70	191
63	71	289
63	72	297
63	73	421
63	74	313
63	75	256
63	76	208
63	77	188
63	78	166
63	79	331
63	80	614
63	81	236
63	82	322
63	83	268
63	84	271
63	85	118
63	86	253
63	87	95
63	88	204
63	89	143
63	90	176
63	91	196
63	92	93
63	93	223
63	94	528
63	95	438
63	96	137
63	97	157
63	98	358
63	99	194
63	100	152
63	101	104
63	102	219
63	103	117

Sieve Passing	Rock ID	Mass M1
63	104	129
63	105	322
63	106	148
63	107	109
63	108	111
63	109	158
63	110	145
63	111	533
63	112	183
63	113	202
63	114	116
63	115	279
63	116	622
63	117	128
63	118	143
63	119	307
63	120	158
63	121	131
63	122	145
63	123	299
63	124	118
63	125	288
63	126	141
63	127	192
63	128	146
63	129	463
63	130	333
63	131	222
63	132	162
63	133	106
63	134	155
63	135	232
63	136	240
63	137	166
63	138	227
63	139	199
63	140	172
63	141	140
63	142	156
63	143	132
90	10	944
90	11	808
90	12	514
90	13	1005
90	14	1322
90	15	673
90	16	934
90	17	334
90	18	322
90	19	548
90	20	474
90	21	410
90	22	813
90	23	830
90	24	400
90	25	379
90	26	686
90	27	647
90	28	753
90	29	494
90	30	661
90	31	624
90	32	745
90	33	913
90	34	889
90	35	600
90	36	1090
90	37	442
90	38	630
90	39	295
90	40	812
90	41	338
90	42	383

Sieve Passing	Rock ID	Mass M1
90	43	790
90	44	301
90	45	244
90	46	708
90	47	549
90	48	1217
90	49	789
90	50	450
90	51	403
90	52	557
90	53	773
90	54	669
90	55	591
90	56	730
90	57	551
90	58	631
90	59	617
90	60	1006
90	61	485
90	62	654
125	1	1510
125	2	1289
125	3	1282
125	4	2202
125	5	1648
125	6	1864
125	7	1432
125	8	1894
125	9	2237

C.3.1.3 Sample C

Sieve Passing	Rock ID	Mass M1
<25	rest	12903
31.5	381	51
31.5	382	51
31.5	383	59
31.5	384	37
31.5	385	55
31.5	386	17
31.5	387	50
31.5	388	43
31.5	389	46
31.5	390	47
31.5	391	64
31.5	392	41
31.5	393	43
31.5	394	46
31.5	395	58
31.5	396	27
31.5	397	48
31.5	398	31
31.5	399	21
31.5	400	38
31.5	401	30
31.5	402	72
31.5	403	37
31.5	404	60
31.5	405	28
31.5	406	35
31.5	407	44
31.5	408	29
31.5	409	32
31.5	410	31
31.5	411	42
31.5	412	63
31.5	413	50
31.5	414	77
31.5	415	22
31.5	416	35
31.5	417	27
31.5	418	11
31.5	419	74
31.5	420	47
31.5	421	60
31.5	422	21
31.5	423	74
31.5	424	26
31.5	425	71
31.5	426	41
31.5	427	38
31.5	428	40
31.5	429	36
31.5	430	39
31.5	431	24
31.5	432	25
31.5	433	13
31.5	434	24
31.5	435	17
31.5	436	31
31.5	437	17
31.5	438	67
31.5	439	54
31.5	440	36
31.5	441	40
31.5	442	18
31.5	443	71
31.5	444	20
31.5	445	15
31.5	446	36
31.5	447	85
31.5	448	28
31.5	449	51

Sieve Passing	Rock ID	Mass M1
31.5	450	36
31.5	451	27
31.5	452	29
31.5	453	18
31.5	454	37
31.5	455	13
31.5	456	20
31.5	457	21
31.5	458	52
31.5	459	44
31.5	460	36
31.5	461	47
31.5	462	37
31.5	463	26
31.5	464	14
31.5	465	58
31.5	466	85
31.5	467	52
31.5	468	46
31.5	469	48
31.5	470	30
31.5	471	26
31.5	472	16
31.5	473	47
31.5	474	40
31.5	475	25
31.5	476	24
31.5	477	24
31.5	478	21
31.5	479	40
31.5	480	20
31.5	481	26
31.5	482	38
31.5	483	32
31.5	484	25
31.5	485	43
31.5	486	30
31.5	487	31
31.5	488	19
31.5	489	34
31.5	490	44
31.5	491	46
31.5	492	25
31.5	493	22
31.5	494	24
31.5	495	53
31.5	496	33
31.5	497	26
31.5	498	39
31.5	499	21
31.5	500	62
31.5	501	55
31.5	502	36
31.5	503	25
31.5	504	14
31.5	505	12
31.5	506	75
31.5	507	16
31.5	508	29
31.5	509	43
31.5	510	22
31.5	511	22
31.5	512	25
31.5	513	57
31.5	514	3+5
31.5	515	31
31.5	516	19
31.5	517	44
31.5	518	41
31.5	519	35

Sieve Passing	Rock ID	Mass M1
31.5	520	53
31.5	521	40
31.5	522	36
31.5	523	30
31.5	524	33
31.5	525	40
31.5	526	27
31.5	527	36
31.5	528	35
31.5	529	32
31.5	530	45
31.5	531	43
31.5	532	22
31.5	533	34
31.5	534	41
31.5	535	42
31.5	536	32
31.5	537	51
31.5	538	46
31.5	539	28
31.5	540	38
31.5	541	28
31.5	542	32
31.5	543	36
31.5	544	25
31.5	545	29
31.5	546	33
31.5	547	37
31.5	548	37
31.5	549	34
31.5	550	59
31.5	551	35
31.5	552	42
31.5	553	21
31.5	554	40
31.5	555	23
31.5	556	68
31.5	557	62
31.5	558	33
31.5	559	37
31.5	560	33
31.5	561	27
31.5	562	31
31.5	563	40
31.5	564	13
31.5	565	24
31.5	566	33
31.5	567	31
31.5	568	48
31.5	569	29
31.5	570	53
31.5	571	13
31.5	572	28
31.5	573	27
31.5	574	42
31.5	575	29
31.5	576	36
31.5	577	36
31.5	578	30
31.5	579	38
31.5	580	26
31.5	581	27
31.5	582	28
31.5	583	39
31.5	584	24
31.5	585	16
31.5	586	23
31.5	587	30
31.5	588	17
31.5	589	44
31.5	590	37
31.5	591	15
31.5	592	24

Sieve Passing	Rock ID	Mass M1
31.5	593	48
31.5	594	19
31.5	595	20
31.5	596	25
31.5	597	35
31.5	598	25
31.5	599	34
31.5	600	30
31.5	601	31
31.5	602	22
31.5	603	26
31.5	604	40
31.5	605	21
31.5	606	17
31.5	607	27
31.5	608	26
31.5	609	40
31.5	610	27
31.5	611	32
31.5	612	37
31.5	613	27
31.5	614	18
31.5	615	52
31.5	616	31
31.5	617	64
31.5	618	49
31.5	619	32
31.5	620	29
31.5	621	17
31.5	622	32
31.5	623	31
31.5	624	15
31.5	625	60
31.5	626	59
31.5	627	51
31.5	628	49
31.5	629	50
31.5	630	48
31.5	631	27
31.5	632	48
31.5	633	73
31.5	634	15
31.5	635	24
31.5	636	22
31.5	637	33
31.5	638	28
31.5	639	37
31.5	640	32
31.5	641	32
31.5	642	27
31.5	643	24
31.5	644	35
31.5	645	27
31.5	646	23
31.5	647	19
31.5	648	21
31.5	649	27
31.5	650	16
31.5	651	16
31.5	652	41
31.5	653	31
31.5	654	19
31.5	655	16
31.5	656	15
31.5	657	26
31.5	658	23
31.5	659	25
31.5	660	40
31.5	661	28
31.5	662	19
31.5	663	21
31.5	664	30
31.5	665	28

Sieve Passing	Rock ID	Mass M1
31.5	666	22
31.5	667	36
31.5	668	20
31.5	669	24
31.5	670	33
31.5	671	17
31.5	672	20
31.5	673	21
31.5	674	42
31.5	675	23
31.5	676	53
31.5	677	13
31.5	678	36
31.5	679	45
31.5	680	38
31.5	681	31
31.5	682	47
31.5	683	33
31.5	684	22
31.5	685	28
31.5	686	24
31.5	687	21
31.5	688	30
31.5	689	31
31.5	690	24
31.5	691	47
31.5	692	37
31.5	693	26
31.5	694	15
31.5	695	30
31.5	696	22
31.5	697	46
31.5	698	20
31.5	699	27
31.5	700	29
31.5	701	46
31.5	702	25
31.5	703	21
31.5	704	27
31.5	705	29
31.5	706	41
31.5	707	26
31.5	708	44
31.5	709	20
31.5	710	29
31.5	711	44
31.5	712	37
45	133	73
45	134	158
45	135	28
45	136	76
45	137	37
45	138	44
45	139	112
45	140	63
45	141	104
45	142	41
45	143	52
45	144	46
45	145	33
45	146	36
45	147	77
45	148	53
45	149	95
45	150	73
45	151	74
45	152	89
45	153	45
45	154	91
45	155	63
45	156	59
45	157	51
45	158	36

Sieve Passing	Rock ID	Mass M1
45	159	78
45	160	39
45	161	38
45	162	46
45	163	35
45	164	98
45	165	89
45	166	58
45	167	50
45	168	75
45	169	50
45	170	44
45	171	38
45	172	106
45	173	53
45	174	74
45	175	69
45	176	62
45	177	85
45	178	49
45	179	163
45	180	138
45	181	100
45	182	50
45	183	41
45	184	71
45	185	79
45	186	88
45	187	53
45	188	70
45	189	61
45	190	51
45	191	78
45	192	138
45	193	51
45	194	46
45	195	83
45	196	59
45	197	60
45	198	43
45	199	47
45	200	41
45	201	74
45	202	47
45	203	118
45	204	135
45	205	299
45	206	58
45	207	130
45	208	194
45	209	130
45	210	117
45	211	73
45	212	112
45	213	49
45	214	91
45	215	110
45	216	55
45	217	100
45	218	78
45	219	169
45	220	50
45	221	61
45	222	70
45	223	40
45	224	105
45	225	73
45	226	131
45	227	130
45	228	96
45	229	86
45	230	106
45	231	56

Sieve Passing	Rock ID	Mass M1
45	232	81
45	233	50
45	234	76
45	235	112
45	236	131
45	237	80
45	238	82
45	239	72
45	240	75
45	241	192
45	242	158
45	243	164
45	244	35
45	245	101
45	246	46
45	247	84
45	248	94
45	249	126
45	250	60
45	251	79
45	252	61
45	253	112
45	254	112
45	255	144
45	256	64
45	257	102
45	258	104
45	259	186
45	260	80
45	261	81
45	262	57
45	263	168
45	264	177
45	265	71
45	266	72
45	267	66
45	268	83
45	269	144
45	270	29
45	271	90
45	272	94
45	273	88
45	274	60
45	275	35
45	276	71
45	277	85
45	278	106
45	279	113
45	280	89
45	281	94
45	282	51
45	283	86
45	284	141
45	285	80
45	286	100
45	287	156
45	288	90
45	289	124
45	290	98
45	291	166
45	292	88
45	293	130
45	294	155
45	295	80
45	296	65
45	297	45
45	298	51
45	299	73
45	300	40
45	301	58
45	302	78
45	303	47
45	304	60

Sieve Passing	Rock ID	Mass M1
45	305	109
45	306	58
45	307	78
45	308	94
45	309	88
45	310	47
45	311	58
45	312	81
45	313	176
45	314	83
45	315	50
45	316	62
45	317	143
45	318	110
45	319	66
45	320	54
45	321	73
45	322	94
45	323	200
45	324	185
45	325	47
45	326	183
45	327	58
45	328	79
45	329	152
45	330	124
45	331	36
45	332	121
45	333	128
45	334	157
45	335	66
45	336	120
45	337	113
45	338	126
45	339	67
45	340	50
45	341	114
45	342	84
45	343	68
45	344	71
45	345	46
45	346	50
45	347	52
45	348	74
45	349	59
45	350	207
45	351	115
45	352	138
45	353	155
45	354	138
45	355	34
45	356	64
45	357	112
45	358	105
45	359	56
45	360	50
45	361	110
45	362	91
45	363	71
45	364	139
45	365	98
45	366	57
45	367	90
45	368	67
45	369	151
45	370	171
45	371	77
45	372	126
45	373	88
45	374	48
45	375	92
45	376	23
45	377	25

Sieve Passing	Rock ID	Mass M1
45	378	28
45	379	32
45	380	51
63	50	244
63	51	146
63	52	185
63	53	316
63	54	171
63	55	294
63	56	279
63	57	179
63	58	289
63	59	225
63	60	166
63	61	234
63	62	206
63	63	211
63	64	701
63	65	196
63	66	319
63	67	391
63	68	359
63	69	189
63	70	171
63	71	243
63	72	240
63	73	297
63	74	163
63	75	142
63	76	295
63	77	431
63	78	385
63	79	230
63	80	186
63	81	317
63	82	380
63	83	178
63	84	175
63	85	170
63	86	319
63	87	146
63	88	308
63	89	230
63	90	211
63	91	223
63	92	161
63	93	248
63	94	348
63	95	184
63	96	120
63	97	192
63	98	133
63	99	200
63	100	189
63	101	195
63	102	261
63	103	219
63	104	98
63	105	175
63	109	163
63	110	207
63	111	173
63	112	159
63	113	271
63	114	192
63	115	234
63	116	185
63	117	343
63	118	330
63	119	154
63	120	143
63	121	250
63	122	261

Sieve Passing	Rock ID	Mass M1
63	123	134
63	124	349
63	125	330
63	126	554
63	127	409
63	128	578
63	129	300
63	130	427
63	131	618
63	132	281
90	10	504
90	11	944
90	12	680
90	13	662
90	14	384
90	15	354
90	16	618
90	17	705
90	18	682
90	19	793
90	20	437
90	21	334
90	22	1081
90	23	453
90	24	572
90	25	724
90	26	473
90	27	1202
90	28	774
90	29	643
90	30	1251
90	31	358
90	32	1240
90	33	493
90	34	872
90	35	1600
90	36	904
90	37	526
90	38	1069
90	39	324
90	40	553
90	41	248
90	42	405
90	43	797
90	44	811
90	45	760
90	46	597
90	47	472
90	48	529
90	49	567
125	1	1468
125	2	1334
125	3	2366
125	4	1341
125	5	1696
125	6	2311
125	7	2317
125	8	1902
125	9	1938

C.3.2 5+

C.3.2.1 Sample A

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
63	103	260	258	13,142	13,249	106	36	77	76	50
90	96	1141	1,139	13,118	13,556	151	67	144	74	73
90	97	1819	1,816	13,098	13,783	198	79	193	90	89
90	98	1453	1,451	13,071	13,632	177	74	168	100	85
90	99	1077	1,076	13,047	13,415	183	51	178	87	55
90	100	573	572	13,020	13,246	110	54	106	83	55
90	101	641	638	13,011	13,256	127	52	107	98	52
90	102	1071	1,069	12,997	13,400	165	51	147	109	54
125	50	2992	NVT	12,969	14,073	173	98	168	129	108
125	51	3172	NVT	12,830	13,918	198	100	188	117	100
125	52	1791	NVT	12,802	13,485	175	103	156	123	98
125	53	2560	NVT	12,768	13,732	176	102	172	118	117
125	54	1839	NVT	12,728	13,425	166	70	155	132	73
125	55	2956	NVT	12,697	13,762	207	80	199	110	93
125	56	4280	NVT	12,665	14,117	255	74	250	154	68
125	57	2278	NVT	12,628	13,490	181	102	177	107	98
125	58	2536	NVT	12,604	13,561	254	70	251	123	72
125	59	2561	NVT	12,559	13,529	173	95	168	125	109
125	60	1808	NVT	12,532	13,210	155	82	132	118	81
125	61	3296	NVT	12,493	13,630	192	102	171	116	109
125	62	2496	NVT	12,450	13,387	188	89	149	145	89
125	63	1608	NVT	12,351	12,952	191	63	181	112	74
125	64	2175	NVT	12,393	13,212	159	90	141	134	97
125	65	2853	NVT	12,320	13,370	228	76	197	131	74
125	66	2461	NVT	11,563	12,476	172	89	168	107	88
125	67	2312	NVT	12,265	13,055	207	71	198	104	83
125	68	2793	NVT	12,228	13,265	217	77	207	122	80
125	69	2462	NVT	12,174	13,083	192	90	151	141	90
125	70	2534	NVT	11,408	12,362	166	73	153	149	75
125	71	1508	NVT	11,360	11,924	150	60	127	115	66
125	72	1724	NVT	12,149	12,778	192	69	183	101	73
125	73	1914	NVT	11,286	11,950	194	97	192	99	92
125	74	1171	NVT	11,257	11,690	149	54	141	132	58
125	75	2657	NVT	12,113	13,099	230	90	222	114	99
125	76	3095	NVT	11,227	12,540	247	81	236	121	75
125	77	2627	NVT	12,080	12,987	230	54	202	147	59
125	78	1739	NVT	12,024	12,685	190	71	176	114	87
125	79	1637	NVT	12,045	12,658	140	103	128	106	105
125	80	2765	NVT	11,183	12,212	205	80	201	118	83
125	81	2916	NVT	11,142	12,245	237	90	236	127	85
125	82	1690	NVT	11,094	11,730	203	59	187	122	57
125	83	2763	NVT	11,985	12,918	202	74	190	126	80
125	84	3936	NVT	11,053	12,380	224	99	220	144	93
125	85	2870	NVT	11,024	12,077	204	107	190	141	108
125	86	2743	NVT	11,945	12,976	237	65	231	154	65
125	87	2065	NVT	17,014	17,708	212	61	186	119	72
125	88	2840	NVT	16,981	17,942	228	63	221	147	65
125	89	1281	NVT	16,935	17,420	159	86	155	97	88
125	90	2880	NVT	16,910	17,973	232	81	212	157	82
125	91	1471	NVT	16,834	17,380	214	48	205	128	56
125	92	1273	NVT	16,737	17,216	151	66	152	103	63
125	93	3456	NVT	16,790	17,975	260	94	260	113	94
125	94	3515	NVT	50,300	51,600	338	48	333	145	49
125	95	2207	NVT	16,629	17,460	148	102	132	115	101
125	104	2199	NVT	11,890	12,738	176	98	158	117	106
125	107	3279	NVT	11,865	13,090	224	115	190	133	110
150	12	4662	NVT	17,078	18,335	217	135	163	162	118
150	13	4639	NVT	16,825	18,385	231	105	222	143	108
150	14	4012	NVT	16,778	18,280	231	129	207	128	123
150	15	3571	NVT	16,693	18,024	265	104	236	166	93
150	16	2876	NVT	16,620	17,708	212	87	199	139	108
150	17	3694	NVT	16,548	17,920	262	59	231	173	60
150	18	4997	NVT	16,484	18,188	231	118	218	163	122
150	19	4578	NVT	16,415	18,116	230	124	204	160	119
150	20	3075	NVT	16,296	17,434	201	72	194	144	77
150	21	3795	NVT	16,350	17,670	240	108	211	148	107
150	22	7096	NVT	50,100	52,650	328	106	323	134	114

Sieve	Rock	Masses				Elongation		Blockiness		
Passing	ID	M1	M3	M2,1	M2,2	L	T	X	Y	Z
150	23	2835	NVT	16,226	17,297	230	71	212	155	68
150	24	4528	NVT	16,047	17,722	276	95	275	140	116
150	25	2910	NVT	16,183	17,250	213	76	185	161	75
150	26	5560	NVT	16,008	18,074	245	104	234	182	108
150	27	3640	NVT	16,099	17,460	201	111	178	158	128
150	28	4013	NVT	16,958	18,443	202	121	163	150	144
150	29	2980	NVT	16,047	17,155	201	102	182	134	99
150	30	2230	NVT	16,891	17,716	214	51	204	156	75
150	31	4099	NVT	15,834	17,266	219	98	203	169	105
150	32	3675	NVT	15,711	17,065	219	106	186	182	104
150	33	3924	NVT	15,765	17,213	231	97	218	165	101
150	34	4166	NVT	15,962	17,529	259	70	248	177	74
150	35	3238	NVT	15,830	17,028	209	80	203	144	78
150	36	5375	NVT	15,651	17,668	275	116	275	147	131
150	37	6061	NVT	15,762	17,974	272	128	271	172	107
150	38	4824	NVT	15,619	17,394	267	106	244	151	98
150	39	5418	NVT	15,565	17,305	268	111	246	184	111
150	40	4408	NVT	15,523	17,011	244	98	233	162	105
150	41	3861	NVT	15,453	16,810	238	90	204	174	103
150	42	5341	NVT	15,400	17,220	250	79	230	156	75
150	43	5847	NVT	50,250	52,450	304	95	299	178	90
150	44	4304	NVT	15,261	17,766	219	76	196	187	78
150	45	3200	NVT	15,201	16,398	187	121	166	143	118
150	46	4068	NVT	15,140	16,653	240	124	191	186	142
150	47	4280	NVT	15,334	16,920	236	103	234	143	103
150	48	3383	NVT	15,063	16,310	207	76	169	161	93
150	49	4196	NVT	14,999	16,559	194	109	187	169	127
150	105	4265	NVT	14,891	16,278	205	112	198	139	107
150	106	3074	NVT	14,948	16,108	189	107	182	128	107
180	1	5566	NVT	51,050	53,050	262	95	208	196	110
180	2	8519	NVT	51,000	54,200	330	106	233	223	95
180	3	4179	NVT	50,900	52,400	251	76	214	210	78
180	4	8187	NVT	50,800	53,600	322	98	303	217	107
180	5	4755	NVT	50,750	52,300	191	115	171	169	113
180	6	4695	NVT	50,650	52,400	227	106	217	187	108
180	7	8152	NVT	50,650	53,400	307	122	296	212	113
180	8	5205	NVT	50,600	52,300	214	120	193	191	108
180	9	5632	NVT	50,550	52,650	247	124	206	166	122
180	10	8056	NVT	50,500	53,550	325	117	309	222	112
180	11	5973	NVT	50,400	52,650	271	100	250	205	102

C.3.2.2 Sample B

Sieve Passing	Rock ID	Mass M1
63	94	507
63	95	551
63	96	278
63	97	332
63	98	420
63	99	366
63	100	322
63	101	342
63	102	198
63	103	115
90	78	1420
90	79	807
90	80	601
90	81	850
90	82	538
90	83	480
90	84	758
90	85	1382
90	86	989
90	87	559
90	88	649
90	89	2361
90	90	1251
90	91	1740
90	92	585
90	93	951
125	31	1842
125	32	2235
125	33	1917
125	34	3163
125	35	1727
125	36	1946
125	37	1307
125	38	1981
125	39	1429
125	40	1626
125	41	3336
125	42	1357
125	43	2786
125	44	2490
125	45	5390
125	46	2042
125	47	2779
125	48	2674
125	49	2062
125	50	2865
125	51	1582
125	52	2372
125	53	2112
125	54	1660
125	55	1973
125	56	1862
125	57	3780
125	58	2675
125	59	1624
125	60	2036
125	61	3048
125	62	3128
125	63	881
125	64	2431
125	65	2447
125	66	2286
125	67	3905
125	68	3088
125	69	3498
125	70	2044
125	71	1163
125	72	1869
125	73	1431
125	74	2676

Sieve Passing	Rock ID	Mass M1
125	75	1733
125	76	1695
125	77	2651
150	10	3844
150	11	2842
150	12	6627
150	13	6924
150	14	4025
150	15	5606
150	16	5067
150	17	4192
150	18	4124
150	19	3886
150	20	3018
150	21	3729
150	22	4757
150	23	3709
150	24	2799
150	25	4177
150	26	3798
150	27	3148
150	28	5040
150	29	4485
150	30	3006
180	2	7255
180	3	5236
180	4	6058
180	5	7515
180	6	9539
180	7	3785
180	8	7064
180	9	8081
200	1	6887

C.3.2.3 Sample C

Sieve Passing	Rock ID	Mass M1
63	127	109
63	128	346
63	129	228
63	130	141
63	131	97
63	132	56
63	133	24
63	134	33
63	135	288
63	136	116
63	137	58
63	138	78
63	139	27
63	140	56
63	141	76
63	142	39
63	143	27
63	144	99
63	145	68
63	146	145
63	147	45
63	148	45
63	149	40
63	150	31
63	151	32
63	152	19
90	104	422
90	105	1389
90	106	977
90	107	1286
90	108	563
90	109	633
90	110	635
90	111	278
90	112	400
90	113	784
90	114	1165
90	115	1392
90	116	2061
90	117	864
90	118	1020
90	119	1115
90	120	1577
90	121	1374
90	122	1517
90	123	1134
90	124	686
90	125	1241
90	126	1009
125	41	3224
125	42	1492
125	43	3520
125	44	2491
125	45	1640
125	46	1252
125	47	916
125	48	2042
125	49	1816
125	50	975
125	51	2134
125	52	2134
125	53	2386
125	54	1376
125	55	2008
125	56	3001
125	57	2383
125	58	1793
125	59	4368
125	60	2218
125	61	2783

Sieve Passing	Rock ID	Mass M1
125	62	1196
125	63	3103
125	64	2831
125	65	2621
125	66	2558
125	67	1375
125	68	1469
125	69	1580
125	70	3269
125	71	1647
125	72	1424
125	73	2049
125	74	3213
125	75	2868
125	76	2961
125	77	1656
125	78	2784
125	79	1377
125	80	2834
125	81	2588
125	82	3628
125	83	3088
125	84	1952
125	85	2550
125	86	2375
125	87	2249
125	88	2376
125	89	3852
125	90	1887
125	91	1851
125	92	1370
125	93	2342
125	94	2302
125	95	1179
125	96	1192
125	97	1965
125	98	2212
125	99	2367
125	100	2176
125	101	1726
125	102	2930
125	103	2213
150	10	4739
150	11	3072
150	12	3248
150	13	3982
150	14	3061
150	15	2970
150	16	3904
150	17	4166
150	18	4484
150	19	4293
150	20	3904
150	21	3342
150	22	2784
150	23	3515
150	24	4191
150	25	4179
150	26	3326
150	27	4276
150	28	4957
150	29	3175
150	30	2956
150	31	6756
150	32	4204
150	33	2796
150	34	4375
150	35	2724
150	36	3262
150	37	4038

Sieve Passing	Rock ID	Mass M1
150	38	2559
150	39	3957
150	40	4522
180	3	3942
180	4	4515
180	5	4616
180	6	5720
180	7	6485
180	8	7972
180	9	3821
200	1	6829
200	2	7882

D. Calculations

In this appendix the data from the measurement campaigns is processed. This has been done per tested grading. The obtained results provide the basis for the analysis of the behaviour of the shape factor. Further information on the measurements themselves is provided in appendix [A]. The database of the tests can be found in appendix [C].

In IJmuiden, at a transhipment quay three different rock gradings have been tested. These are 22-90 mm. (approx. 1-3 inch), 2-5 inch (approx. 45-125 mm) and a 2-8 inch (approx. 45-180 mm) rock gradings. From each of the gradings five samples have been taken, indicated A-E. On each sample a sieve test has been performed. Furthermore the nominal diameters are examined. As a result for each sample the shape factor can be studied. On sample A also specific density tests and shape tests have been performed. In section D.20, D.1.2 and D.1.3 the 22-90, 2-5 and 2-8 gradings have been analysed respectively.

In Slovag, at a quarry site two rock gradings have been tested. These are a 1-5 inch (approx. 22-125 mm.) and a 5+ inch (approx. 125+ mm.) rock grading. From each of the gradings three samples have been taken, indicated A-C. On each sample a sieve test has been performed. Furthermore the nominal diameters are examined. As a result for each sample the shape factor can be studied. On sample A also density tests and shape tests have been performed. In section D.2 and D.2.2 the 1-5 and 5+ gradings have been analysed respectively. Moreover the data from both gradings has been combined resulting in 1-5+ samples of a conceptual 1-5+ grading. These samples are analysed in section D.2.3.

For the analyses of the samples the method applied in general is identical. This standard method is elaborated upon in section D.1.1.1; the analysis of sample 22-90 A. Deviations from this method are explained per sample. Section D.1.1.1 can therefore be used as a reference for the analysis method.

D.1 IJmuiden

D.1.1 IJmuiden 22-90

Origin: Carrieres de Sprimont et de Chanxhe, Belgium
Aggregate type: Gneiss/Granite
Shape type: Fresh

D.1.1.1 Sample A

Amount of rocks: 209

Sieve test

In Table D-1 the results of the sieve test are presented. The mass of each sieve fraction (2nd column) is determined by summation of the individual rock masses. These sieve fractions masses have been expressed as a percentage of the total sample mass (3rd column). In the last column the obtained mass percentages have been in accumulated.

Table D-1 - sieve test results 22-90 A

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.1	1.5	1.5
31.5-45	8.3	11.7	13.3
45-63	14.9	21.0	34.3
63-90	27.5	38.9	73.2
90-125	14.7	20.8	94.0
125-180	4.2	6.0	100.0
total	70.6	100.0	-

In Figure D.1-1 the accumulated percentages have been plotted versus the associated sieves sizes, resulting in a sieve curve. The percentage of the total mass that is able to pass a specific sieve is easily read from this graph. Moreover for each cumulative percentage the associated sieve size that would have been required can be approximated by linear interpolation. In this way the value for d_{50} is determined.

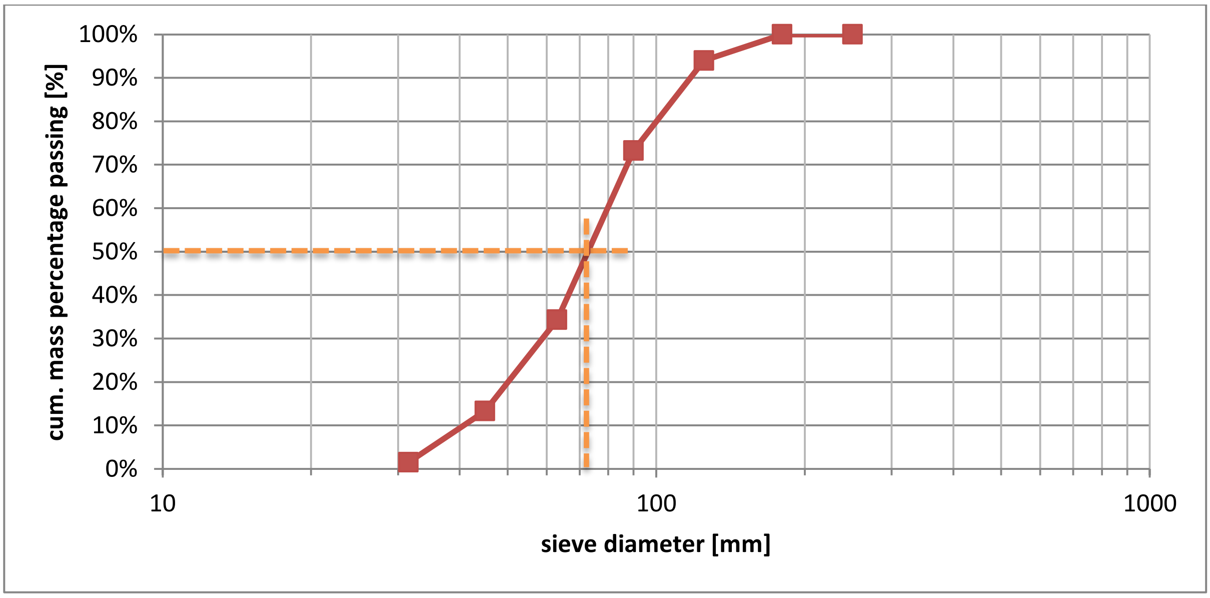


Figure D.1-1 - sieve curve 22-90 A

In Table D-2 nine sieve diameters interpolated from the sieve curve of Figure D.1-1 are listed. The values provide insight in the coarseness and width of the grading. The median sieve diameter d_{50}, abbreviated (MSD) is the most important parameter in the table since it is applied to determine the shape factor. The diameters d_5, d_{10}, d_{90} and d_{98} represent the extreme lower limit (EUL), nominal lower limit (NLL), nominal upper limit (NUL) and extreme upper limit (EUL) of the grading respectively. Furthermore d_{85} is presented as it is used to indicate the width of the grading.

Table D-2 - Interpolated sieve diameters 22-90 A

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	35.5
d10 (NLL)	41.2
d15	46.5
d25	55.0
d50 (MSD)	73.9
d60	80.8
d85	109.8
d90 (NUL)	118.3
d98 (EUL)	161.7

Grading width: d_{85}/d_{15} = 2.36. Wide coarse grading according to the Rock Manual (2007).

The mass of a stockpile is normal distributed over the rock sizes that occur in general. A sample representative for the stockpile should therefore also comply to this property. For example this means 50 percent of the mass consists of rock that has a sieve diameter $\leq d_{50}$ and as a result, logically 50 percent of the mass consists of rock that has a sieve diameter $\geq d_{50}$. In other words; the upper and lower x percent should contain the same fraction of the total sample mass.
The sampling process however is rather arbitrary and causes the sample to be practically never normal distributed. It is therefore required to check the samples 'rate of being normal distributed'. In order to do so the sieve curve of Figure D.1-2 has been plotted on a vertical Gaussian axis and horizontal logarithmic axis in Figure D.1-1. A perfectly normal distributed sample would yield a perfectly straight line. The black line in Figure D.1-2 is a linear best fit of the data and is included to assess the samples deviation from a perfect normal distribution. Samples that are significantly non-normal distributed may result in unrealistic interpolated sieve diameters and thus unreliable values for d_{50}.

From Figure D.1-2 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

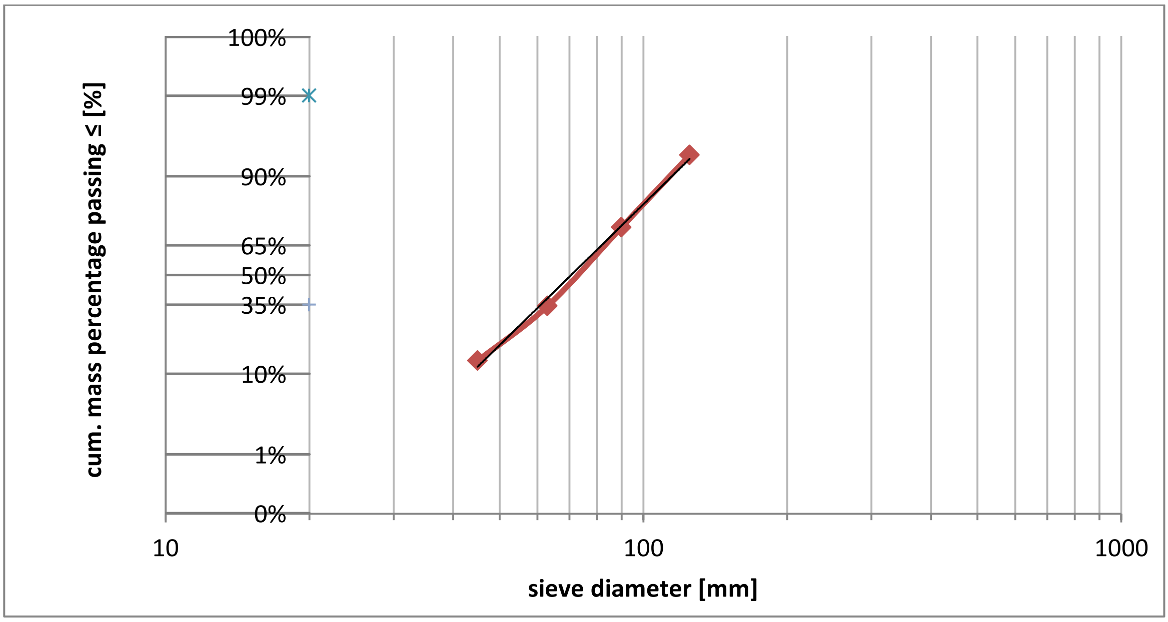


Figure D.1-2 - Gaussian sieve curve 22-90 A

d_n-analysis

For each individual rock the nominal diameter is calculated by the cubic root of the individual rock volume. The individual rock volumes have been determined by submersion into water and application of the Archimedes principle. In equation (1) form d_n is calculated by:

$$d_n = \sqrt[3]{V_{arch}} \quad [1]$$

The calculated nominal diameters are ranked in order of increases value. The associated masses are expressed as percentages of the total mass and accumulated, alike the analysis if the sieve diameters. In Figure D.1-3 the nominal diameters are plotted versus the associated accumulated mass percentages. The resulting figure is referred to as the nominal sieve curve. For each cumulative mass percentage the associated nominal diameter can be interpolated. In this way the value for d_{n50} is determined.

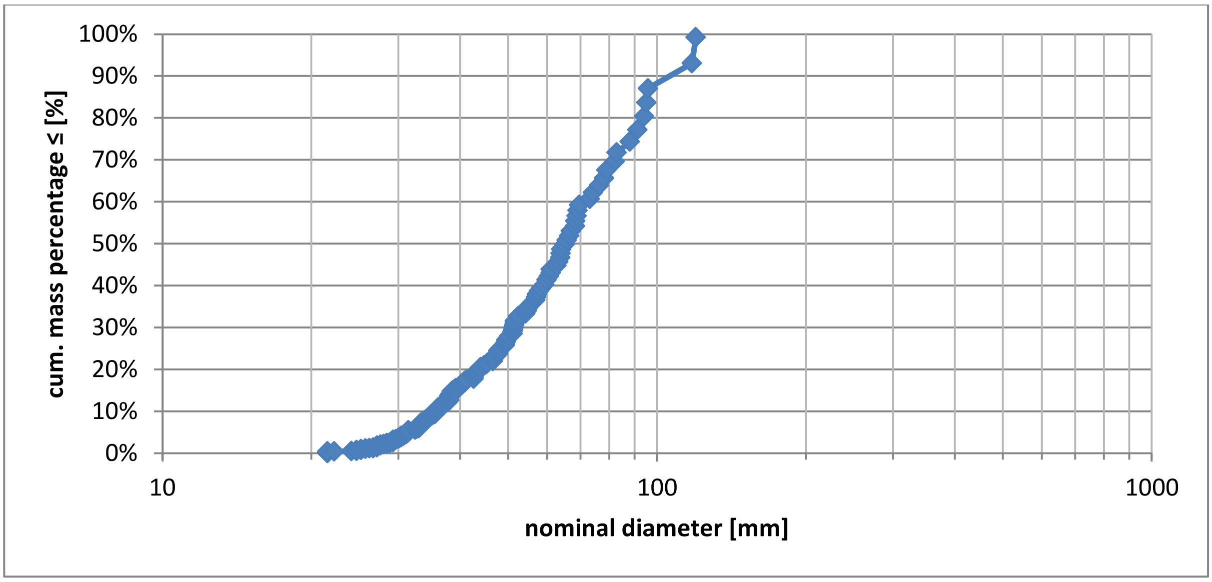


Figure D.1-3 - nominal sieve curve 22-90 A

From the above it can be concluded that the interpolation of nominal diameter values is dependent on two parameters, viz.: 1) the individual rock masses; to calculate the associate cumulative mass percentages, and 2) the individual rock volumes; to calculate nominal diameters. The correlation of both parameters is known as the rock density. It is given the (practically uniform) material in the sample has an approximated average rock density of 2650 kg/m³. From equation (1) it is observed nominal diameters are related to rock volume by a cubic relation. Rock volumes on their turn are linearly dependent on rock density. The dependency of the nominal sieve curve on rock density is therefore examined here.
In order to do so the individual rock densities have been calculated by the ratio of the individual rock masses and Archimedes volumes. The obtained individual rock densities are plotted versus the associated nominal diameters in Figure D.1-4. In the graph quite some variation in the individual rock densities is observed. In addition, it is clear the bandwidth of the scatter tends to decrease for increasing nominal diameters. In the region of the relatively small rocks the densities even show outliers of approximately 2300 and 3200 kg/m³. In contrast, in the region of the larger rocks the densities converge to the expected value of approximately 2650 kg/m³. The observed pattern can be explained by the flaws experienced during submersion of the rock. The most important difficulty was the creation of waves. Those waves impact the outcome the balance displays. The errors induced are of the same order of magnitude for each submerged rock. As a result the relative error increases for decreasing rock size.

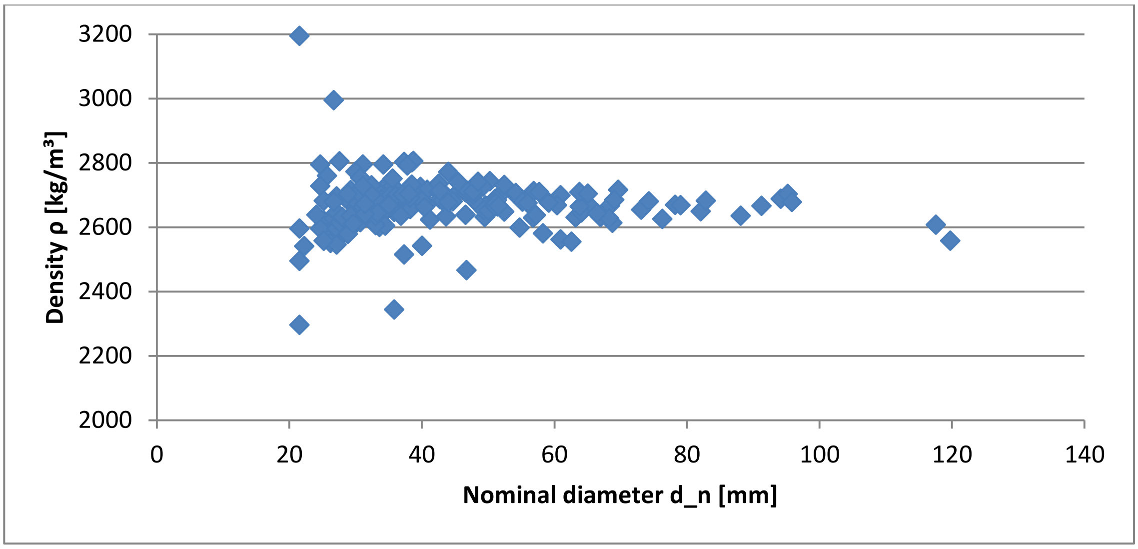


Figure D.1-4 - individual Archimedes rock densities 22-90 A

The average of the densities is 2669 kg/m³, the median is 2675 kg/m³ and the modus is 2661 kg/m³. Here the median value is the middle value of the densities ranked in order of increasing diameter. The modus represents the value that occurs most. These three different representations of 'a centre value' of the density are all slightly greater than but relatively close to the expected value of 2650 kg/m³.

The influence of the density scatter on the nominal sieve curve is examined by comparing with a nominal sieve curve derived on the basis of a uniform density. The value of the uniform density is determined by the taking the average density of the rocks in the 63-90 and 90-120 fraction, see Figure D.1-5. The rock volumes found on the basis of submersion and application of the Archimedes principle are considered sufficiently accurate. The found value of 2653 kg/m³ closely approximates the expected density of 2650 kg/m³ which approves this assumptions.

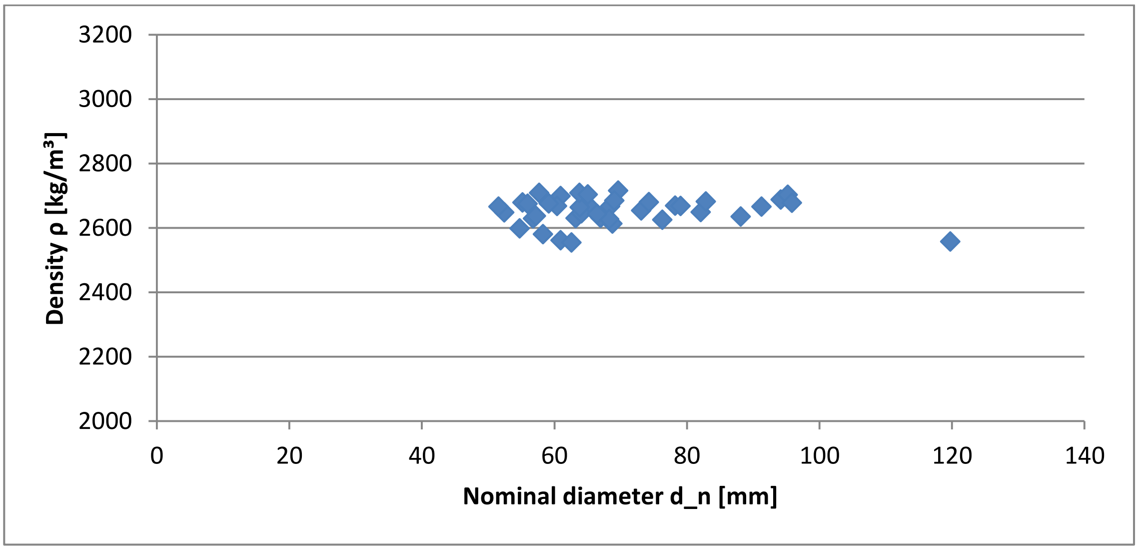


Figure D.1-5 - individual Archimedes rock densities of rock fractions 63-90 and 90-125

By application of the uniform density of 2653 kg/m³ modified volumes are obtained for all individual rocks. These volumes are applied to recalculated the nominal diameters of the rocks. The applied formula is given in equation (2).

$$d_{n\_mod} = \sqrt[3]{\frac{M}{\rho_{uni}}} \qquad [2]$$

A 'modified' nominal sieve curve including the modified nominal diameters is depicted in Figure D.1-6. At first sight the trends in the graph seems very similar to the graph of Figure D.1-3.

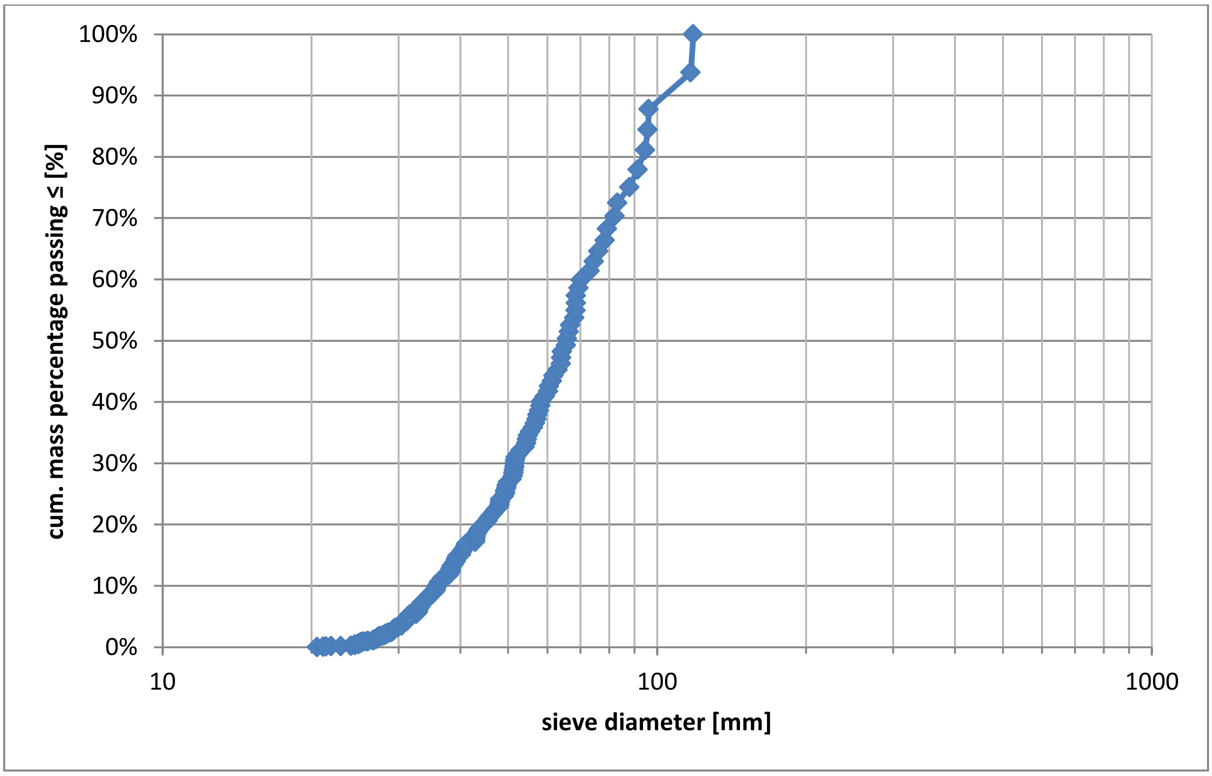


Figure D.1-6 - modified nominal sieve curve 22-90 A

In order to assess the reliability of the nominal sieve curve of Figure D.1-3 specific d_n-values are compared to the d_n-value found in Figure D.1-6, see Figure D.1-7, Figure D.1-8 and Table D-3.

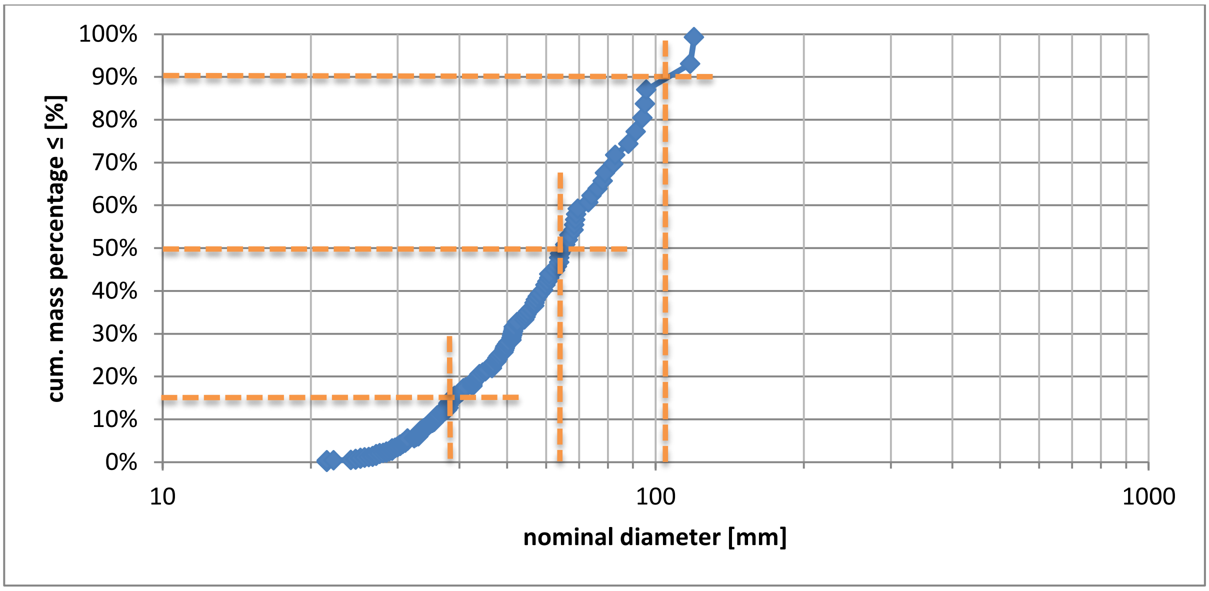


Figure D.1-7 -nominal diameter approximation

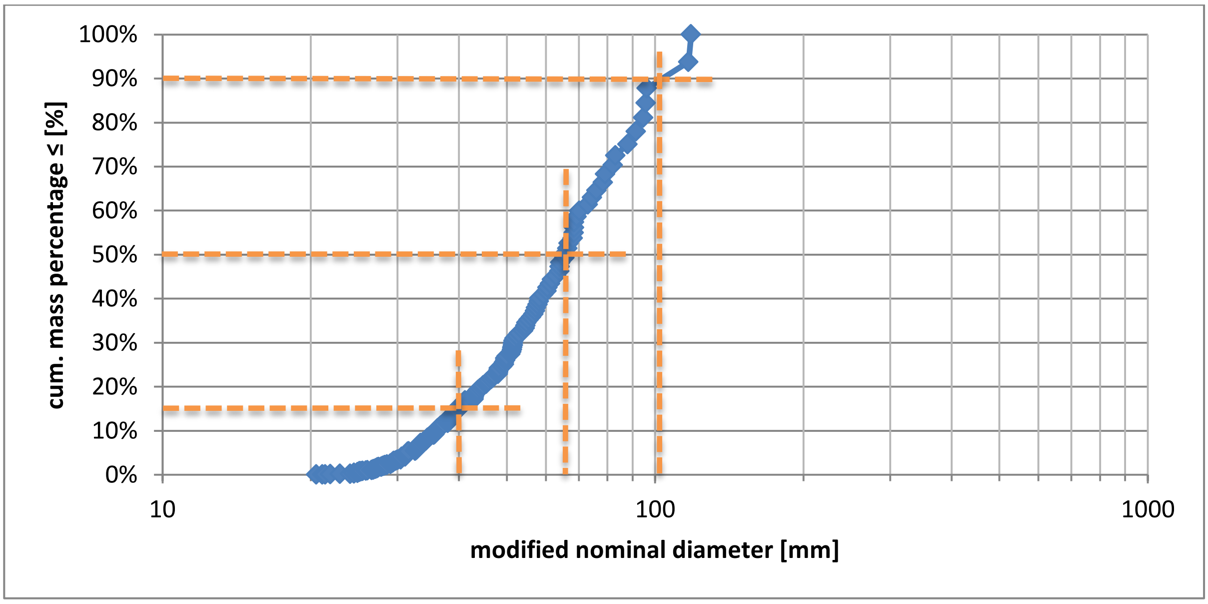


Figure D.1-8 - modified nominal diameter approximation

In Table D-3 the interpolated nominal diameters based on both the Archimedes and the modified volumes are listed.

Table D-3 - comparison of dn-values acc. to Archimedes and modified volumes 22-90 A

nominal diameter	**acc. to Archimedes volumes**	**acc. to modified volumes**
	[mm]	[mm]
d_{n5}	31.4	31.4
d_{n15}	38.7	39.9
d_{n50}	65.2	65.7
d_{n90}	106.7	103.9
d_{n98}	119.4	117.9

It is clear the nominal diameters found on the basis of the Archimedes volumes do not significantly differ from the modified nominal diameters. It is therefore concluded the observed scatter in the densities found on the basis of the Archimedes does not cause the nominal sieve diameter to be unrealistic. Therefore the nominal diameters on the basis of the Archimedes volumes are applied in the further analysis of this sample.

Shape factors F_x

By the quotient of the interpolated values of the sieve diameters and nominal diameters found in the above, shape factors are calculated and given in Table D-4. Note that the values of the nominal diameter and sieve diameter represented in a shape factor may refer to different rocks.

Table D-4 - shape factors 22-90 A

nominal diameter			**sieve diameter**		**shape factor**		
[mm]	Arc	mod	[mm]		[mm]	Arc	mod
dn5	31.4	31.4	d5	35.5	F5	0.886	0.885
dn15	38.7	39.9	d15	46.5	F15	0.833	0.858
dn50	65.2	65.7	d50	73.9	F50	0.883	0.889
dn90	106.7	103.9	d90	118.3	F90	0.902	0.878
dn98	119.4	117.9	d98	161.7	F98	0.738	0.729

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.88, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-9.

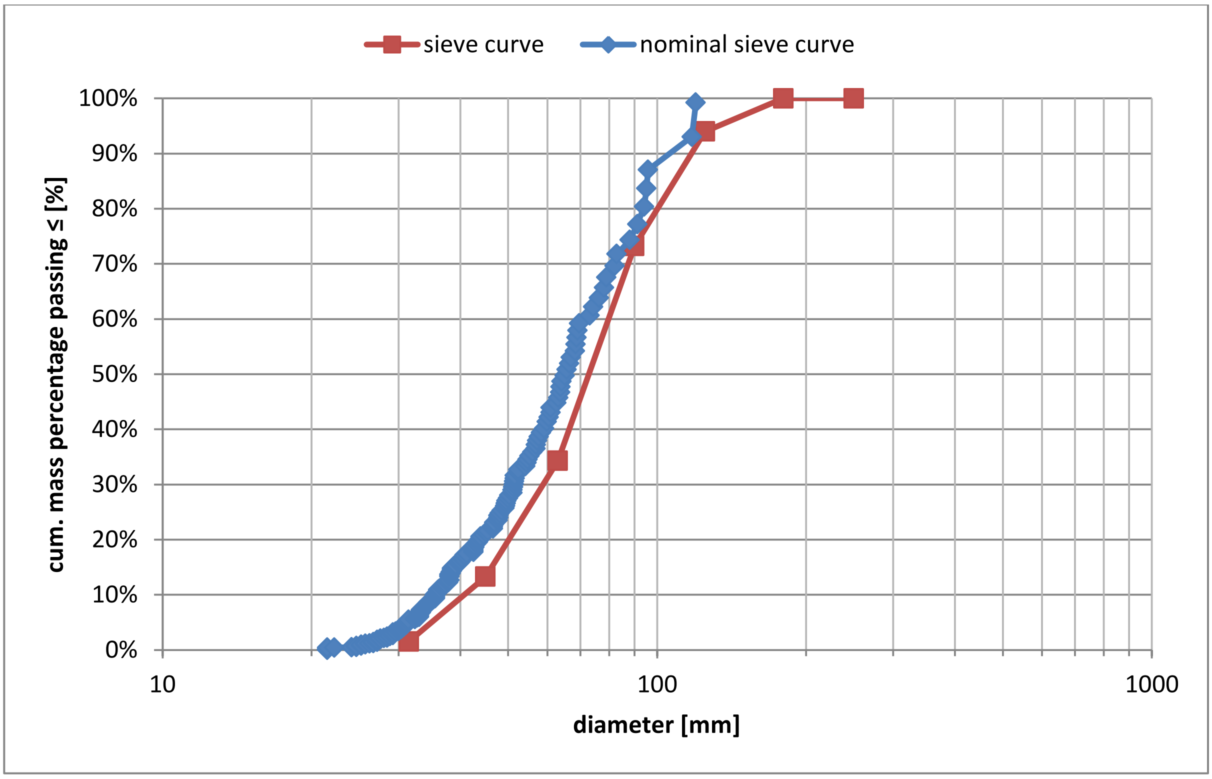


Figure D.1-9 - curves 22-90 A

In Figure D.1-10 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. In this way the quality of 0.84 for the shape factor can be visually examined. In the ideal case both lines would exactly overlap each other. It is concluded that for small rocks the nominal diameters are well approximated by a value of 0.84 times the sieve curve. For large rocks the approximation is less accurate and starts to fluctuate.

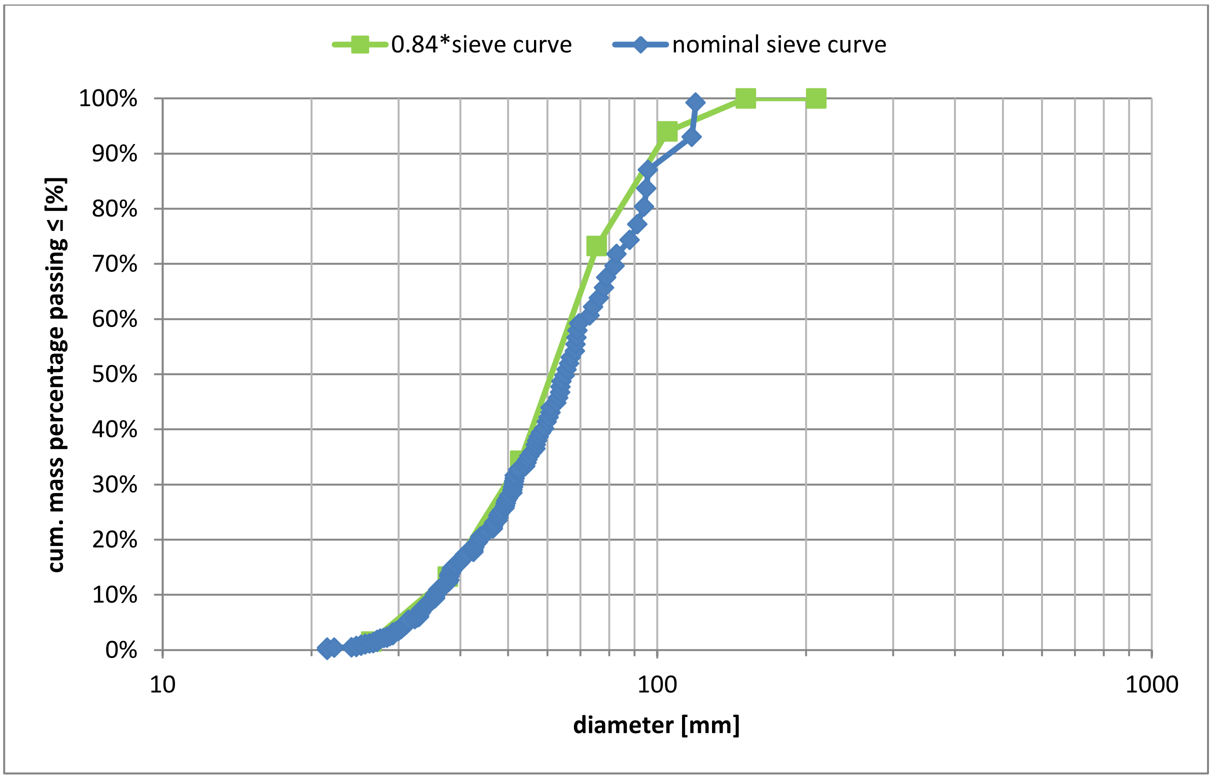


Figure D.1-10 - verification shape factor 22-90 A

Shape test

In the shape tests the length, thickness and dimensions of the smallest enclosing rectanguloid box of all individual rocks have been measured. These parameters are applied in describing the shapes of the rock by its elongation and blockiness. Elongation is calculated rather straightforwardly by the quotient of length and thickness. Blockiness is calculated by the quotient of an individual rock volume and the volume of the enclosing rectanguloid box. The rock volumes determined by the application of the Archimedes principle are applied in the calculation of the blockiness. In Table D-5 and Table D-6 the minimum, maximum and average values of the elongation and blockiness are listed per sieve fraction.

Table D-5 - elongation 22-90 A

	Elongation		
	minimum [-]	maximum [-]	average [-]
0-31.5	1.58	3.35	2.23
31.5-45	1.00	4.62	2.26
45-63	1.42	5.29	2.12
63-90	1.43	3.72	2.16
90-125	1.57	2.93	2.00
125-180	1.45	1.45	1.45
total	1.00	5.29	2.04

Table D-6 -blockiness 22-90 A

	Blockiness		
	minimum [%]	maximum [%]	average [%]
0-31.5	36.90	53.90	45.25
31.5-45	16.77	89.19	45.79
45-63	33.68	60.99	45.02
63-90	29.86	58.75	43.86
90-125	32.38	62.48	48.51
125-180	35.02	35.02	35.02
total	16.77	89.19	43.91

It is stressed that the calculated elongation and blockiness values in the 90-125 and 125-180 mm fraction are based on the an amount of 6 respectively 1 rock(s). This explains the minimum, maximum and average value of both elongation and blockiness is equal for the 125-180mm fraction. These values are rather questionable and are therefore not considered representative for the entire pile. Considering only the 0-31.5, 31.5-45, 45-63 and 63-90 fractions the minimum value for elongation is 1.00, meaning length equals thickness. The maximum value of elongation observed in these rocks is 5.29. No significant trends in elongation are observed over the fractions. Considering the average elongations also no significant trend is observed. The average value of the elongation of the considered fractions is 2.20.

Considering the same fractions the minimum value blockiness is on 16.77 percent, which is considered rather low. The maximum value for blockiness is 89.19 percent, which is considered rather high. No significant trends in blockiness are observed over the fractions. Considering the average blockiness' also no significant trend is observed. The average value of the blockiness of the considered fractions is 45.20. The found average values of elongation and blockiness do agree with values normally found in practice.

D.1.1.2 Sample B

Amount of rocks: 232

Sieve test

On this sample a sieve test is performed similar to that on sample A. A sieve curve is obtained by application of the method explained for sample A. The results of the sieve test for sample B are presented in Table D-7.

Table D-7 - sieve test results 22-90 B

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	0.9	1.5	1.5
31.5-45	10.0	16.3	17.9
45-63	11.6	19.0	36.9
63-90	21.9	35.9	72.7
90-125	16.7	27.3	100.0
125-180	0.0	0.0	-
total	61.1	100.0	-

The associate sieve curve representing sample B is given in Figure D.1-11.

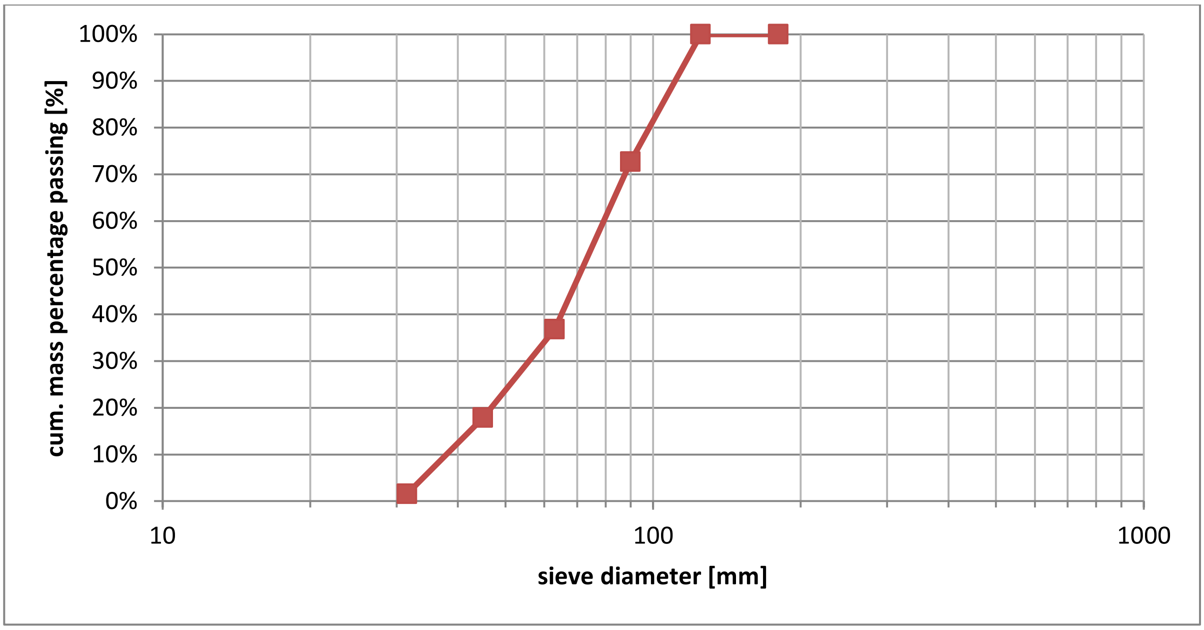


Figure D.1-11 - sieve curve 22-90 B

In Table D-8 nine sieve diameters interpolated from Figure D.1-11 are listed.

Table D-8 - Interpolated sieve diameters 22-90 B

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	34.4
d10 (NLL)	38.5
d15	42.6
d25	51.8
d50 (MSD)	72.9
d60	80.4
d85	105.8
d90 (NUL)	112.2
d98 (EUL)	122.4

Grading width: d_{85}/d_{15} = 2.48. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-12 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

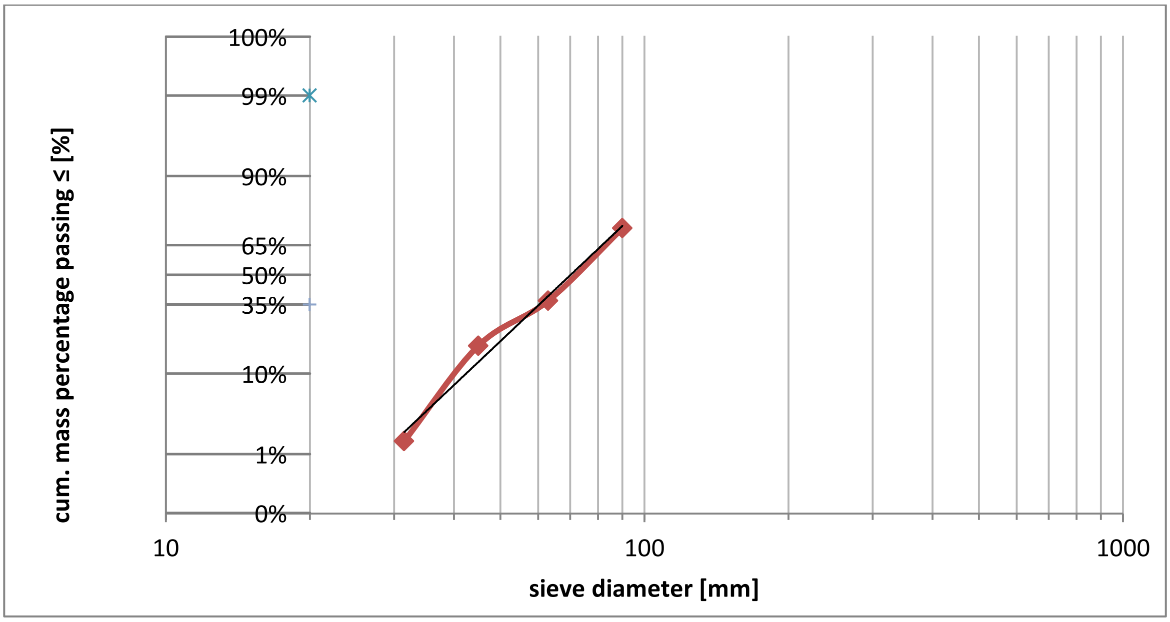


Figure D.1-12 - Gaussian sieve curve 22-90 B

d_n- analysis

On this sample a d_n-analysis is performed similar to that on sample A. However the individual rock volumes are unknown since they are not determined by the submersion technique. The volumes are therefore calculated by the quotient of mass and density. Since also the densities of the individual rocks were not measured the uniform density calculated in sample A (2653 kg/m³) is applied. As both samples are extracted from the same stockpile this is assumption is considered applicable. The formula applied is given in equation (2). The resulting nominal sieve curve of sample B is given in Figure D.1-13.

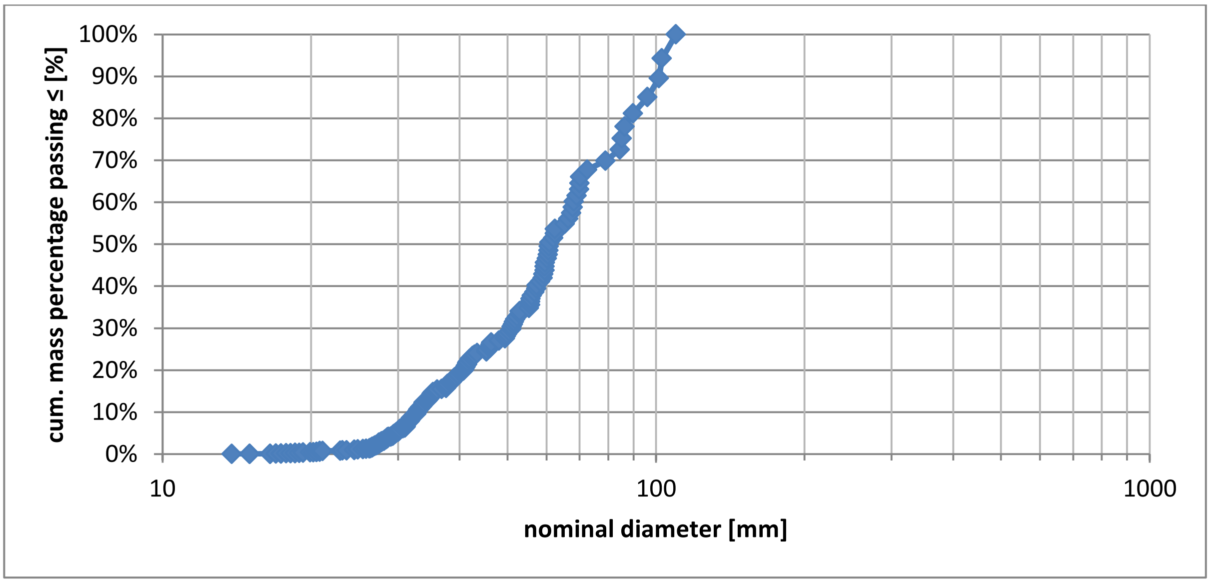


Figure D.1-13 - nominal sieve curve 22-90 B

In Table D-9 nominal diameters interpolated from Figure D.1-13 have been listed.

Table D-9 - nominal diameters 22-90 B

	nominal diameter
	[mm]
dn5	29.7
dn15	35.9
dn50	60.8
dn90	101.5
dn98	107.3

Shape factors F_x

By the quotient of the interpolated values of the sieve diameters and nominal diameters found in the above, shape factors are calculated and given in Table D-10. Note that the values of the nominal diameter and sieve diameter represented in a shape factor may refer to different rocks.

Table D-10 - shape factors 22-90 B

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	29.7	d5	34.4	F5	0.864
dn15	35.9	d15	42.6	F15	0.841
dn50	60.8	d50	72.9	F50	0.834
dn90	101.5	d90	112.2	F90	0.905
dn98	107.3	d98	122.4	F98	0.876

It is concluded the shape factor is not constant for the sample. The shape factor tends to increase for increasing rock size. The value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.84, which equals the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-14.

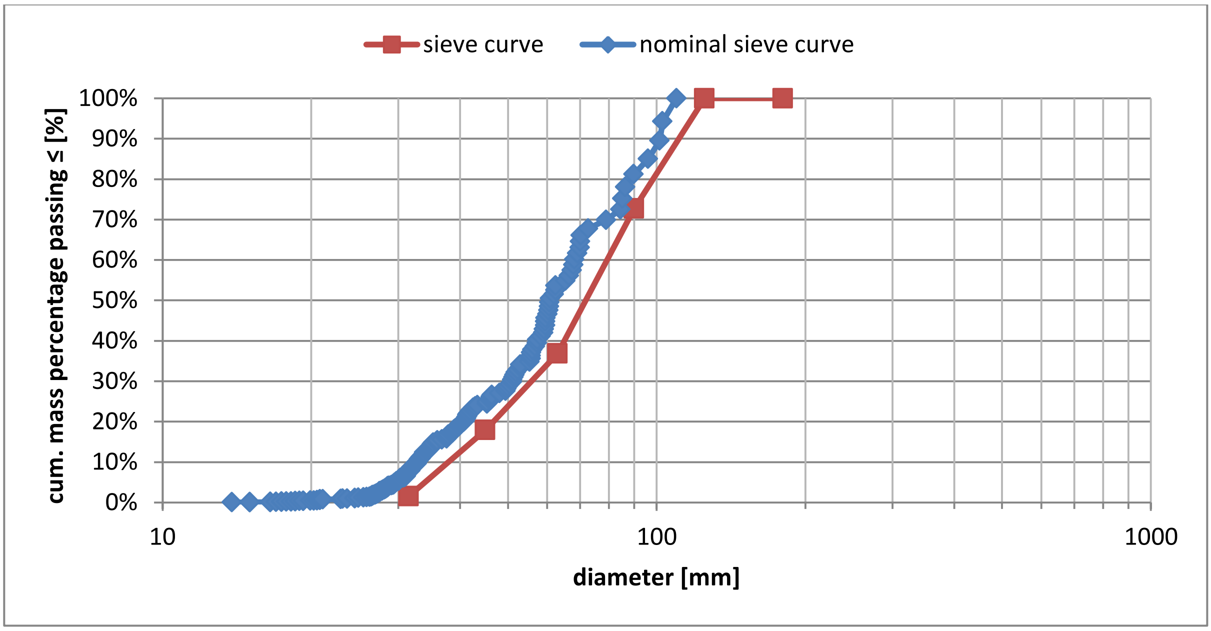


Figure D.1-14 - curves 22-90 B

In Figure D.1-15 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. In this way the quality of 0.84 for the shape factor can be visually examined. In the ideal case both lines would exactly overlap each other. It is concluded that up to a cumulative mass percentage passing of 70 percent, the value of 0.84 yields a well approximation for the quotient of nominal diameters and sieve diameters. At 50 percent cumulative mass passing both lines are actually overlapping each other, which means 0.84 perfectly fits the relation described by shape factor here. For large rocks the approximation is less accurate; here the value of 0.84 underestimates the shape factor.

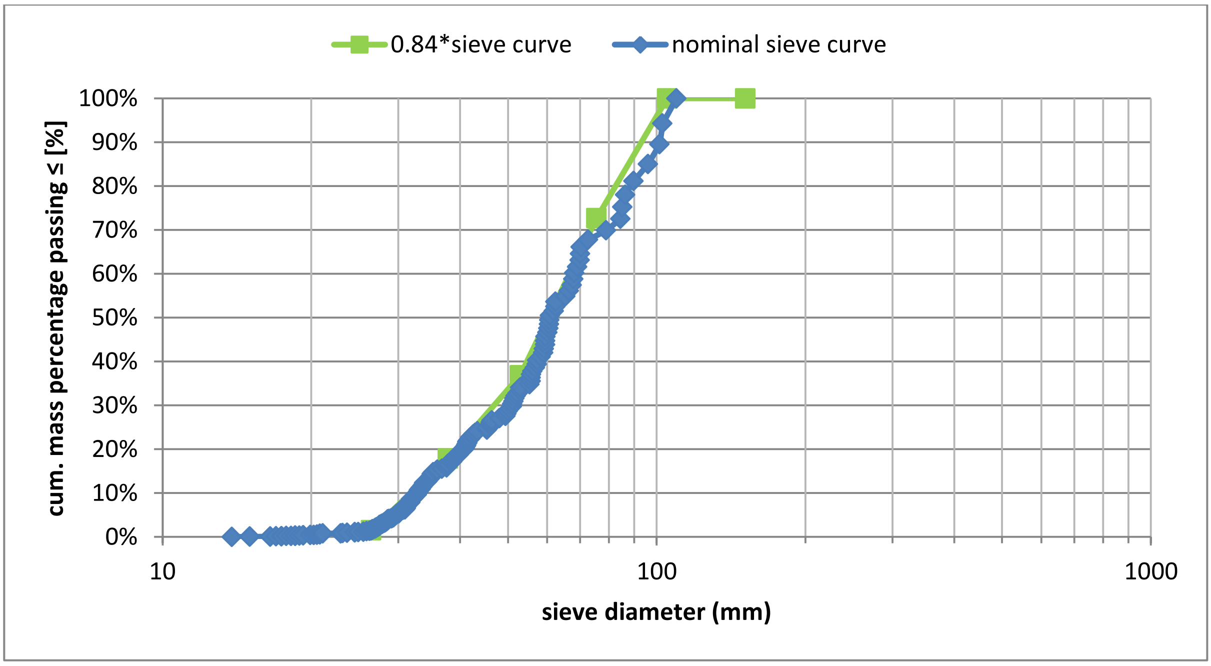


Figure D.1-15 - verification shape factor 22-90 B

D.1.1.3 Sample C

Amount of rocks: 218

Sieve test

On this sample a sieve test similar to that on sample A is performed. A sieve curve is obtained by application of the method explained for sample A. The results of the sieve test for sample C are presented in Table D-11.

Table D-11 - sieve test results 22-90 C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	0.5	0.7	0.7
31.5-45	8.6	12.5	13.2
45-63	11.8	17.2	30.4
63-90	27.1	39.5	69.9
90-125	13.2	19.2	89.0
125-180	7.5	11.0	100.0
total	68.7	100.0	-

The associate sieve curve representing sample C is given in Figure D.1-16.

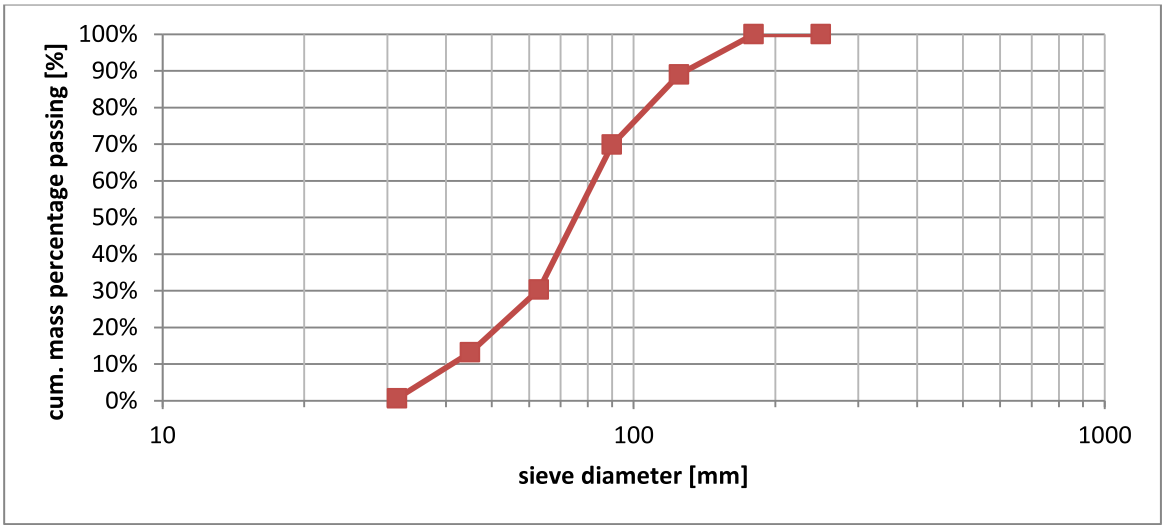


Figure D.1-16 - sieve curve 22-90 C

In Table D-12 nine sieve diameters interpolated from Figure D.1-16 are listed.

Table D-12 - Interpolated sieve diameters 22-90 C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	36.2
d10 (NLL)	41.6
d15	46.9
d25	57.4
d50 (MSD)	76.4
d60	83.3
d85	117.7
d90 (NUL)	129.9
d98 (EUL)	170.0

Grading width: d_{85}/d_{15} = 2.51. Wide coarse grading according to the Rock Manual (2007)

From Figure D.1-17 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

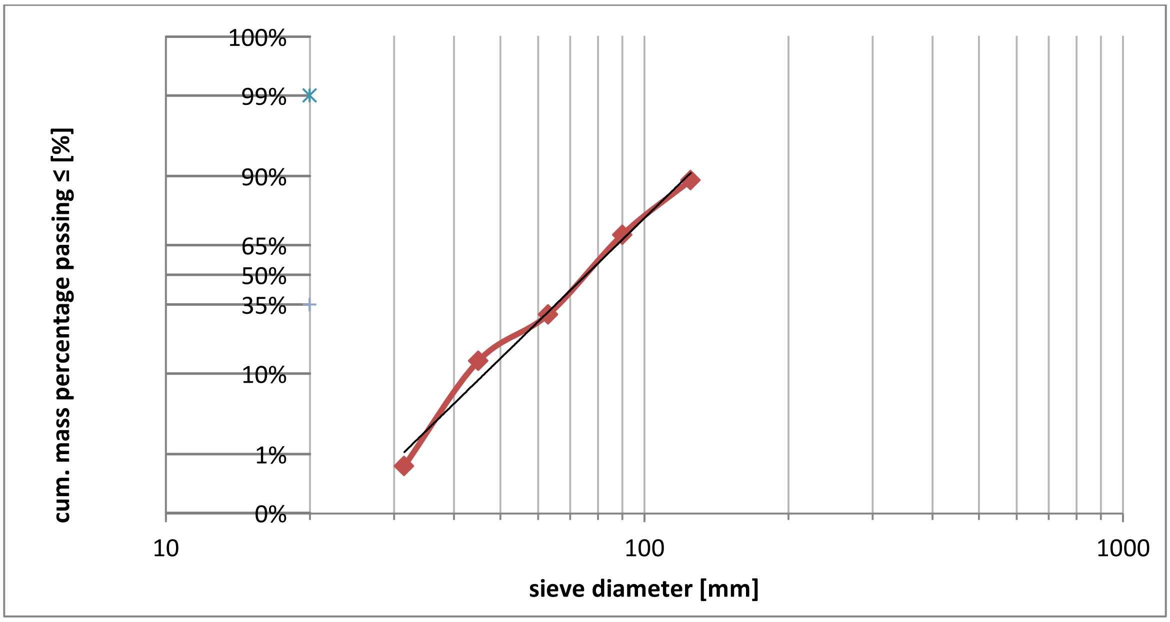


Figure D.1-17 - Gaussian sieve curve 22-90 C

d_n- analysis

On this sample a d_n-analysis is performed similar to that on sample A. However the individual rock volumes are unknown since they are not determined by the submersion technique. The volumes are therefore calculated by the quotient of mass and density. Since also the densities of the individual rocks were not measured the uniform density calculated in sample A (2653 kg/m³) is applied. As both samples are extracted from the same stockpile this is assumption is considered applicable. The formula applied is given in equation (2). The resulting nominal sieve curve of sample C is given in Figure D.1-18.

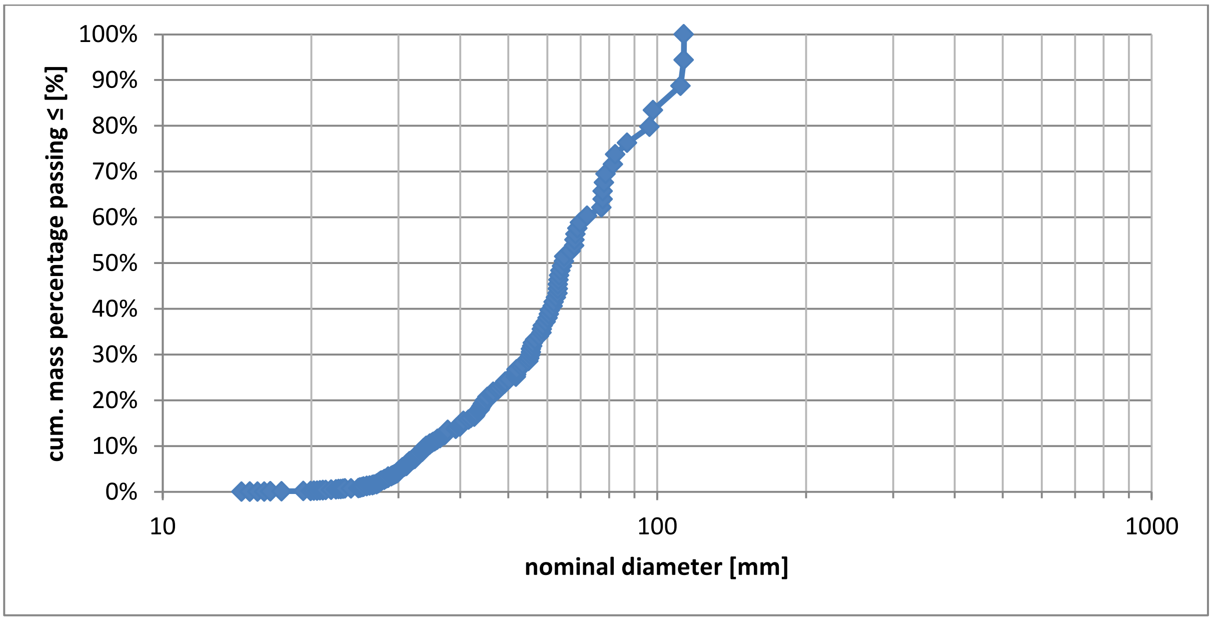


Figure D.1-18 - nominal sieve curve 22-90 C

In Table D-13 nominal diameters interpolated from Figure D.1-18 have been listed.

Table D-13 - nominal diameters 22-90 C

	nominal diameter [mm]
dn5	30.4
dn15	40.2
dn50	64.6
dn90	112.0
dn98	113.3

Shape factors F_x

By the quotient of the interpolated values of the sieve diameters and nominal diameters found in the above, shape factors are calculated and given in Table D-16. Note that the values of the nominal diameter and sieve diameter represented in a shape factor may refer to different rocks.

Table D-14 - shape factors 22-90 C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	30.4	d5	36.2	F5	0.840
dn15	40.2	d15	46.9	F15	0.858
dn50	64.6	d50	76.4	F50	0.846
dn90	112.0	d90	129.9	F90	0.862
dn98	113.3	d98	170.0	F98	0.667

It is concluded the shape factor is not constant for the sample. The shape factor has a relatively constant value of approximately 0.85 for the 5, 15, 50 and 90- percentage values. The value for F_{98} has a significantly smaller value of 0.67. The value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.85, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-19.

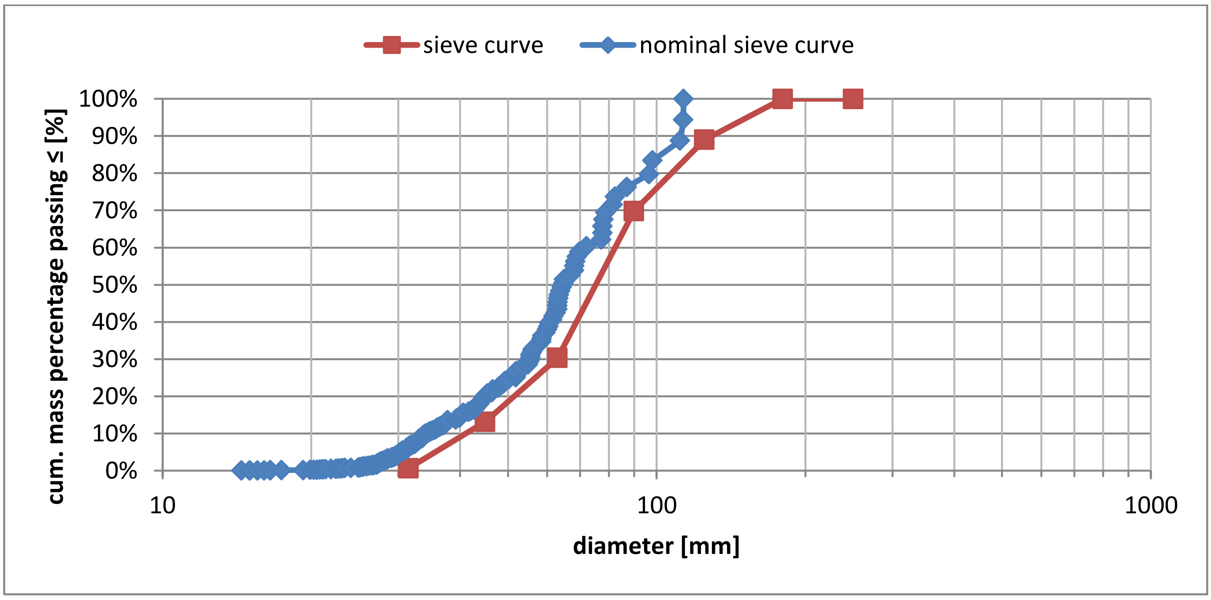


Figure D.1-19 - curves 22-90 C

In Figure D.1-20 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. In this way the quality of 0.84 for the shape factor can be visually examined. In the ideal case both lines would exactly overlap each other. It is concluded that the value of 0.84 well approximates the value of the shape factor. At 50 percent cumulative mass passing both lines are actually overlapping each other, which means 0.84 perfectly fits the relation described by shape factor here. Only still for the largest rocks in the sample the approximation weakens. However, this conclusion is not solid since it is based on the observation of the nominal diameters of only two rocks.

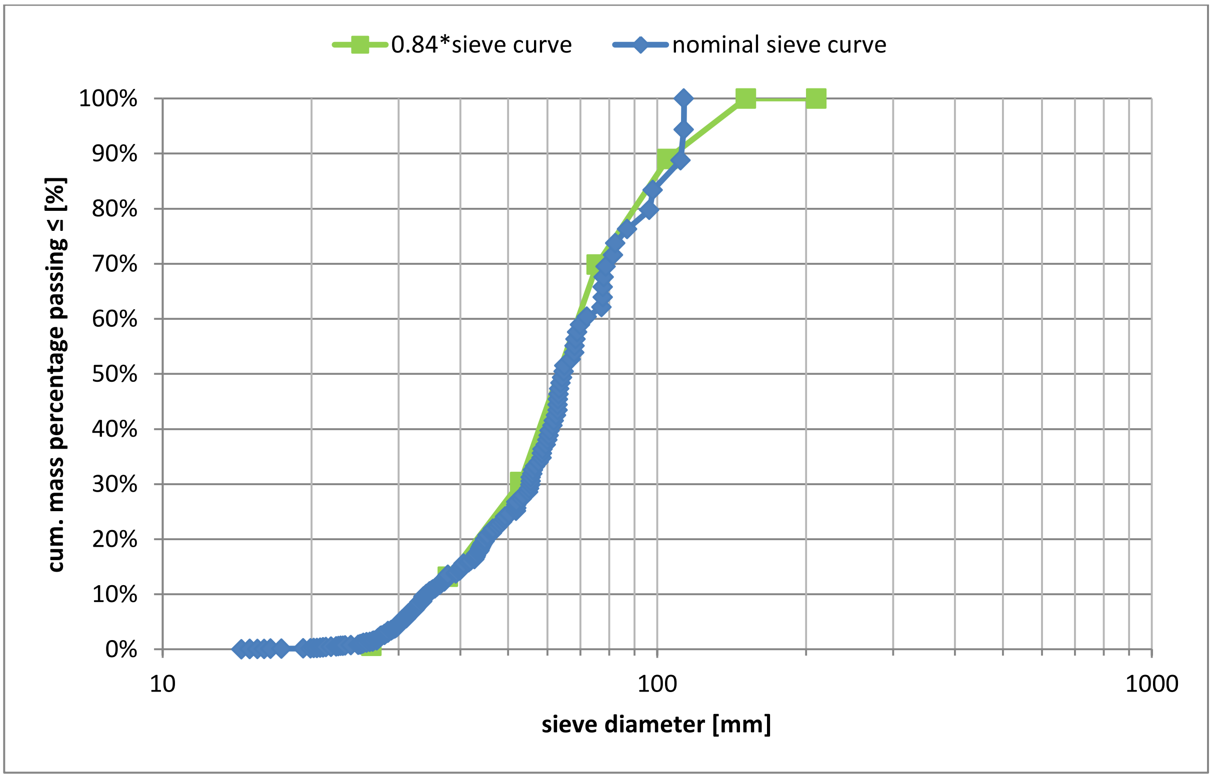


Figure D.1-20 - verification shape factor 22-90 C

D.1.1.4 Sample D

Amount of rocks: 265

Sieve test

On this sample a sieve test is performed similar to that on sample A. A sieve curve is obtained by application of the method explained for sample A. The results of the sieve test for sample D are presented in Table D-15.

Table D-15 - sieve test results 22-90 D

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.2	1.5	1.5
31.5-45	10.3	12.8	14.3
45-63	16.0	19.8	34.1
63-90	27.5	34.1	68.2
90-125	22.4	27.9	96.1
125-180	3.1	3.9	100.0
total	80.5	100.0	-

The associate sieve curve representing sample C is given in Figure D.1-21.

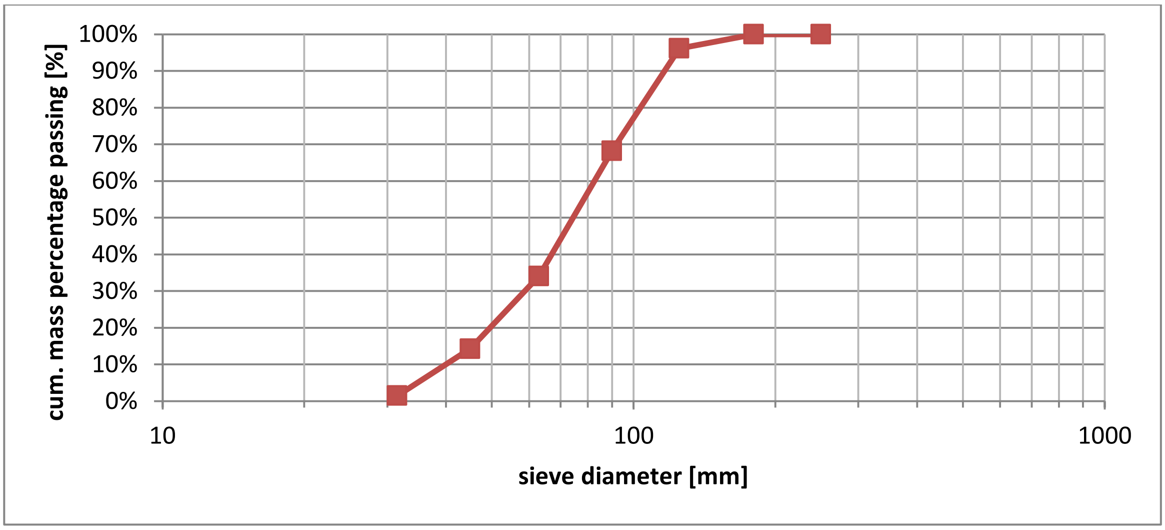


Figure D.1-21 - sieve curve 22-90 D

In Table D-16 nine sieve diameters interpolated from Figure D.1-16 are listed.

Table D-16 - Interpolated sieve diameters 22-90 D

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	35.2
d10 (NLL)	40.5
d15	45.6
d25	54.7
d50 (MSD)	75.6
d60	83.5
d85	111.0
d90 (NUL)	117.3
d98 (EUL)	151.7

Grading width: d_{85}/d_{15} = 2.43. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-22 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

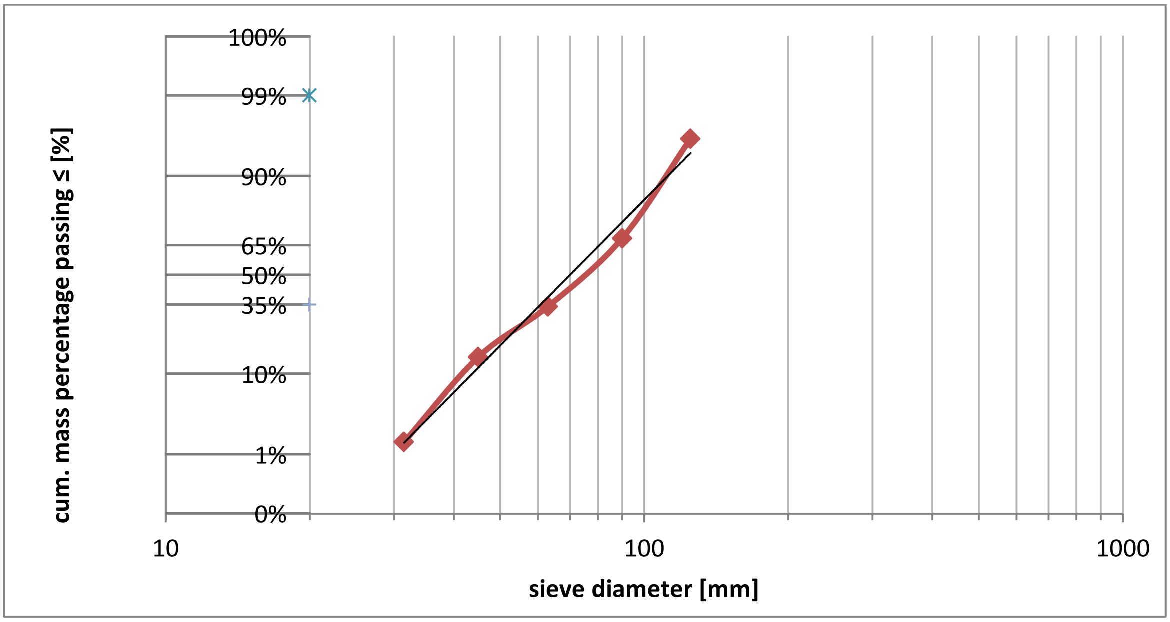


Figure D.1-22 - Gaussian sieve curve 22-90 D

d_n- analysis

On this sample a d_n-analysis is performed similar to that on sample A. However the individual rock volumes are unknown since they are not determined by the submersion technique. The volumes are therefore calculated by the quotient of mass and density. Since also the densities of the individual rocks were not measured the uniform density calculated in sample A (2653 kg/m³) is applied. As both samples are extracted from the same stockpile this is assumption is considered applicable. The formula applied is given in equation (2). The resulting nominal sieve curve of sample D is given in Figure D.1-23.

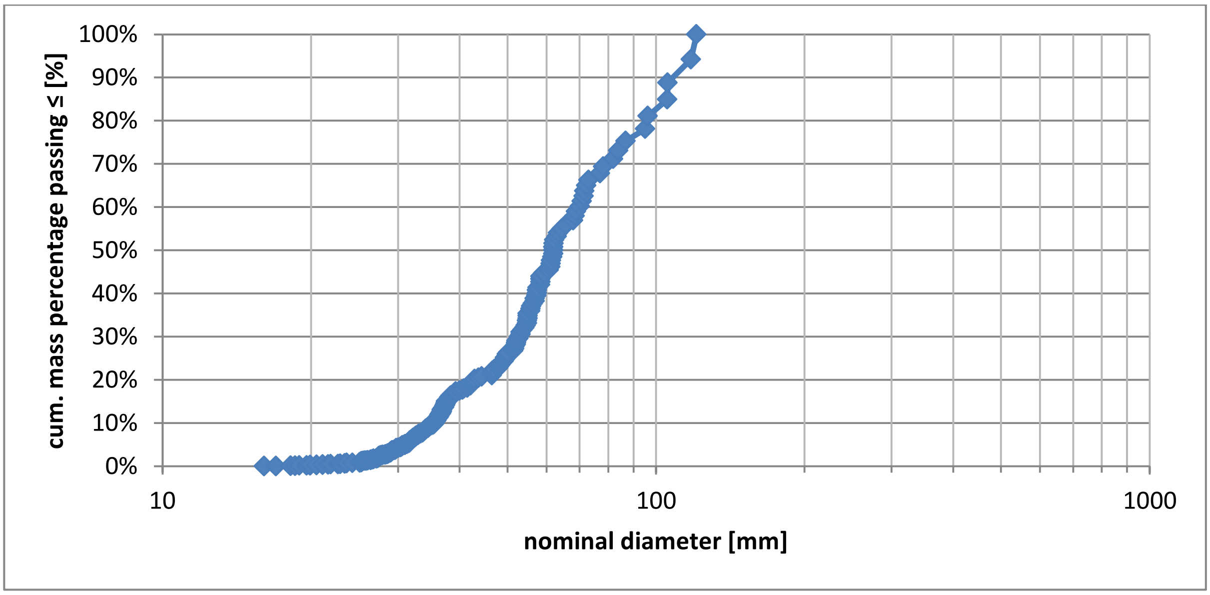


Figure D.1-23 - nominal sieve curve 22-90 D

In Table D-23 nominal diameters interpolated from Figure D.1-26 have been listed.

Table D-17 - nominal diameters 22-90 D

nominal diameter	
	[mm]
dn5	31.0
dn15	37.6
dn50	62.0
dn90	108.3
dn98	119.7

Shape factors F_x

By the quotient of the interpolated values of the sieve diameters and nominal diameters found in the above, shape factors are calculated and given in Table D-18. Note that the values of the nominal diameter and sieve diameter represented in a shape factor may refer to different rocks.

Table D-18 - shape factors 22-90 D

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	31.0	d5	35.2	F5	0.881
dn15	37.6	d15	45.6	F15	0.824
dn50	62.0	d50	75.6	F50	0.820
dn90	108.3	d90	117.3	F90	0.923
dn98	119.7	d98	151.7	F98	0.790

It is concluded the shape factor is not constant for the sample. Its value fluctuates between approximately 0.80 and 0.90. The value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.82, which is slightly smaller than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-24.

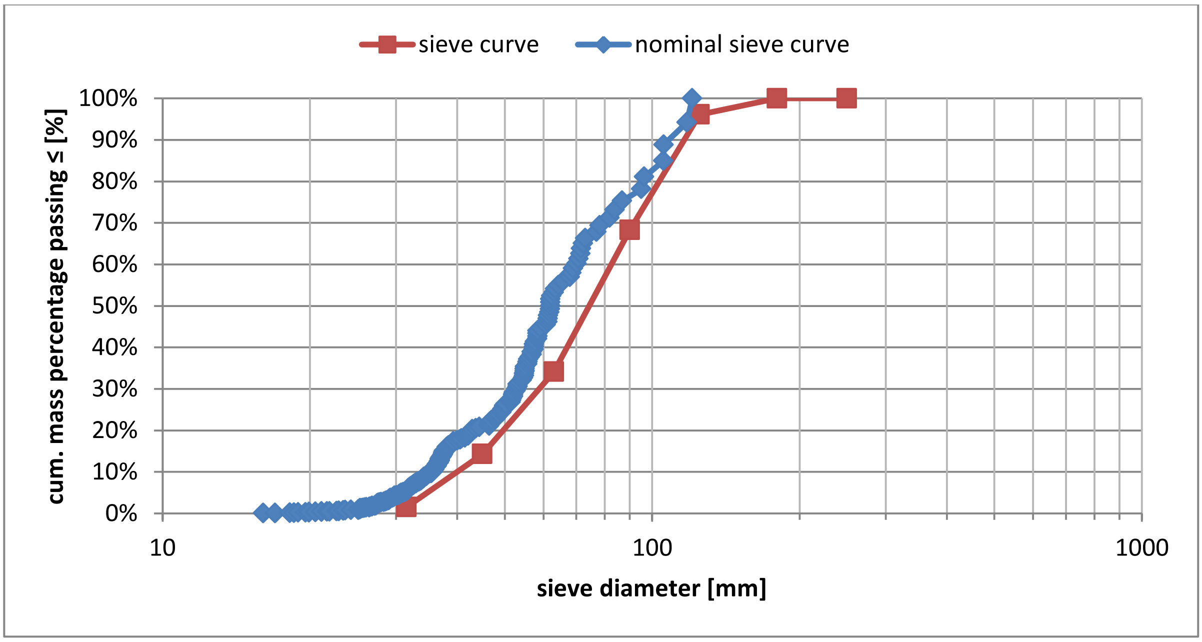


Figure D.1-24 - curves 22-90 D

In Figure D.1-25 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. In this way the quality of 0.84 for the shape factor can be visually examined. In the ideal case both lines would exactly overlap each other. It is concluded that up to a cumulative mass percentage passing of 70 percent, the value of 0.84 yields a well approximation for the quotient of nominal diameters and sieve diameters. At 50 percent cumulative mass passing both lines are actually overlapping each other, which means 0.84 perfectly fits the relation described by shape factor here. For large rocks the approximation is less accurate; here the value of 0.84 underestimates the shape factor.

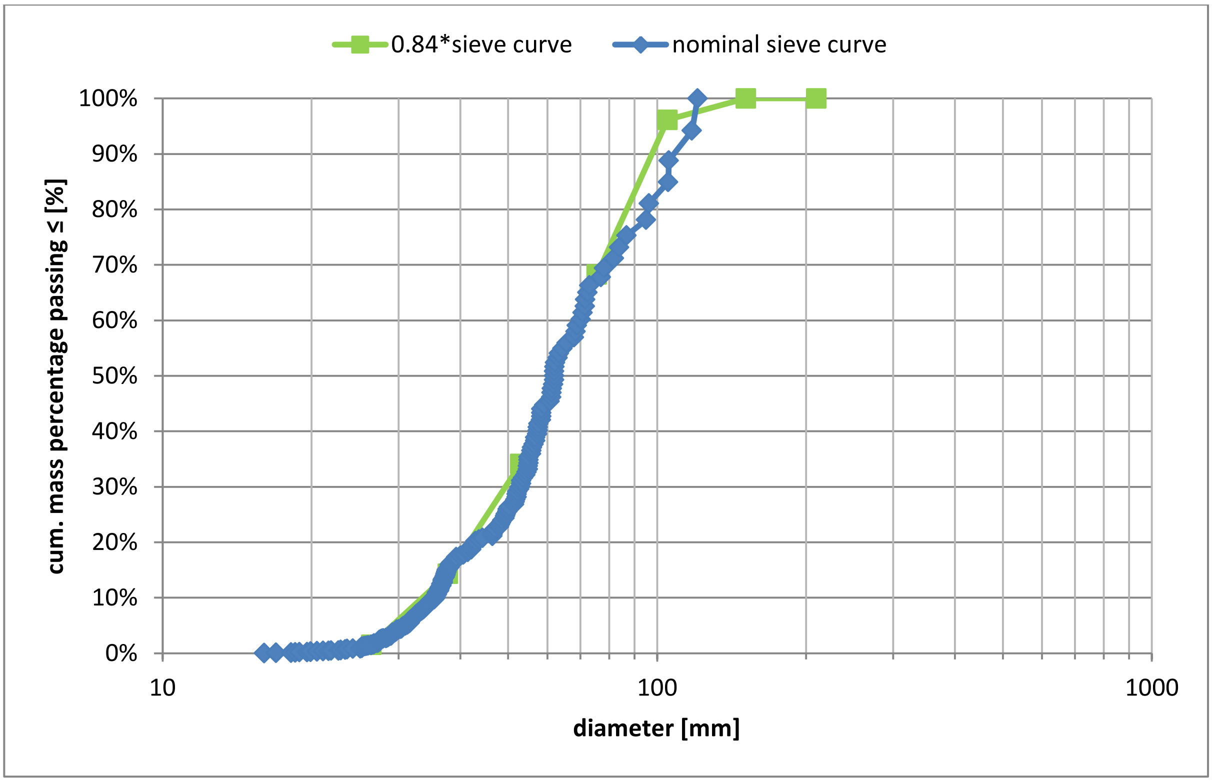


Figure D.1-25 - verification shape factor 22-90 D

D.1.1.5 Sample E

Amount of rocks: 304

Sieve test

On this sample a sieve test is performed similar to that on sample A. A sieve curve is obtained by application of the method explained for sample A. The results of the sieve test for sample E are presented inTable D-19.

Table D-19 - sieve test results 22-90 E

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.9	3.2	3.2
31.5-45	14.4	24.0	27.1
45-63	13.5	22.6	49.7
63-90	15.8	26.4	76.2
90-125	14.3	23.8	100
125-180			
total	59.9	100	-

The associate sieve curve representing sample C is given inFigure D.1-26.

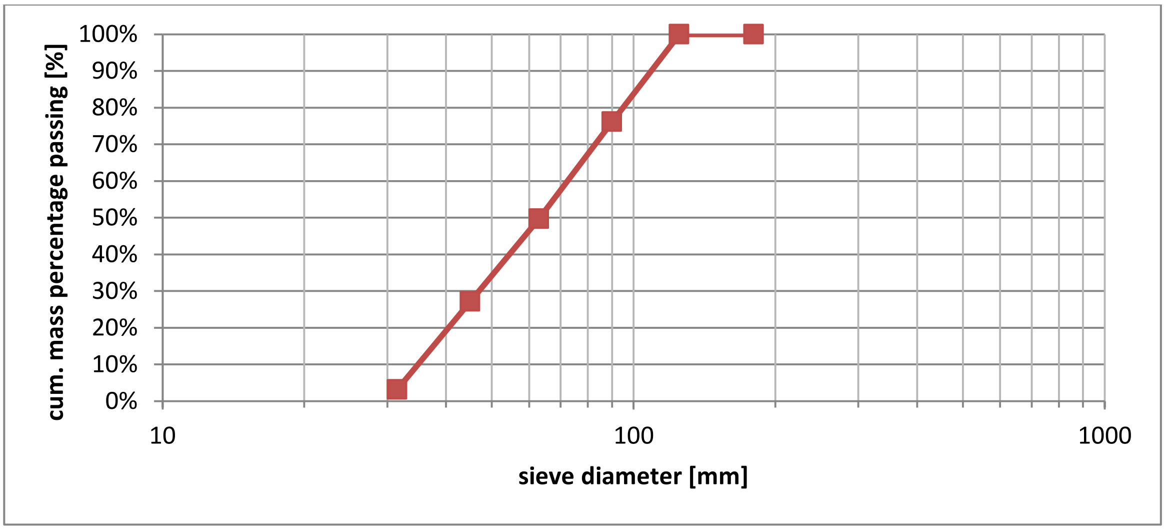


Figure D.1-26 - sieve curve 22-90 E

In Table D-20 nine sieve diameters interpolated from Figure D.1-26 are listed.

Table D-20 - Interpolated sieve diameters 22-90 E

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	32.5
d10 (NLL)	35.3
d15	38.2
d25	43.8
d50 (MSD)	63.3
d60	73.5
d85	103.0
d90 (NUL)	110.3
d98 (EUL)	122.1

Grading width: d_{85}/d_{15} = 2.70. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-27 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

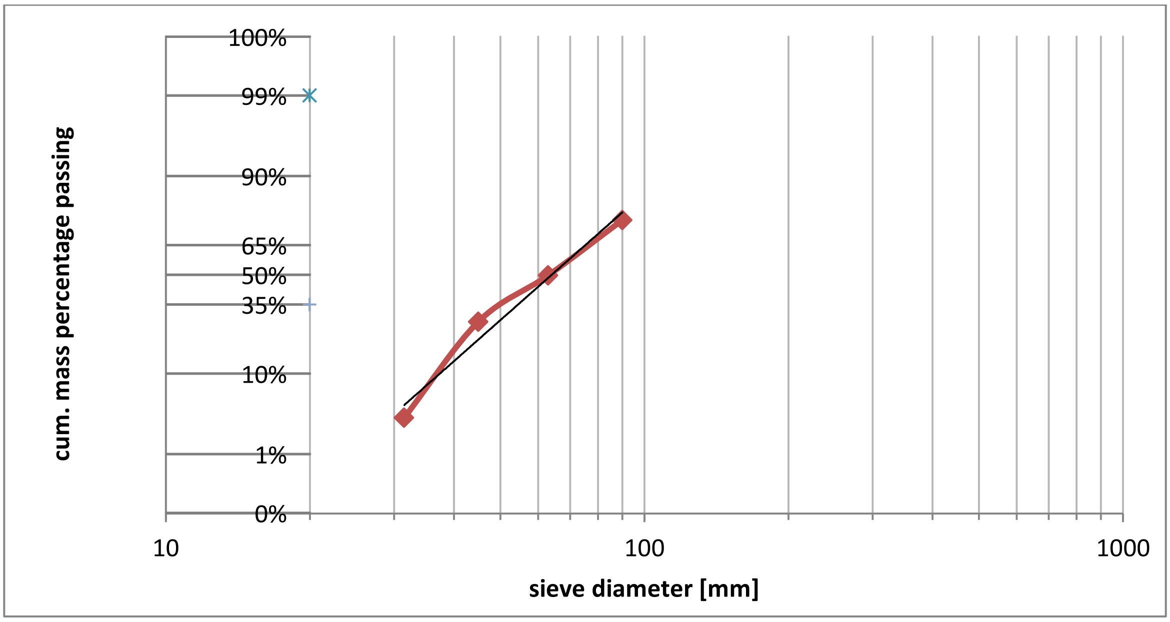


Figure D.1-27 - Gaussian sieve curve 22-90 E

d_n- analysis

On this sample a d_n-analysis is performed similar to that on sample A. However the individual rock volumes are unknown since they are not determined by the submersion technique. The volumes are therefore calculated by the quotient of mass and density. Since also the densities of the individual rocks were not measured the uniform density calculated in sample A (2653 kg/m³) is applied. As both samples are extracted from the same stockpile this is assumption is considered applicable. The formula applied is given in equation (2). The resulting nominal sieve curve of sample E is given in Figure D.1-28.

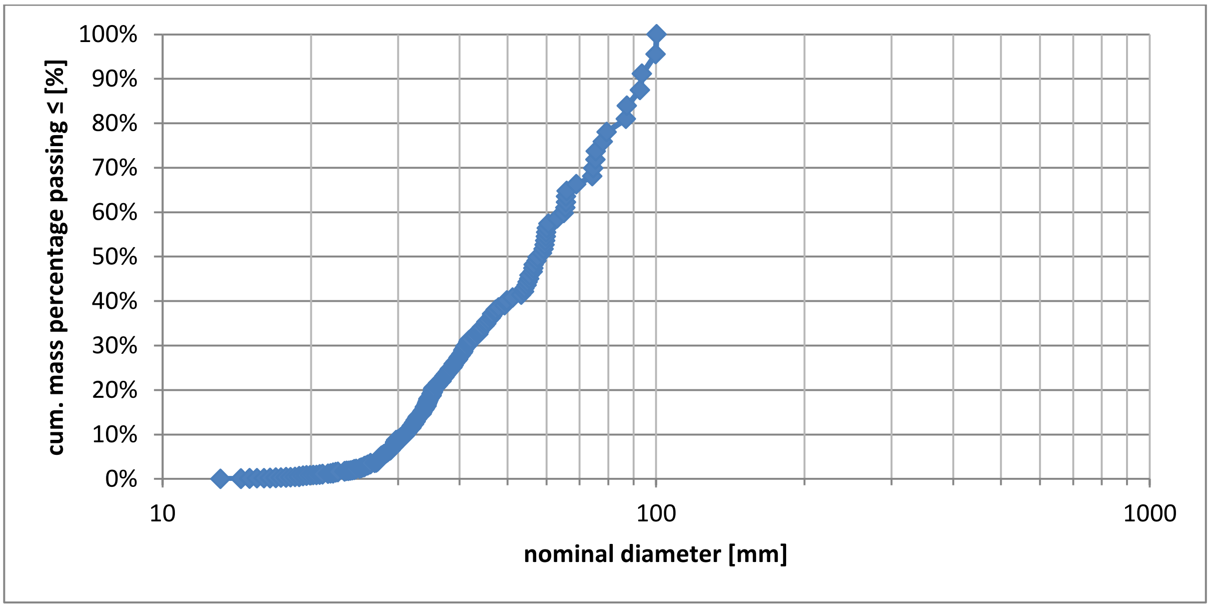


Figure D.1-28 - nominal sieve curve 22-90 E

In Table D-21 nominal diameters interpolated from Figure D.1-28 have been listed.

Table D-21 - nominal diameters 22-90 E

	nominal diameter [mm]
dn5	27.8
dn15	33.6
dn50	57.7
dn90	93.5
dn98	100.1

Shape factors F_x

By the quotient of the interpolated values of the sieve diameters and nominal diameters found in the above, shape factors are calculated and given in Table D-22. Note that the values of the nominal diameter and sieve diameter represented in a shape factor may refer to different rocks.

Table D-22 - shape factors 22-90 E

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	27.8	d5	32.5	F5	0.855
dn15	33.6	d15	38.2	F15	0.882
dn50	57.7	d50	63.3	F50	0.912
dn90	93.5	d90	110.3	F90	0.848
dn98	100.1	d98	122.1	F98	0.820

It is concluded the shape factor is not constant for the sample. Its value fluctuates between approximately 0.82 and 0.91. The value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.91, which is significantly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-29.

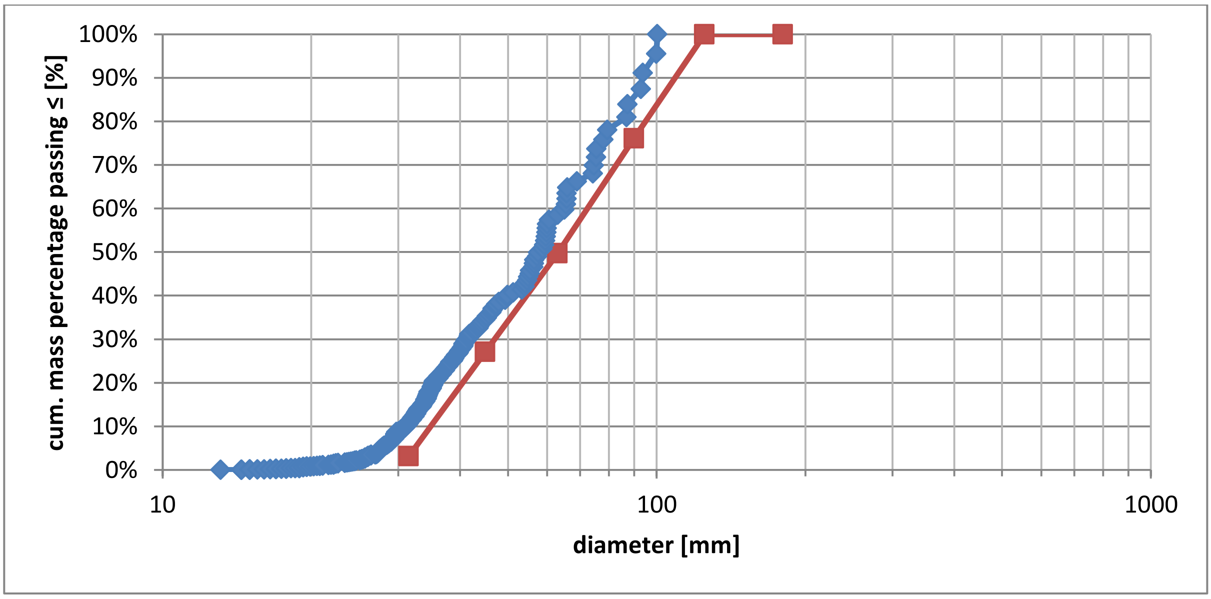


Figure D.1-29 - curves 22-90 E

In Figure D.1-30 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. In this way the quality of 0.84 for the shape factor can be visually examined. In the ideal case both lines would exactly overlap each other. It is concluded that for small rocks (d_n ≤ approx. 40 mm) the nominal diameters are well approximated by a value of 0.84 times the sieve curve. For larger rocks the approximation is less accurate and starts to show some fluctuation. In general 0.84 tends to underestimate the shape factor. Please note that for the largest rocks in the sample 0.84 is again a well approximation.

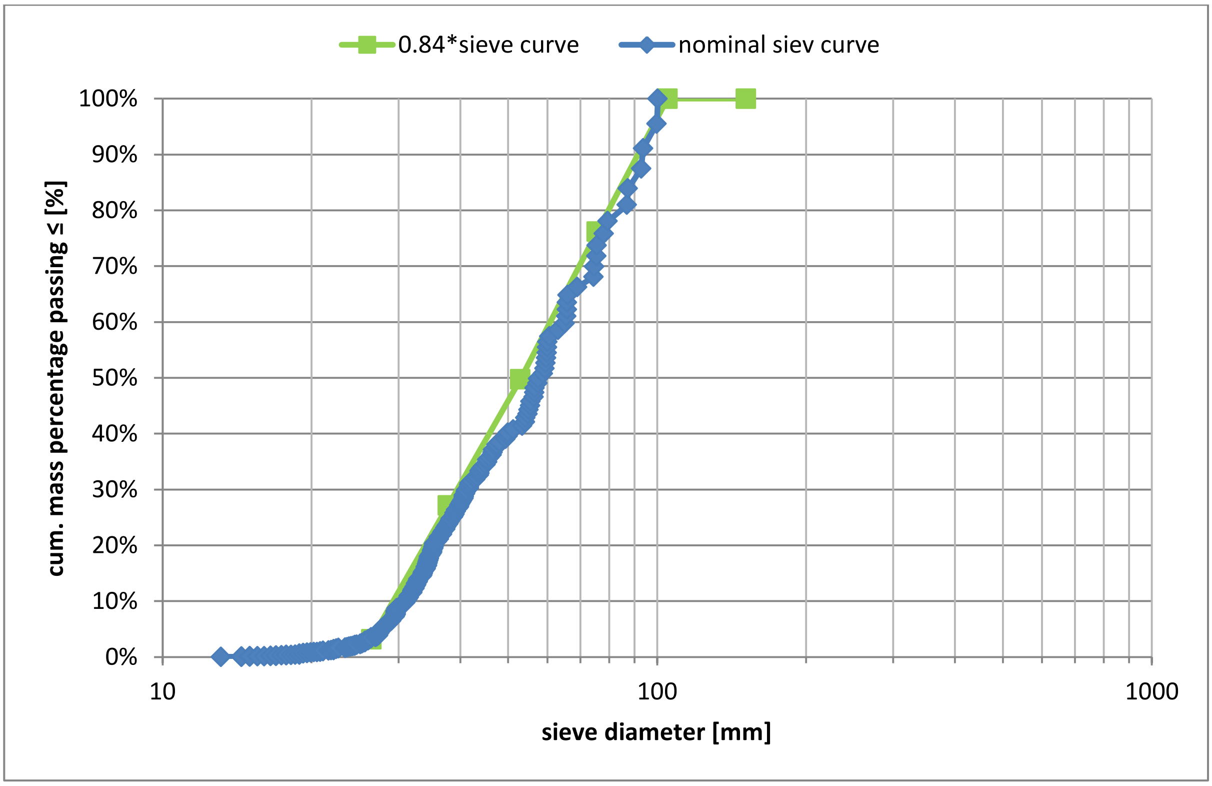


Figure D.1-30 - verification shape factor 22-90 E

D.1.1.6 Sample A-E Combined

Amount of rocks: 1209

The data represented in this sample is equivalent to the data of sample A-E together. It stressed that the results based on the combined sample is not equal to the average of the results of the separate samples.

Sieve test

On this combined sample a sieve test similar to that on sample A is performed. A sieve curve is obtained by application of the method explained for sample A. The results of the sieve test for the combined sample A-E are presented in Table D-23.

Table D-23 - sieve test results 22-90 A-E

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	5.6	1.6	1.6
31.5-45	51.5	15.1	16.8
45-63	67.8	19.9	36.6
63-90	119.8	35.2	71.8
90-125	81.2	23.8	95.6
125-180	14.9	4.4	100.0
total	340.9	100.0	-

The associate sieve curve representing the combined sample A-E is given in Figure D.1-31.

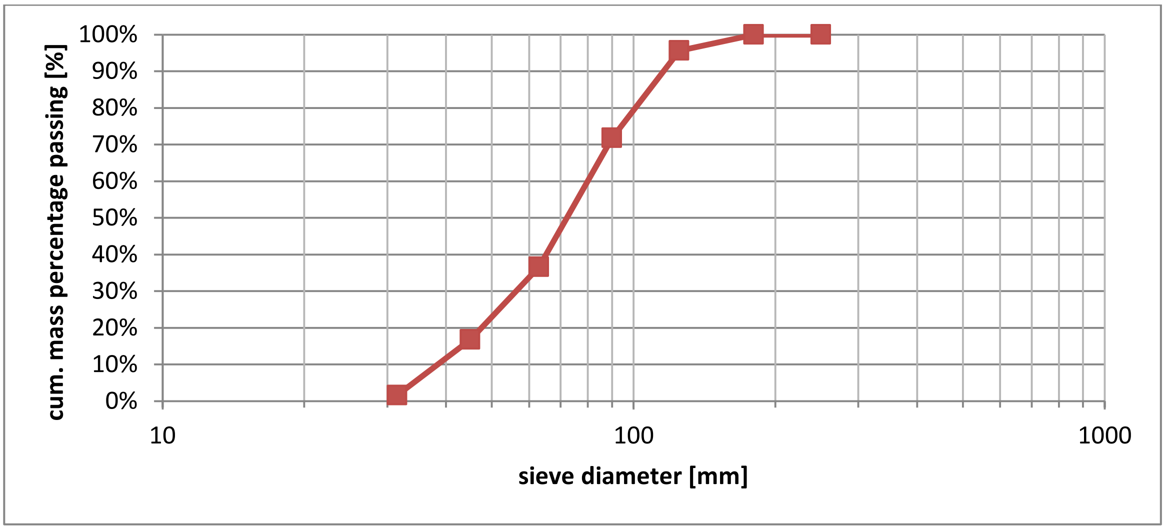


Figure D.1-31 - sieve curve 22-90 A-E

In Table D-24 nine sieve diameters interpolated from Figure D.1-31 are listed.

Table D-24 - Interpolated sieve diameters 22-90 A-E

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	34.5
d10 (NLL)	39.0
d15	43.4
d25	52.5
d50 (MSD)	73.3
d60	80.9
d85	109.4
d90 (NUL)	116.7
d98 (EUL)	154.9

Grading width: d_{85}/d_{15} = 2.52. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-32 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

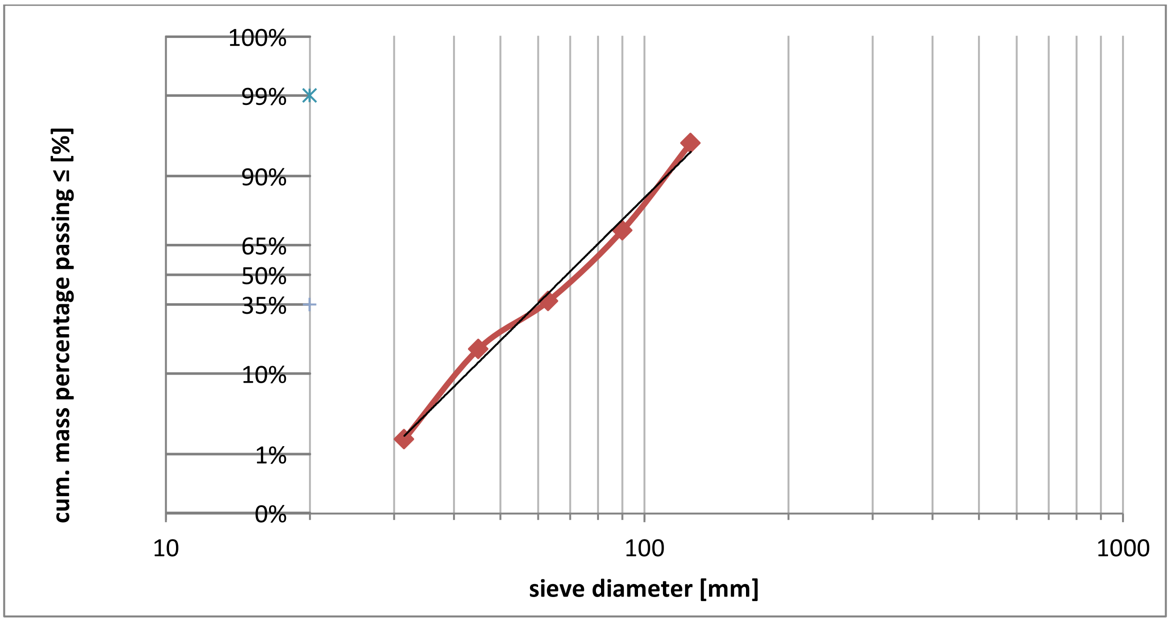


Figure D.1-32 - Gaussian sieve curve 22-90 A-E

d_n- analysis

On this combined sample a d_n-analysis is performed similar to that on sample A. For the d_n-values of sample A the values based on the uniform rock density (2653 kg/m³), are applied in this analysis. In this way the input data for the nominal sieve curve of the combined sample is uniform. The resulting nominal sieve curve of the combined sample is given in Figure D.1-33.

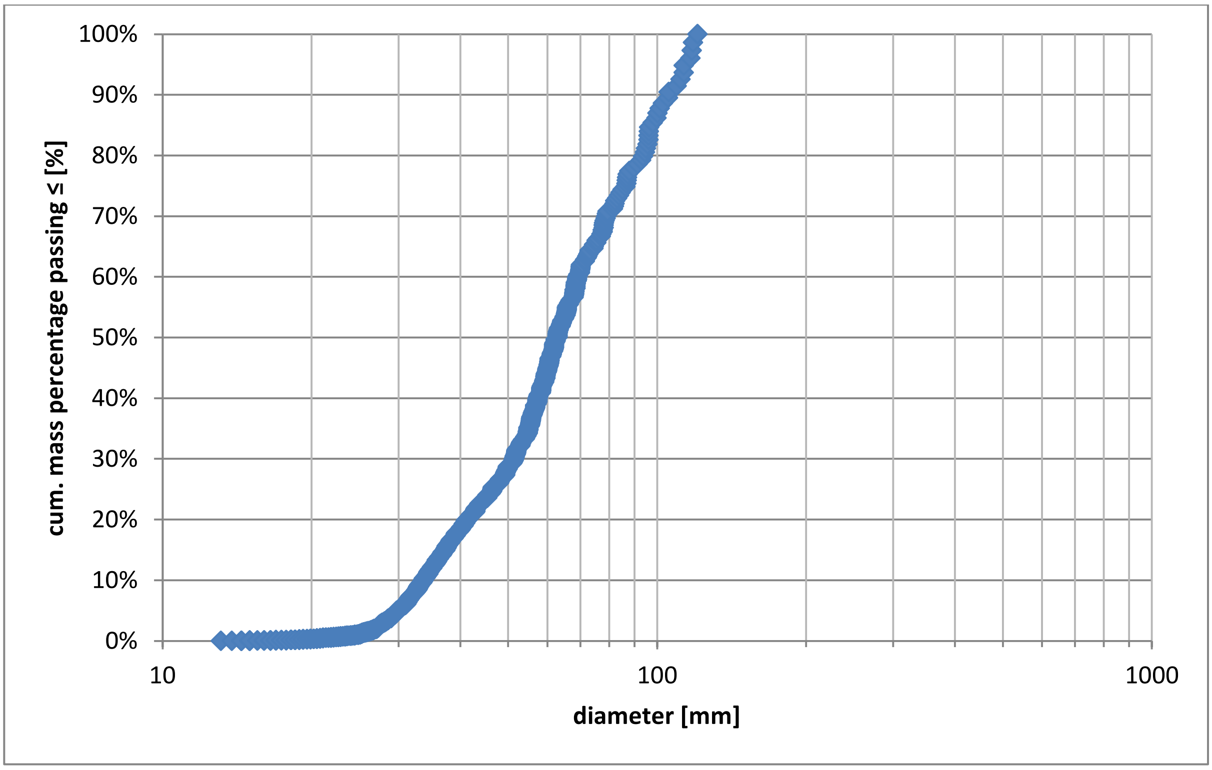


Figure D.1-33 - nominal sieve curve 22-90 A-E

In Table D-25 nominal diameters interpolated from Figure D.1-33 have been listed.

Table D-25 - nominal diameters 22-90 A-E

	nominal diameter
	[mm]
dn5	29.9
dn15	37.3
dn50	62.9
dn90	105.5
dn98	118.0

Shape factors F_x

By the quotient of the interpolated values of the sieve diameters and nominal diameters found in the above, shape factors are calculated and given in Table D-26. Note that the values of the nominal diameter and sieve diameter represented in a shape factor may refer to different rocks.

Table D-26 - shape factors 22-90 E

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	29.9	d5	34.5	F5	0.867
dn15	37.3	d15	43.4	F15	0.860
dn50	62.9	d50	73.3	F50	0.859
dn90	105.5	d90	116.7	F90	0.904
dn98	118.0	d98	154.9	F98	0.762

It is concluded the shape factor is not constant for the sample. In particular its value is fluctuating in case of the higher percentages; for F_{90} it first increases to a value of approximately 0.90 to decrease to a value of 0.77 for F_{98}. The value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.86, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-34.

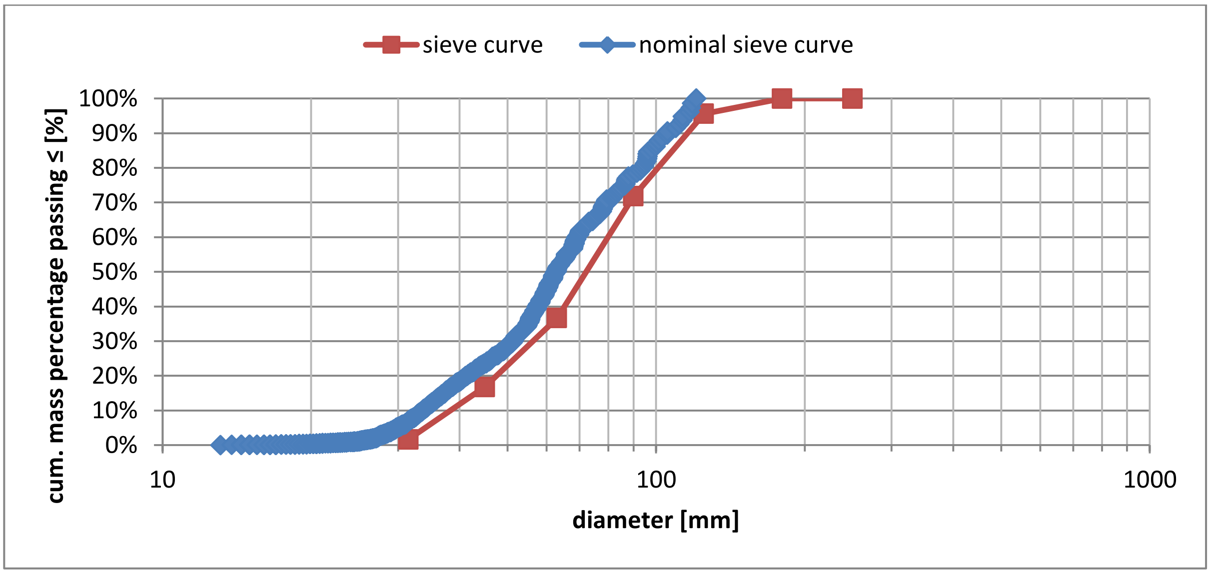


Figure D.1-34 - curves 22-90 A-E

In Figure D.1-35 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. In this way the quality of 0.84 for the shape factor can be visually examined. In the ideal case both lines would exactly overlap each other. It is concluded that in general 0.84 well approximates the value of the shape factor. For the larger however fluctuations are observed. For rocks (approx. 115 mm ≥ d_n ≥ 70 mm) 0.84 underestimates the value of the shape factor. In case of the largest rocks (d_n ≥ approx. 115 mm) 0.84 overestimates the value of the shape factor.

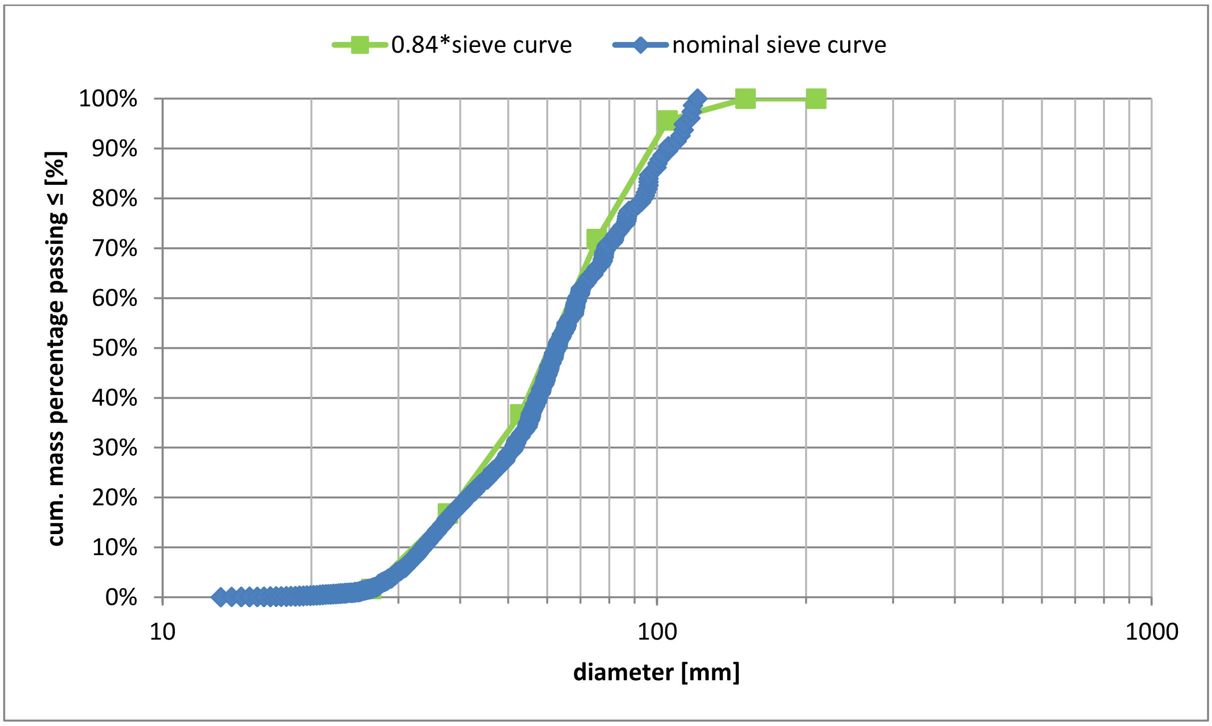


Figure D.1-35 - verification shape factor 22-90 A-E

D.1.1.7 Conclusions

The information gained on the shape factor of the 22-90 material is listed in Table D-27. It is concluded the value of the shape factor F_{50} – the value commonly applied in practice – is fluctuating between a value of 0.82-0.91 for the individual samples. The combined sample yields the value of 0.86 for F_{50}. Furthermore for each sample it is concluded the shape factor is not constant for none of the samples. Moreover, in general the value decreases considerably for the 98 cumulative mass percentage.

Table D-27 - shape factor 22-90

	Sample	A	B	C	D	E	A-E
ELL	dn5	31.418	29.675	30.412	30.996	27.800	29.912
	d5	35.487	34.354	36.185	35.187	32.520	34.498
	F5	0.885	0.864	0.840	0.881	0.855	0.867
NLL	dn15	39.883	35.858	40.247	37.598	33.641	37.329
	d15	46.472	42.615	46.914	45.642	38.156	43.428
	F15	0.858	0.841	0.858	0.824	0.882	0.860
MED	dn50	65.661	60.776	64.615	61.957	57.726	62.923
	d50	73.877	72.901	76.422	75.565	63.268	73.261
	F50	0.889	0.834	0.846	0.820	0.912	0.859
NUL	dn90	103.898	101.511	111.965	108.269	93.504	105.505
	d90	118.268	112.176	129.936	117.316	110.321	116.739
	F90	0.878	0.905	0.862	0.923	0.848	0.904
EUL	dn98	117.894	107.294	113.314	119.736	100.127	118.031
	d98	161.686	122.435	169.987	151.659	122.064	154.863
	F98	0.729	0.876	0.667	0.790	0.820	0.762

D.1.2 2-5 IJmuiden

Origin: Oster pukk og Sand AS, Norway
Aggregate type: Gneiss
Shape type: Fresh

For this rock grading equal tests have been performed in comparison with the 22-90 material. In general the data is also processed in a similar way therefor. As a result this paragraph will only focus on the results of the processed data and only significant deviations in the processing method are mentioned. For explanations on the calculations and graphs please consult paragraph 0.

D.1.2.1 Sample A

Amount of rocks: 359

In this sample a fraction of rather fine material was present ($d_n \approx 10$ mm). This fraction is referred to as rest. The material is not examined into detail, only the total mass of this fraction is measured: 0.034 kg.

Sieve test

Numerical information on the sieve test is given in Table D-28.

Table D-28 - sieve test results 2-5 A

fraction	**mass**	**percentage**	**accum. percentage**
[mm]	[kg]	[%]	[%]
rest	0.0	0.0	0.0
0-31.5	1.9	2.4	2.4
31.5-45	12.8	15.6	18.0
45-63	18.4	22.4	40.4
63-90	22.1	27.0	67.4
90-125	13.9	16.9	84.3
125-180	12.9	15.7	100.0
total	82.0	100.0	-

The resulting sieve curve is given in Figure D.1-36

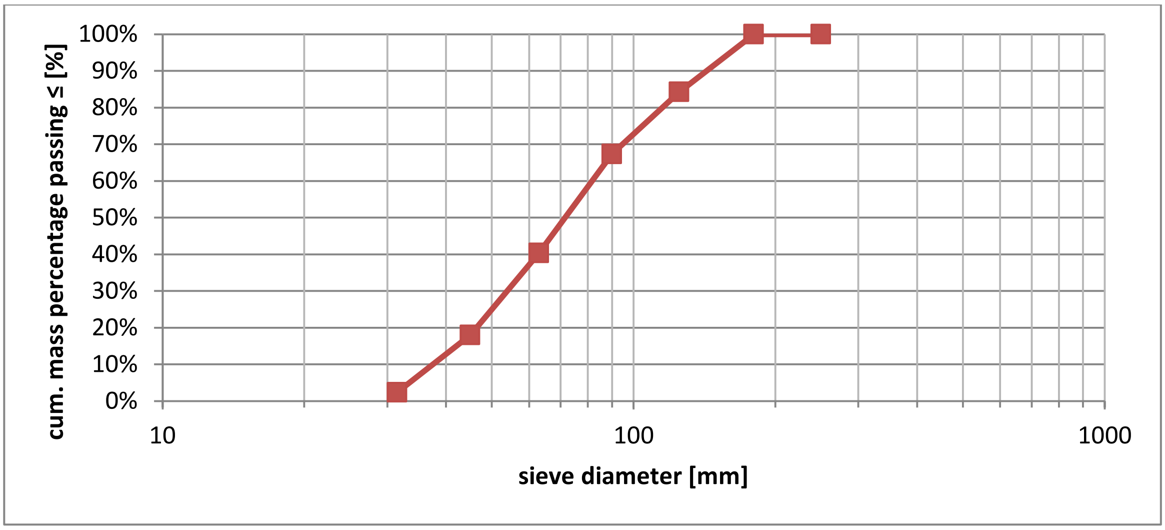


Figure D.1-36 - sieve curve 2-5 A

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-29.

Table D-29 - Interpolated sieve diameters 2-5 A

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	33.7
d10 (NLL)	38.1
d15	42.4
d25	50.6
d50 (MSD)	72.6
d60	82.6
d85	127.6
d90 (NUL)	145.1
d98 (EUL)	173.0

Grading width: d_{85}/d_{15} = 3.01. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-32 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

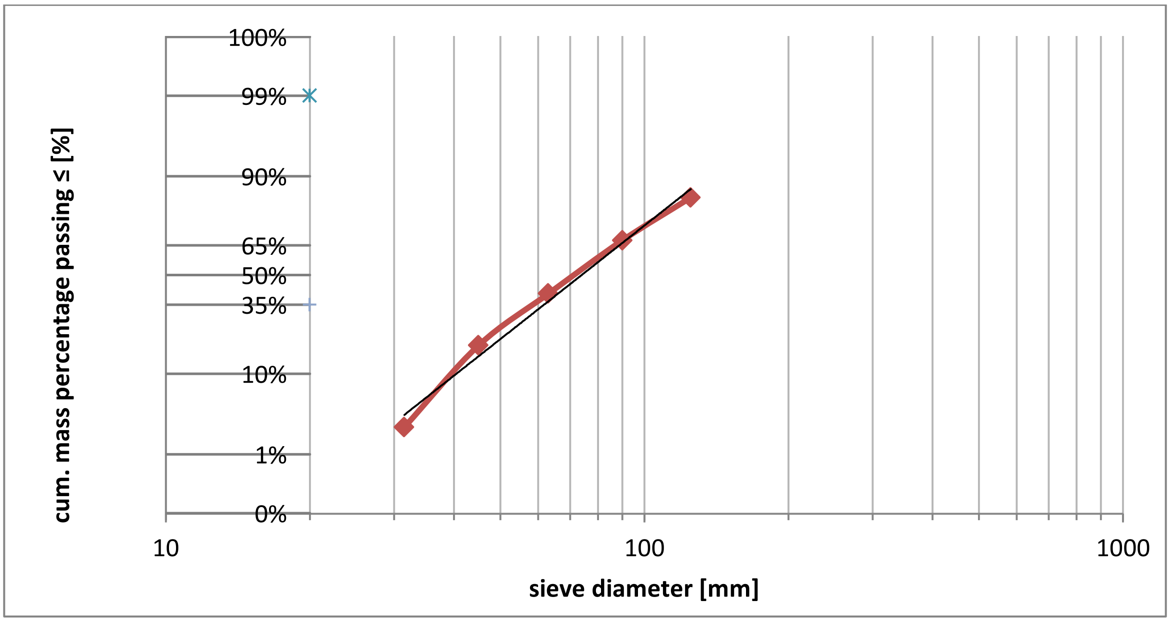


Figure D.1-37 - Gaussian sieve curve 2-5 A

d_n-analysis

The nominal sieve curve including the nominal diameters calculated by the volumes determined according to the Archimedes method is given in Figure D.1-38.

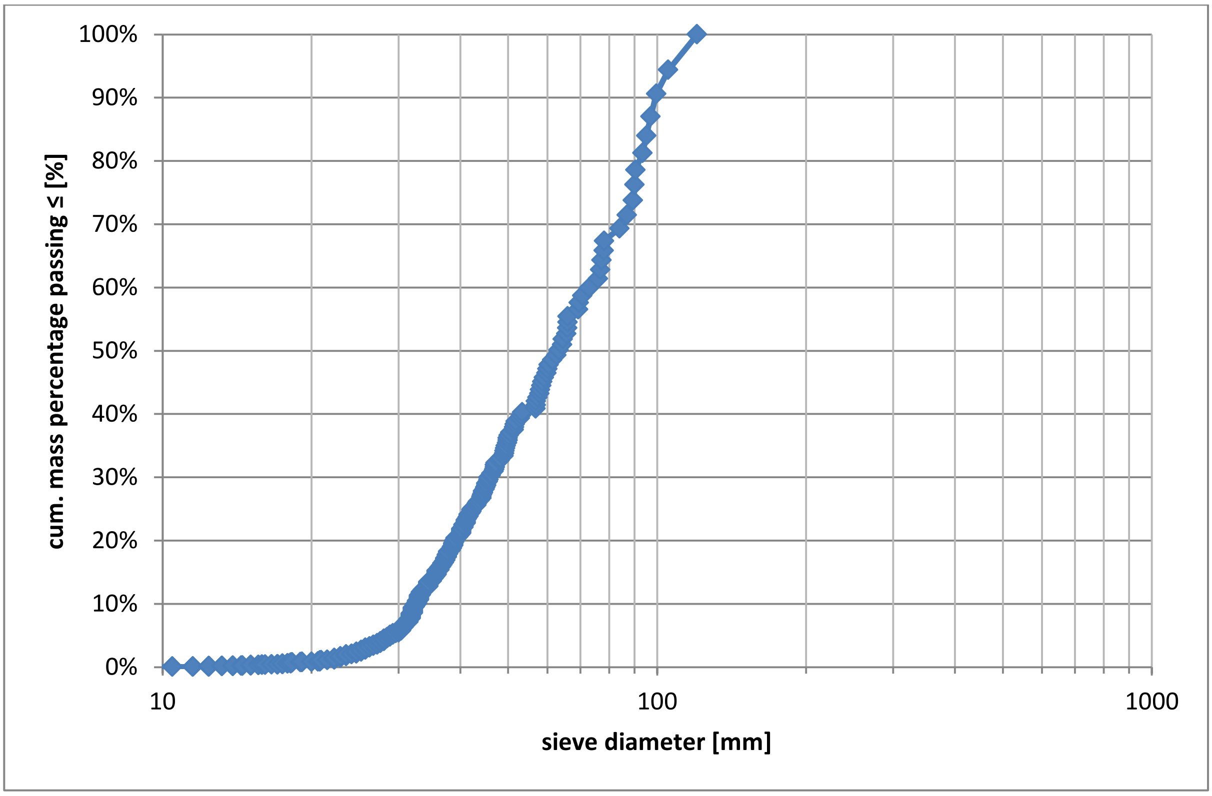


Figure D.1-38 - nominal sieve curve 2-5 A

Again the impact of scattering densities is examined. In the individual rock densities are presented.

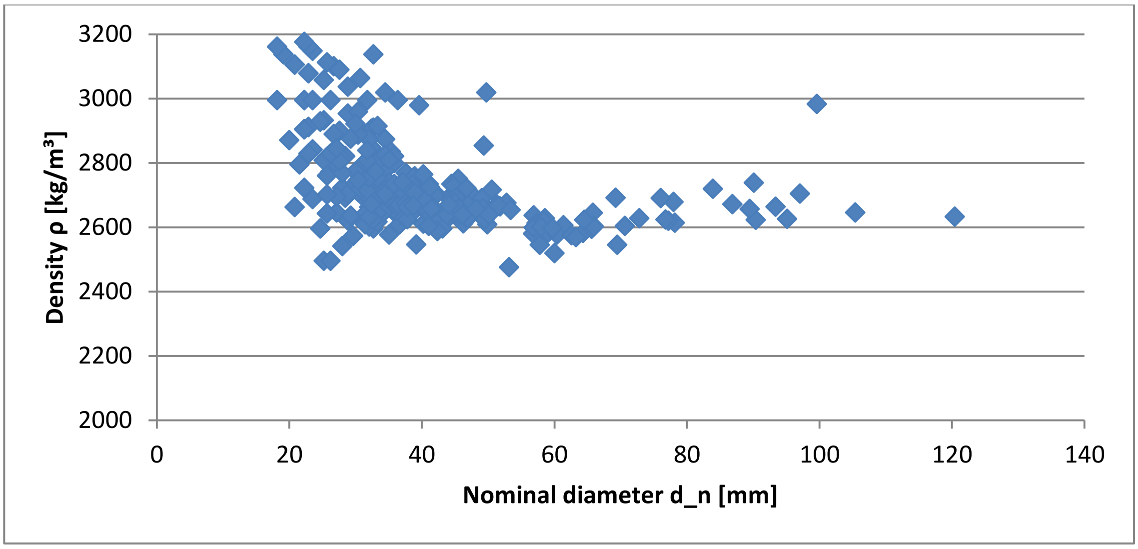


Figure D.1-39 - individual Archimedes rock densities 2-5 A

The average of the densities is 2770 kg/m³, the median is 2709 kg/m³ and the modus is 2661 kg/m³. It is concluded a lot of scatter is present, in particular for the smaller rock. By application of a uniform density the nominal diameters are recalculated. The uniform

density is determined by the average density of the rocks in the 63-90 and 90-125 fractions and has a value of 2616 kg/m³.
The nominal sieve curve including the nominal diameters calculated by the volumes according to the uniform density of 2616 kg/m³ is given in Figure D.1-40.

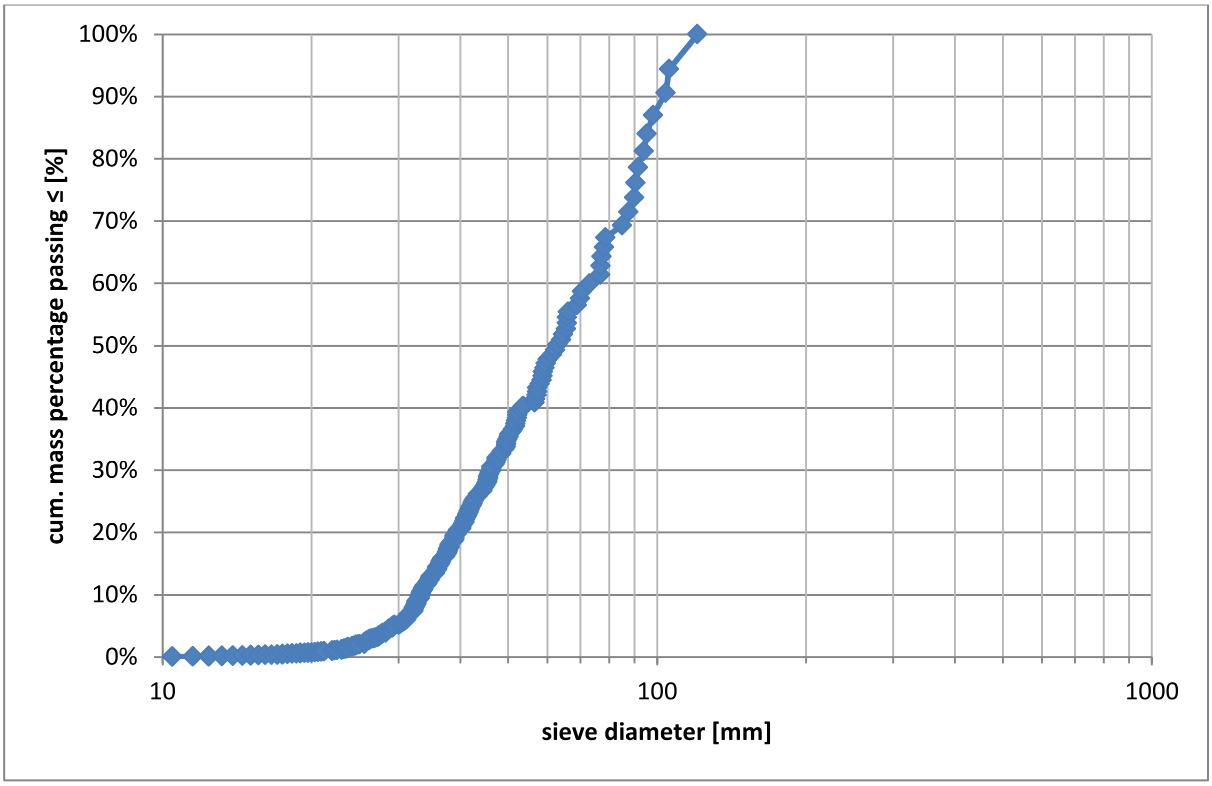


Figure D.1-40 - modified nominal sieve curve 2-5 A

In Table D-3 the interpolated nominal diameters based on both the Archimedes and the modified volumes are listed.

Table D-30 - comparison of dn-values acc. to Archimedes and modified volumes 2-5 A

nominal diameter	**acc. to Archimedes volumes**	**acc. to modified volumes**
	[mm]	[mm]
d_{n5}	28.9	29.3
d_{n15}	35.9	36.4
d_{n50}	63.2	62.8
d_{n90}	99.2	103.1
d_{n98}	115.1	115.4

From Table D-30 it is concluded the differences in the nominal diameters found on basis of the Archimedes volumes or on basis of the uniform density are relatively small. In case of the median nominal diameter both values are even equal. It is therefore concluded the observed scatter in the densities found on the basis of the Archimedes does not cause the nominal sieve diameter to be unrealistic. Therefore the nominal diameters on the basis of the Archimedes volumes are applied in this sample. However caution has to be taken when the d_n90 is used.

Shape factors F_x

The shape factors are given in Table D-31.

Table D-31 - shape factors 2-5 A

nominal diameter			sieve diameter		shape factor		
[mm]	Arc	mod	[mm]		[mm]	Arc	mod
dn5	28.9	29.3	d5	33.7	F5	0.855	0.868
dn15	35.9	36.4	d15	42.4	F15	0.846	0.859
dn50	63.2	62.8	d50	72.6	F50	0.870	0.865
dn90	99.2	103.1	d90	145.1	F90	0.684	0.717
dn98	115.1	115.4	d98	173.0	F98	0.665	0.667

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.87, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-41.

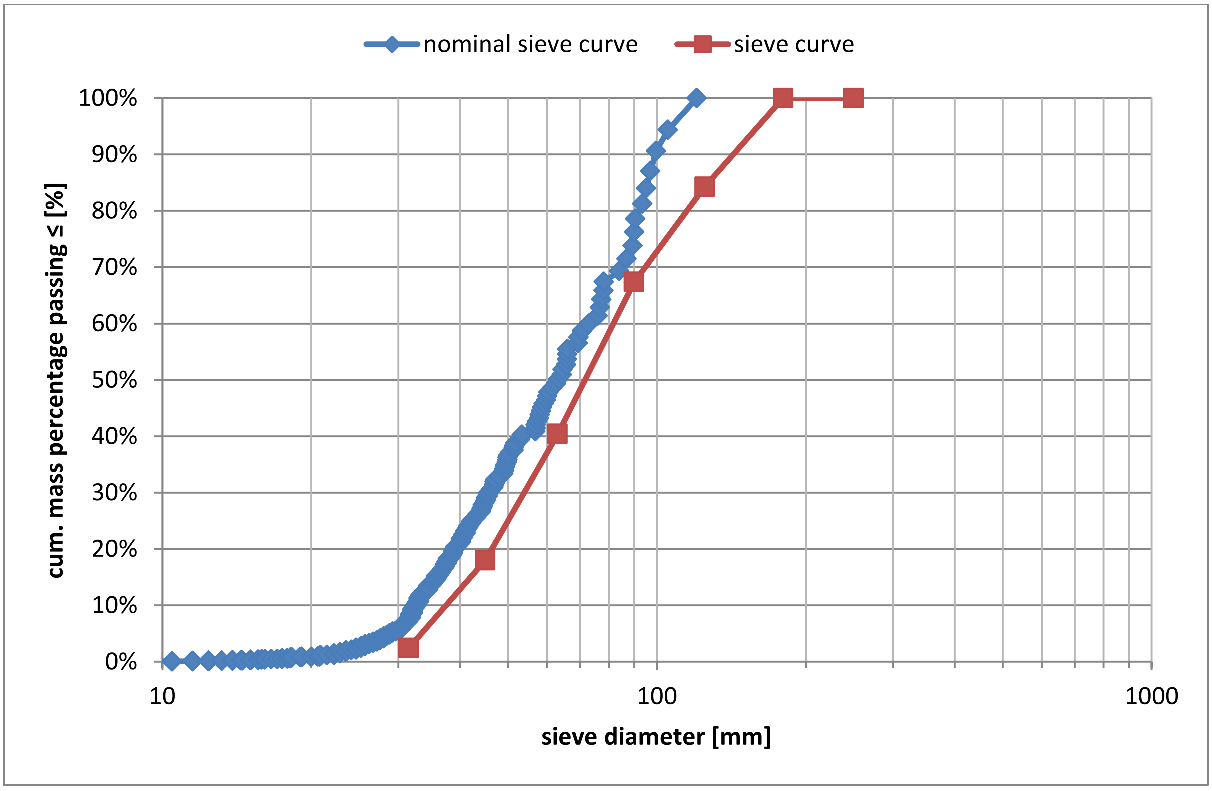


Figure D.1-41 - curves 2-5 A

In Figure D.1-42 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are well approximated by a value of 0.84 times the sieve curve. For the largest rocks 0.84 times the sieve diameter significantly overestimates the nominal diameters.

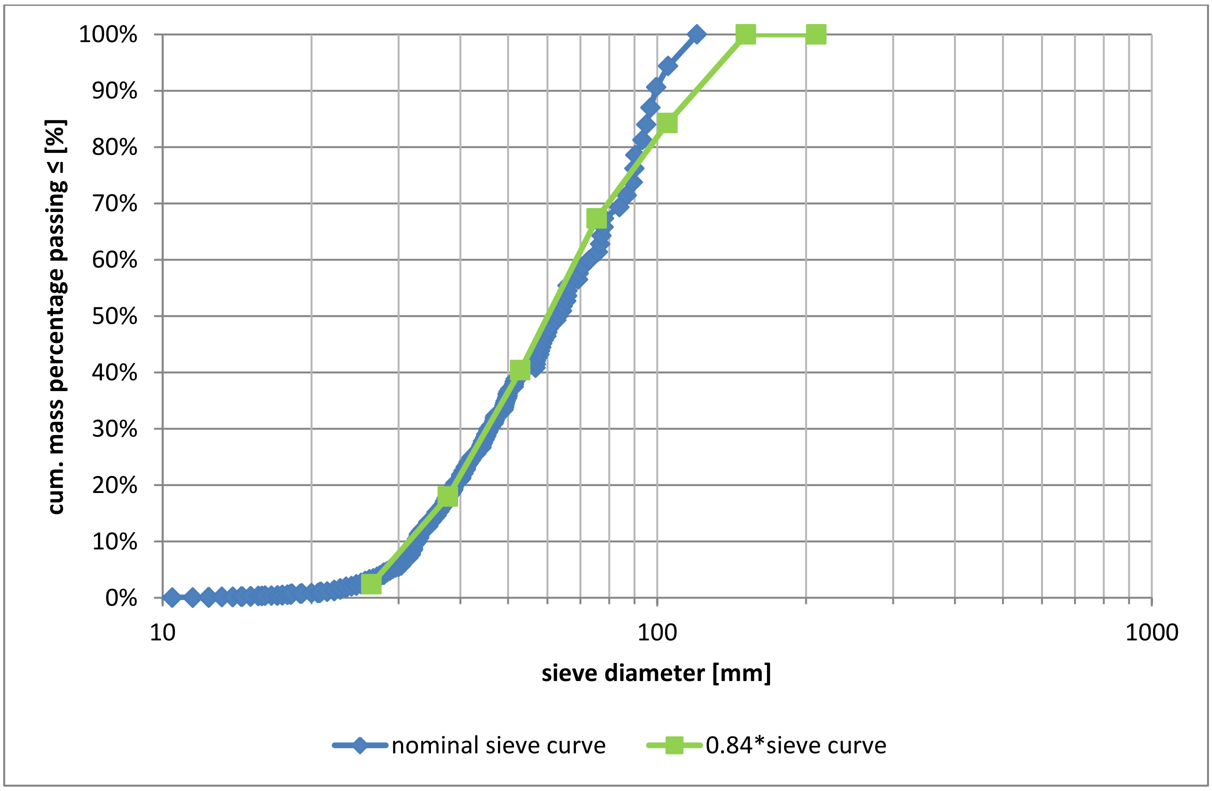


Figure D.1-42 - verification shape factor 2-5 A

Shape test

In Table D-32 and Table D-33 an overview is given of the minimum, maximum and average values of the elongation and blockiness respectively.

Table D-32 - elongation 2-5 A

	Elongation		
	minimum [-]	maximum [-]	average [-]
0-31.5	1.41	4.73	2.42
31.5-45	1.00	4.29	2.33
45-63	1.45	5.50	2.29
63-90	1.57	3.89	2.30
90-125	1.95	2.83	2.32
125-180	2.29	4.61	3.57
total	1.00	5.50	2.36

Table D-33 -blockiness 2-5 A

	Blockiness		
	minimum [%]	maximum [%]	average [%]
0-31.5	28.63	60.61	45.01
31.5-45	27.75	62.33	46.37
45-63	26.26	65.10	45.91
63-90	32.35	57.43	44.19
90-125	38.52	51.97	45.48
125-180	42.83	52.12	47.72
total	26.26	65.10	45.83

It is stressed that the calculated elongation and blockiness values in the 90-125 and 125-180 mm fraction are based on the an amount of 7 respectively 4 rocks. The statistical meaning of the values representing these fractions is therefore questionable.

Considering only the 0-31.5, 31.5-45, 45-63 and 63-90 fractions the minimum value for elongation is 1.00, meaning length equals thickness. The maximum value of elongation observed in these rocks is 5.50. If the 125-180 fraction is disregarded, the average elongation seems rather constant. Furthermore, the minima slightly fluctuate and the maxima tend to decrease. It is concluded variation in elongation decreases for increasing rock size. Considering blockiness no significant trends are observed. The average values found for elongation and blockiness considering all rocks are approximately 2.36 and 45 percent, which do agree with values normally found in practice.

D.1.2.2 Sample B

Amount of rocks: 257

Sieve test

Numerical information on the sieve test is given in Table D-34.

Table D-34 - sieve test results 2-5 B

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.2	1.5	1.5
31.5-45	10.9	14.2	15.8
45-63	13.4	17.5	33.3
63-90	17.6	23.1	56.4
90-125	17.6	23.0	79.4
125-180	15.7	20.6	100.0
total	76.3	100.0	-

The resulting sieve curve is given in Figure D.1-43.

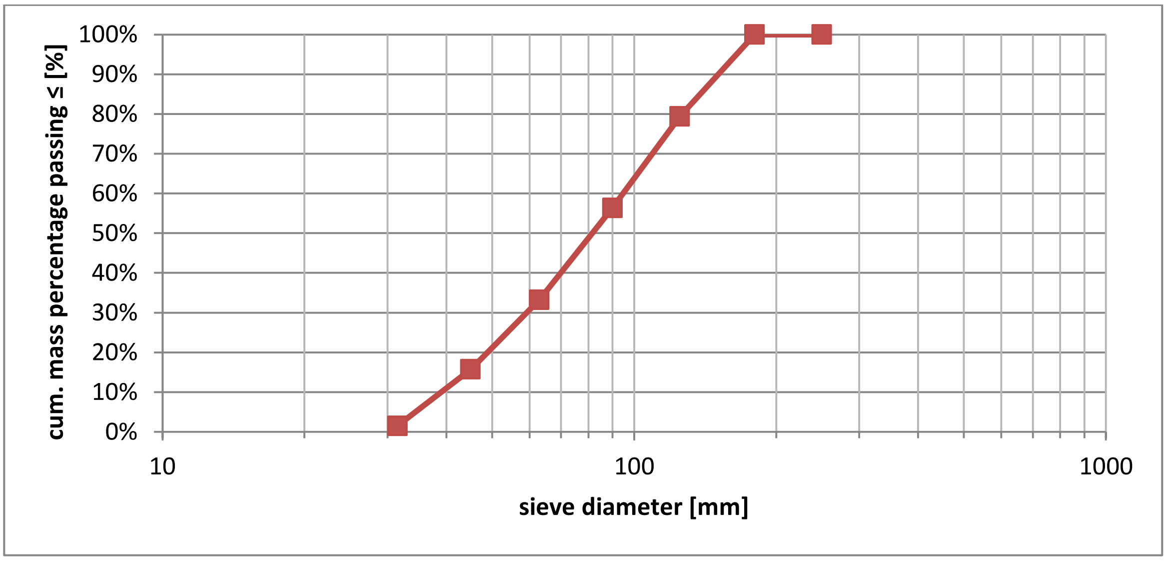


Figure D.1-43 - sieve curve 2-5 B

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-35.

Table D-35 - Interpolated sieve diameters 2-5 B

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	34.8
d10 (NLL)	39.5
d15	44.3
d25	54.5
d50 (MSD)	82.6
d60	95.5
d85	140.0
d90 (NUL)	153.3
d98 (EUL)	174.7

Grading width: d_{85}/d_{15} = 3.16. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-44 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

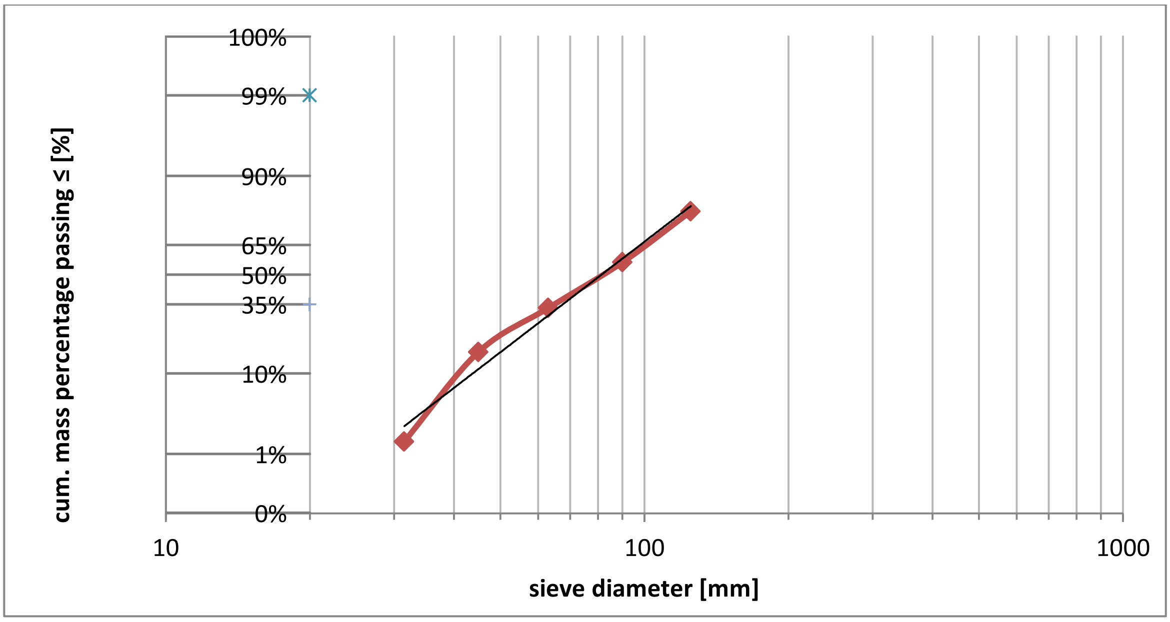


Figure D.1-44 - Gaussian sieve curve 2-5 B

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2626 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-45.

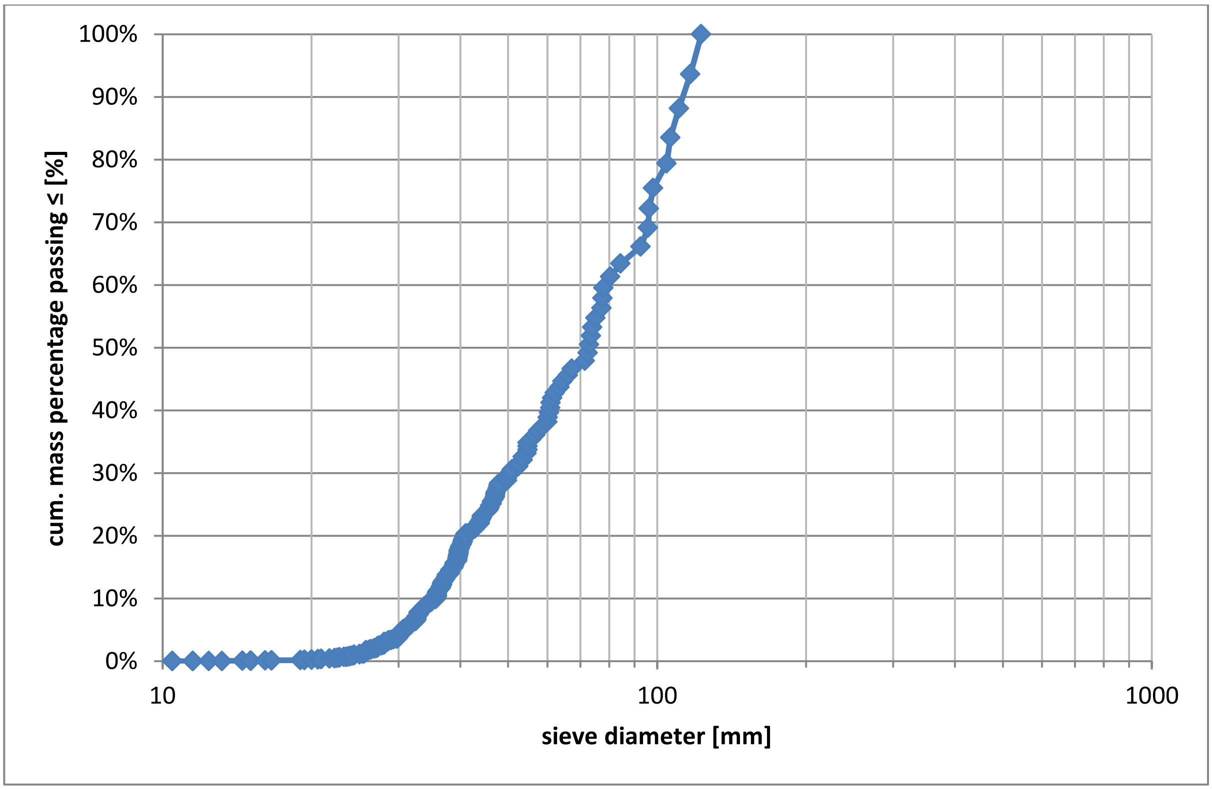


Figure D.1-45 - nominal sieve curve 2-5 B

In Table D-36 nominal diameters interpolated from Figure D.1-45 have been listed.

Table D-36 - nominal diameters 2-5 B

	nominal diameter [mm]
dn5	30.6
dn15	38.8
dn50	72.7
dn90	112.8
dn98	121.0

Shape factors F_x

The shape factors are given in Table D-37

Table D-37 - shape factors 2-5 B

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	30.6	d5	34.8	F5	0.880
dn15	38.8	d15	44.3	F15	0.875
dn50	72.7	d50	82.6	F50	0.881
dn90	112.8	d90	153.3	F90	0.736
dn98	121.0	d98	174.7	F98	0.692

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.88, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-46.

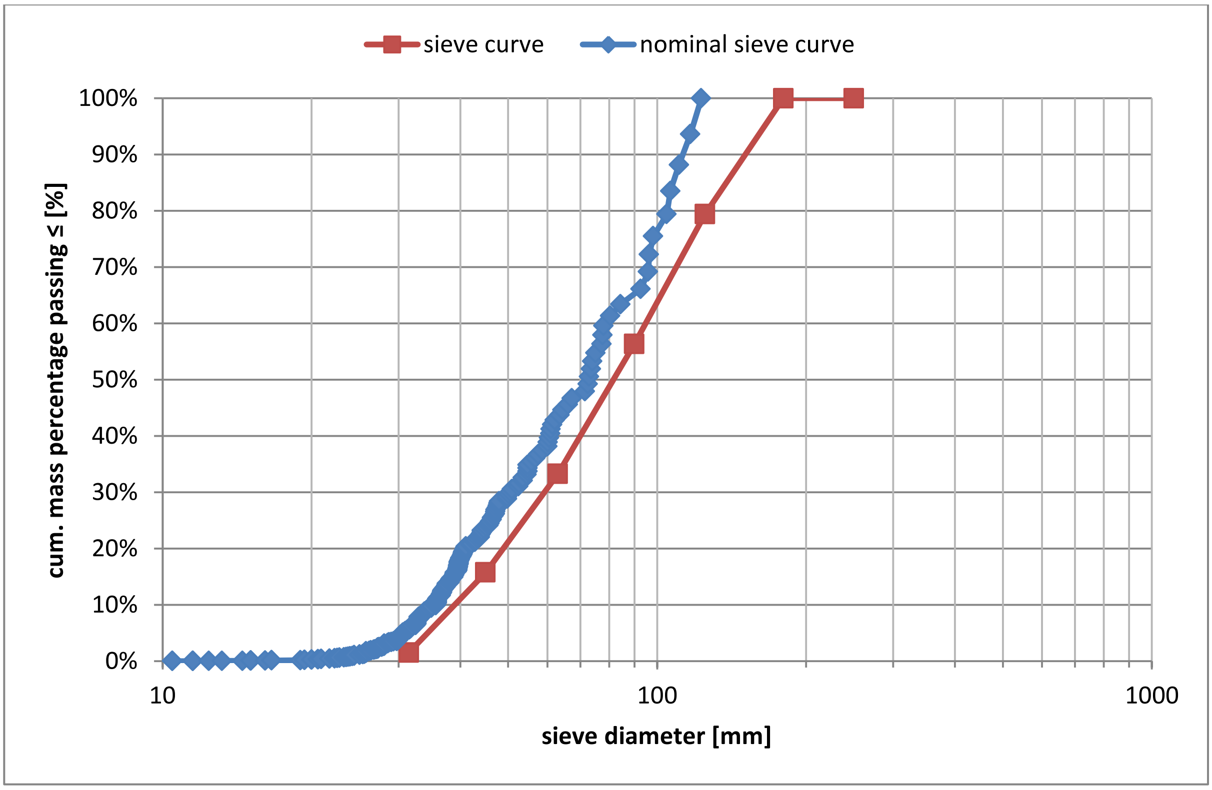


Figure D.1-46 - sieve curves 2-5 B

In Figure D.1-47 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are well approximated by a value of 0.84 times the sieve curve. For the largest rocks 0.84 times the sieve diameter significantly overestimates the nominal diameters.

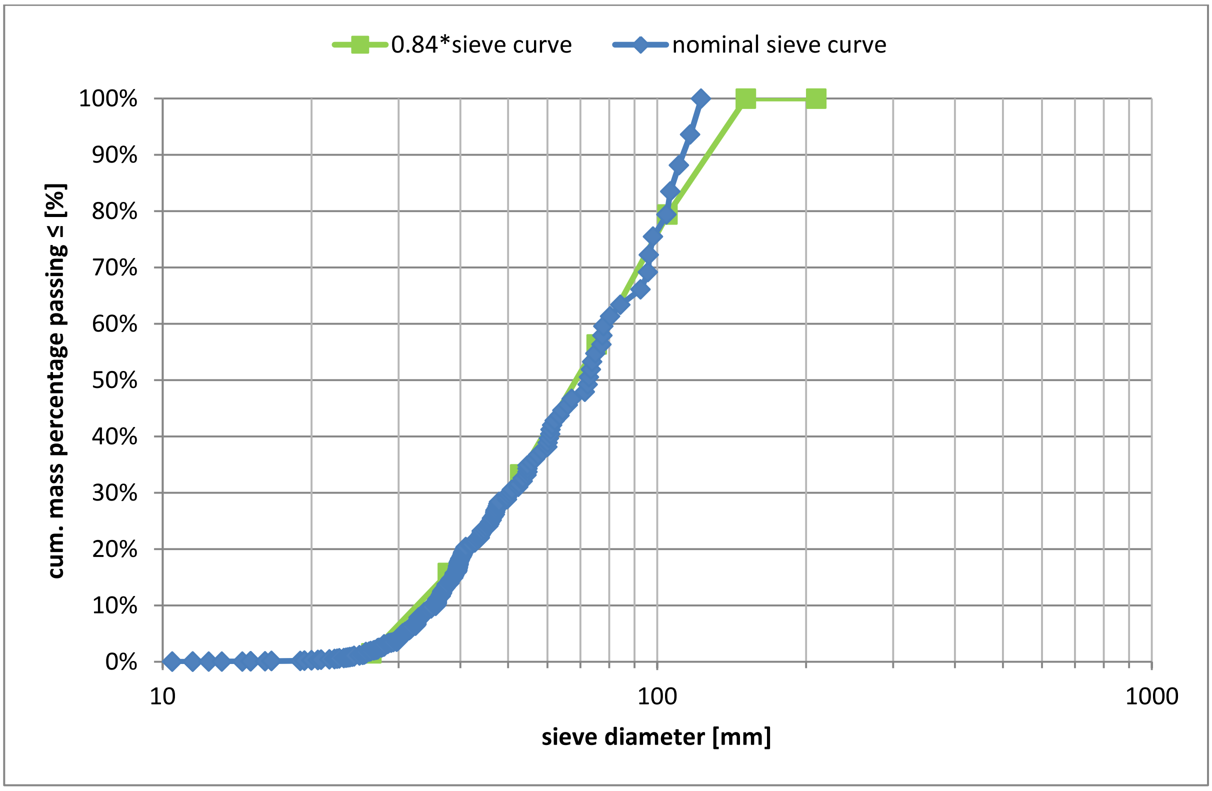


Figure D.1-47 - verification shape factor 2-5 B

D.1.2.3 Sample C

Amount of rocks: 243

Sieve test

Numerical information on the sieve test is given in Table D-38.

Table D-38 - sieve test results 2-5 C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.2	1.6	1.6
31.5-45	9.1	13.0	14.6
45-63	17.4	24.8	39.4
63-90	15.1	21.5	60.9
90-125	17.8	25.3	86.2
125-180	9.7	13.8	100.0
total	70.2	100.0	-

The resulting sieve curve is given in Figure D.1-48.

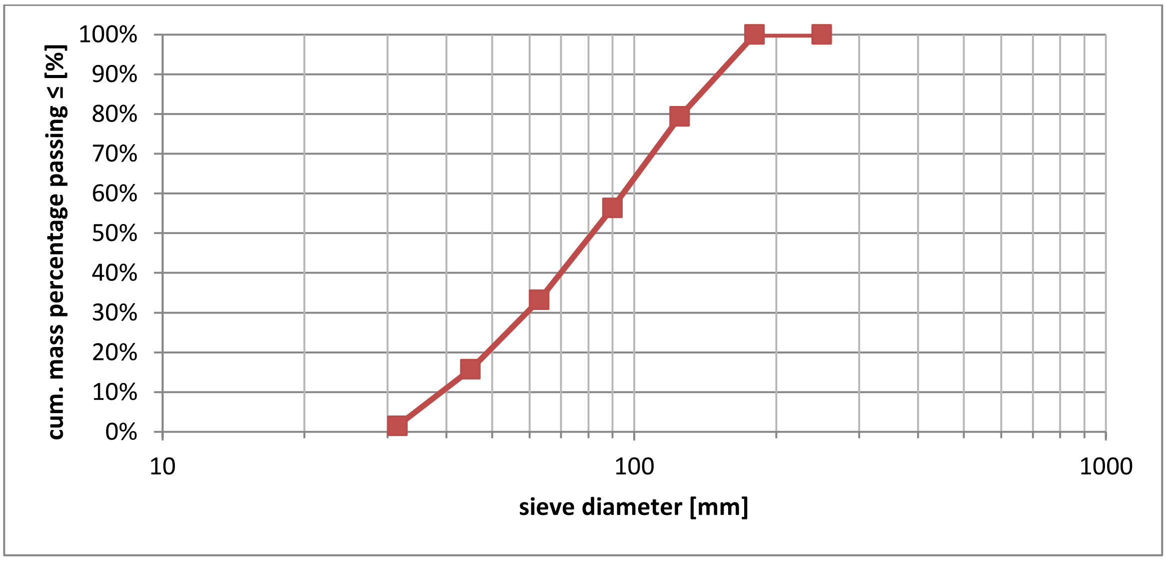


Figure D.1-48 - sieve curve 2-5 C

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-39.

Table D-39 - Interpolated sieve diameters 2-5 C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	35.0
d10 (NLL)	40.2
d15	45.3
d25	52.5
d50 (MSD)	76.3
d60	88.8
d85	123.3
d90 (NUL)	140.1
d98 (EUL)	172.0

Grading width: d_{85}/d_{15} = 2.72. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-49 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

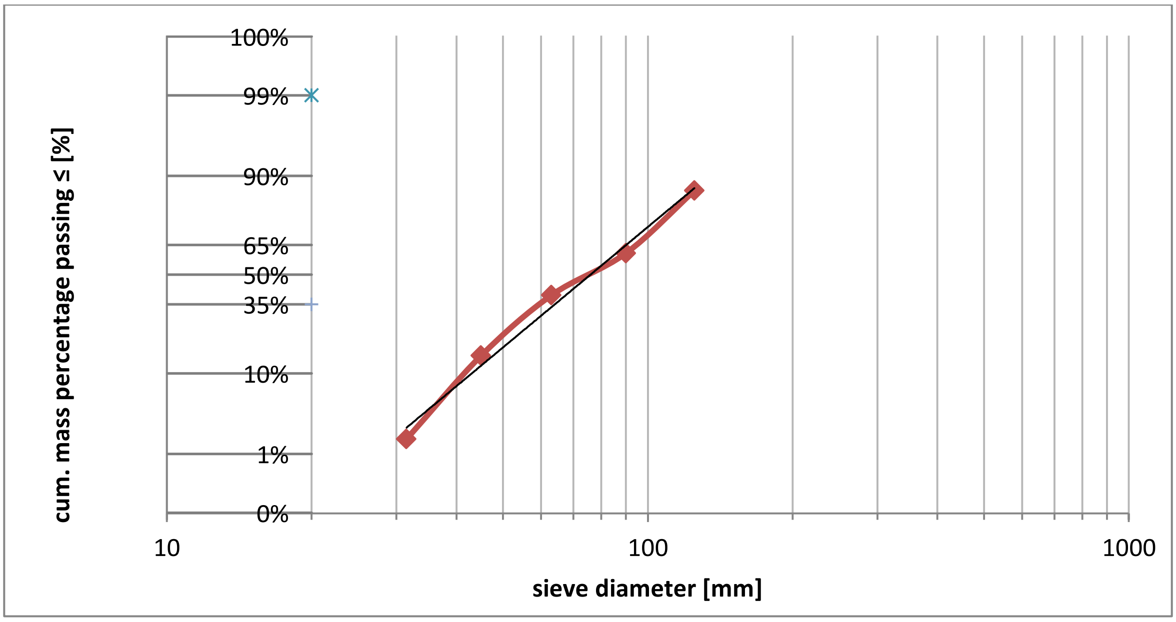


Figure D.1-49 - Gaussian sieve curve 2-5 C

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2626 kg/m³. As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-50.

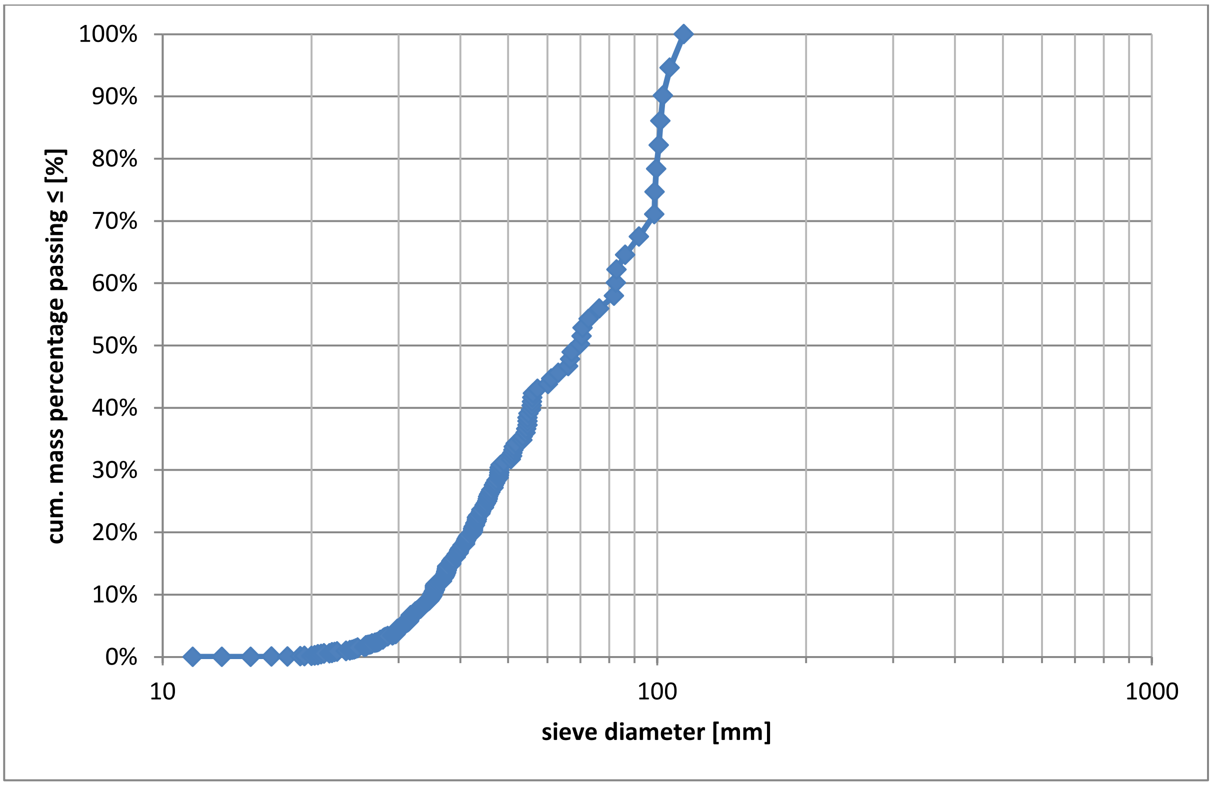


Figure D.1-50 - nominal sieve curve 2-5 C

In Table D-36 nominal diameters interpolated from Figure D.1-50 have been listed.

Table D-40 - nominal diameters 2-5 C

	nominal diameter [mm]
dn5	30.6
dn15	38.4
dn50	69.5
dn90	102.8
dn98	110.6

Shape factors F_x

The shape factors are given in Table D-41.

Table D-41 - shape factors 22-90 C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	30.6	d5	35.0	F5	0.874
dn15	38.4	d15	45.3	F15	0.848
dn50	69.5	d50	76.3	F50	0.911
dn90	102.8	d90	140.1	F90	0.734
dn98	110.6	d98	172.0	F98	0.643

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.92, which is significantly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-51.

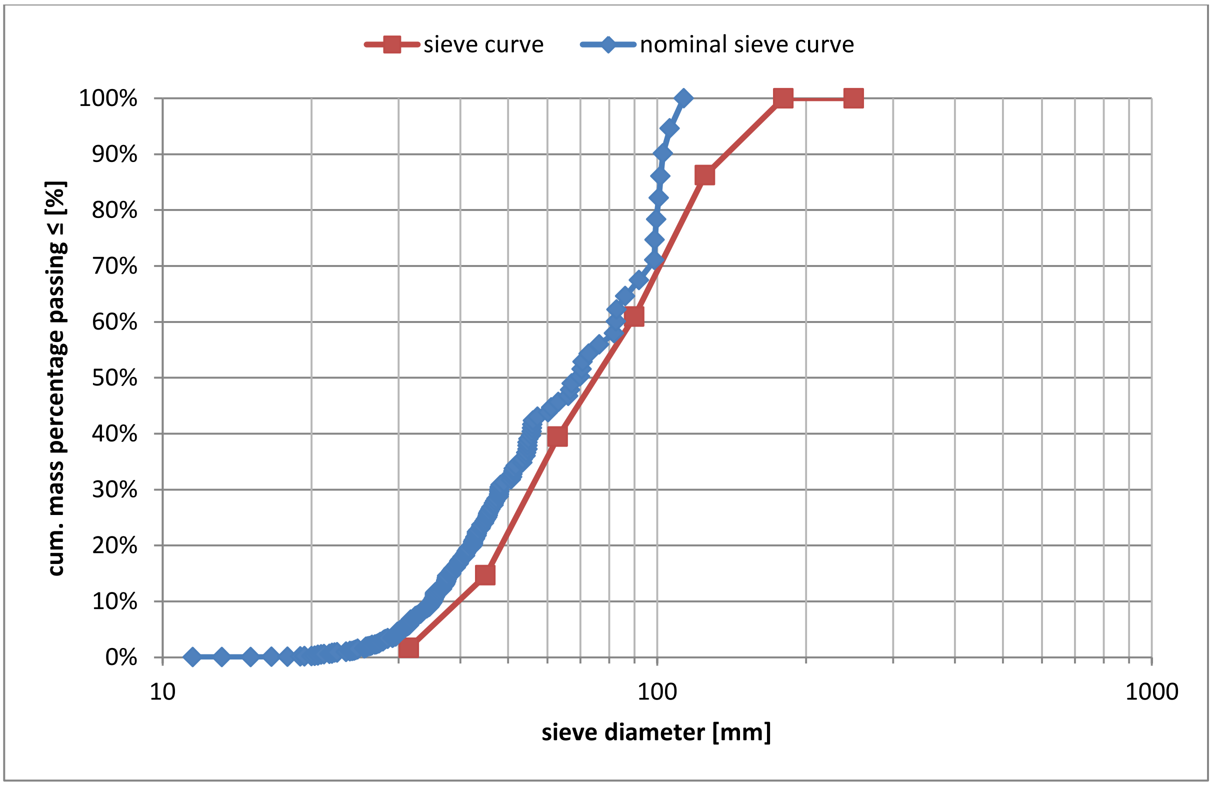


Figure D.1-51 - sieve curves 2-5 C

In Figure D.1-52 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks (up to a nominal diameter of 50 mm) the nominal diameters are well approximated by a value of 0.84 times the sieve curve. For larger rocks the approximation is not very accurate and fluctuates. The largest rocks (nominal diameter > 100 mm) the nominal diameters are significantly overestimated by a shape factor of 0.84 times the sieve diameter.

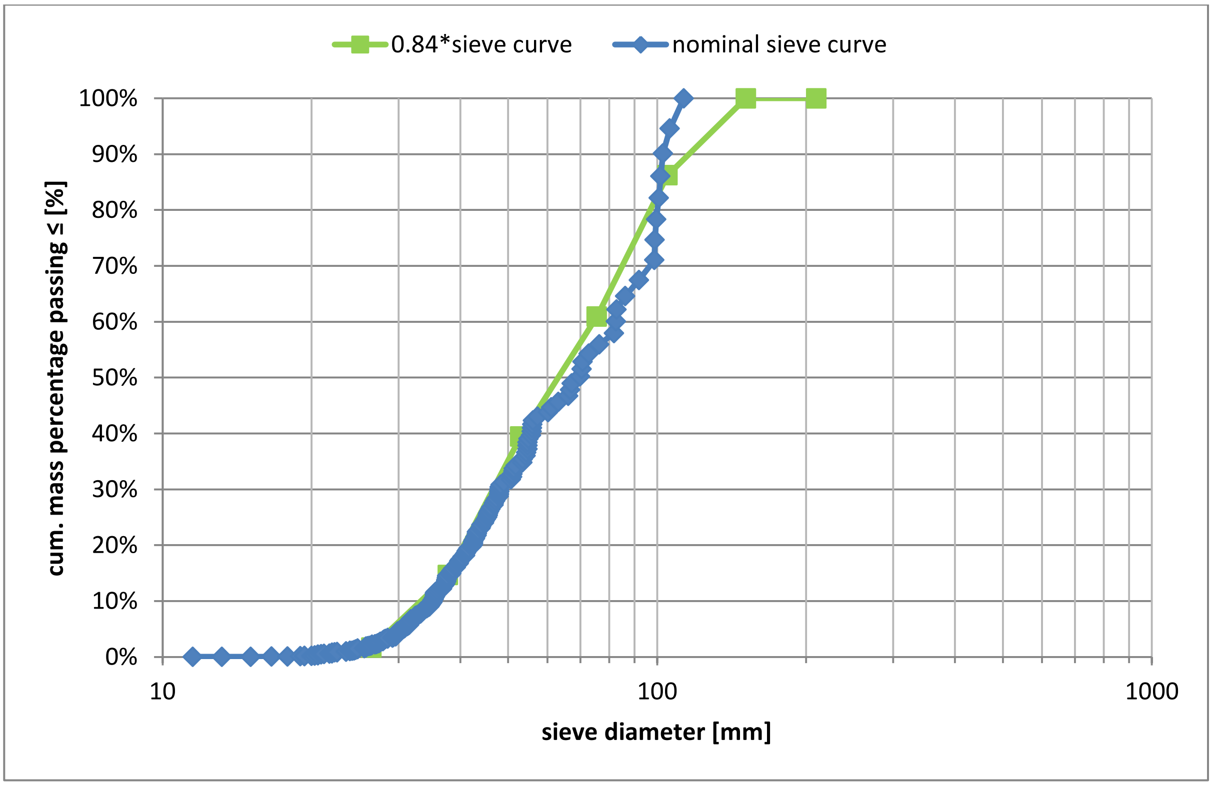


Figure D.1-52 - verification shape factor 22-90 C

D.1.2.4 Sample D

Amount of rocks: 241

Sieve test

Numerical information on the sieve test is given in Table D-42. Please note this sample contained a rock in the 180-250 mm-fraction.

Table D-42 - sieve test results 2-5 D

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.4	2.3	2.3
31.5-45	11.0	18.5	20.8
45-63	13.6	22.9	43.7
63-90	10.0	16.8	60.5
90-125	4.6	7.7	68.2
125-180	14.0	23.6	91.8
180-250	4.8	8.2	100.0
total	59.4	100.0	-

The resulting sieve curve is given in Figure D.1-53.

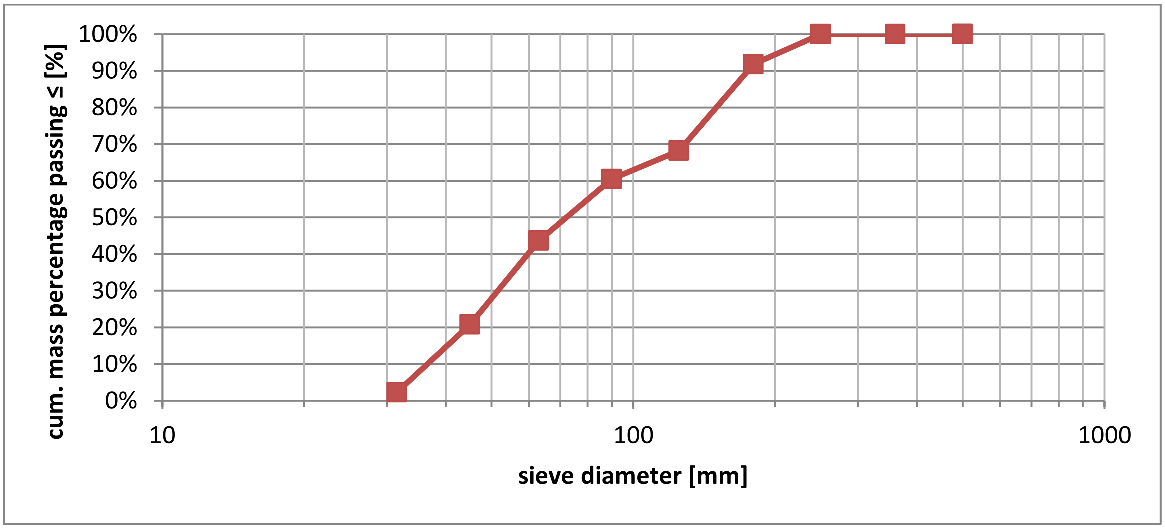


Figure D.1-53 - sieve curve 2-5 D

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-43.

Table D-43 - Interpolated sieve diameters 2-5 D

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	33.5
d10 (NLL)	37.1
d15	40.8
d25	48.3
d50 (MSD)	73.2
d60	89.2
d85	164.1
d90 (NUL)	175.7
d98 (EUL)	232.9

Grading width: d_{85}/d_{15} = 4.02. Very wide coarse grading according to the Rock Manual (2007).

From Figure D.1-54 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

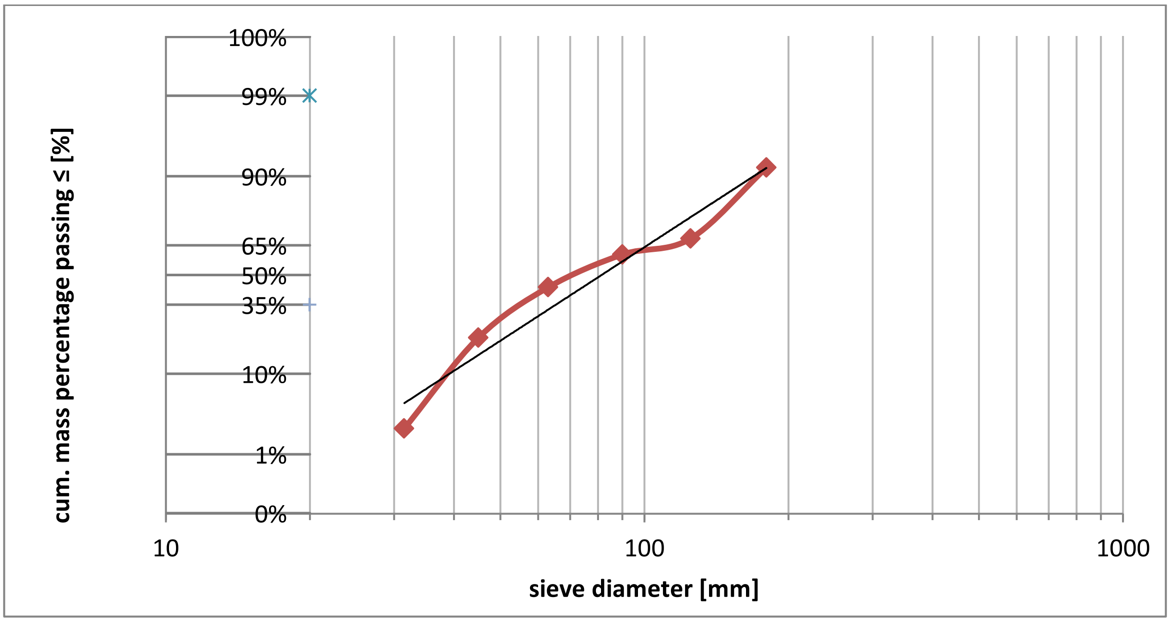


Figure D.1-54 - Gaussian sieve curve 2-5 D

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2626 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-55.

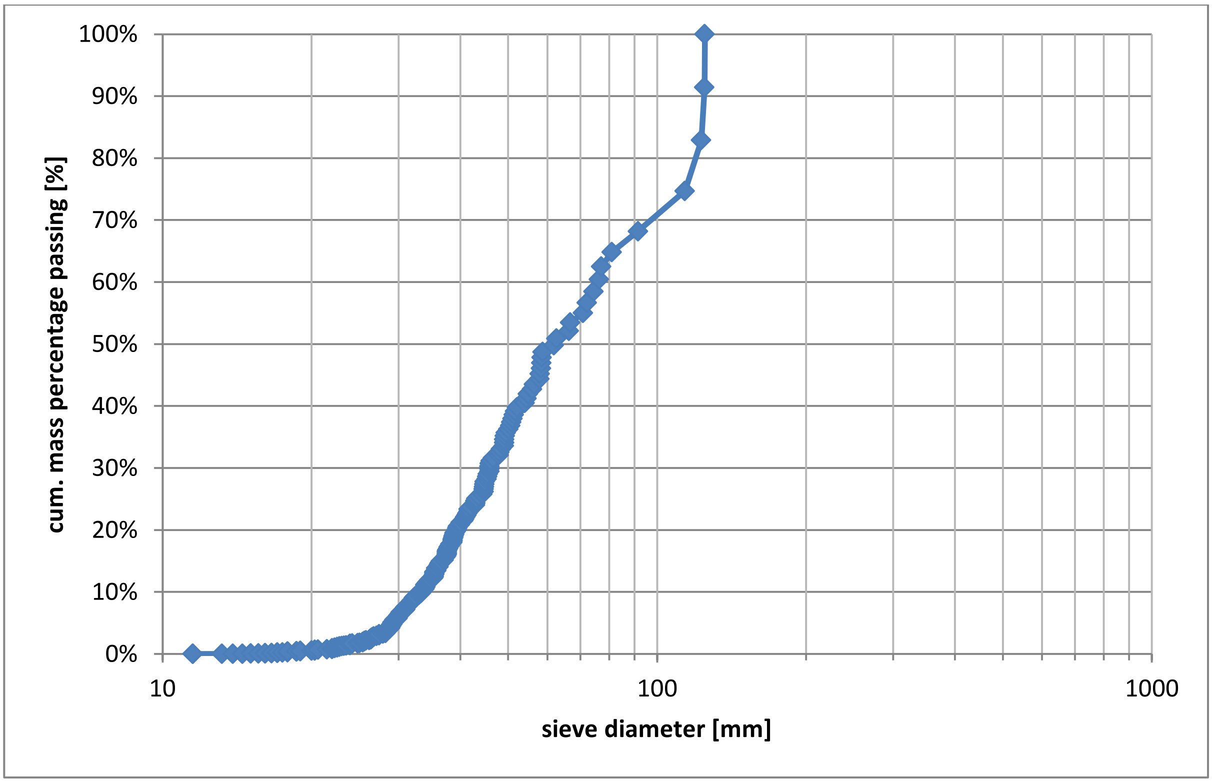


Figure D.1-55 - nominal sieve curve 2-5 D

In Table D-44 nominal diameters interpolated from Figure D.1-55 have been listed.

Table D-44 - nominal diameters 2-5 D

	nominal diameter [mm]
dn5	29.2
dn15	36.7
dn50	62.1
dn90	124.4
dn98	124.8

Shape factors F_x

The shape factors are given in Table D-45.

Table D-45 - shape factors 2-5 D

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	29.2	d5	33.5	F5	0.872
dn15	36.7	d15	40.8	F15	0.900
dn50	62.1	d50	73.2	F50	0.848
dn90	124.4	d90	175.7	F90	0.708
dn98	124.8	d98	232.9	F98	0.536

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.85, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-56.

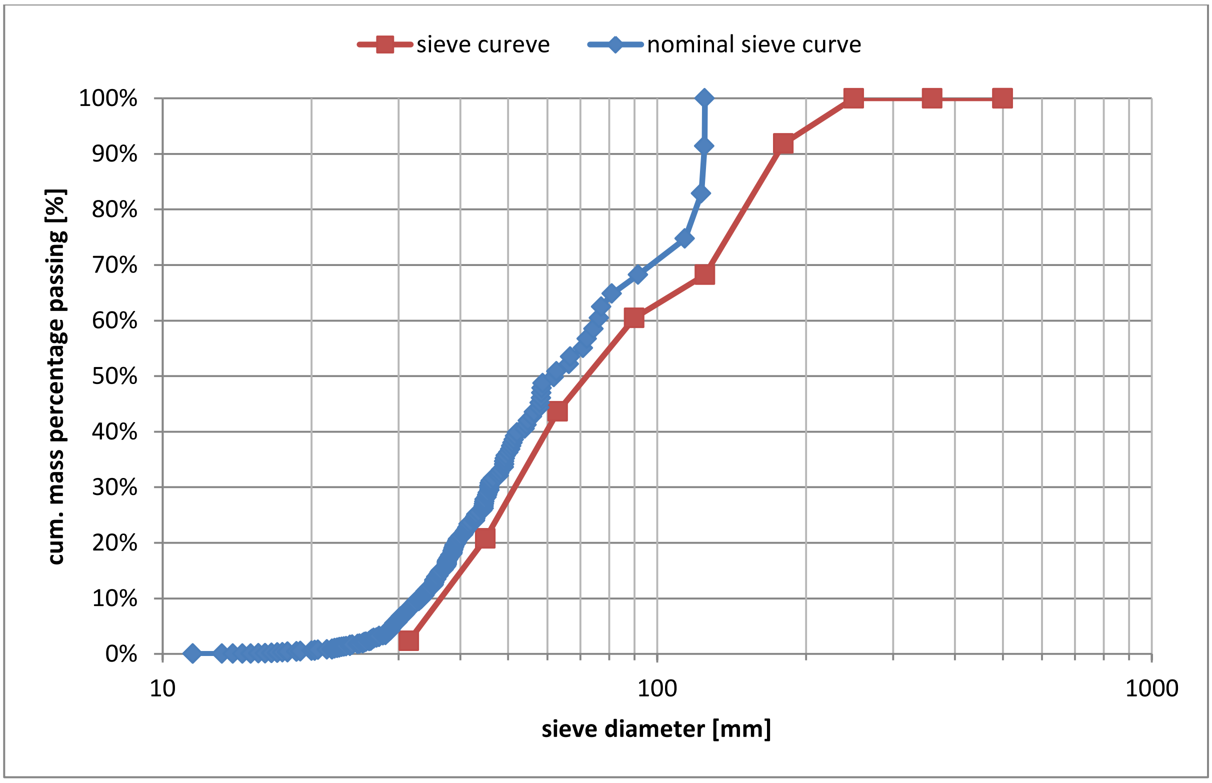


Figure D.1-56 - sieve curves 2-5 D

In Figure D.1-57 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are well approximated by a value of 0.84 times the sieve curve. For the largest rocks 0.84 times the sieve diameter significantly overestimates the nominal diameters.

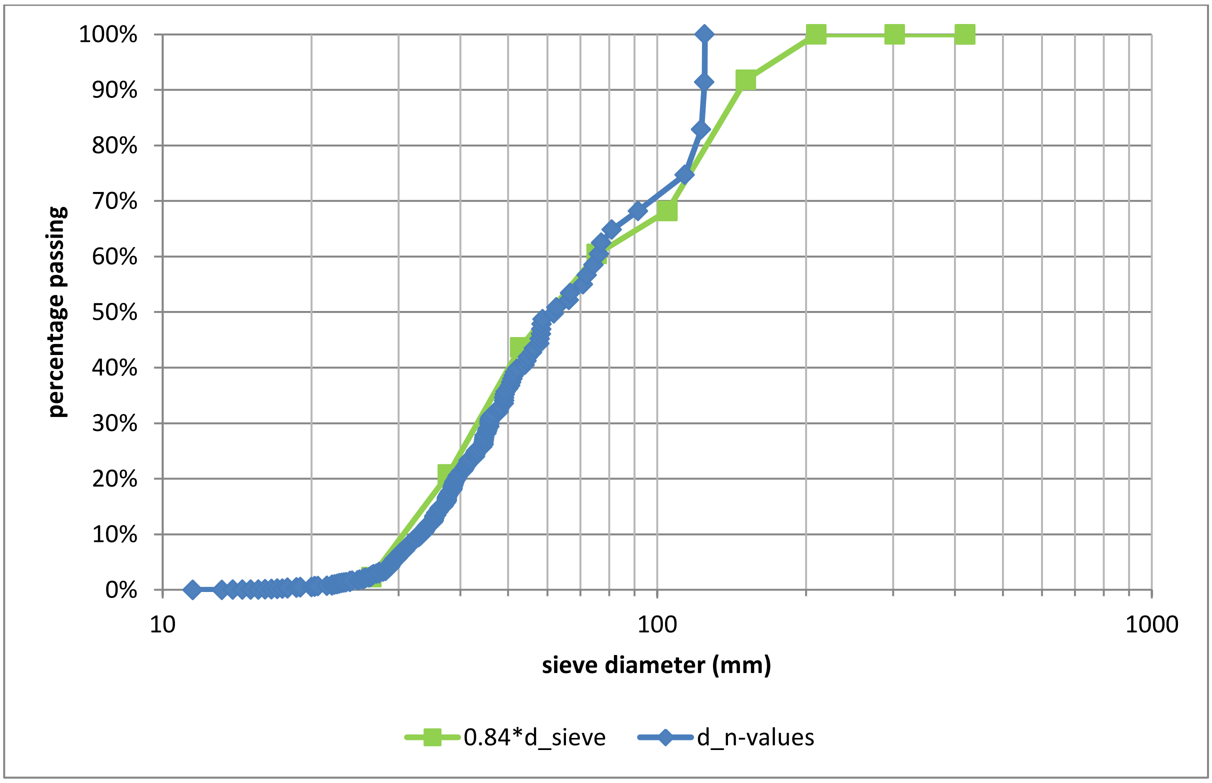


Figure D.1-57 - verification shape factor 2-5 D

Sample E

Amount of rocks: 255

Sieve test

Numerical information on the sieve test is given in Table D-46.

Table D-46 - sieve test results 2-5 E

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.6	2.1	2.1
31.5-45	9.2	12.1	14.2
45-63	14.9	19.6	33.7
63-90	16.2	21.2	54.9
90-125	28.9	37.9	92.9
125-180	5.4	7.1	100.0
total	76.1	100.0	-

The resulting sieve curve is given in Figure D.1-58.

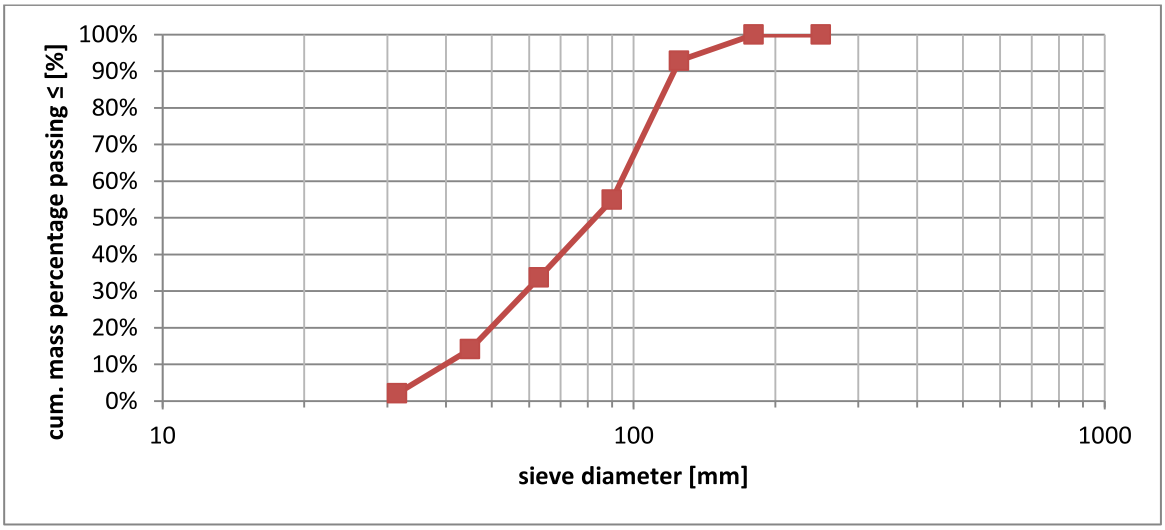


Figure D.1-58 - sieve curve 2-5 E

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-47.

Table D-47 - Interpolated sieve diameters 2-5 E

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	34.8
d10 (NLL)	40.3
d15	45.8
d25	55.0
d50 (MSD)	83.7
d60	94.7
d85	117.7
d90 (NUL)	122.4
d98 (EUL)	164.6

Grading width: d_{85}/d_{15} = 2.57. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-59 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

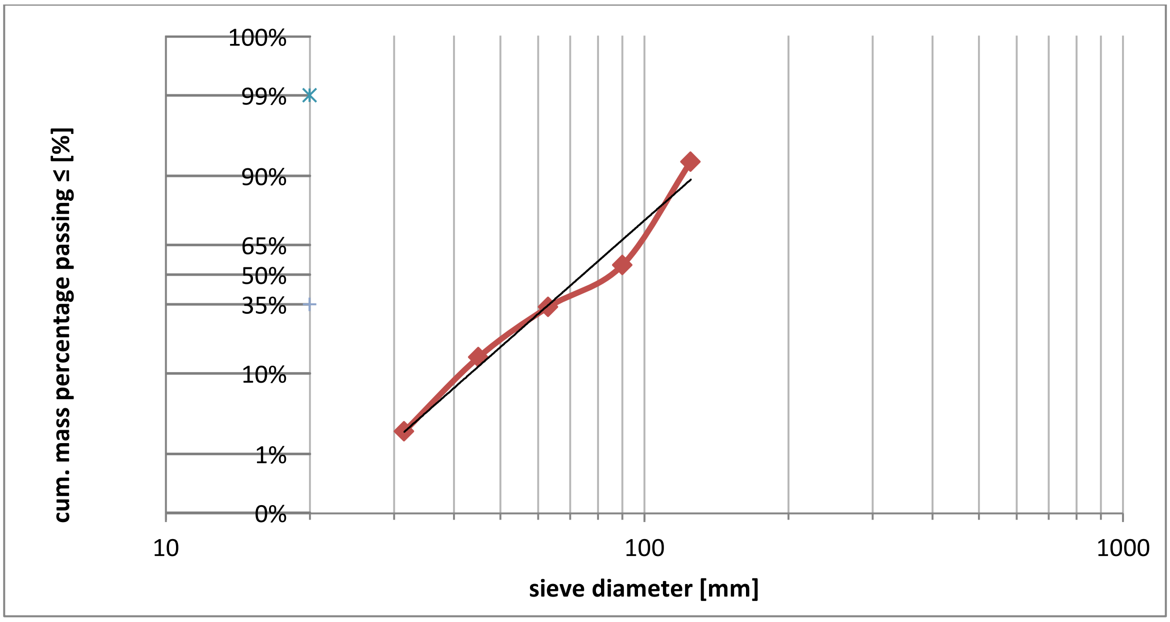


Figure D.1-59 - Gaussian sieve curve 2-5 E

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2626 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-60.

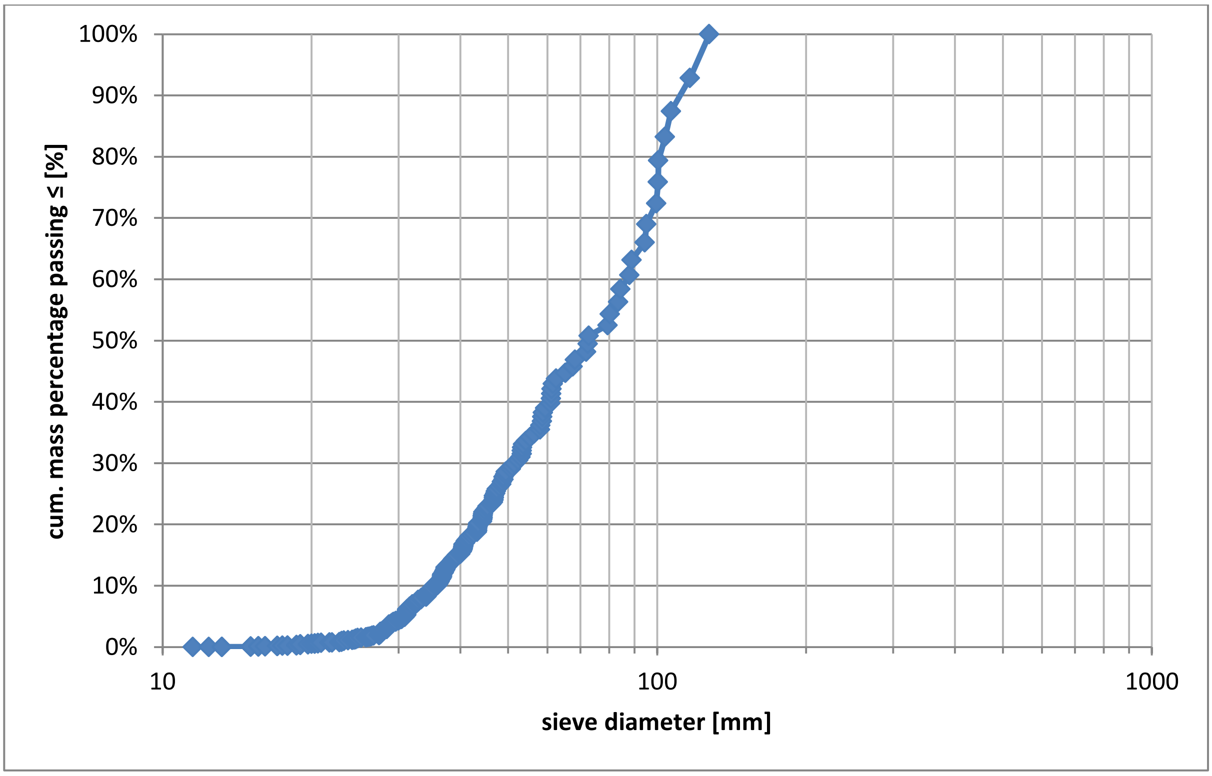


Figure D.1-60 - nominal sieve curve 2-5 E

In Table D-48 nominal diameters interpolated from Figure D.1-60 have been listed.

Table D-48 - nominal diameters 2-5 E

	nominal diameter
	[mm]
dn5	30.9
dn15	39.5
dn50	72.6
dn90	111.4
dn98	124.5

Shape factors F_x

The shape factors are given in Table D-49.

Table D-49 - shape factors 2-5 E

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	30.9	d5	34.8	F5	0.889
dn15	39.5	d15	45.8	F15	0.863
dn50	72.6	d50	83.7	F50	0.867
dn90	111.4	d90	122.4	F90	0.911
dn98	124.5	d98	164.6	F98	0.756

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.87, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-61.

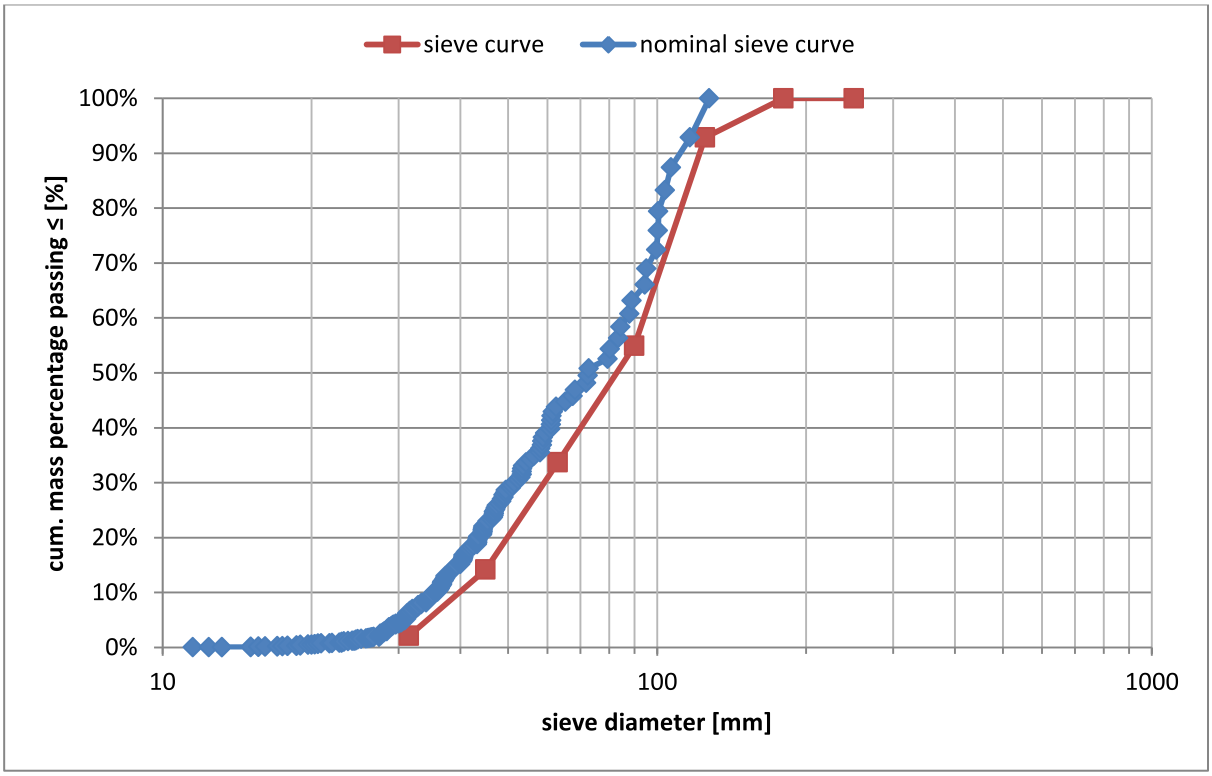


Figure D.1-61 - sieve curves 2-5 E

In Figure D.1-62 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are well approximated by a value of 0.84 times the sieve curve. For the largest rocks 0.84 times the sieve diameter significantly overestimates the nominal diameters.

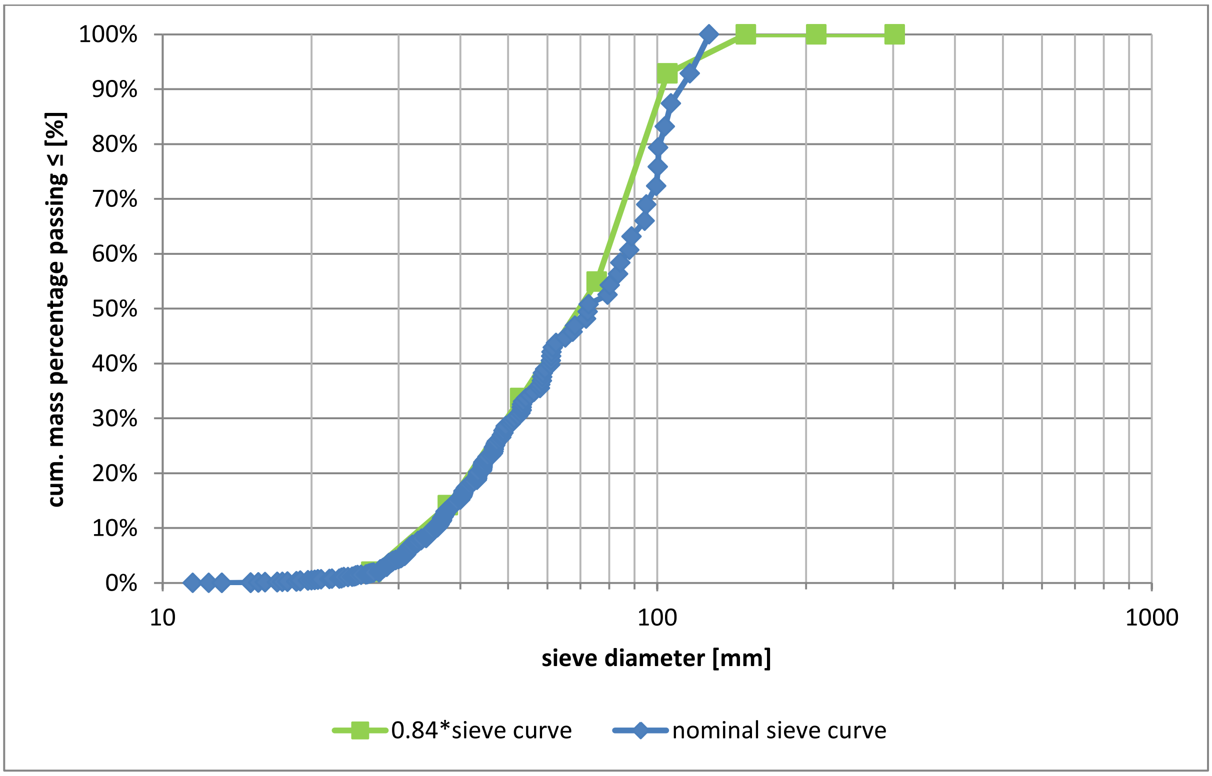


Figure D.1-62 - verification shape factor 2-5 E

D.1.2.5 Sample A-E Combined

Amount of rocks: 1356

The data represented in this sample is equivalent to the data of sample A-E together. It stressed that the results based on the combined sample is not equal to the average of the results of the separate samples.

Sieve test

Numerical information on the sieve test is given in Table D-50.

Table D-50 - sieve test results 2-5 A-E

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	7.3	2.0	2.0
31.5-45	52.9	14.5	16.5
45-63	77.6	21.3	37.9
63-90	81.0	22.2	60.1
90-125	82.7	22.7	82.8
125-180	57.8	15.9	98.7
180-250	4.8	1.3	100.0
total	364.0	100.0	-

The resulting sieve curve is given in Figure D.1-63.

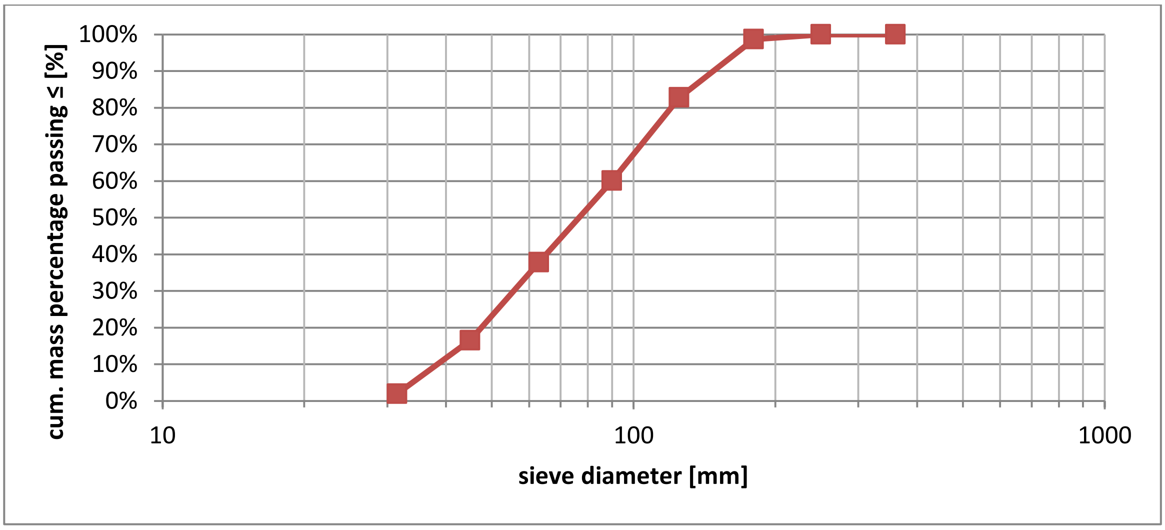


Figure D.1-63 - sieve curve 2-5 A-E

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-51.

Table D-51 - Interpolated sieve diameters 2-5 A-E

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	34.3
d10 (NLL)	38.9
d15	43.6
d25	52.2
d50 (MSD)	77.7
d60	89.9
d85	132.6
d90 (NUL)	150.0
d98 (EUL)	177.7

Grading width: d_{85}/d_{15} = 3.04. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-59 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

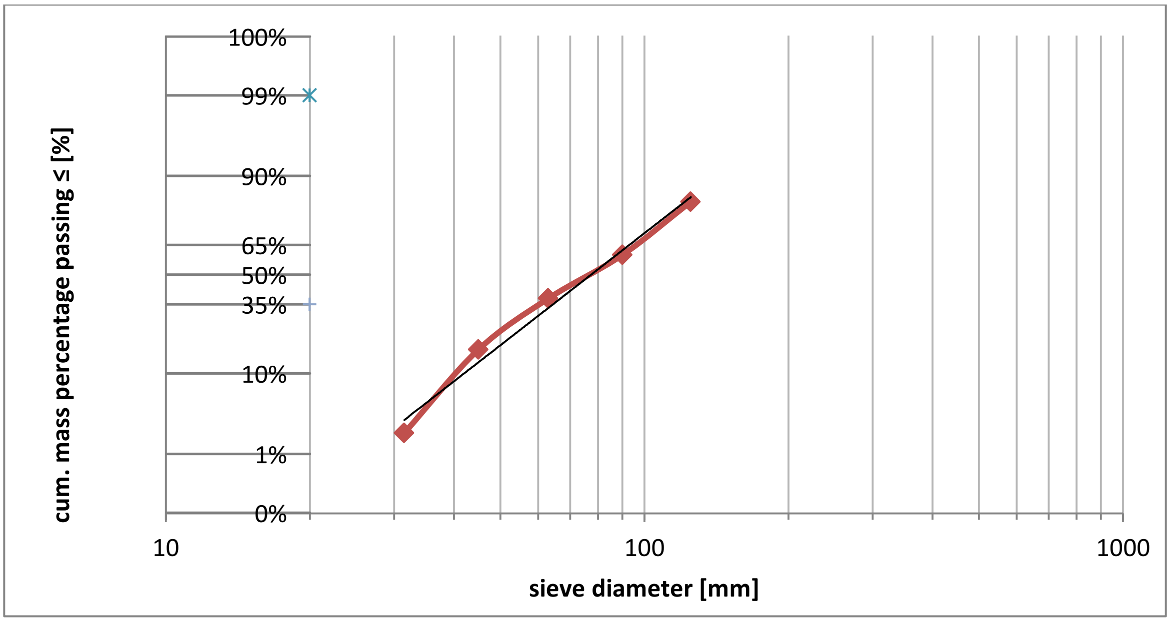


Figure D.1-64 - Gaussian sieve curve 2-5 A-E

d_n-analysis

The volumes required to determine the nominal diameters are calculated by the quotient of mass and density. Also for sample A the nominal diameters this method is applied to assure uniform information. The resulting nominal sieve curve is given in Figure D.1-65.

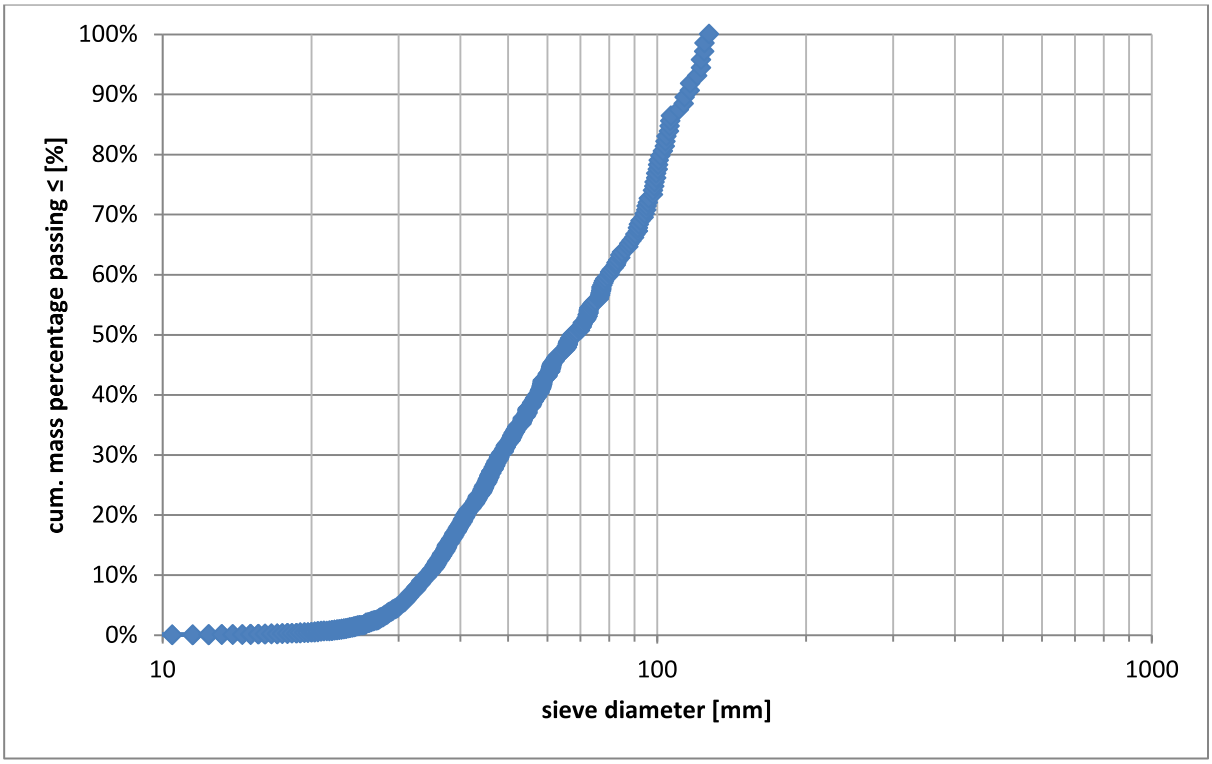


Figure D.1-65 - nominal sieve curve 2-5 A-E

In Table D-52 nominal diameters interpolated from Figure D.1-65 have been listed.

Table D-52 - nominal diameters 2-5 A-E

nominal diameter	[mm]
dn5	30.3
dn15	37.7
dn50	67.6
dn90	115.1
dn98	124.8

Shape factors F_x

The shape factors are given in Table D-53.

Table D-53 - shape factors 2-5 A-E

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	30.3	d5	34.3	F5	0.882
dn15	37.7	d15	43.6	F15	0.866
dn50	67.6	d50	77.7	F50	0.869
dn90	115.1	d90	150.0	F90	0.767
dn98	124.8	d98	177.7	F98	0.702

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.87, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-66.

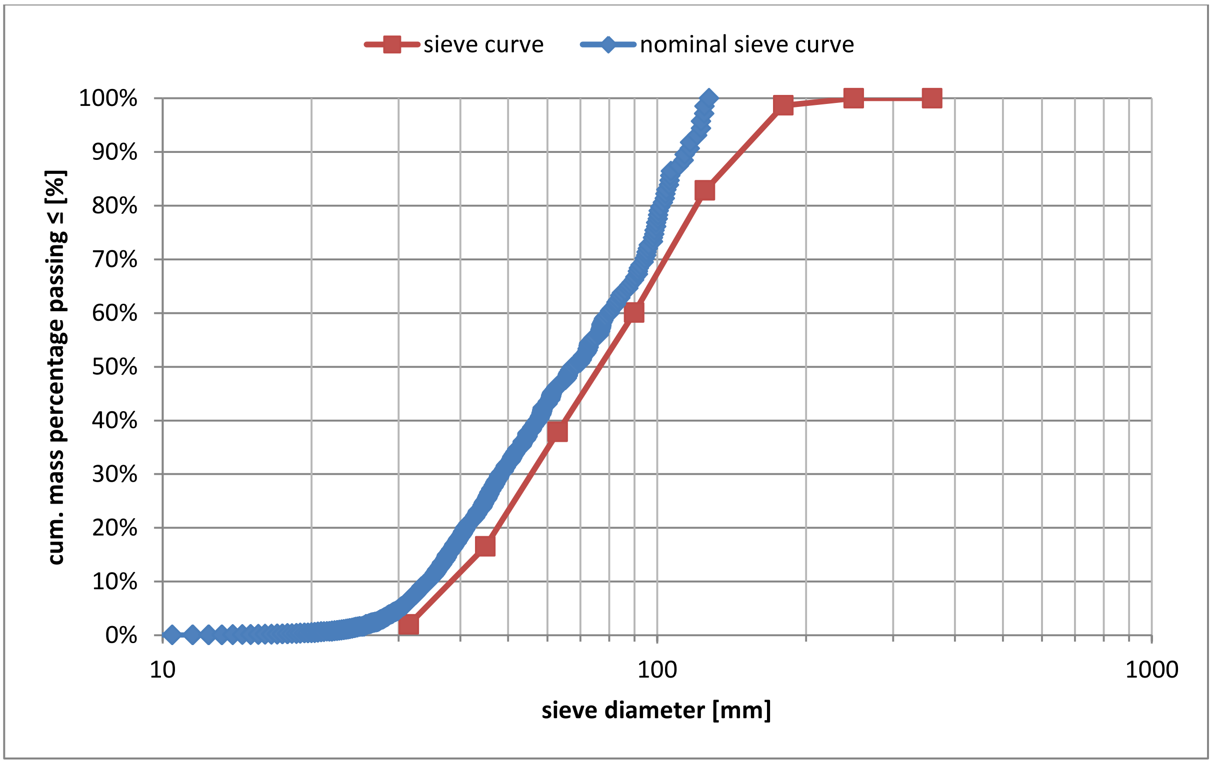


Figure D.1-66 - sieve curves 2-5 A-E

In Figure D.1-67 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the curves show reasonable overlap, especially for the relatively small rocks (nominal diameter < approx.. 60 mm). For the larger rocks the approximation is less accurate and starts to fluctuate. The nominal diameters of the largest rocks (nominal diameter > 100 mm) are significantly overestimated by the approximation.

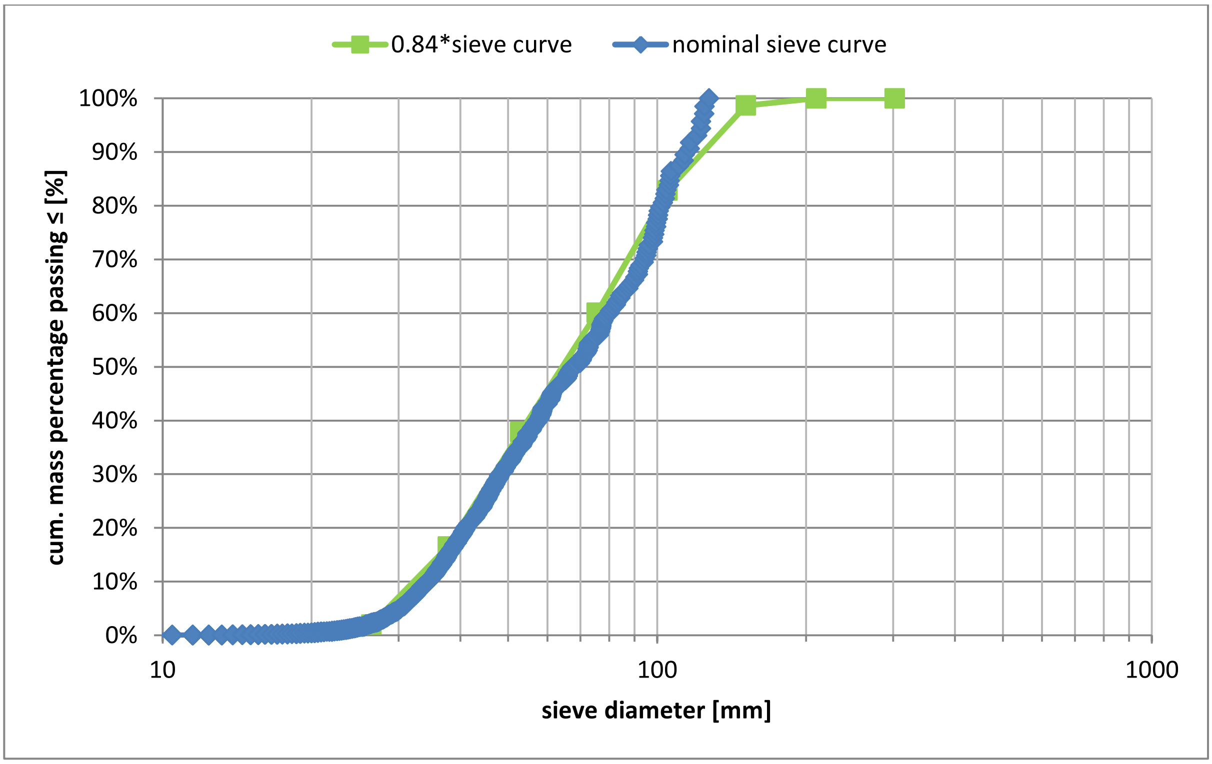


Figure D.1-67 - verification shape factor 2-5 A-E

D.1.2.6 Conclusions

The information gained on the shape factor of the 2-5 material is listed in Table D-56. It is concluded the value of the shape factor F_{50} – the value commonly applied in practice – is fluctuating between a value of 0.85-0.91 for the individual samples. The combined sample yields the value of 0.87 for F_{50}. Furthermore for each sample it is concluded the shape factor is not constant for none of the samples. Moreover, in general the value decreases considerably for the 98 cumulative mass percentage. Except from sample E the same holds the 90 cumulative mass percentage.

Table D-54 - shape factor 2-5

	Sample	A	B	C	D	E	A-E
ELL	dn5	29.289	30.615	30.597	29.182	30.878	30.257
	d5	33.742	34.801	34.982	33.462	34.751	34.290
	F5	0.868	0.880	0.875	0.872	0.889	0.882
NLL	dn15	36.434	38.764	38.391	36.708	39.498	37.724
	d15	42.399	44.285	45.257	40.770	45.768	43.574
	F15	0.859	0.875	0.848	0.900	0.863	0.866
MED	dn50	62.821	72.729	69.505	62.065	72.620	67.563
	d50	72.608	82.571	76.256	73.178	83.713	77.742
	F50	0.865	0.881	0.911	0.848	0.867	0.869
NUL	dn90	103.103	112.774	102.790	124.383	111.422	115.086
	d90	145.072	153.306	140.061	175.720	122.356	149.955
	F90	0.711	0.736	0.734	0.708	0.911	0.767
EUL	dn98	115.407	120.978	110.616	124.826	124.494	124.803
	d98	173.014	174.661	172.012	232.847	164.584	177.683
	F98	0.667	0.693	0.643	0.536	0.756	0.702

D.1.3 2-8 IJmuiden

Origin: Skipavika quarry, south-eastern tip of Sandøyna island, Norway
Aggregate type: Gneiss
Shape type: Fresh

For this rock grading equal tests have been performed in comparison with the 22-90 and 2-5 material. In general the data is also processed in a similar way therefor. As a result this paragraph will only focus on the results of the processed data and only significant deviations in the processing method are mentioned. For explanations on the calculations and graphs please consult paragraph 0.

D.1.3.1 Sample A

Amount of rocks: 201

Sieve test

Numerical information on the sieve test is given in Table D-55.

Table D-55 - sieve test results 2-8 A

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	0.2	0.1	0.1
31.5-45	4.5	2.5	2.6
45-63	20.6	11.2	13.8
63-90	36.8	20.1	33.9
90-125	38.7	21.1	54.9
125-180	55.8	30.4	85.4
180-250	26.8	14.6	100.0
total	183.5	100.0	-

The resulting sieve curve is given in Figure D.1-68

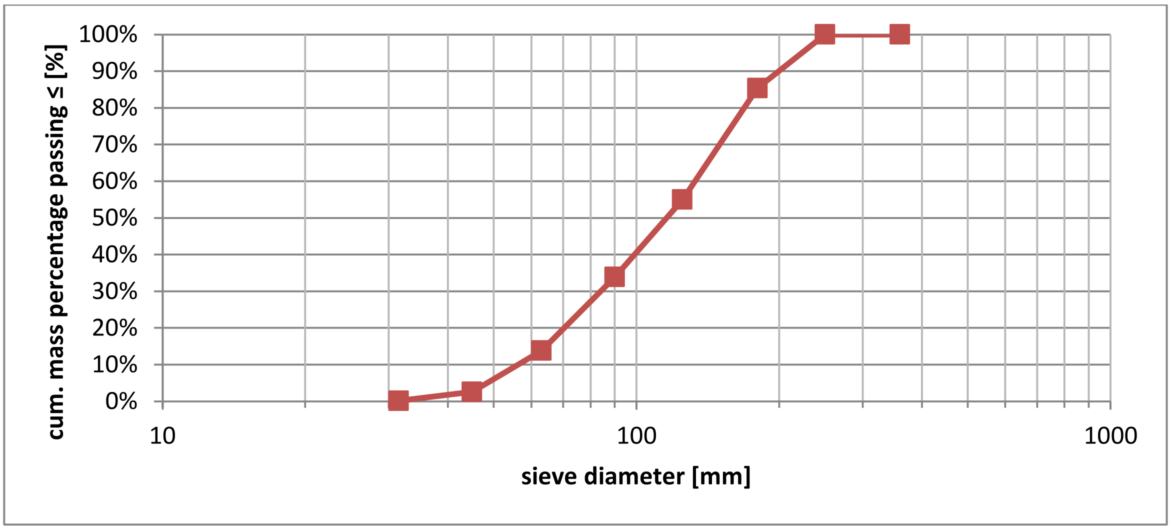


Figure D.1-68 - sieve curve 2-8 A

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-56.

Table D-56 - Interpolated sieve diameters 2-8 A

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	48.9
d10 (NLL)	56.9
d15	64.6
d25	78.1
d50 (MSD)	116.8
d60	134.1
d85	179.3
d90 (NUL)	202.1
d98 (EUL)	240.4

Grading width: d_{85}/d_{15} = 2.77. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-69 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

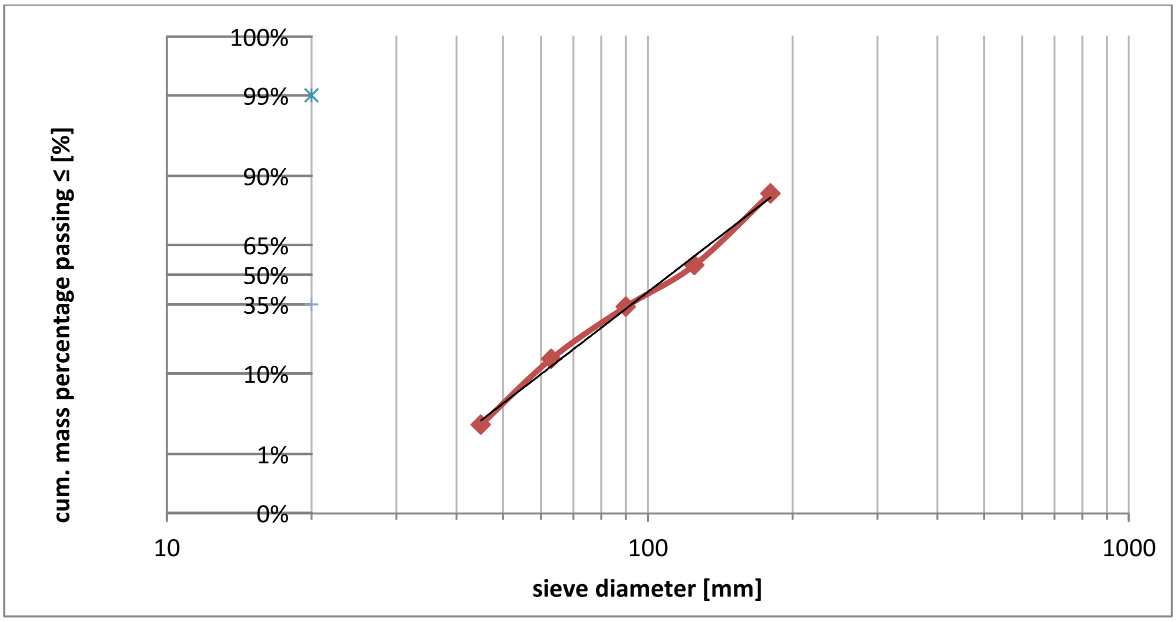


Figure D.1-69 - Gaussian sieve curve 2-8 A

d_n-analysis

The nominal sieve curve including the nominal diameters calculated by the volumes determined according to the Archimedes method is given in Figure D.1-70.

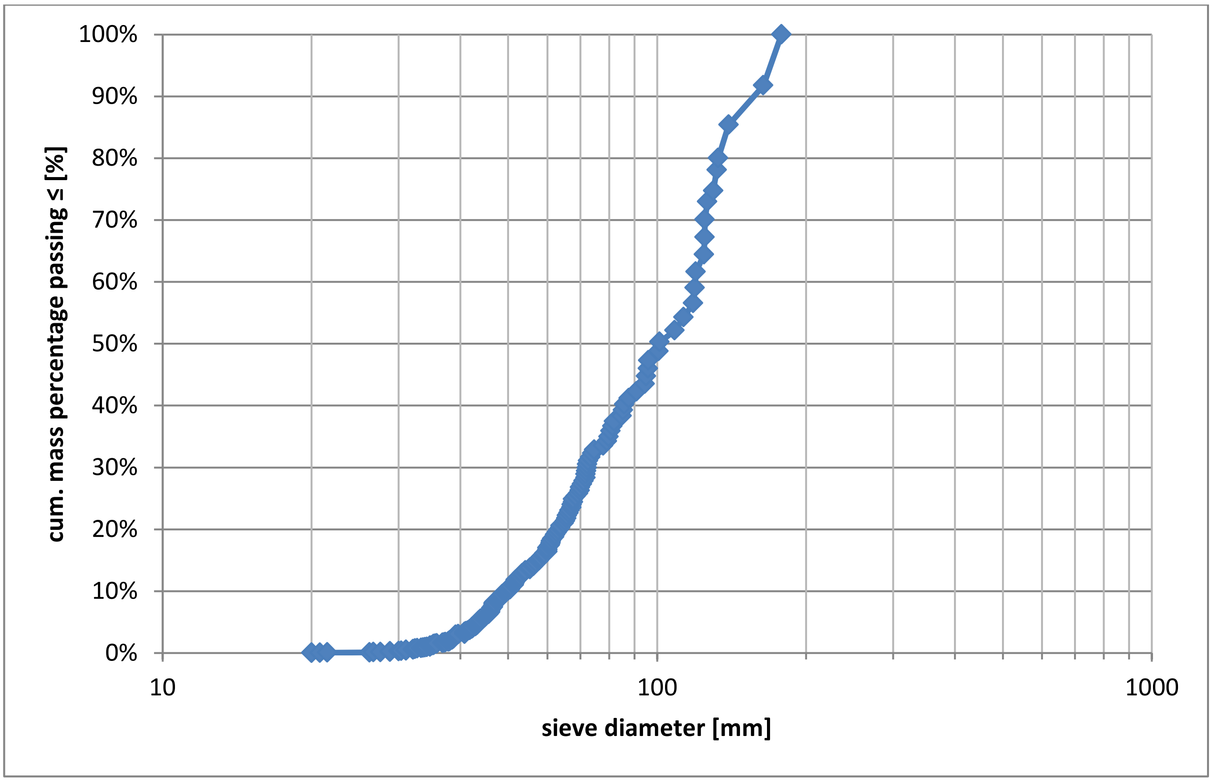


Figure D.1-70 - nominal sieve curve 2-8 A

Again the impact of scattering densities is examined. In Figure D.1-71 the individual rock densities are presented.

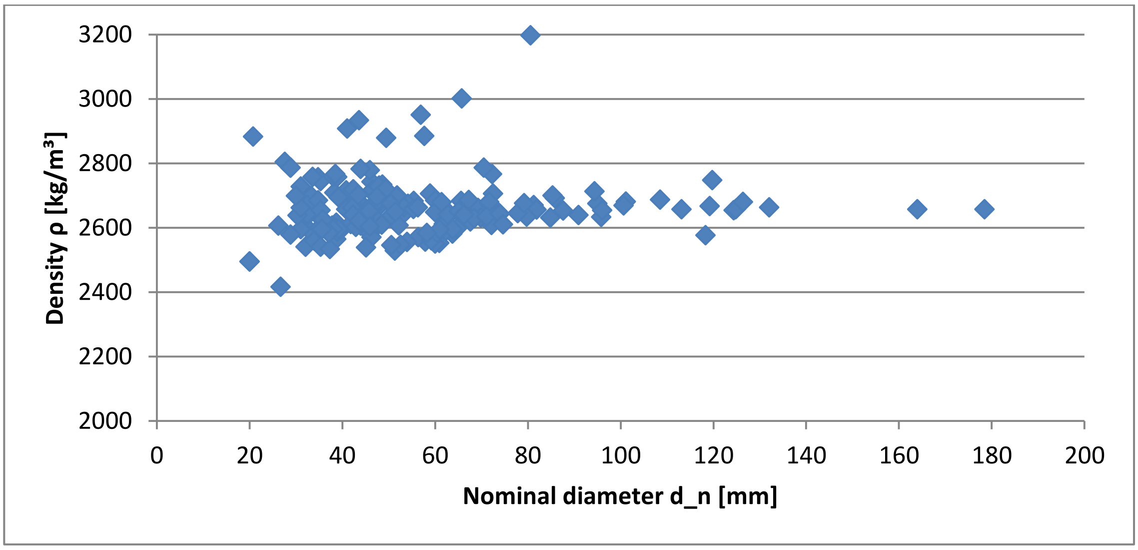


Figure D.1-71 - individual Archimedes rock densities 2-8 A

The average of the densities is 2688 kg/m³, the median is 2653 kg/m³ and the modus is 2595 kg/m³. It is concluded a lot of scatter is present, in particular for the smaller rock. By application of a uniform density the nominal diameters are recalculated. The uniform density is determined by the average density of the rocks in the 63-90 and 90-125 fractions and has a value of 2657 kg/m³. The nominal sieve curve including the nominal diameters calculated by the volumes according to the uniform density of 2657 kg/m³ is given in Figure D.1-72.

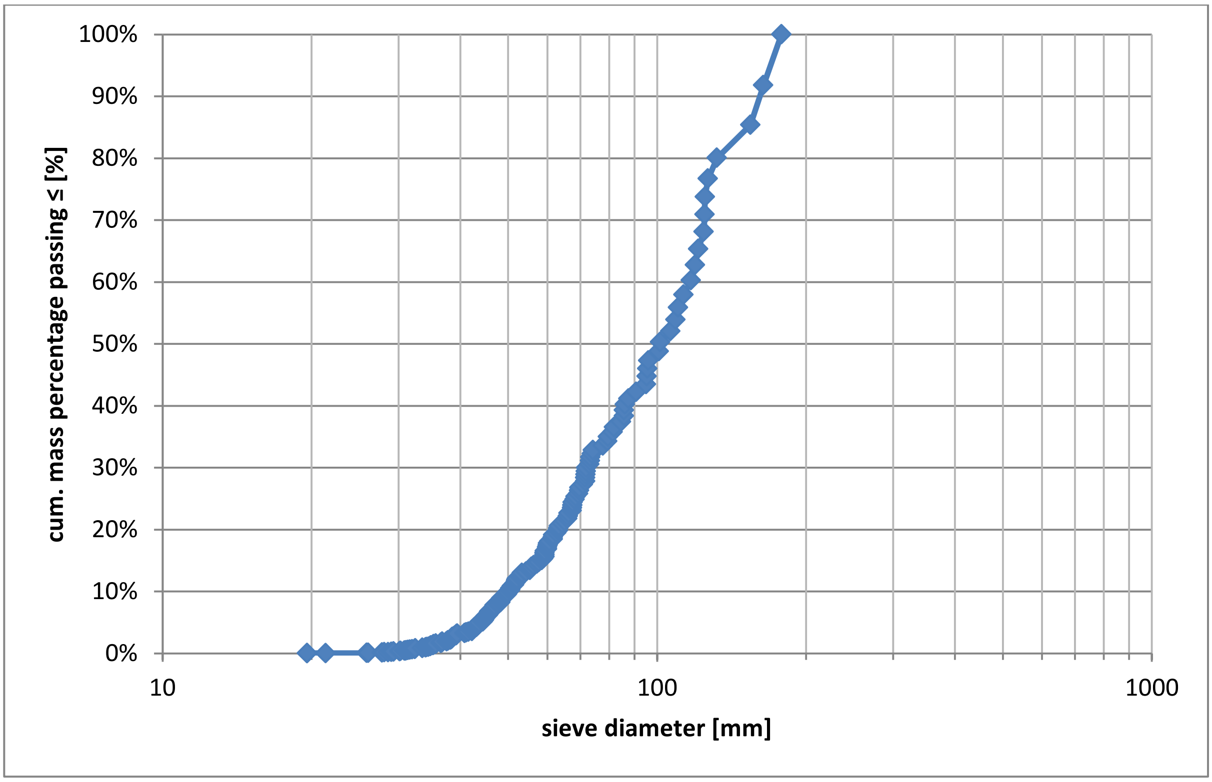


Figure D.1-72 - modified nominal sieve curve 2-8 A

In Table D-57 the interpolated nominal diameters based on both the Archimedes and the modified volumes are listed.

Table D-57 - comparison of dn-values acc. to Archimedes and modified volumes 2-8 A

nominal diameter	acc. to Archimedes volumes	acc. to modified volumes
	[mm]	[mm]
d_{n5}	43.6	43.7
d_{n15}	57.8	58.4
d_{n50}	101.1	101.4
d_{n90}	157.3	161.4
d_{n98}	175.0	175.0

It is concluded that the values of the nominal diameters found on the basis of both methods hardly differ. It is therefore concluded the observed scatter in the densities found on the basis of the Archimedes does not cause the nominal sieve diameter to be unrealistic. Therefore the nominal diameters on the basis of the Archimedes volumes are applied in this sample.

Shape factors F_x

The shape factors are given in Table D-58.

Table D-58 - shape factors 2-8 A

nominal diameter			sieve diameter		shape factor		
[mm]	Arc	mod	[mm]		[mm]	Arc	mod
dn5	43.6	43.7	d5	48.9	F5	0.892	0.895
dn15	57.8	58.4	d15	64.6	F15	0.894	0.903
dn50	101.1	101.4	d50	116.8	F50	0.866	0.868
dn90	157.3	161.4	d90	202.1	F90	0.778	0.798
dn98	175.0	175.0	d98	240.4	F98	0.728	0.728

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.87, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-73.

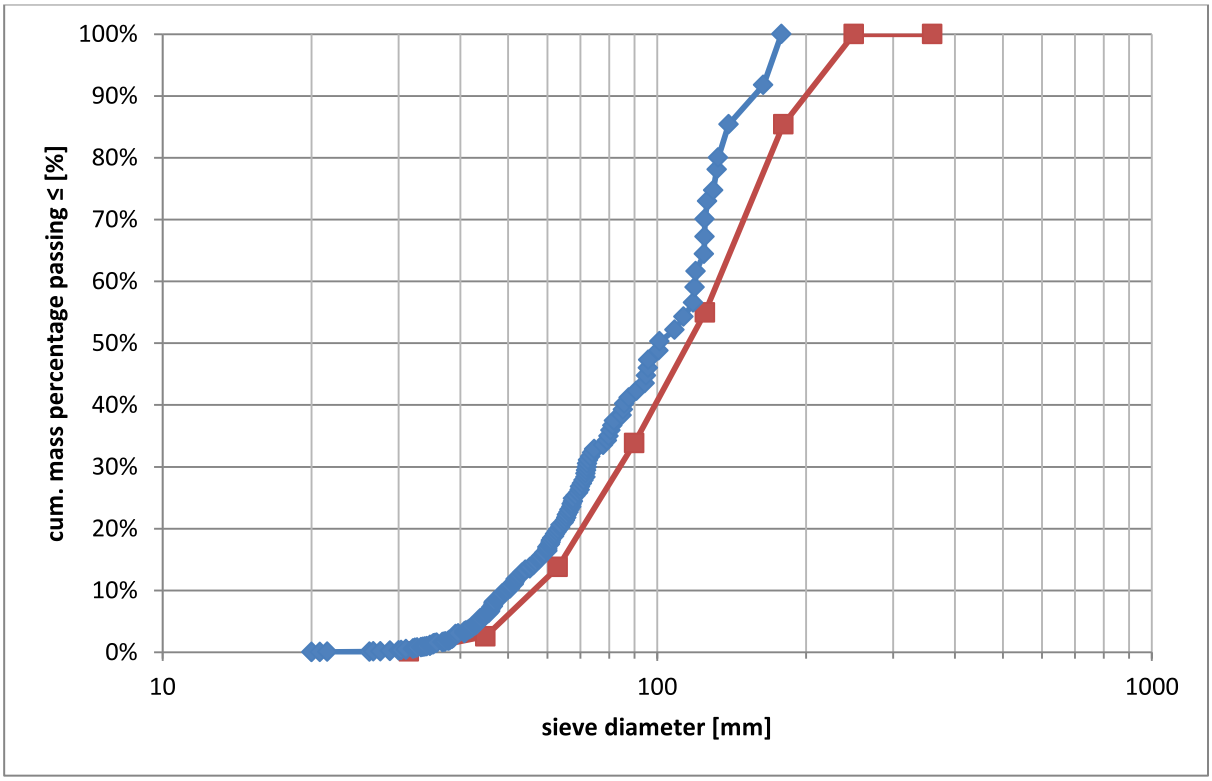


Figure D.1-73 - curves 2-8 A

In Figure D.1-74 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are slightly underestimated by a value of 0.84 times the sieve curve. For larger rocks (nominal diameter > 100 mm) the accuracy of the approximation further decreases. For the largest rock (nominal diameter > approx. 125 mm) the value of the shape factor overestimates the relation between nominal and sieve diameter.

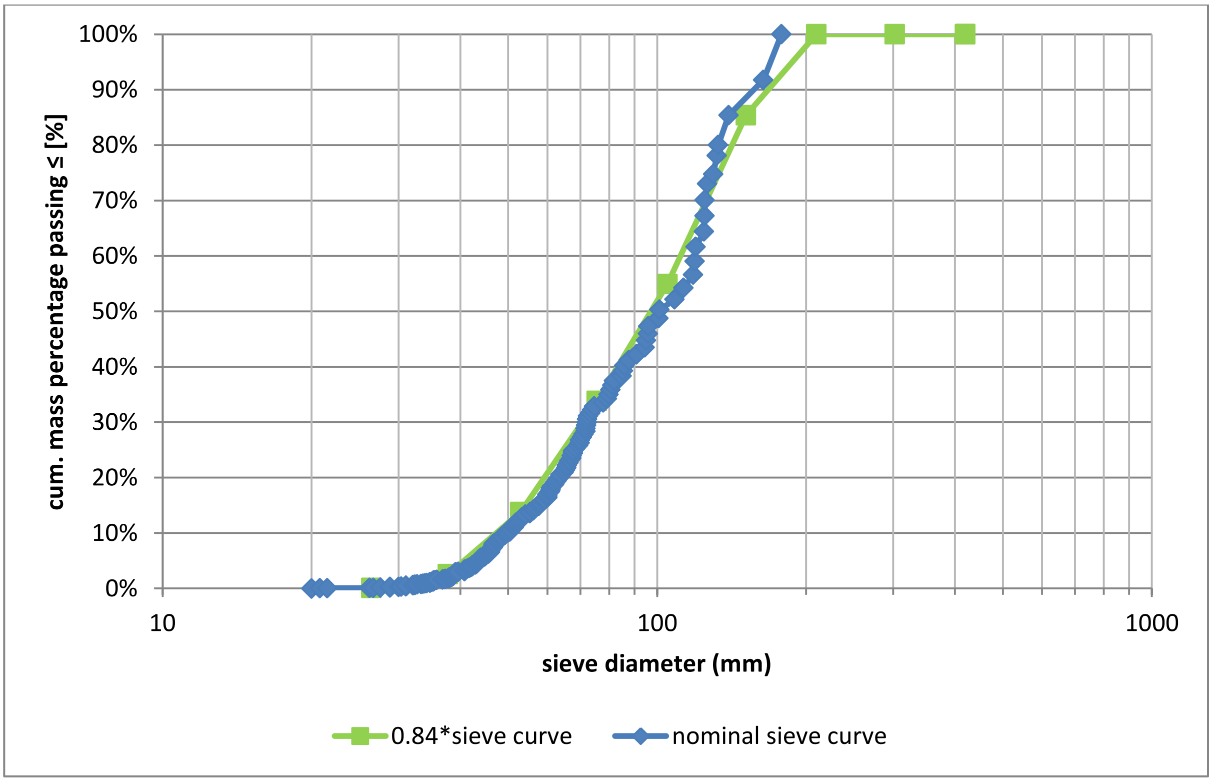


Figure D.1-74 - verification shape factor 2-8 A

Shape test

In Table D-59 and Table D-60 an overview is given of the minimum, maximum and average values of the elongation and blockiness respectively.

Table D-59 - elongation 2-8 A

	Elongation		
	minimum [-]	maximum [-]	average [-]
0-31.5	1.45	2.81	2.27
31.5-45	1.35	4.50	2.33
45-63	1.24	4.46	2.38
63-90	1.27	3.94	2.24
90-125	1.67	4.68	2.41
125-180	1.64	3.96	2.49
180-250	2.74	3.18	2.96
total	1.24	4.68	2.44

Table D-60 -blockiness 2-8 A

	Blockiness		
	minimum [%]	maximum [%]	average [%]
0-31.5	44.37	89.48	57.72
31.5-45	33.06	73.93	45.93
45-63	31.75	96.51	46.65
63-90	31.90	57.17	46.25
90-125	29.58	60.48	43.42
125-180	30.50	50.89	44.56
180-250	39.59	53.98	46.78
total	29.58	96.51	47.28

It is stressed that the calculated elongation and blockiness values in the 0-31.5 and 180-250 mm fraction are based on the an amount of 6 respectively 2 rocks. The statistical meaning of the values representing these fractions is therefore questionable.

Considering only the 31.5-45, 45-63, 63-90, 90-125 and 125-180 fractions the minimum value for elongation is 1.24. The maximum value of elongation observed in these rocks is 4.68. Furthermore, the minima, maxima and average elongation is rather constant over the fractions. Considering blockiness for the same fractions the minimum and maximum blockiness found are 29 respectively 97 percent approximately. 97 percent blockiness represents an almost perfect block shape, which is not found in the sample and therefore most probably the result of a measurement error. The average blockiness values over the fractions are relatively constant. It is concluded no significant trends are observed in elongation nor blockiness for this sample.

D.1.3.2 Sample B

Amount of rocks: 232

Sieve test

Numerical information on the sieve test is given in Table D-61.

Table D-61 - sieve test results 2-8 B

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	0.949	0.6	0.6
31.5-45	4.767	3.0	3.6
45-63	19.355	12.1	15.7
63-90	39.855	25.0	40.7
90-125	24.657	15.5	56.1
125-180	41.052	25.7	81.9
180-250	28.931	18.1	100.0
total	159.6	100.0	-

The resulting sieve curve is given in Figure D.1-75.

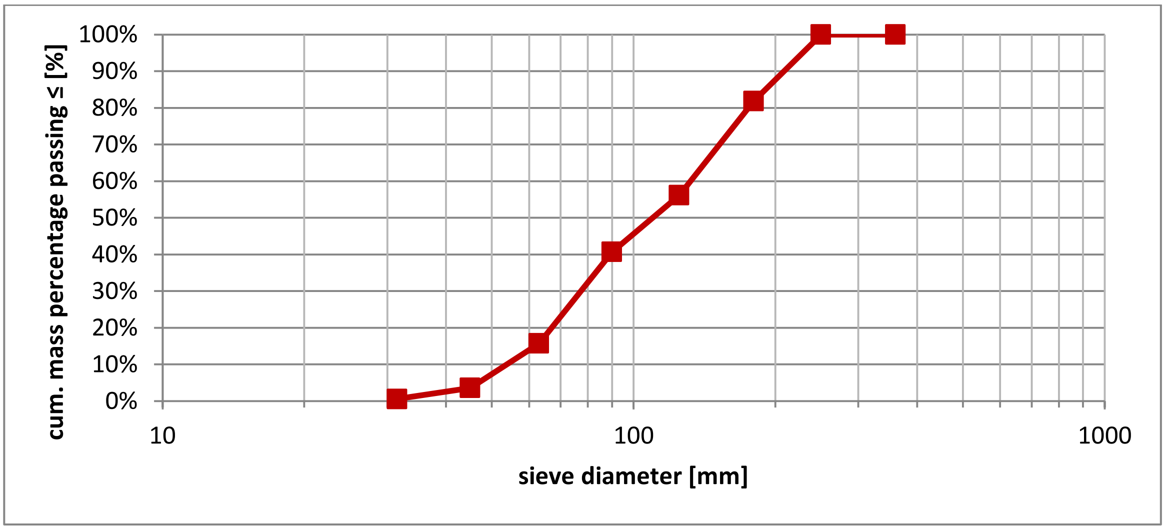


Figure D.1-75 - sieve curve 2-8 B

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-62.

Table D-62 - Interpolated sieve diameters 2-8 B

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	47.1
d10 (NLL)	54.5
d15	61.9
d25	73.0
d50 (MSD)	111.1
d60	133.3
d85	192.1
d90 (NUL)	211.4
d98 (EUL)	242.3

Grading width: d_{85}/d_{15} = 3.10. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-76 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

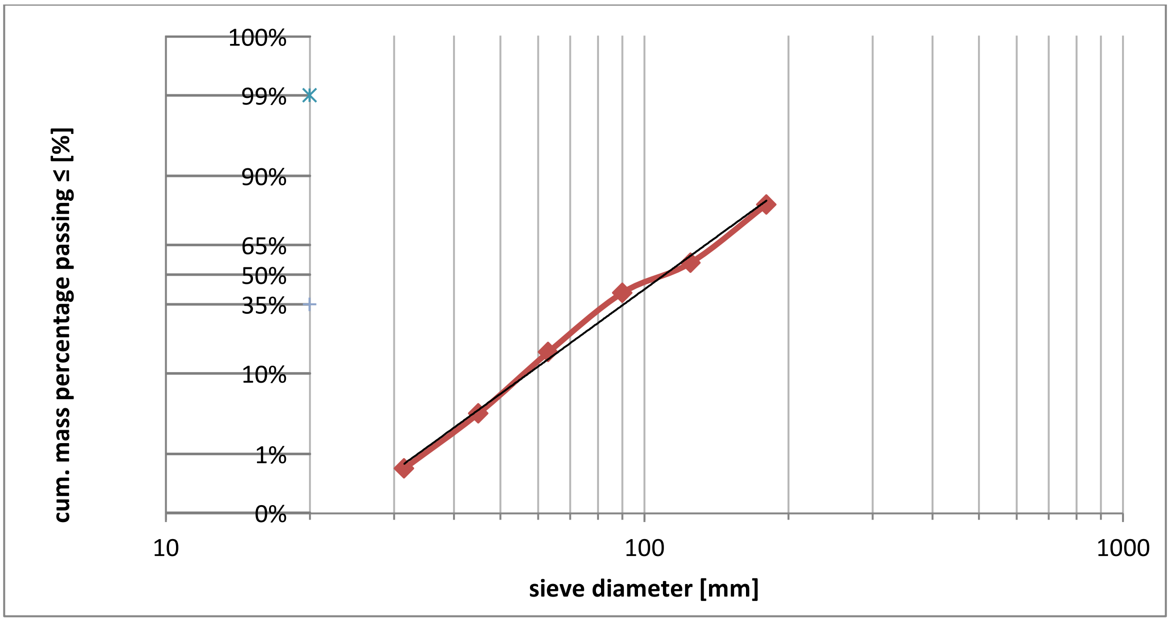


Figure D.1-76 - Gaussian sieve curve 2-8 B

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2657 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-77.

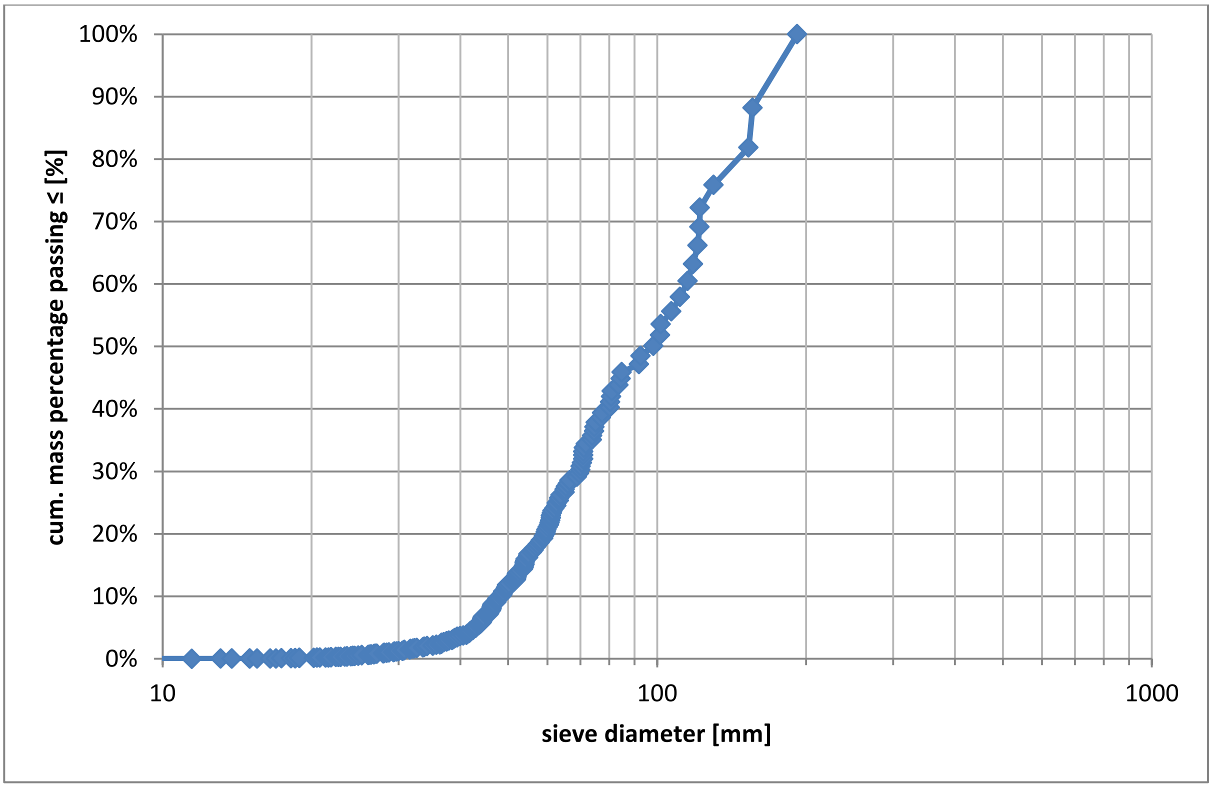


Figure D.1-77 - nominal sieve curve 2-8 B

In Table D-63 nominal diameters interpolated from Figure D.1-77 have been listed.

Table D-63 - nominal diameters 2-8 B

nominal diameter	
	[mm]
dn5	43.0
dn15	53.9
dn50	98.1
dn90	161.6
dn98	186.0

Shape factors F_x

The shape factors are given in Table D-64.

Table D-64 - shape factors 2-8 B

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	43.0	d5	47.1	F5	0.913
dn15	53.9	d15	61.9	F15	0.871
dn50	98.1	d50	111.1	F50	0.883
dn90	161.6	d90	211.4	F90	0.764
dn98	186.0	d98	242.3	F98	0.768

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.89, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-78.

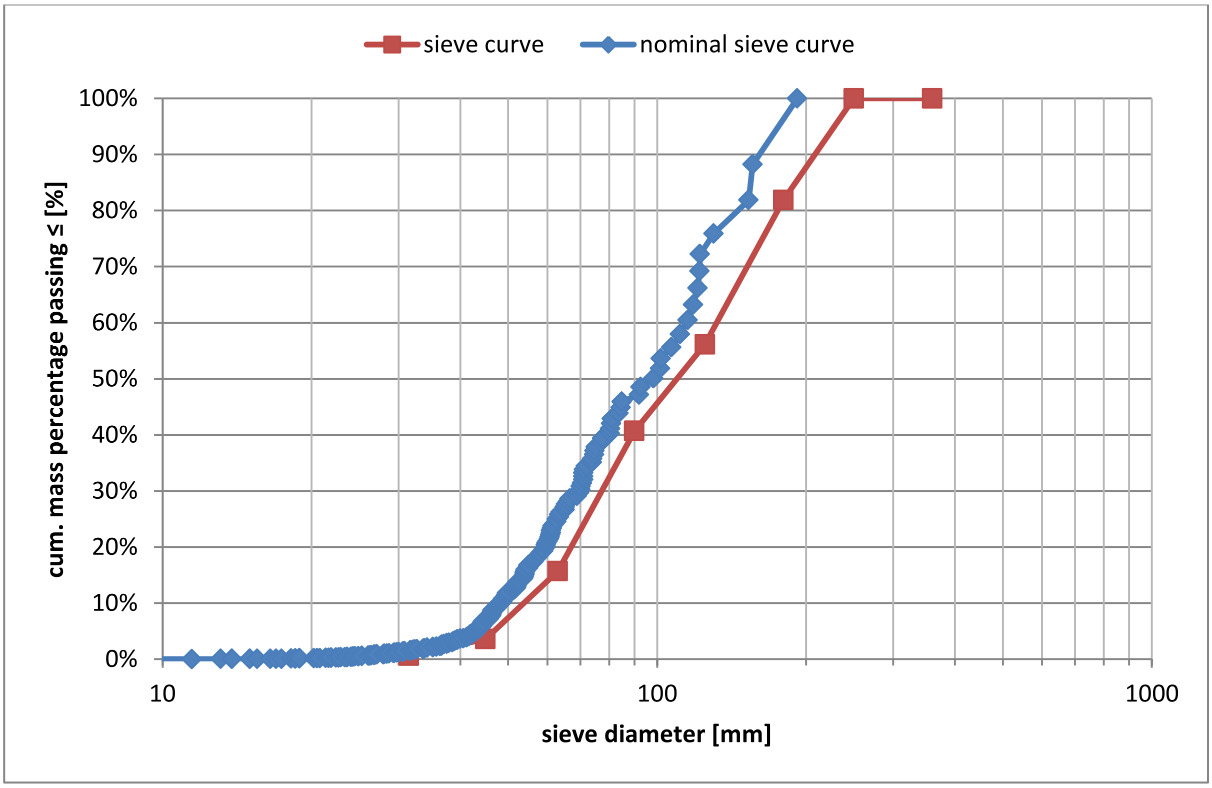


Figure D.1-78 - sieve curves 2-8 B

In Figure D.1-79 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are slightly underestimated by a value of 0.84 times the sieve curve. For larger rocks (nominal diameter > 120 mm) the accuracy of the approximation further decreases. For the largest rock (nominal diameter > approx. 150 mm) the value of the shape factor overestimates the relation between nominal and sieve diameter.

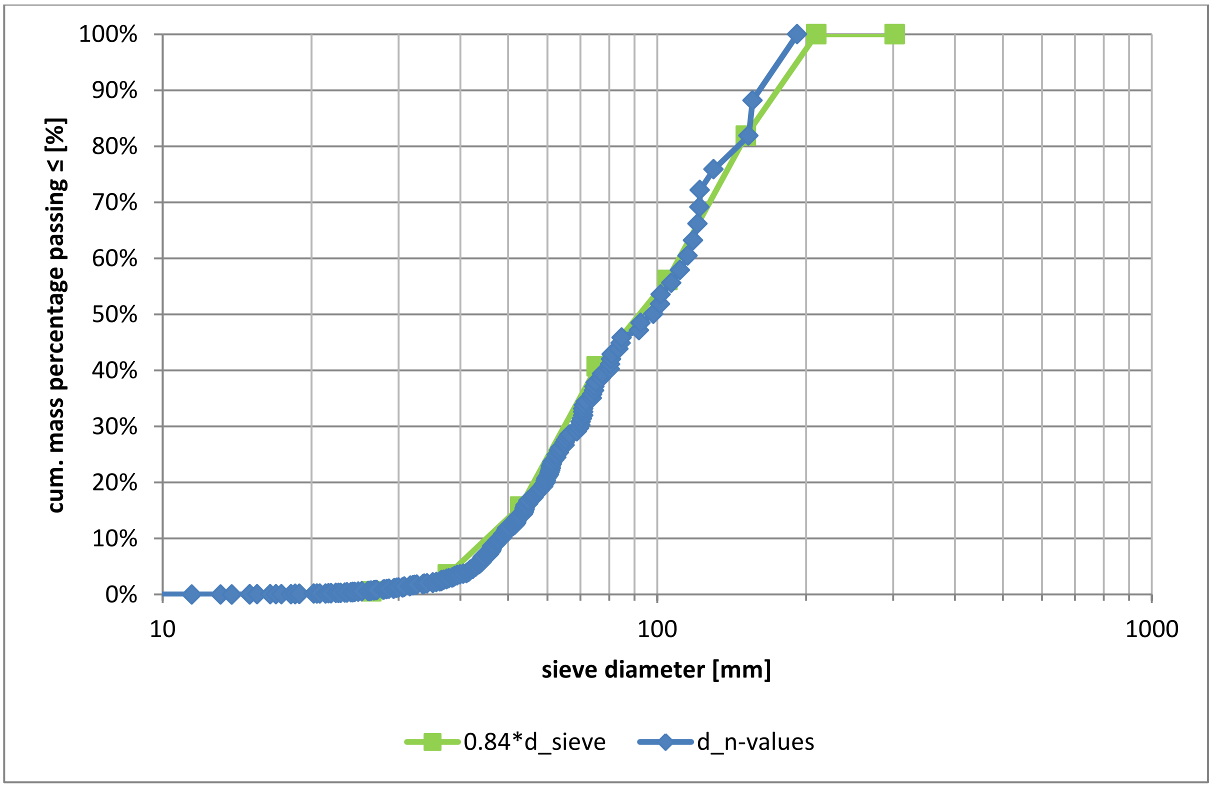


Figure D.1-79 - verification shape factor 2-8 B

D.1.3.3 Sample C

Amount of rock: 335

Sieve test

Numerical information on the sieve test is given in Table D-65.

Table D-65 - sieve test results 2-8 C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	2.066	0.9	0.9
31.5-45	9.69	4.4	5.4
45-63	16.626	7.6	13.0
63-90	41.618	19.1	32.1
90-125	53.865	24.7	56.7
125-180	67.406	30.9	87.6
180-250	27.03	12.4	100.0
total	218.3	100.0	-

The resulting sieve curve is given in Figure D.1-80.

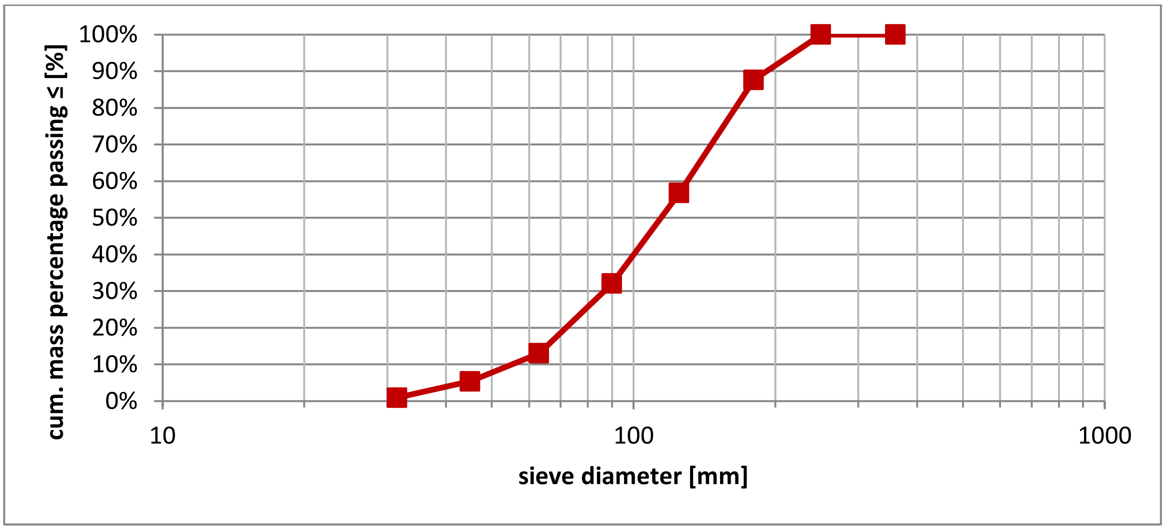


Figure D.1-80 - sieve curve 2-8 C

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-66.

Table D-66 - Interpolated sieve diameters 2-8 C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	43.8
d10 (NLL)	55.9
d15	65.8
d25	80.0
d50 (MSD)	115.4
d60	130.8
d85	175.3
d90 (NUL)	193.5
d98 (EUL)	238.7

Grading width: d_{85}/d_{15} = 2.66. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-81 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

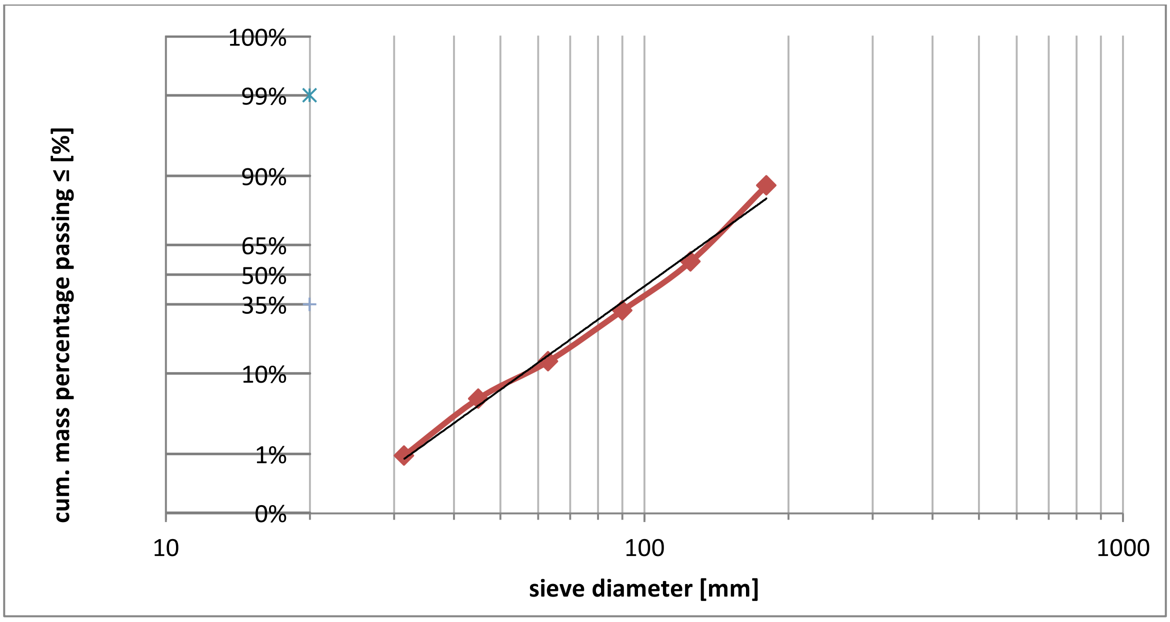


Figure D.1-81 - Gaussian sieve curve 2-8 C

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2657 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-82.

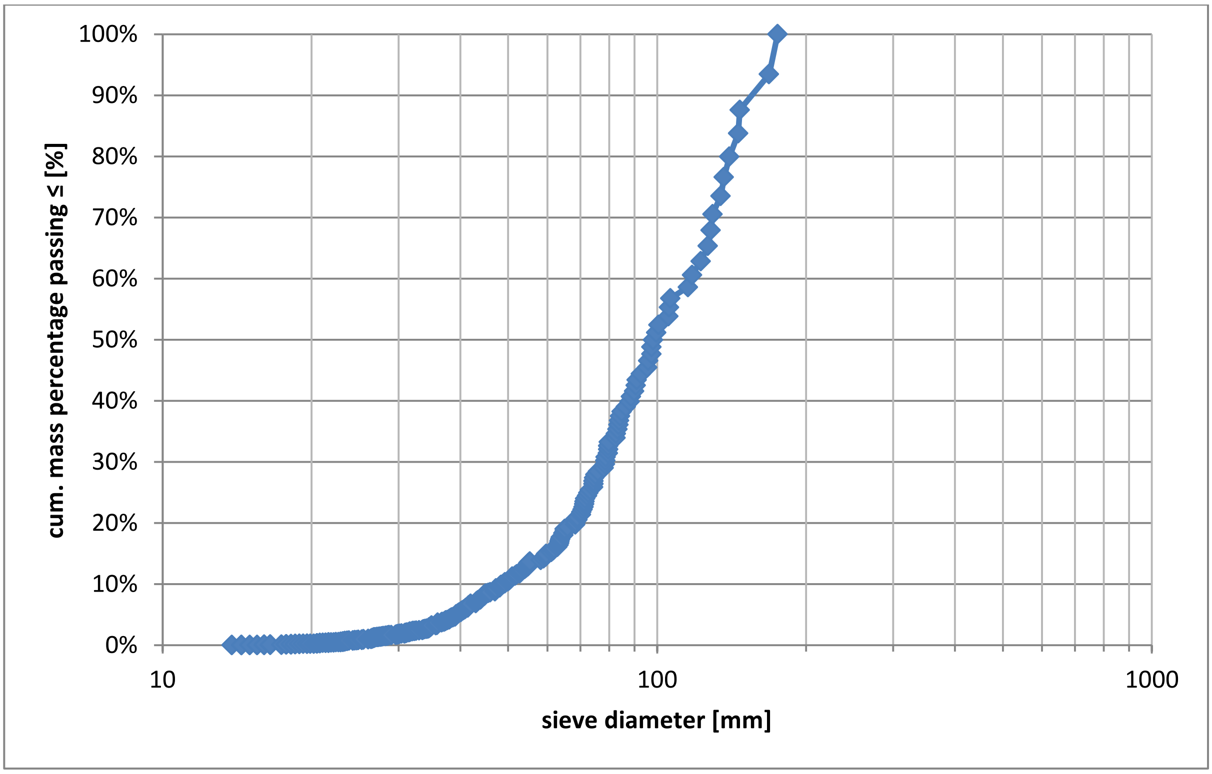


Figure D.1-82 - nominal sieve curve 2-8 C

In Table D-67 nominal diameters interpolated from Figure D.1-77 have been listed.

Table D-67 - nominal diameters 2-8 C

	nominal diameter
	[mm]
dn5	39.3
dn15	59.9
dn50	98.3
dn90	155.8
dn98	173.2

Shape factors F_x

The shape factors are given in Table D-68.

Table D-68 - shape factors 2-8 C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	39.3	d5	43.8	F5	0.896
dn15	59.9	d15	65.8	F15	0.910
dn50	98.3	d50	115.4	F50	0.851
dn90	155.8	d90	193.5	F90	0.805
dn98	173.2	d98	238.7	F98	0.726

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.85, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-83.

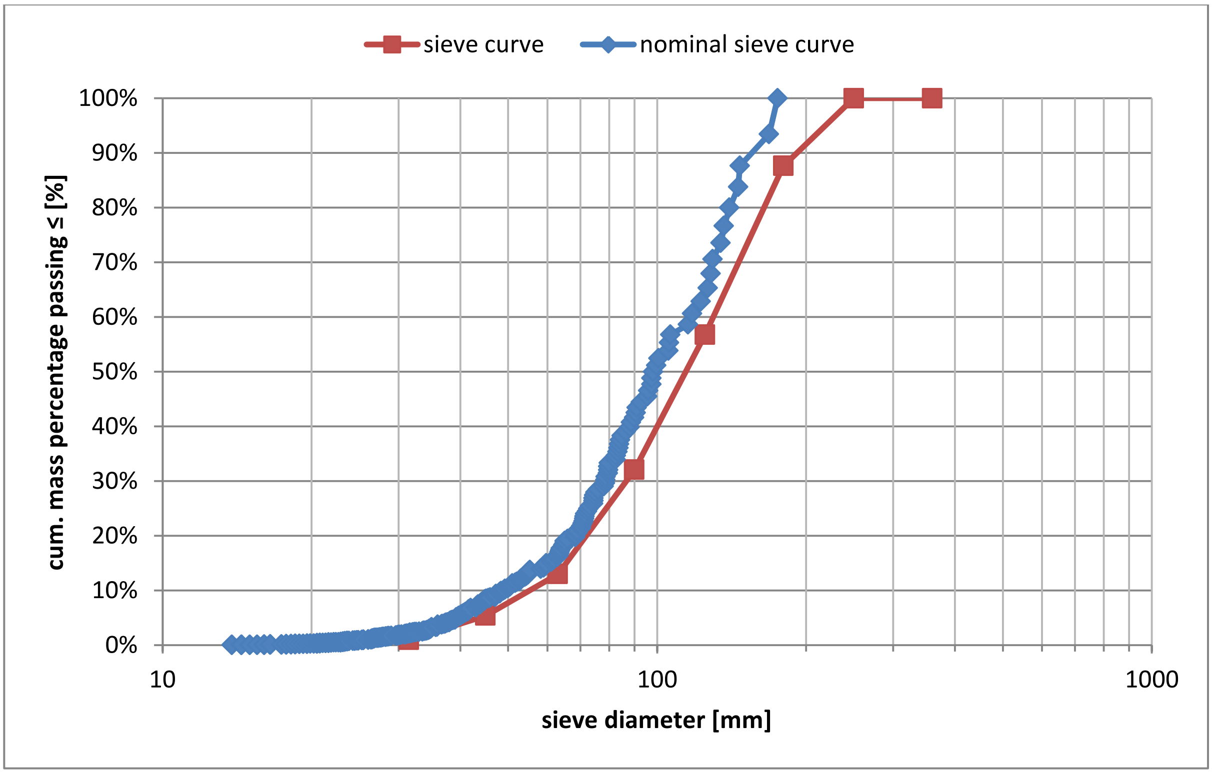


Figure D.1-83 - sieve curves 2-8 C

In Figure D.1-84 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are slightly underestimated by a value of 0.84 times the sieve curve. For larger rocks (nominal diameter > 120 mm) the accuracy of the approximation further decreases. For the largest rock (nominal diameter > approx. 150 mm) the value of the shape factor overestimates the relation between nominal and sieve diameter.

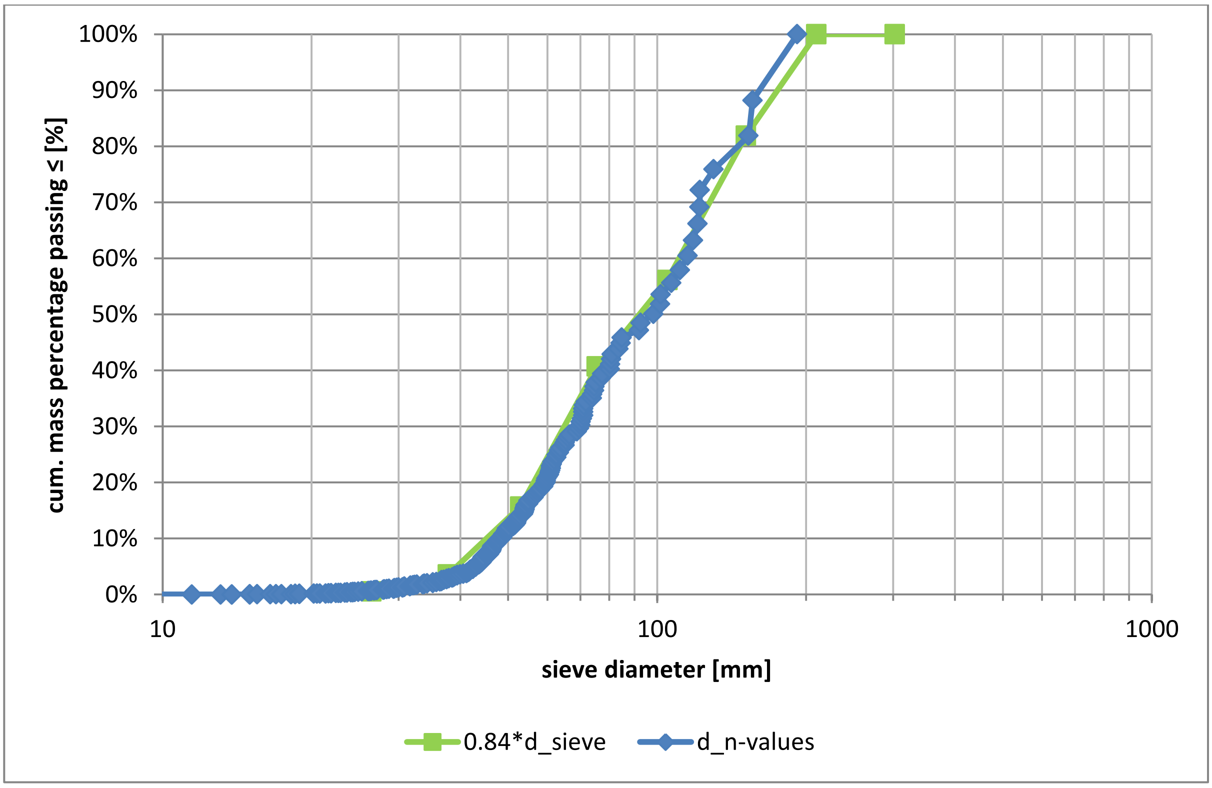


Figure D.1-84 - verification shape factor 2-8 C

D.1.3.4 Sample D

Amount of rock: 294

Sieve test

Numerical information on the sieve test is given in Table D-69.

Table D-69 - sieve test results 2-8 D

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.347	0.8	0.8
31.5-45	6.175	3.5	4.2
45-63	24.103	13.5	17.7
63-90	30.976	17.3	35.1
90-125	43.135	24.2	59.2
125-180	45.359	25.4	84.6
180-250	27.459	15.4	100.0
total	178.6	100.0	-

The resulting sieve curve is given in Figure D.1-85.

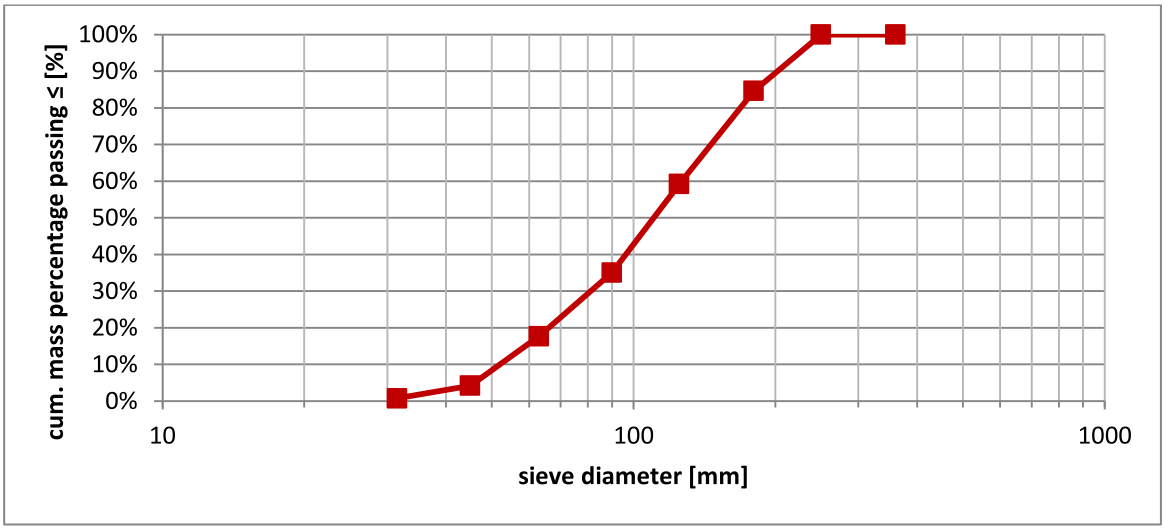


Figure D.1-85 - sieve curve 2-8 D

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-70.

Table D-70 - Interpolated sieve diameters 2-8 D

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	46.1
d10 (NLL)	52.7
d15	59.4
d25	74.4
d50 (MSD)	111.7
d60	126.7
d85	181.7
d90 (NUL)	204.5
d98 (EUL)	240.9

Grading width: d_{85}/d_{15} = 3.06. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-86 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

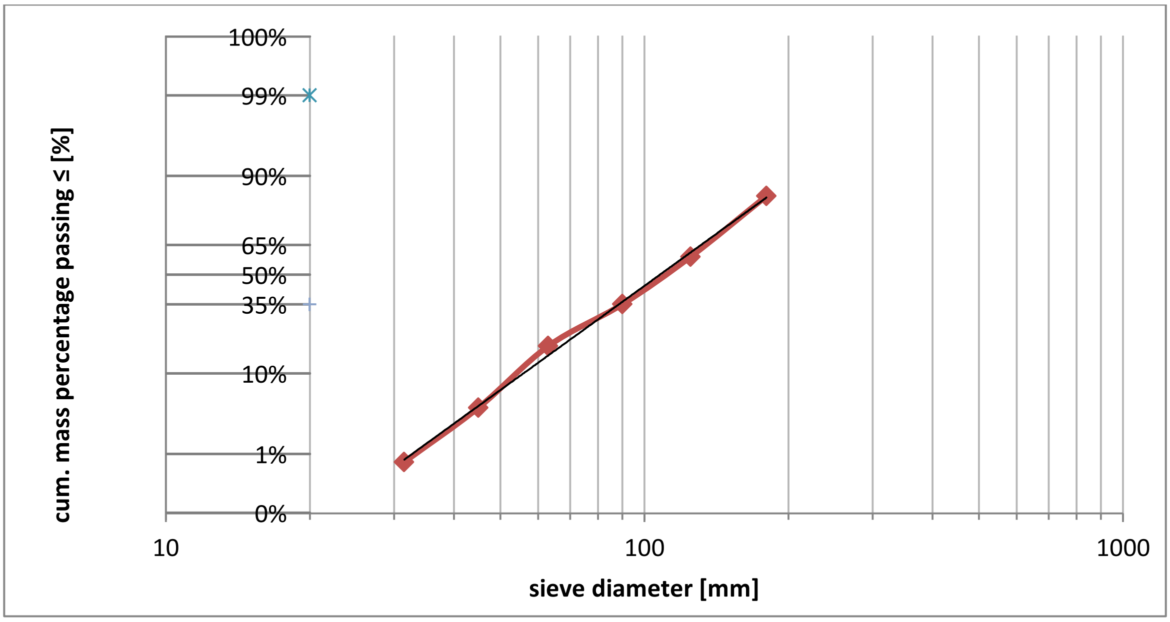


Figure D.1-86 - Gaussian sieve curve 2-8 D

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2657 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-87.

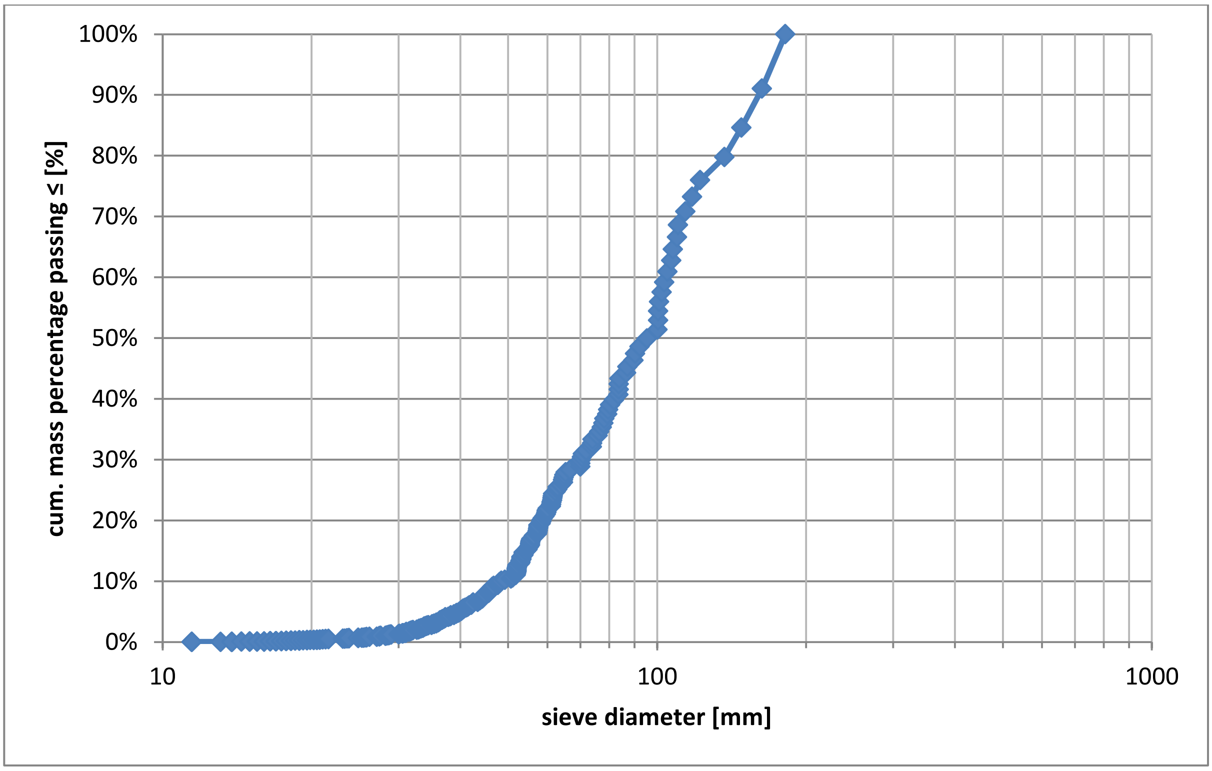


Figure D.1-87 - nominal sieve curve 2-8 D

In Table D-71 nominal diameters interpolated from Figure D.1-87 have been listed.

Table D-71 - nominal diameters 2-8 D

	nominal diameter [mm]
dn5	39.9
dn15	54.4
dn50	95.8
dn90	160.6
dn98	177.5

Shape factors F_x

The shape factors are given in Table D-72.

Table D-72 - shape factors 2-8 D

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	39.9	d5	46.1	F5	0.867
dn15	54.4	d15	59.4	F15	0.916
dn50	95.8	d50	111.7	F50	0.858
dn90	160.6	d90	204.5	F90	0.785
dn98	177.5	d98	240.9	F98	0.737

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.89, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-88.

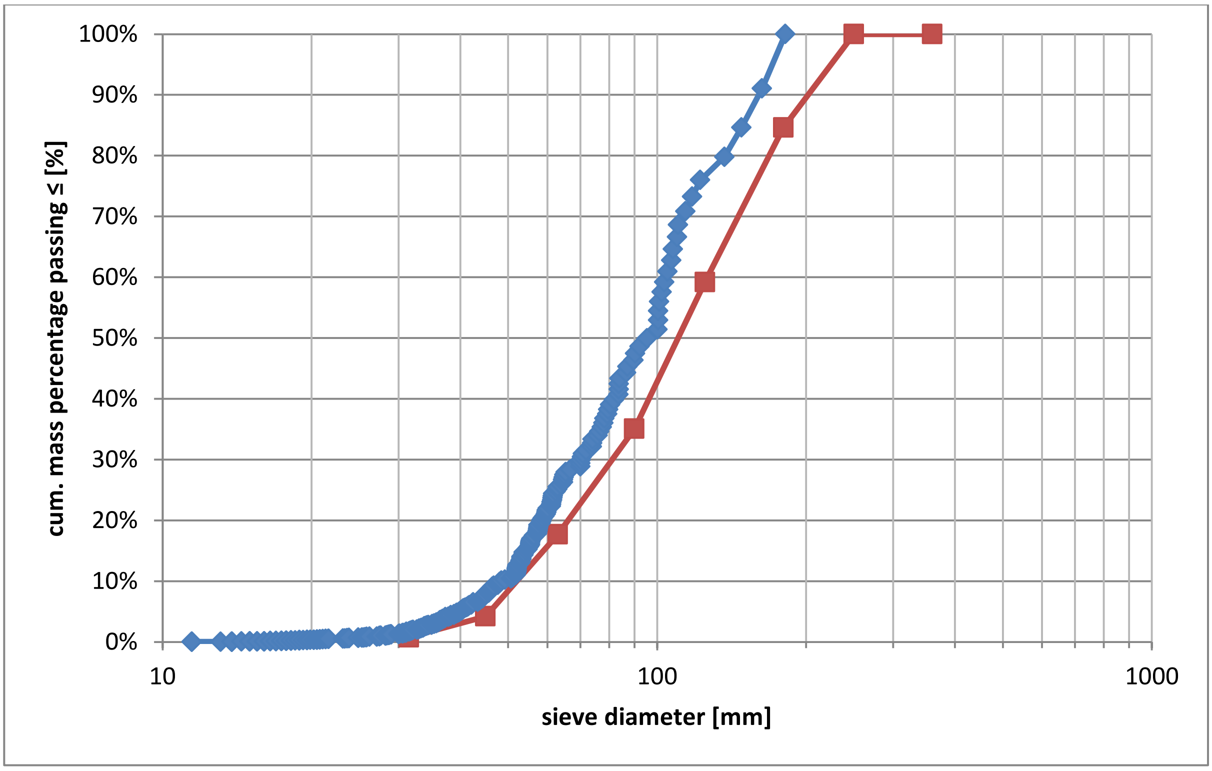


Figure D.1-88 - sieve curves 2-8 D

In Figure D.1-89 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are slightly underestimated by a value of 0.84 times the sieve curve. For larger rocks (nominal diameter > 120 mm) the accuracy of the approximation further decreases. For the largest rock (nominal diameter > approx. 150 mm) the value of the shape factor overestimates the relation between nominal and sieve diameter.

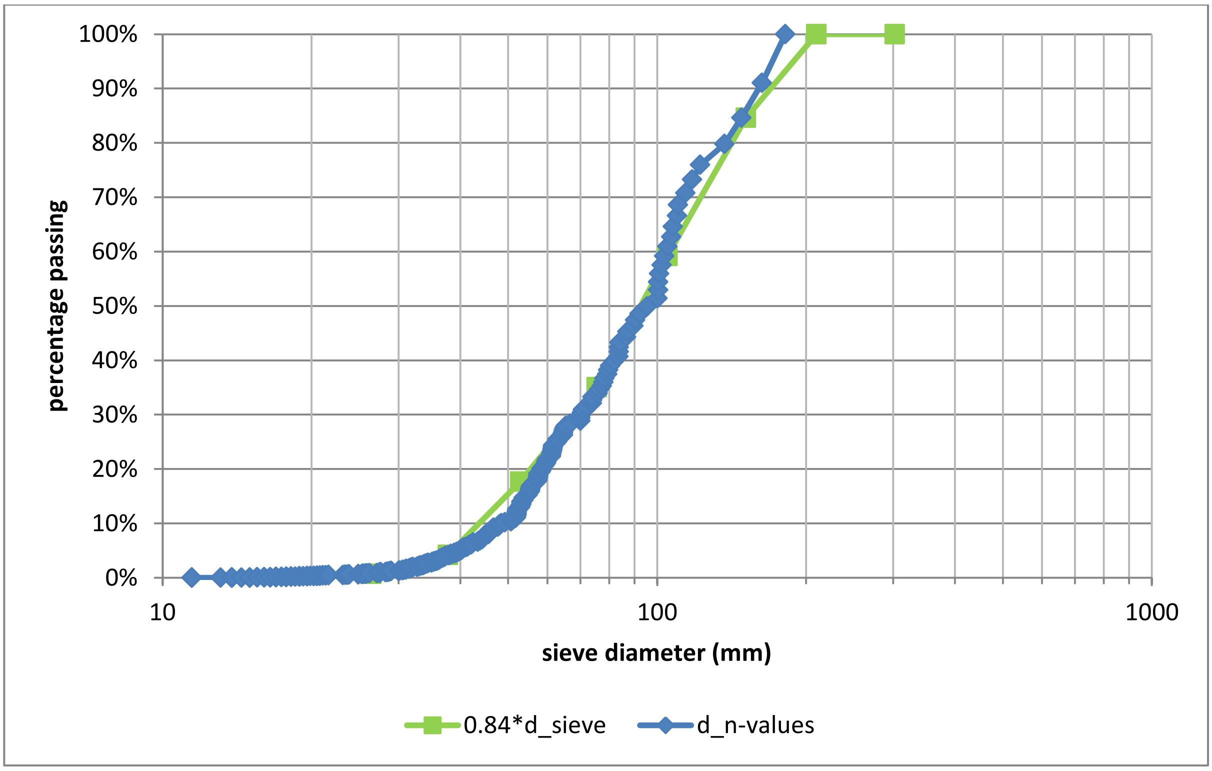


Figure D.1-89 - verification shape factor 2-8 D

D.1.3.5 Sample E

Amount of rock: 228

Sieve test

Numerical information on the sieve test is given in Table D-73.

Table D-73 - sieve test results 2-8 E

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	0.8	0.4	0.45
31.5-45	5.3	2.8	3.26
45-63	16.8	8.9	12.19
63-90	31.4	16.7	28.86
90-125	33.4	17.7	46.60
125-180	54.6	29.0	75.59
180-250	45.981	24.4	100.00
total	188.4	100.0	-

The resulting sieve curve is given in Figure D.1-90.

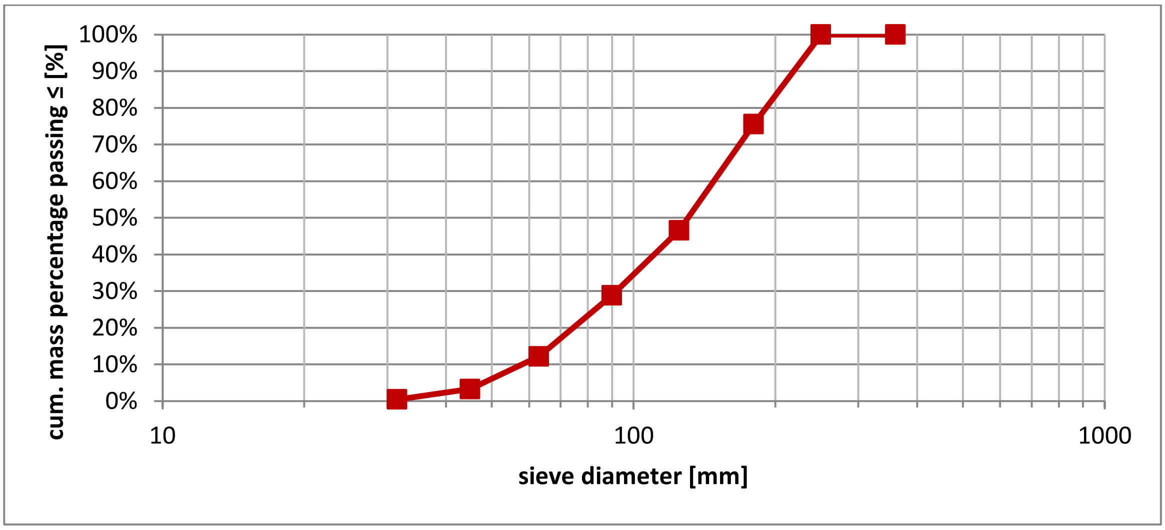


Figure D.1-90 - sieve curve 2-8 E

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-74.

Table D-74 - Interpolated sieve diameters 2-8 E

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	48.5
d10 (NLL)	58.6
d15	67.6
d25	83.8
d50 (MSD)	131.5
d60	150.4
d85	207.0
d90 (NUL)	221.3
d98 (EUL)	244.3

Grading width: d_{85}/d_{15} = 3.06. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-91 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

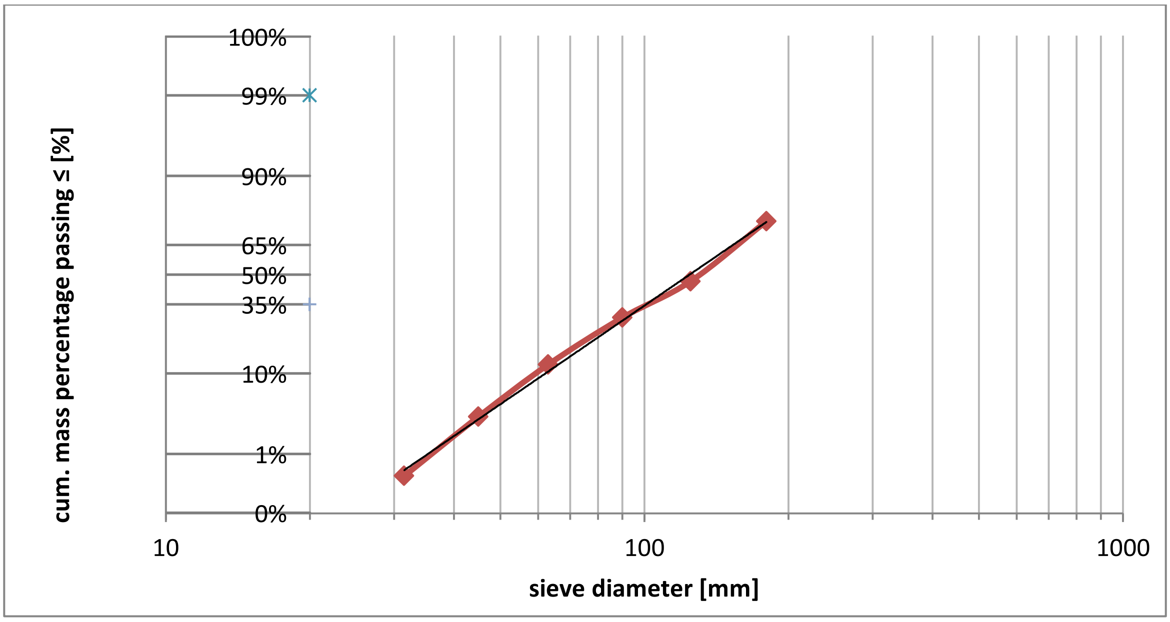


Figure D.1-91 - Gaussian sieve curve 2-8 E

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2657 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.1-92.

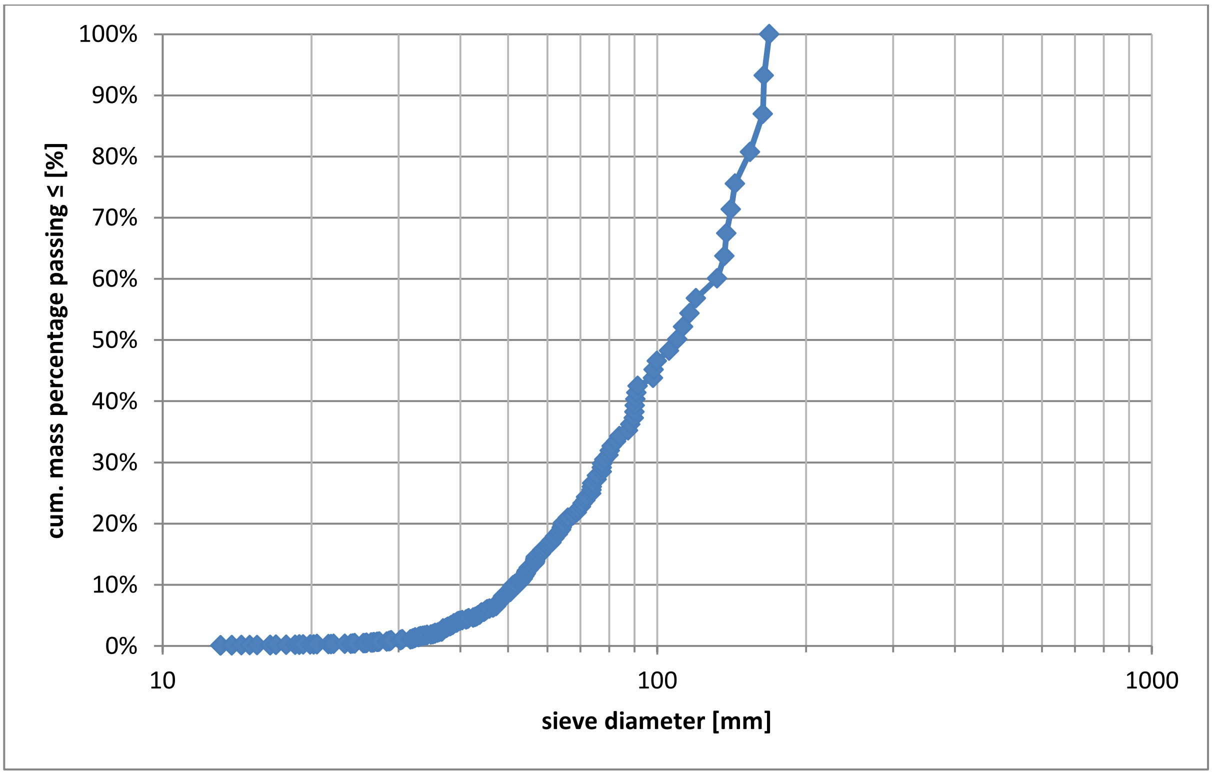


Figure D.1-92 - nominal sieve curve 2-8 E

In Table D-75 nominal diameters interpolated from Figure D.1-77 have been listed.

Table D-75 - nominal diameters 2-8 E

	nominal diameter [mm]
dn5	43.5
dn15	58.0
dn50	109.6
dn90	164.1
dn98	167.4

Shape factors F_x

The shape factors are given in Table D-76.

Table D-76 - shape factors 2-8 E

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	43.5	d5	48.5	F5	0.897
dn15	58.0	d15	67.6	F15	0.858
dn50	109.6	d50	131.5	F50	0.834
dn90	164.1	d90	221.3	F90	0.742
dn98	167.4	d98	244.3	F98	0.685

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.89, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-93.

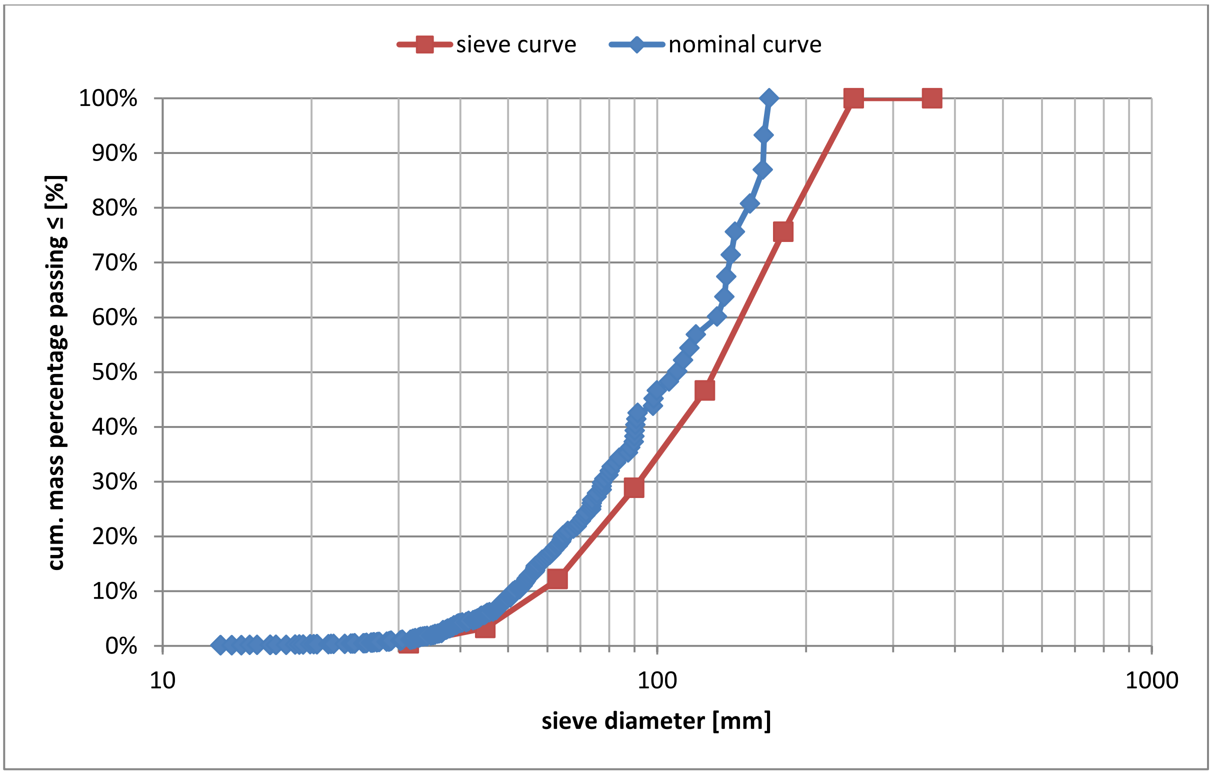


Figure D.1-93 - sieve curves 2-8 E

In Figure D.1-94 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are slightly underestimated by a value of 0.84 times the sieve curve. For larger rocks (nominal diameter > 120 mm) the accuracy of the approximation further decreases. For the largest rock (nominal diameter > approx. 150 mm) the value of the shape factor overestimates the relation between nominal and sieve diameter.

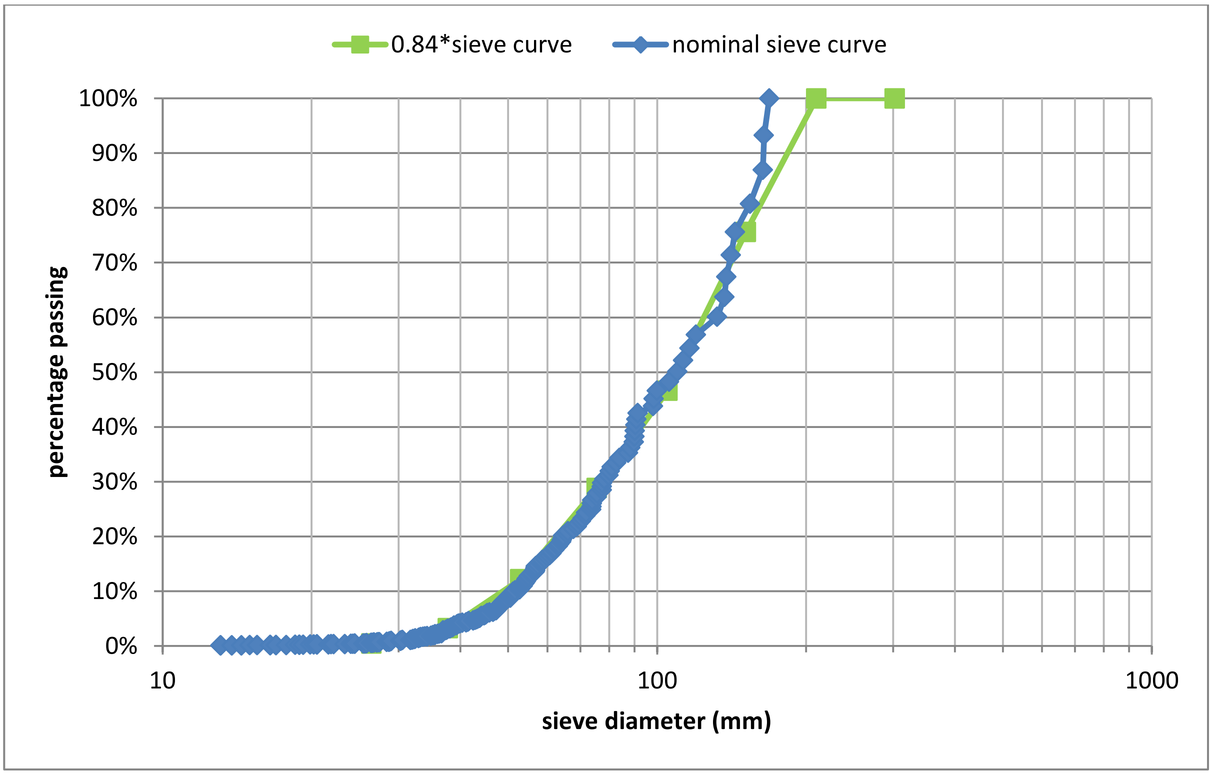


Figure D.1-94 - verification shape factor 2-8 E

D.1.3.6 Sample A-E

Amount of rock: 1290

The data represented in this sample is equivalent to the data of sample A-E together. It stressed that the results based on the combined sample is not equal to the average of the results of the separate samples.

Sieve test

Numerical information on the sieve test is given in Table D-77.

Table D-77 - sieve test results 2-8 A-E

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	5.4	0.6	0.59
31.5-45	30.4	3.3	3.86
45-63	97.5	10.5	14.36
63-90	180.7	19.5	33.83
90-125	193.8	20.9	54.70
125-180	264.3	28.5	83.17
180-250	156.2	16.8	100.00
total	928.3	100.0	-

The resulting sieve curve is given in Figure D.1-95.

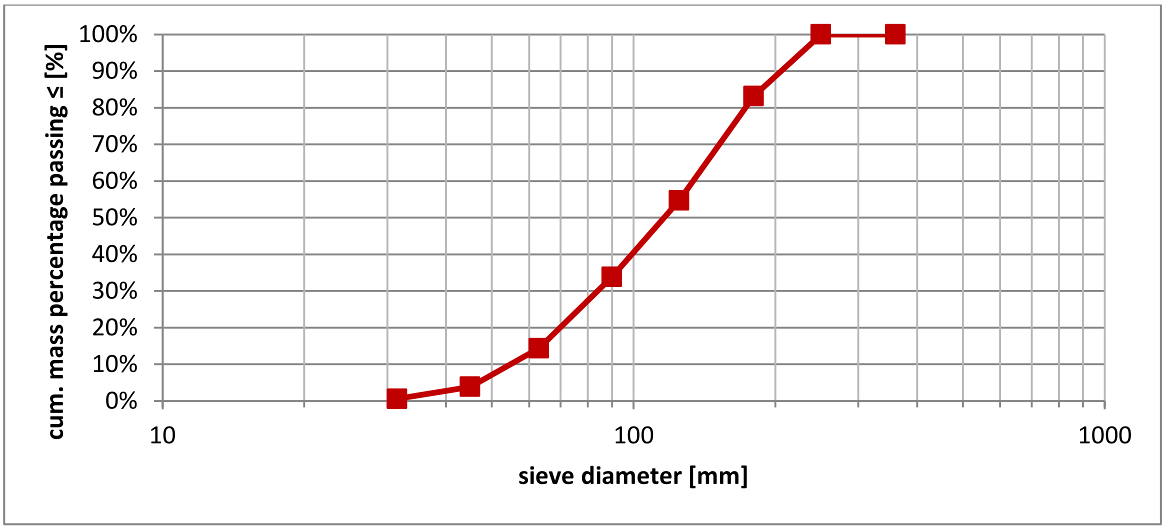


Figure D.1-95 - sieve curve 2-8 A-E

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-78.

Table D-78 - Interpolated sieve diameters 2-8 A-E

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	47.0
d10 (NLL)	55.5
d15	63.9
d25	77.8
d50 (MSD)	117.1
d60	135.2
d85	187.6
d90 (NUL)	208.4
d98 (EUL)	241.7

Grading width: d_{85}/d_{15} = 3.94. Wide coarse grading according to the Rock Manual (2007).

From Figure D.1-96 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

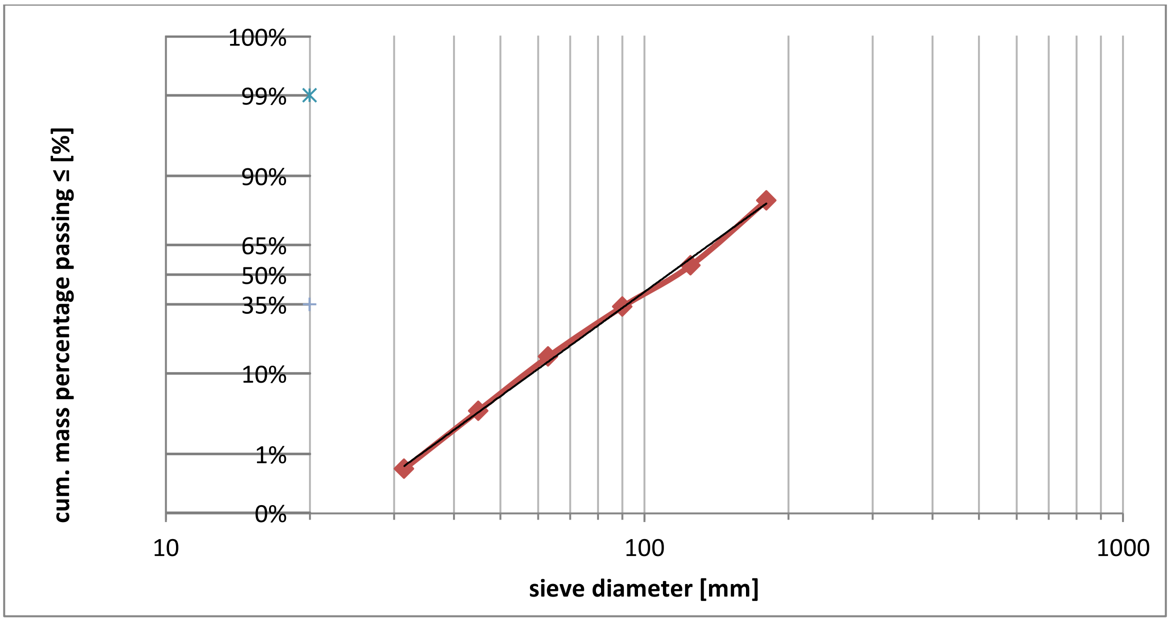


Figure D.1-96 - Gaussian sieve curve 2-8 A-E

d_n-analysis

The volumes required to determine the nominal diameters are calculated by the quotient of mass and density. Also for sample A the nominal diameters this method is applied to assure uniform information. The resulting nominal sieve curve is given in Figure D.1-97.

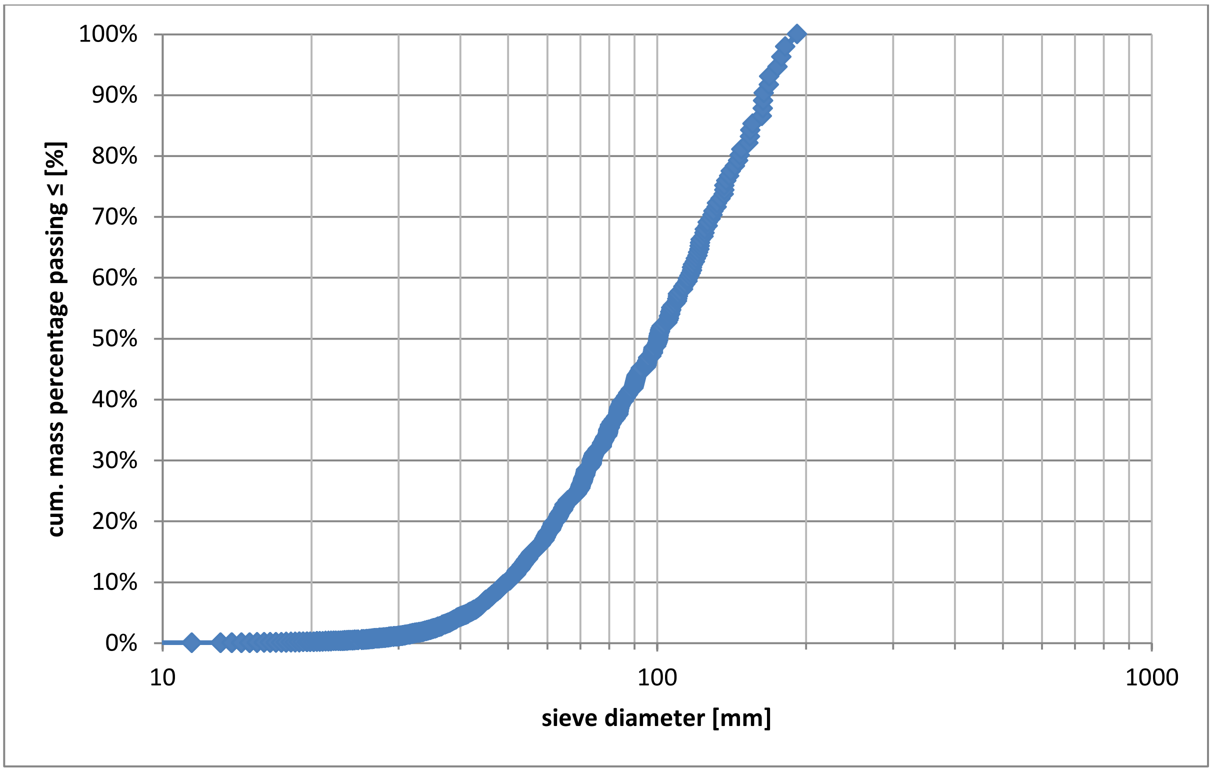


Figure D.1-97 - nominal sieve curve 2-8 A-E

In Table D-79 nominal diameters interpolated from Figure D.1-97 have been listed.

Table D-79 - nominal diameters 2-8 A-E

	nominal diameter
	[mm]
dn5	41.7
dn15	56.4
dn50	100.7
dn90	164.4
dn98	181.9

Shape factors F_x

The shape factors are given in Table D-80.

Table D-80 - shape factors 2-8 A-E

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	41.7	d5	47.0	F5	0.889
dn15	56.4	d15	63.9	F15	0.882
dn50	100.7	d50	117.1	F50	0.859
dn90	164.4	d90	208.4	F90	0.789
dn98	181.9	d98	241.7	F98	0.752

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.87, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.1-98.

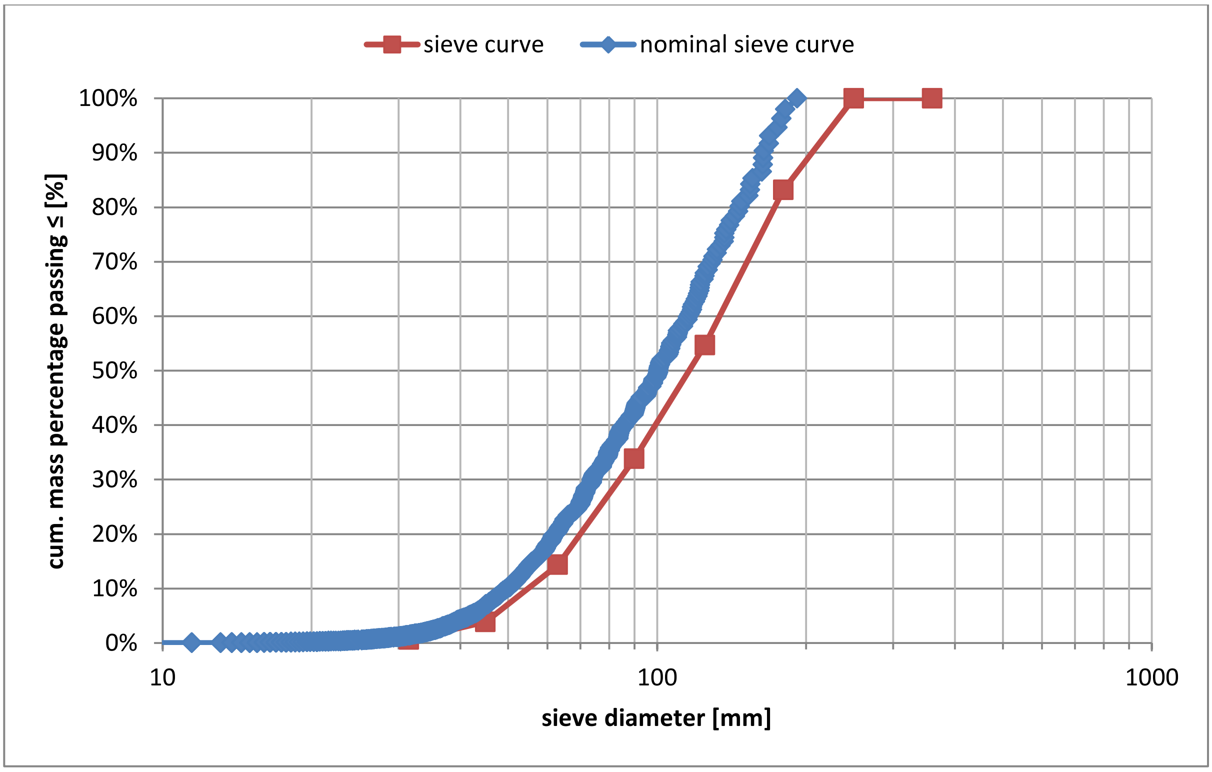


Figure D.1-98 - sieve curves 2-8 A-E

In Figure D.1-99 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the curves show reasonable overlap, especially for the relatively small rocks (nominal diameter < approx.. 60 mm). For the larger rocks the approximation is less accurate and starts to fluctuate. The nominal diameters of the largest rocks (nominal diameter > 100 mm) are significantly overestimated by the approximation.

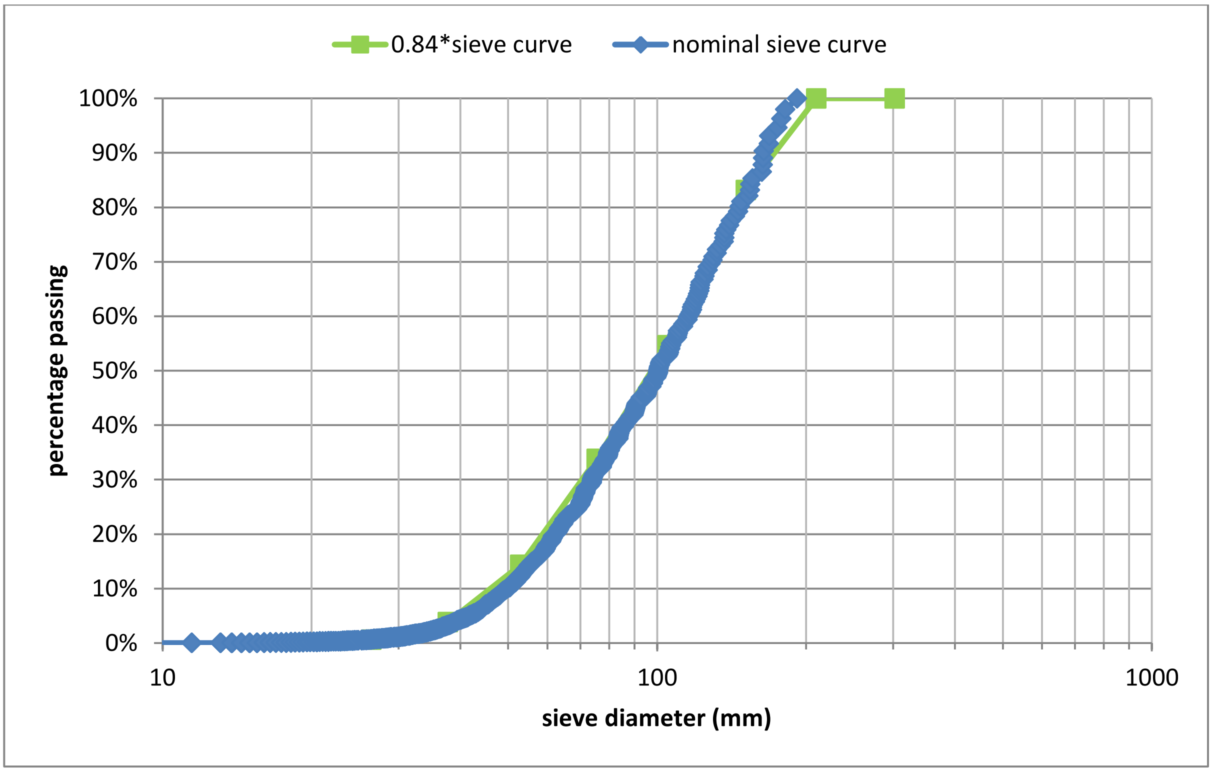


Figure D.1-99 - verification shape factor 2-8 A-E

D.1.3.7 Conclusions

The information gained on the shape factor of the 2-8 material is listed in Table D-81. It is concluded the value of the shape factor F_{50} – the value commonly applied in practice – is fluctuating between a value of 0.83-0.88 for the individual samples. The combined sample yields the value of 0.86 for F_{50}. Furthermore for each sample it is concluded the shape factor is not constant for none of the samples. Moreover, in general the value decreases significantly for the 90 and 98 cumulative mass percentage.

Table D-81 - shape factor 2-8

	Sample	A	B	C	D	E	A-E
ELL	dn5	43.732	42.984	39.279	39.916	43.521	41.731
	d5	48.889	47.104	43.828	46.050	48.503	46.947
	F5	0.895	0.913	0.896	0.867	0.897	0.889
NLL	dn15	58.355	53.944	59.927	54.398	57.968	56.353
	d15	64.634	61.943	65.831	59.384	67.559	63.884
	F15	0.903	0.871	0.910	0.916	0.858	0.882
MED	dn50	101.363	98.058	98.254	95.788	109.639	100.661
	d50	116.786	111.089	115.439	111.645	131.452	117.117
	F50	0.868	0.883	0.851	0.858	0.834	0.859
NUL	dn90	161.383	161.560	155.791	160.584	164.121	164.426
	d90	202.133	211.392	193.466	204.482	221.318	208.408
	F90	0.798	0.764	0.805	0.785	0.742	0.789
EUL	dn98	174.984	185.995	173.239	177.532	167.442	181.858
	d98	240.427	242.278	238.693	240.896	244.264	241.682
	F98	0.728	0.768	0.726	0.737	0.685	0.752

D.2 **Slovag**

D.2.1 1-5 Slovag

Origin: Wergeland Halsvik AS, Norway
Aggregate type: Basaltic rock
Shape type: Fresh

D.2.1.1 Sample A

Amount of rock: 148

Sieve test

Numerical information on the sieve test is given in Table D-82.

Table D-82 - sieve test results 1-5 A

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤31.5	1.2	1.5	1.46
31.5-45	2.9	3.7	5.11
45-63	7.8	9.8	14.90
63-90	30.8	38.7	53.58
90-125	33.3	41.8	95.36
125-150	3.7	4.6	100.00
total	79.7	100.0	-

The resulting sieve curve is given in Figure D.2-1.

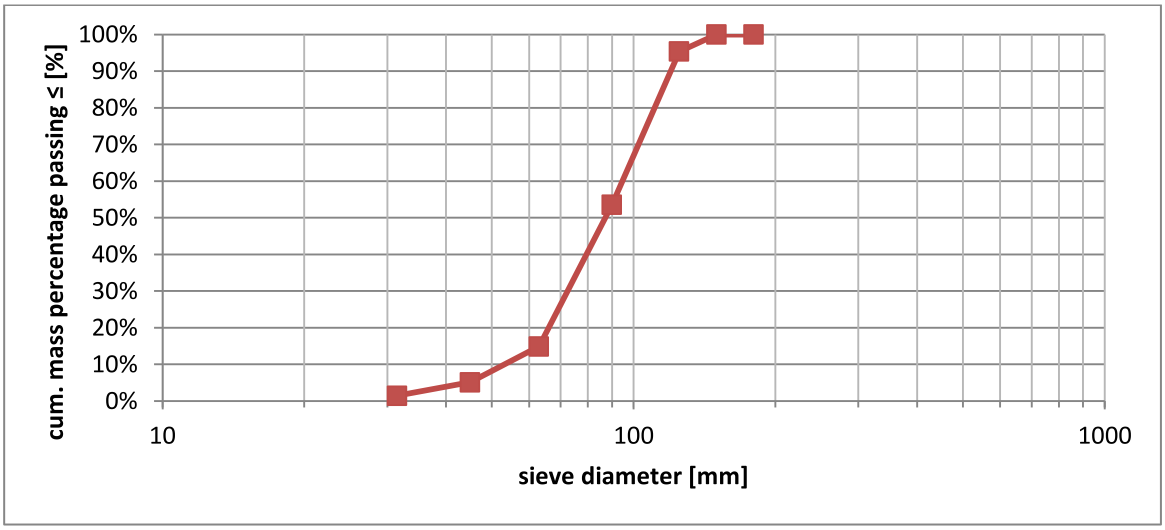


Figure D.2-1 - sieve curve 1-5 A

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-83.

Table D-83 - Interpolated sieve diameters 1-5 A

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	44.6
d10 (NLL)	54.0
d15	63.1
d25	70.1
d50 (MSD)	87.5
d60	95.4
d85	116.3
d90 (NUL)	120.5
d98 (EUL)	139.2

Grading width: d_{85}/d_{15} = 1.84. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-2 it is observed the samples mass distribution shows significant deviation over the sieve fractions from the expected normal distribution. Care should be taken during interpreting the interpolated sieve diameters.

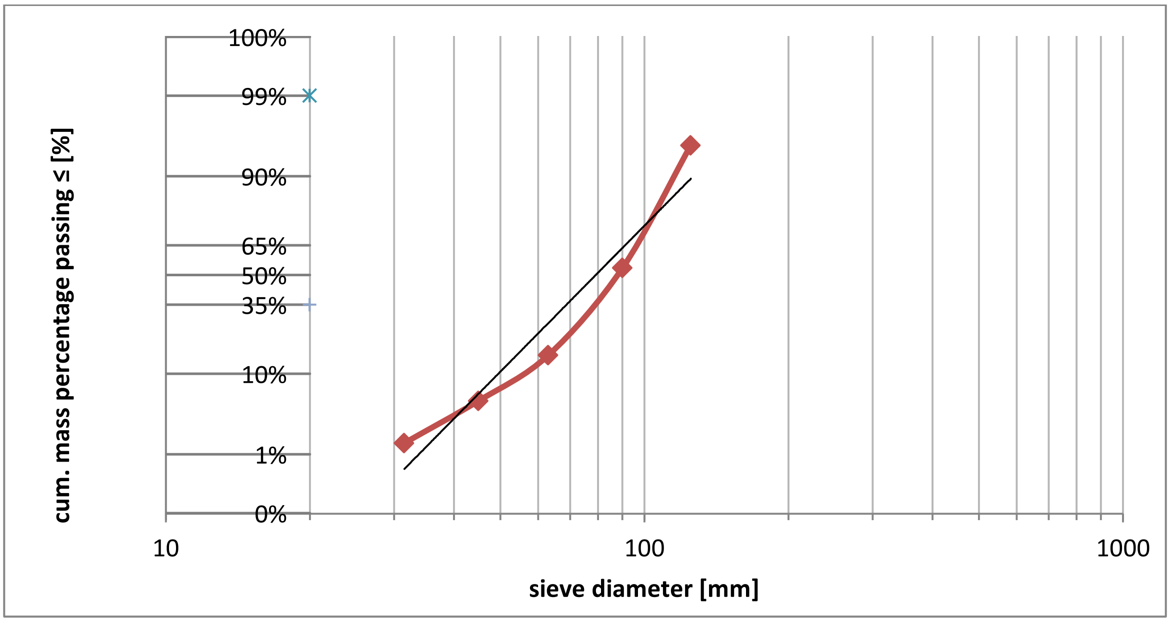


Figure D.2-2 - Gaussian sieve curve 1-5 A

d_n-analysis

The nominal sieve curve including the nominal diameters calculated by the volumes determined according to the Archimedes method is given in Figure D.2-3.

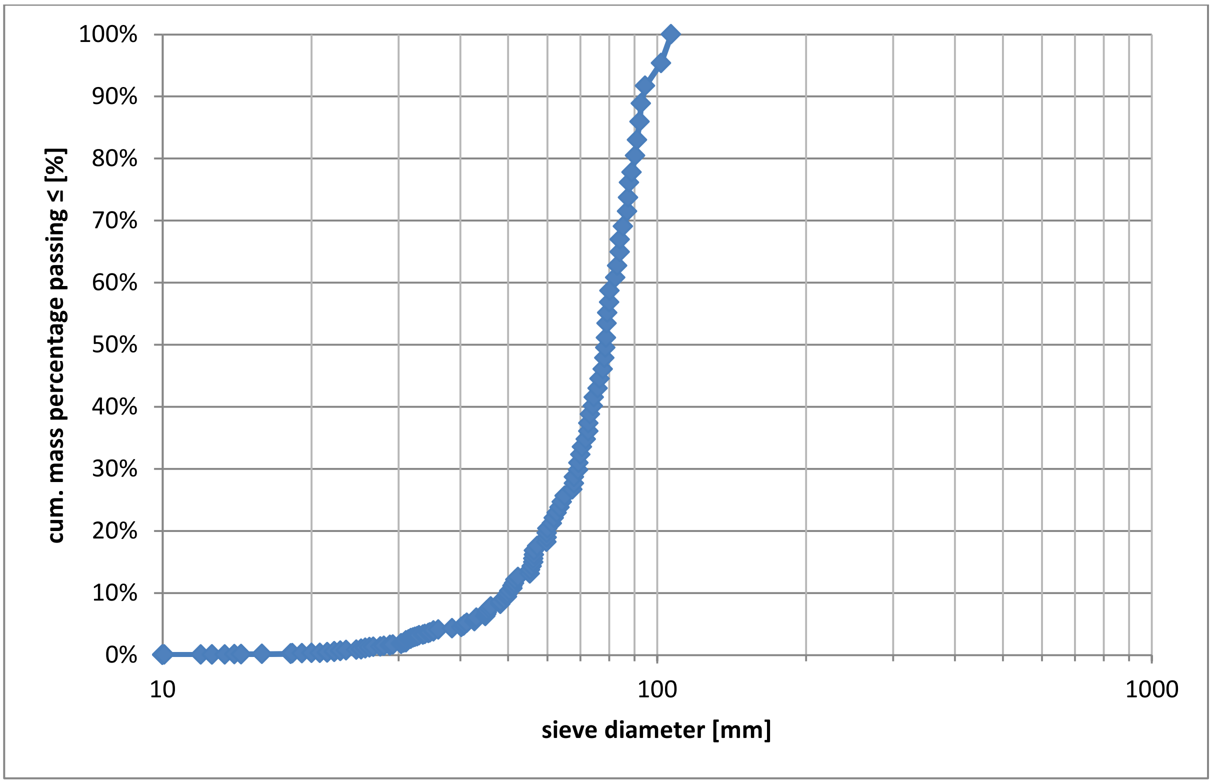


Figure D.2-3 - nominal sieve curve 1-5 A

Again the impact of scattering densities is examined. In Figure D.2-4 the individual rock densities are presented.

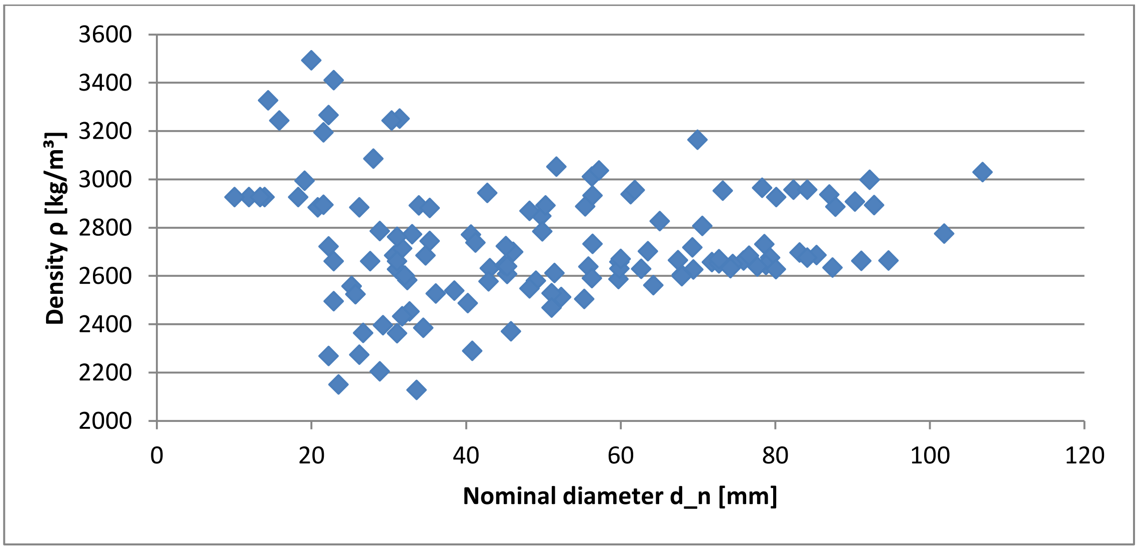


Figure D.2-4 - individual Archimedes rock densities 1-5 A

The average of the densities is 2740 kg/m³, the median is 2684 kg/m³ and the modus is 2926 kg/m³. It is concluded a lot of scatter is present, in particular for the smaller rock. By application of a uniform density the nominal diameters are recalculated. The uniform density is determined by the average density of the rocks in the 63-90 and 90-125 fractions and has a value of 2748 kg/m³. Moreover the densities of the larger rocks (nominal diameter > approx. 70 mm) tend to concentrate in two distinct bands at values of approximately 2650 and 2950 kg/m³. The observed convergence can be explained by the occurrence of different rock types in the rock face. It is concluded the uniformity of the rock is considerably low. The influence of density scatter on the determination of the shape factor is however still based on the assumption of uniform density to yield results that can be compared with the results from the IJmuiden tests and analyses.

By application of a uniform density the nominal diameters are recalculated. The uniform density is determined by the average density of the rocks in the 63-90 and 90-125 fractions and has a value of 2748 kg/m³. The nominal sieve curve based on the recalculated nominal diameters is given in Figure D.2-55.

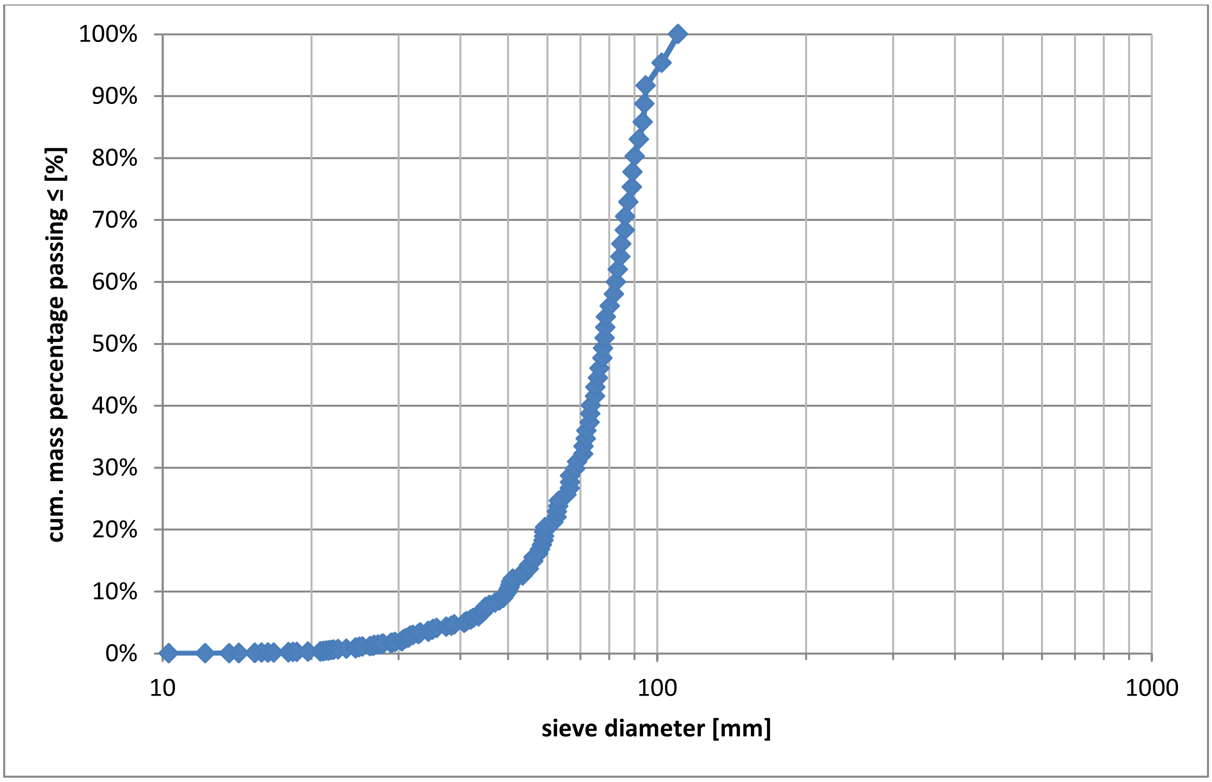


Figure D.2-5 - modified nominal sieve curve 1-5 A

The observation of two distinct density bands can however not be ignored. Therefore the above analysis is redone by application of two distinct densities. These densities are determined on the basis of a subdivision of the rock in 63-90 and 90-125 fractions into normal density rock (Archimedes density < 2800 kg/m³) and high density rock (Archimedes density > 2800 kg/m³), see Figure D.2-56 and Figure D.2-57.

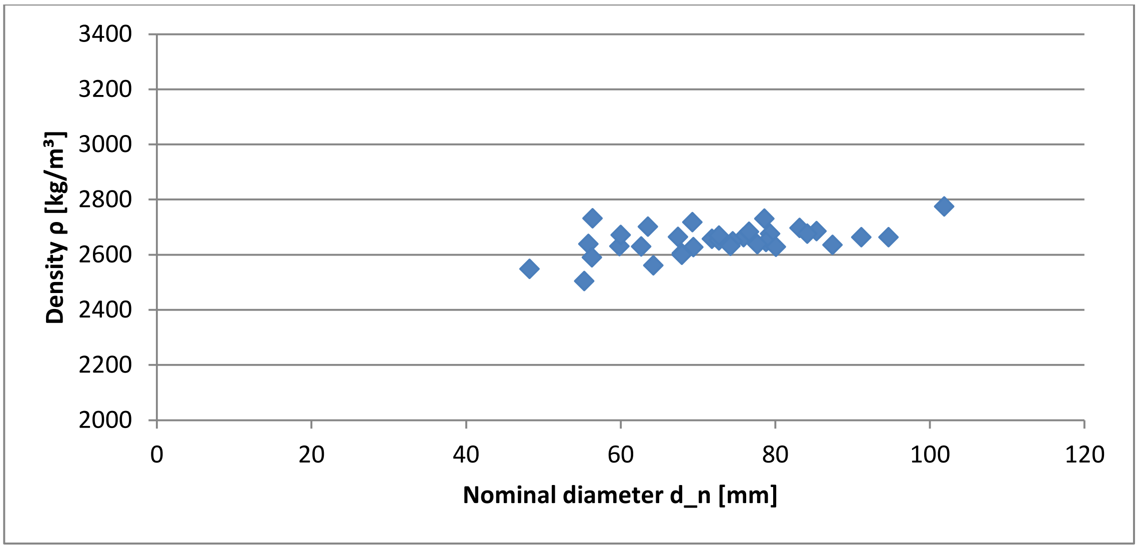


Figure D.2-6 – densities < 2800 kg/m³

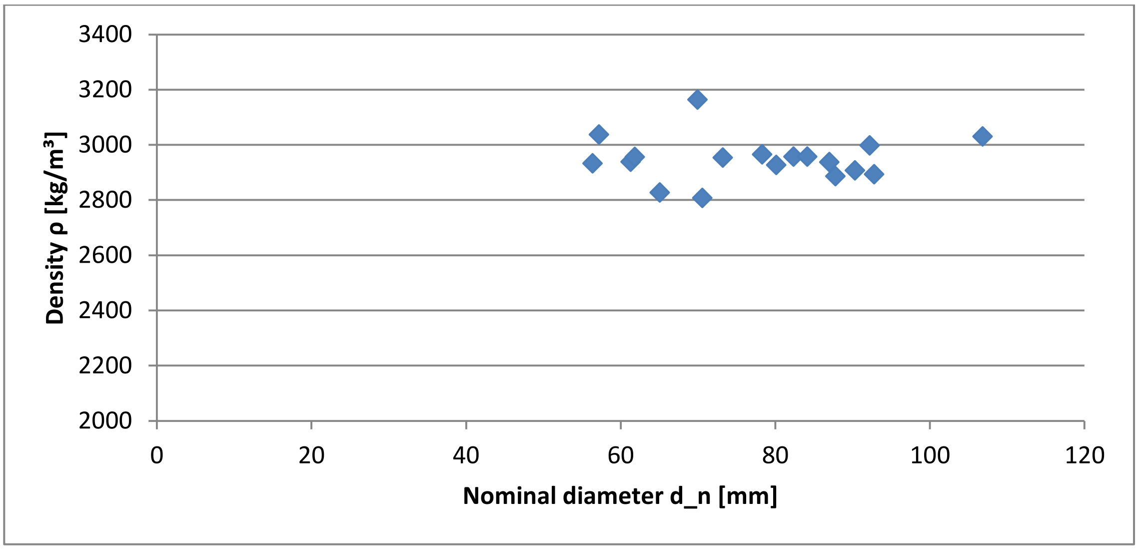


Figure D.2-7 - densities > 2800 kg/m³

The found averages of the normal density and high density rock are 2651 kg/m³ and 2948 kg/m³ respectively. To calculate the nominal diameters the value of 2651 kg/m³ is applied for all rocks having an Archimedes density below 2800 kg/m³. Accordingly the value of 2948 is applied for all rocks having an Archimedes density above 2800 kg/m³.

The resulting nominal sieve curve is given in Figure D.2-58.

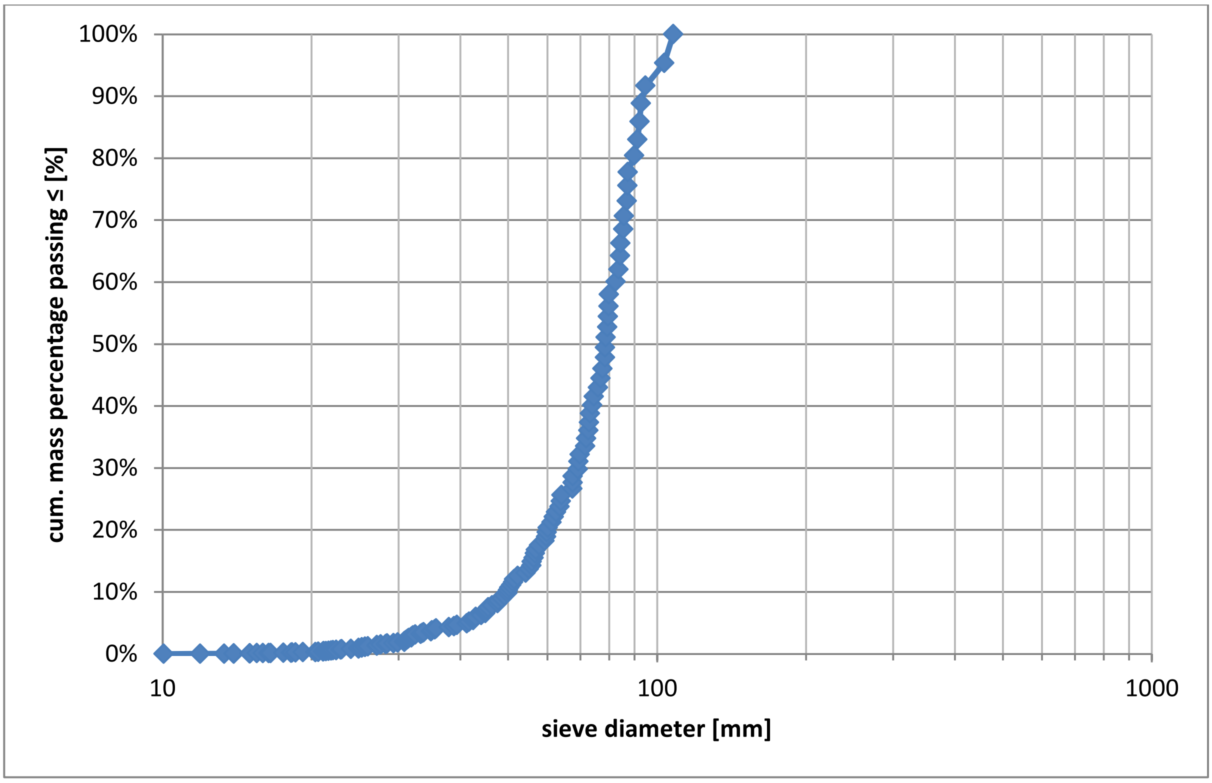


Figure D.2-8 - nominal sieve curve acc. to normal density and high density

In Table D-84 the interpolated nominal diameters based on both the Archimedes, modified and specific volumes are listed.

Table D-84 - comparison of dn-values acc. to Archimedes and modified volumes 1-5+ A

nominal diameter	acc. to Arc volumes	acc. Mod volumes	acc. to spec volumes
	[mm]	[mm]	[mm]
dn5	41.0	40.9	41.4
dn15	56.3	56.3	55.9
dn50	78.7	78.1	78.6
dn90	93.6	94.6	93.6
dn98	104.7	106.8	105.9

From Table D-84 it is concluded the differences in the nominal diameters found on basis of the three different methods are relatively small. In case of the median nominal diameter the largest difference is found between the value found by the Archimedes method and the modified method: 0.6 mm. This implies a relative error approximately of only 0.5 percent. It is therefore concluded the observed scatter in the densities do not cause the nominal diameters found by either method to be unrealistic. Therefore the nominal diameters on the basis of the Archimedes volumes are applied in this sample.

Shape factors F_x

The shape factors are given in Table D-85.

Table D-85 - shape factors 1-5 A

nominal diameter				sieve diameter		shape factor			
[mm]	Arc	mod	spec	[mm]		[mm]	Arc	mod	spec
dn5	41.0	40.9	41.4	d5	44.6	F5	0.919	0.917	0.928
dn15	56.3	56.3	55.9	d15	63.1	F15	0.893	0.893	0.887
dn50	78.7	78.1	78.6	d50	87.5	F50	0.899	0.892	0.899
dn90	93.6	94.6	93.6	d90	120.5	F90	0.777	0.785	0.777
dn98	104.7	106.8	105.9	d98	139.2	F98	0.752	0.767	0.761

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.89-0.90, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-9.

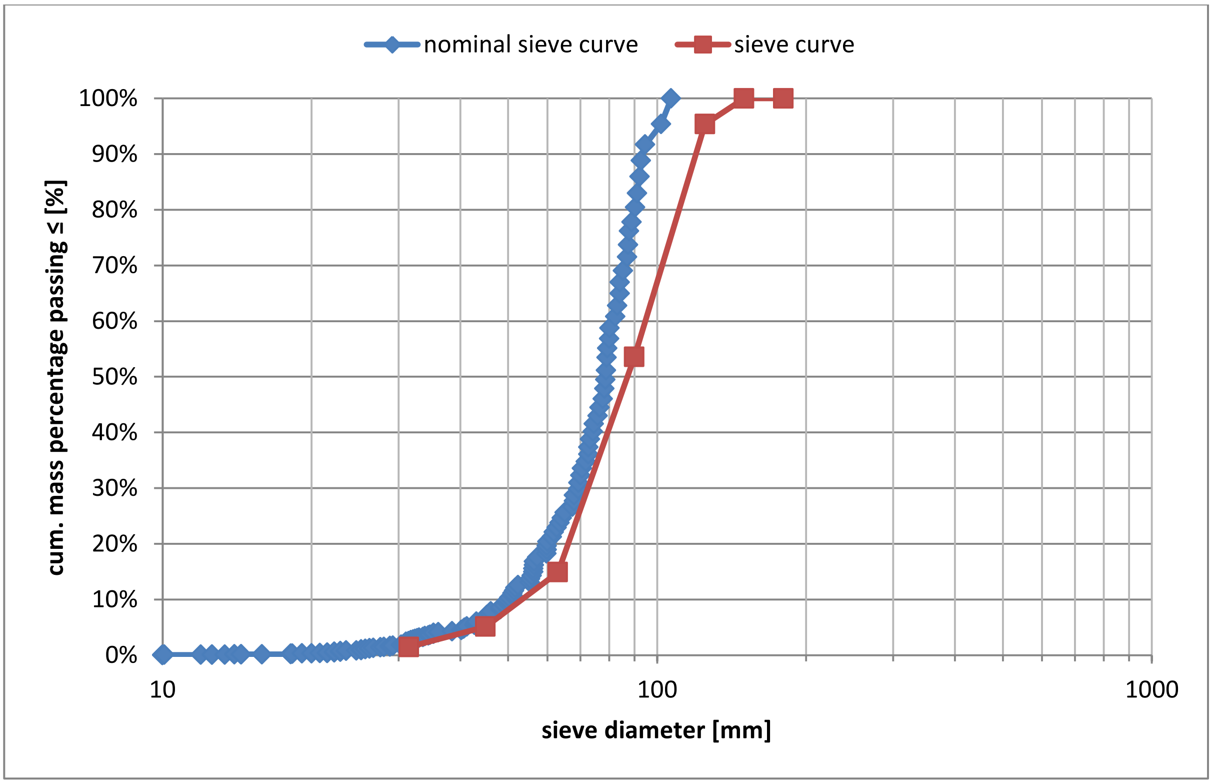


Figure D.2-9 - curves 1-5 A

In Figure D.2-10 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the product of shape factor and sieve diameter slightly underestimated the nominal diameter for rocks having a nominal diameter of 40 to 80 mm. Larger rocks is overestimated by the approximation.

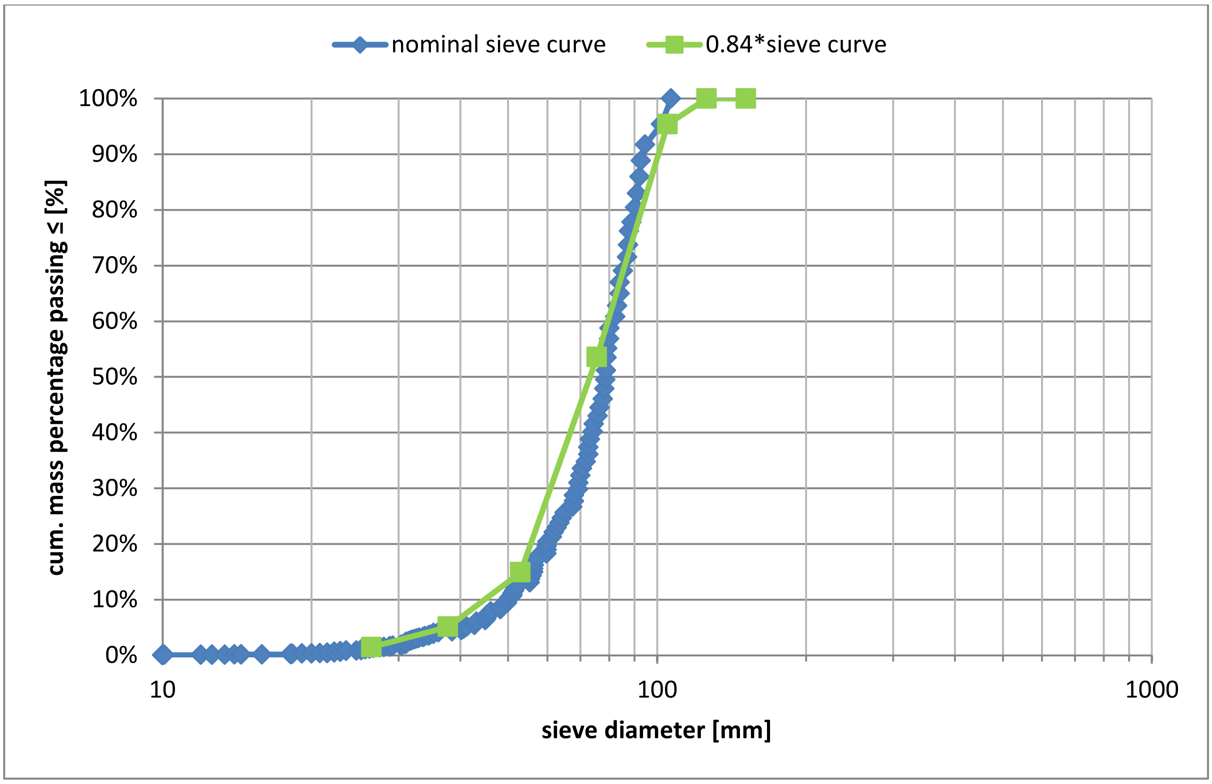


Figure D.2-10 - verification shape factor 1-5 A

Shape test

In Table D-86 and Table D-87 an overview is given of the minimum, maximum and average values of the elongation and blockiness respectively.

Table D-86 - elongation 1-5 A

	Elongation		
	minimum [-]	maximum [-]	average [-]
0-31.5	1.42	5.00	3.02
31.5-45	1.61	4.93	2.76
45-63	1.64	6.44	2.89
63-90	1.45	7.07	2.70
90-125	1.38	4.02	2.22
125-150	1.91	1.91	1.91
total	1.38	7.07	2.76

Table D-87 -blockiness 1-5 A

	Blockiness		
	minimum [%]	maximum [%]	average [%]
0-31.5	11.20	64.76	44.43
31.5-45	29.72	63.19	43.94
45-63	29.95	52.77	41.77
63-90	28.53	61.76	40.20
90-125	31.00	51.59	40.76
125-150	52.17	52.17	52.17
total	11.20	64.74	42.48

It is stressed that the calculated elongation and blockiness values in the 125-180 mm fraction is based on the only 1 rock. This value as a result has no statistical value and is left out the analysis.

Considering the other fractions the minimum value for elongation is 1.38. The maximum value of elongation observed in these rocks is 7.07. Furthermore the minima is rather constant over the fractions, for the maxima significant fluctuations are observed. The average elongation tends to decrease over the sieve fractions. Considering blockiness the minimum and maximum blockiness found are 11 respectively 65 percent approximately. 11 percent blockiness represents a very hollow shape, which is not found in the sample and therefore most probably the result of a measurement error. The other average blockiness values over the fractions are relatively constant. It is concluded no significant trends are observed in elongation nor blockiness for this sample.

D.2.1.2 Sample B

Amount of rock: 534

Sieve test

Numerical information on the sieve test is given in Table D-88.

Table D-88 - sieve test results 1-5 B

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤31.5	6.9	7.3	7.27
31.5-45	19.4	20.6	27.82
45-63	18.4	19.4	47.26
63-90	34.4	36.5	83.73
90-125	15.4	16.3	100.00
total	94.4	100.0	-

The resulting sieve curve is given in Figure D.2-61.

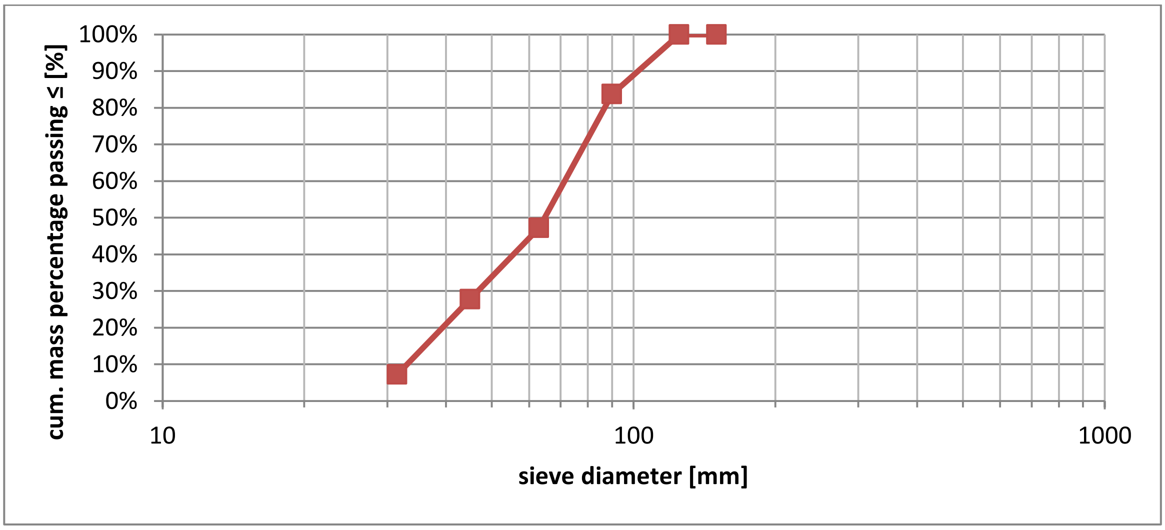


Figure D.2-11 - sieve curve 1-5 B

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-89.

Table D-89 - Interpolated sieve diameters 1-5 B

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	21.7
d10 (NLL)	33.3
d15	36.6
d25	43.1
d50 (MSD)	65.0
d60	72.4
d85	92.7
d90 (NUL)	103.5
d98 (EUL)	120.7

Grading width: d_{85}/d_{15} = 2.54. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-12 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

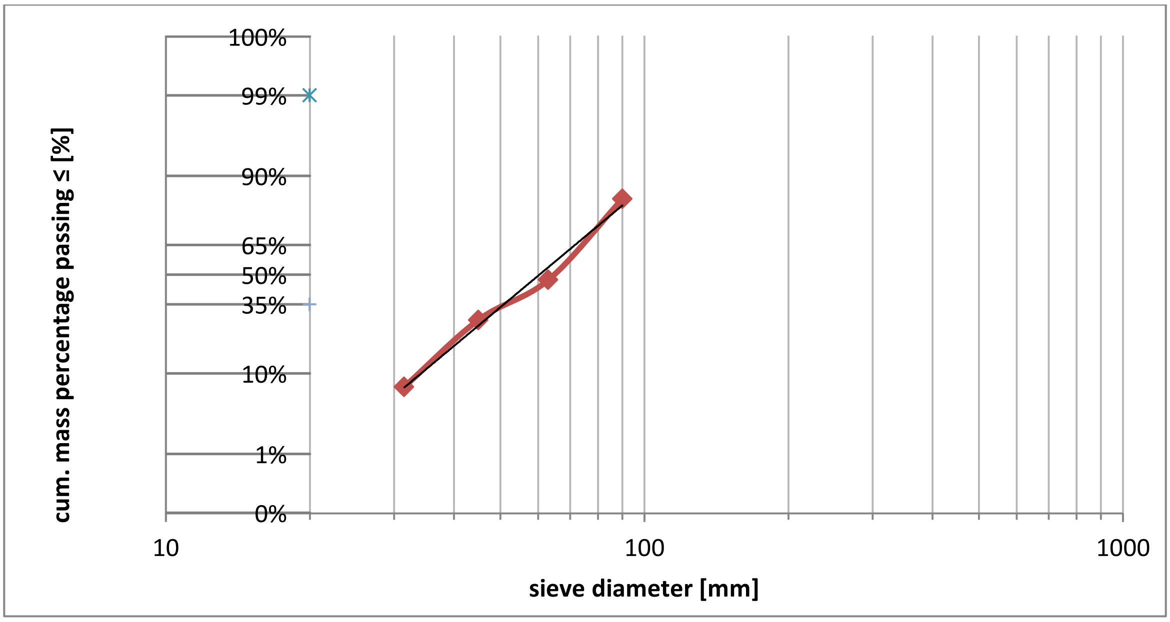


Figure D.2-12 - Gaussian sieve curve 1-5 B

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2750 kg/m³. As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.2-13.

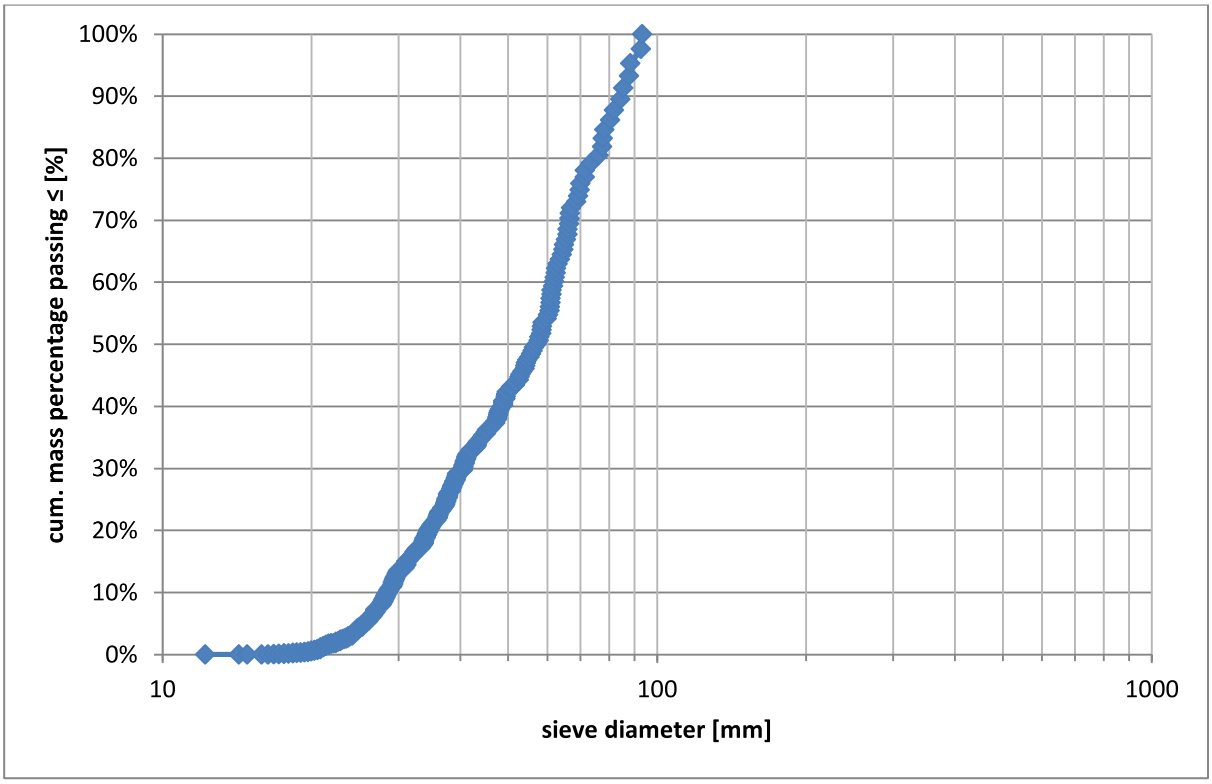


Figure D.2-13 - nominal sieve curve 1-5 B

In Table D-90 nominal diameters interpolated from Figure D.2-13 have been listed.

Table D-90 - nominal diameters 1-5 B

	nominal diameter
	[mm]
dn5	43.0
dn15	53.9
dn50	98.1
dn90	161.6
dn98	186.0

Shape factors F_x

The shape factors are given in Table D-91.

Table D-91 - shape factors 1-5 B

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	43.0	d5	47.1	F5	0.913
dn15	53.9	d15	61.9	F15	0.871
dn50	98.1	d50	111.1	F50	0.883
dn90	161.6	d90	211.4	F90	0.764
dn98	186.0	d98	242.3	F98	0.768

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.88, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-14.

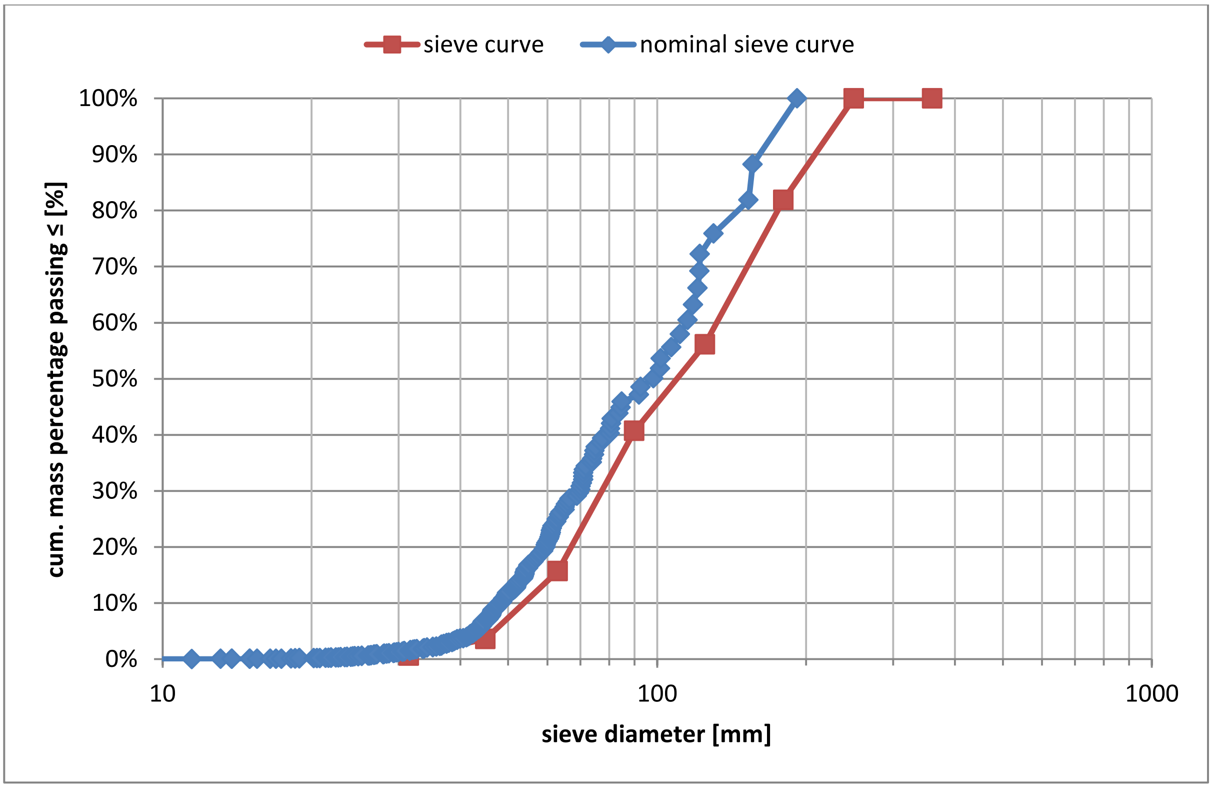


Figure D.2-14 - sieve curves 1-5 B

In Figure D.2-15 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the nominal diameters are in general approximated rather well by the product of shape factor and sieve diameter. For larger rocks (nominal diameter > 120 mm) the accuracy however decreases slightly.

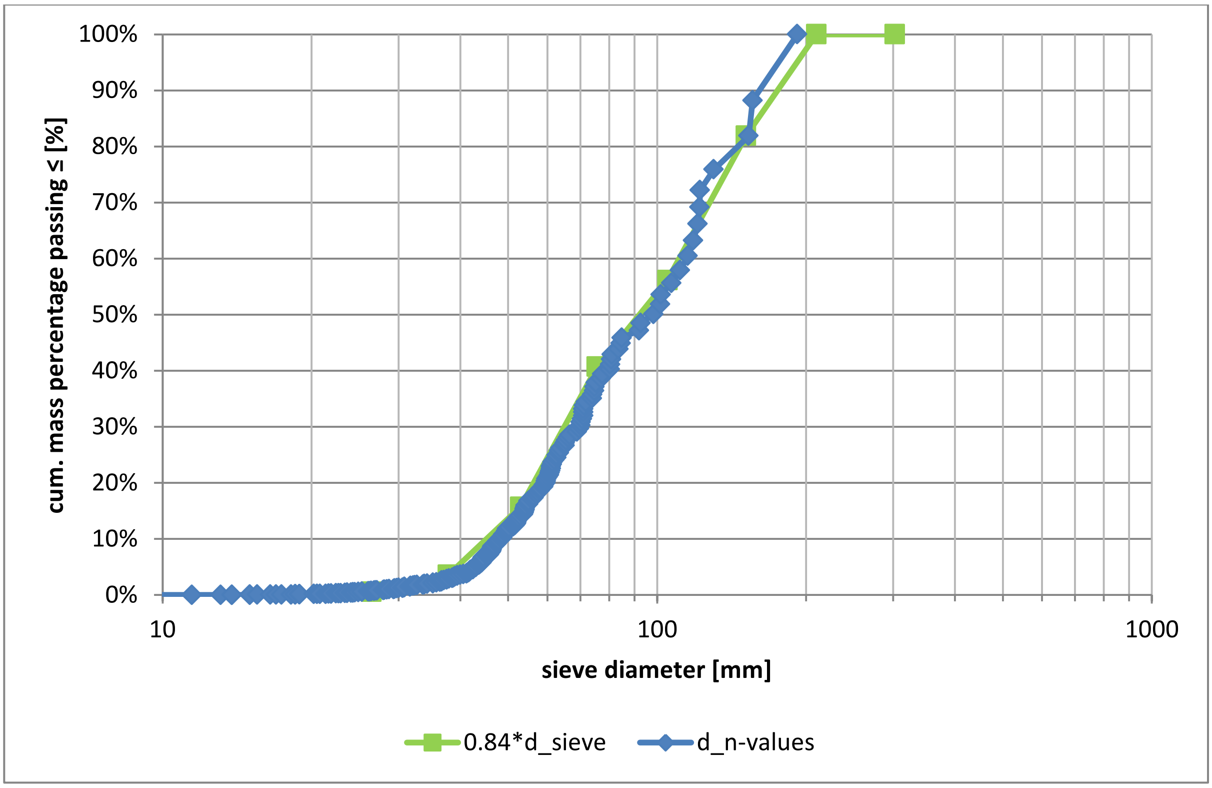


Figure D.2-15 - verification shape factor 1-5 B

Sample C
Amount of rock: 709

Sieve test

Numerical information on the sieve test is given in Table D-92.

Table D-92 - sieve test results 1-5 C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤25	12.9	11.7	11.70
25-31.5	11.4	10.3	22.01
31.5-45	21.5	19.5	41.46
45-63	20.5	18.6	60.05
63-90	27.4	24.8	84.89
90-125	16.7	15.1	100.00
total	110.3	100.0	-

The resulting sieve curve is given in Figure D.2-16.

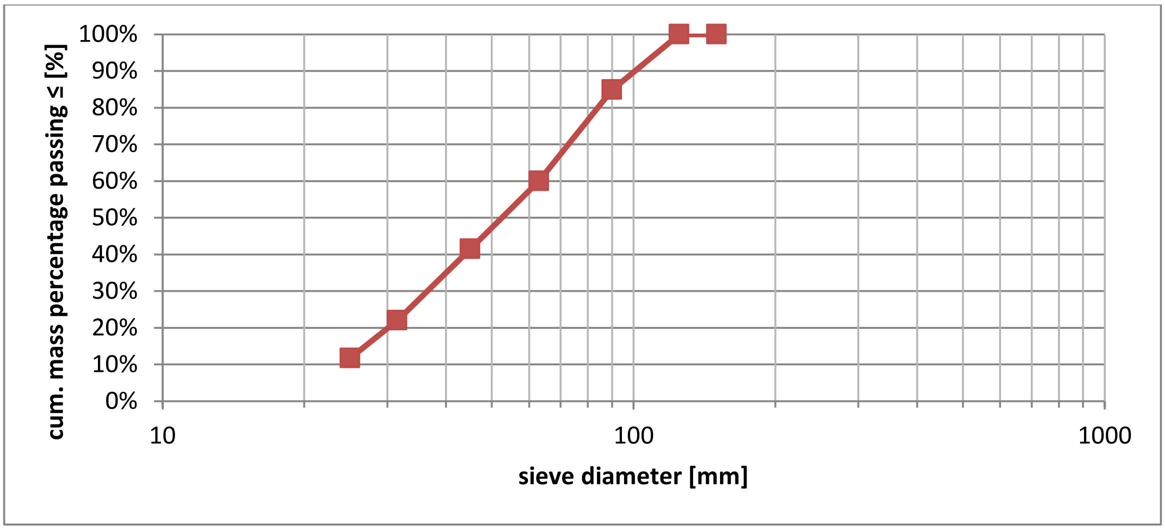


Figure D.2-16 - sieve curve 1-5 C

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-93.

Table D-93 - Interpolated sieve diameters 1-5 C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	-
d10 (NLL)	-
d15	27.1
d25	33.6
d50 (MSD)	53.3
d60	63.0
d85	90.3
d90 (NUL)	101.8
d98 (EUL)	120.4

Since more than 10 percent of the mass passed the smallest applied sieve, the sieve diameters associated with 5 and 10 cumulative mass percent could not be determined by interpolation. This problem can be overcome by application of an extrapolation technique. Since the uncertainties that would have introduced by extrapolation and its eventual effect on the determination of the shape factor this technique is not applied and the d_5 and d_{10} values are left blank.

Grading width: d_{85}/d_{15} = 3.33. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-17 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

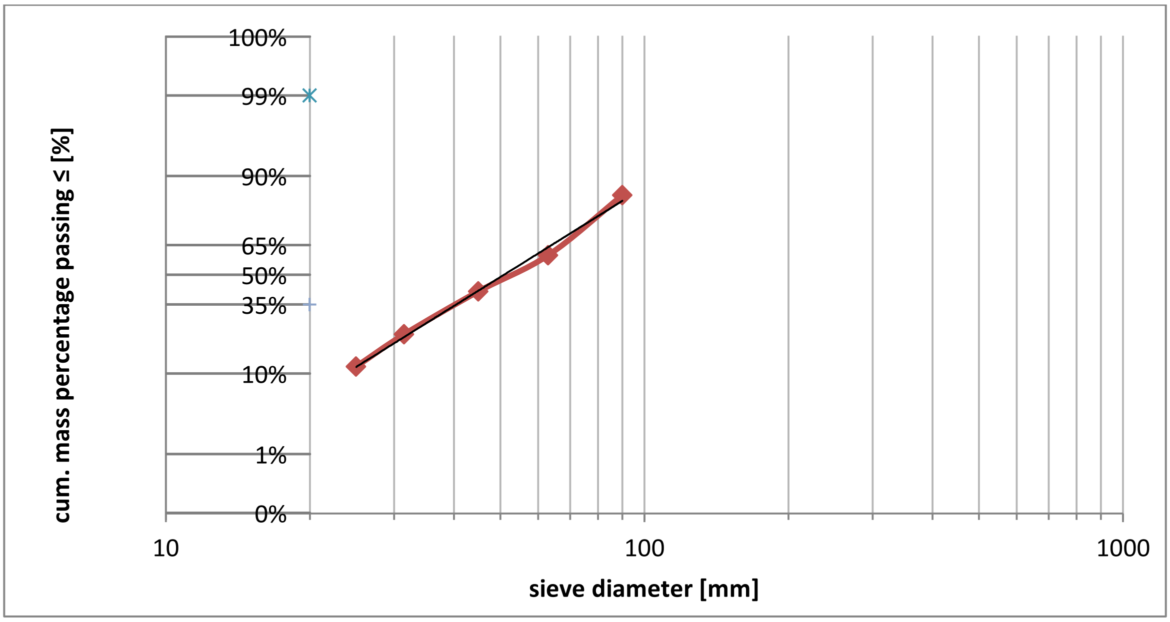


Figure D.2-17 - Gaussian sieve curve 1-5 C

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2750 kg/m³. As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.2-18.

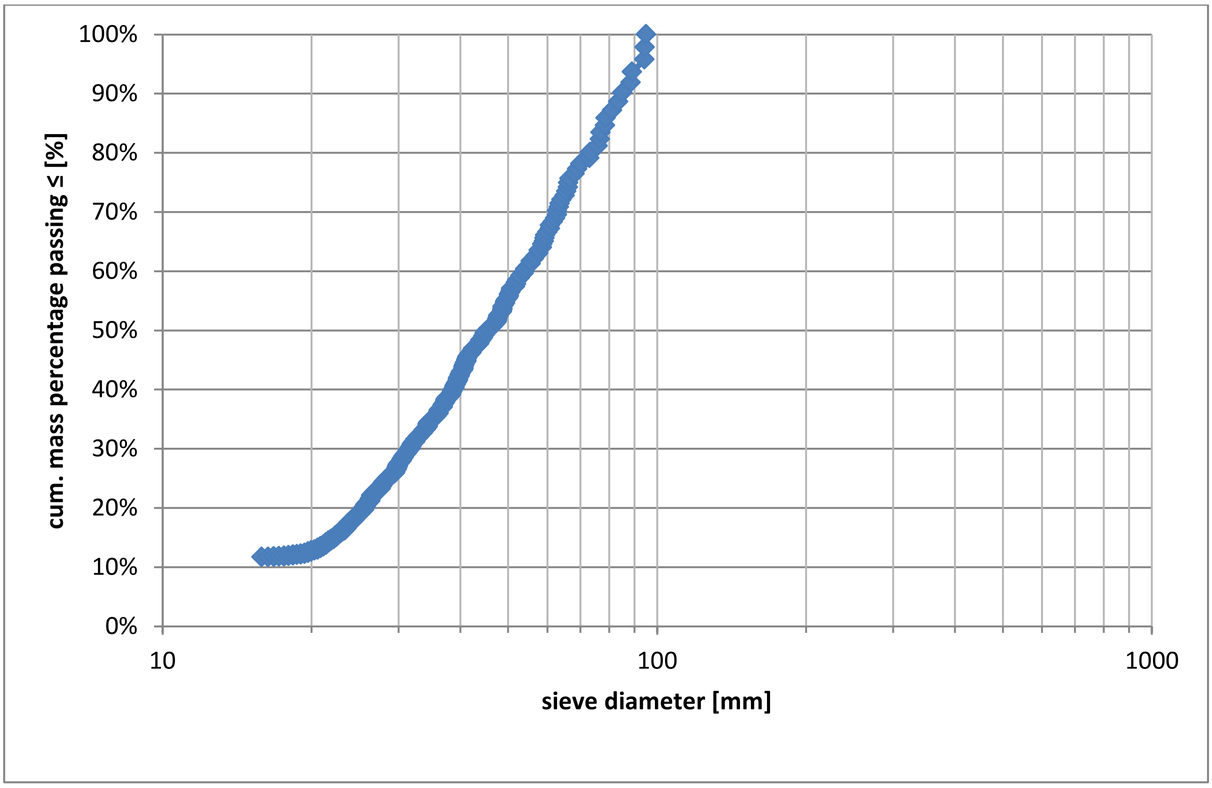


Figure D.2-18 - nominal sieve curve 1-5 C

In Table D-132 nominal diameters interpolated from Figure D.2-18 have been listed.

Table D-94 - nominal diameters 1-5 C

	nominal diameter [mm]
dn5	13.7
dn15	22.2
dn50	45.6
dn90	84.9
dn98	94.5

Shape factors F_x

The shape factors are given in Table D-95.

Table D-95 - shape factors 1-5 C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	13.7	d5	-	F5	-
dn15	22.2	d15	27.1	F15	0.819
dn50	45.6	d50	53.3	F50	0.856
dn90	84.9	d90	101.8	F90	0.834
dn98	94.5	d98	120.4	F98	0.785

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.86, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-19.

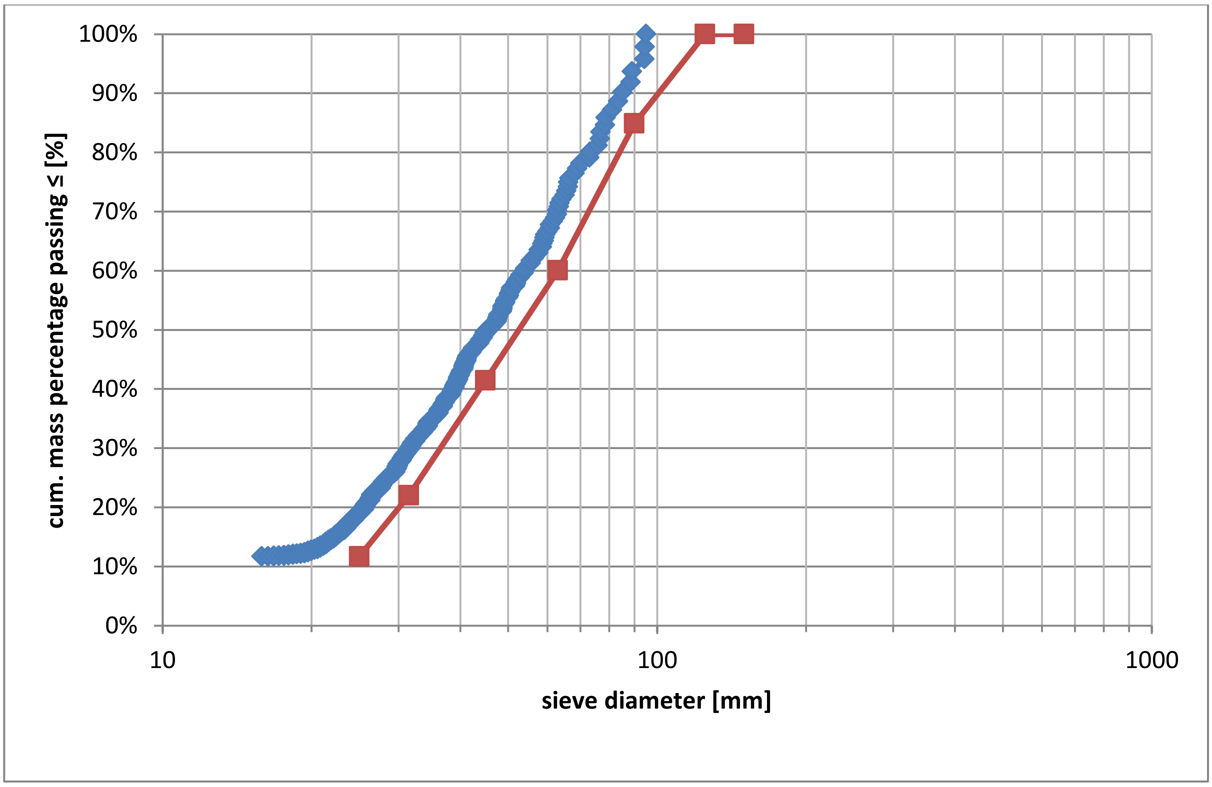


Figure D.2-19 - sieve curves 1-5 C

In Figure D.2-20 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the nominal diameters are in general approximated rather well by the product of shape factor and sieve diameter. For larger rocks (nominal diameter > 120 mm) the accuracy however decreases slightly.

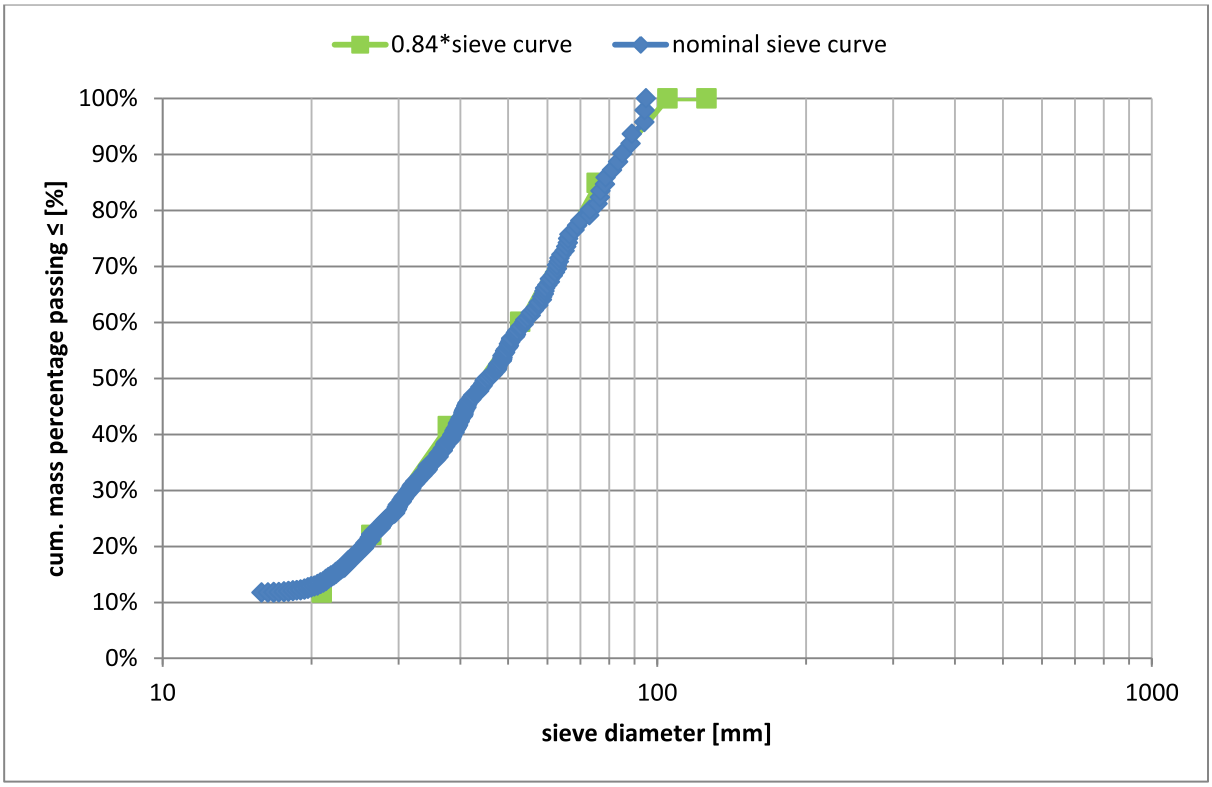


Figure D.2-20 - verification shape factor 1-5 C

D.2.1.3 Sample A-C combined

Amount of rock: 1391

The data represented in this sample is equivalent to the data of sample A-C together. It stressed that the results based on the combined sample is not equal to the average of the results of the separate samples.

Sieve test

Numerical information on the sieve test is given in Table D-96.

Table D-96 - sieve test results 1-5 A-C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤25	12.9	4.5	4.5
25-31.5	19.4	6.8	11.4
31.5-45	43.8	15.4	26.8
45-63	46.7	16.4	43.2
63-90	92.6	32.6	75.7
90-125	65.3	23.0	98.7
125-150	3.7	1.3	100.0
total	284.4	100.0	-

The resulting sieve curve is given in Figure D.2-21.

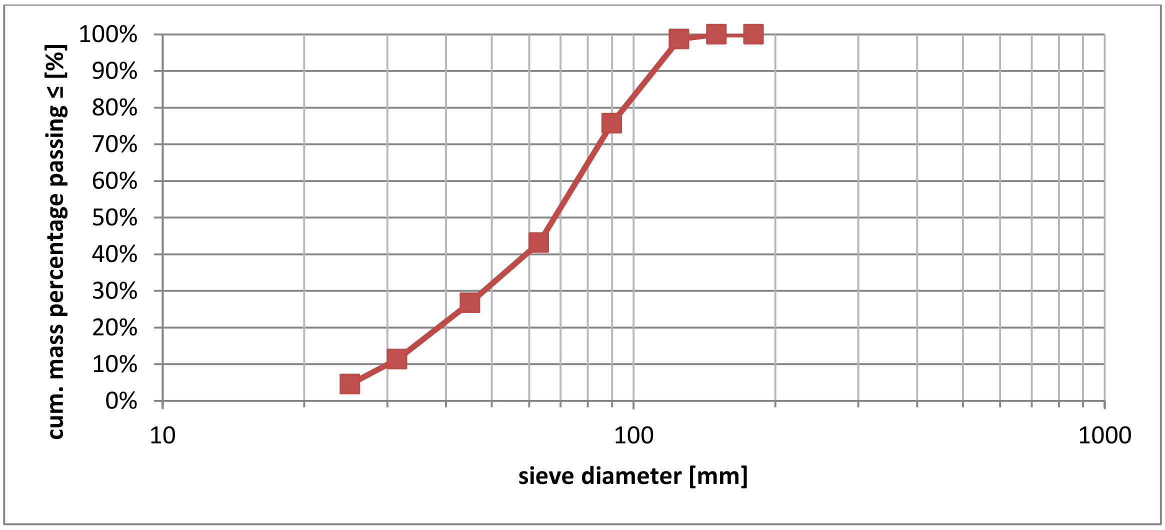


Figure D.2-21 - sieve curve 1-5 A-C

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-97.

Table D-97 - Interpolated sieve diameters 1-5 A-C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	25.44
d10 (NLL)	30.20
d15	34.69
d25	43.46
d50 (MSD)	68.67
d60	76.96
d85	104.12
d90 (NUL)	111.74
d98 (EUL)	123.93

Grading width: d_{85}/d_{15} = 3.00. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-22 it is observed the samples mass distribution shows significant deviation over the sieve fractions from the expected normal distribution. Care should be taken during interpreting the interpolated sieve diameters.

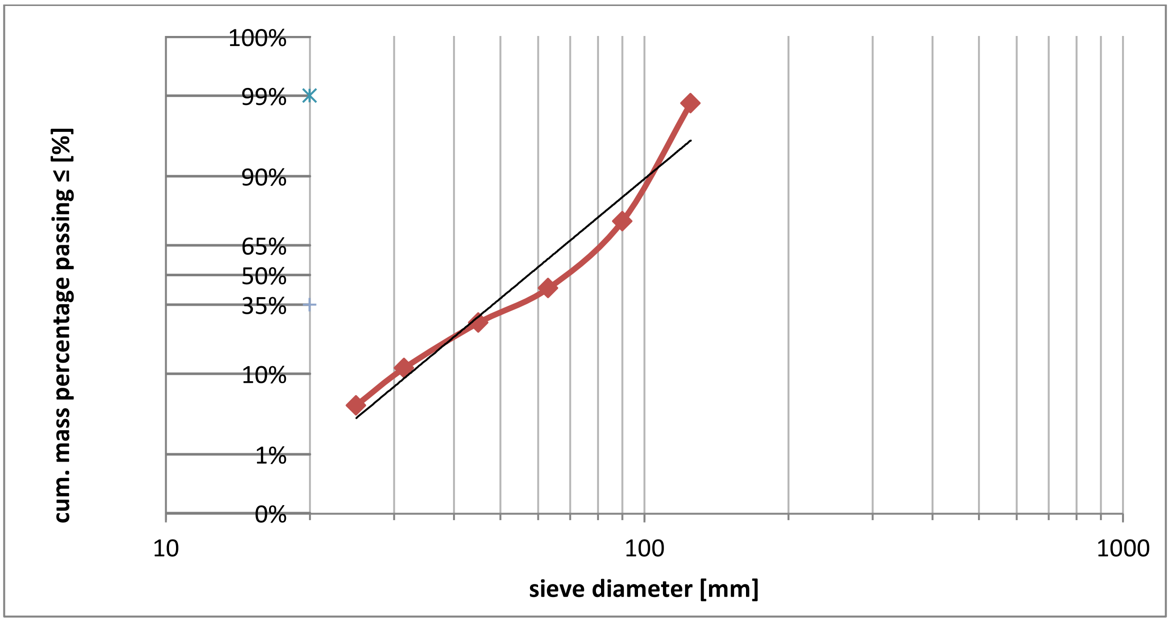


Figure D.2-22 - Gaussian sieve curve A-C

d_n-analysis

The volumes required to determine the nominal diameters are calculated by the quotient of mass and density. Also for sample A the nominal diameters this method is applied to assure uniform information. The resulting nominal sieve curve is given in Figure D.2-23.

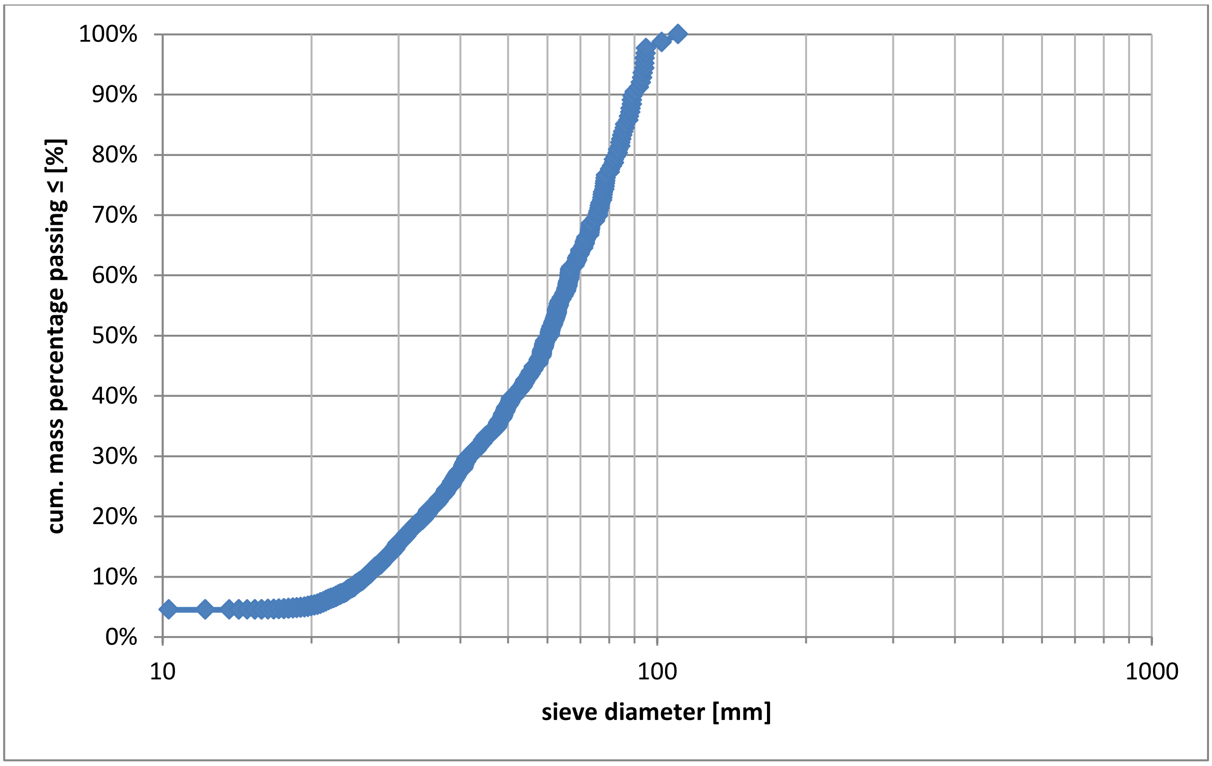


Figure D.2-23 - nominal sieve curve 1-5 A-C

In Table D-98 nominal diameters interpolated from Figure D.2-23 have been listed.

Table D-98 - nominal diameters 1-5 A-C

	nominal diameter [mm]
dn5	19.4
dn15	29.7
dn50	60.7
dn90	89.6
dn98	97.4

Shape factors F_x

The shape factors are given in Table D-99.

Table D-99 - shape factors 1-5 A-C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	19.4	d5	25.4	F5	0.762
dn15	29.7	d15	34.7	F15	0.856
dn50	60.7	d50	68.7	F50	0.884
dn90	89.6	d90	111.7	F90	0.802
dn98	97.4	d98	123.9	F98	0.786

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.88, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-24.

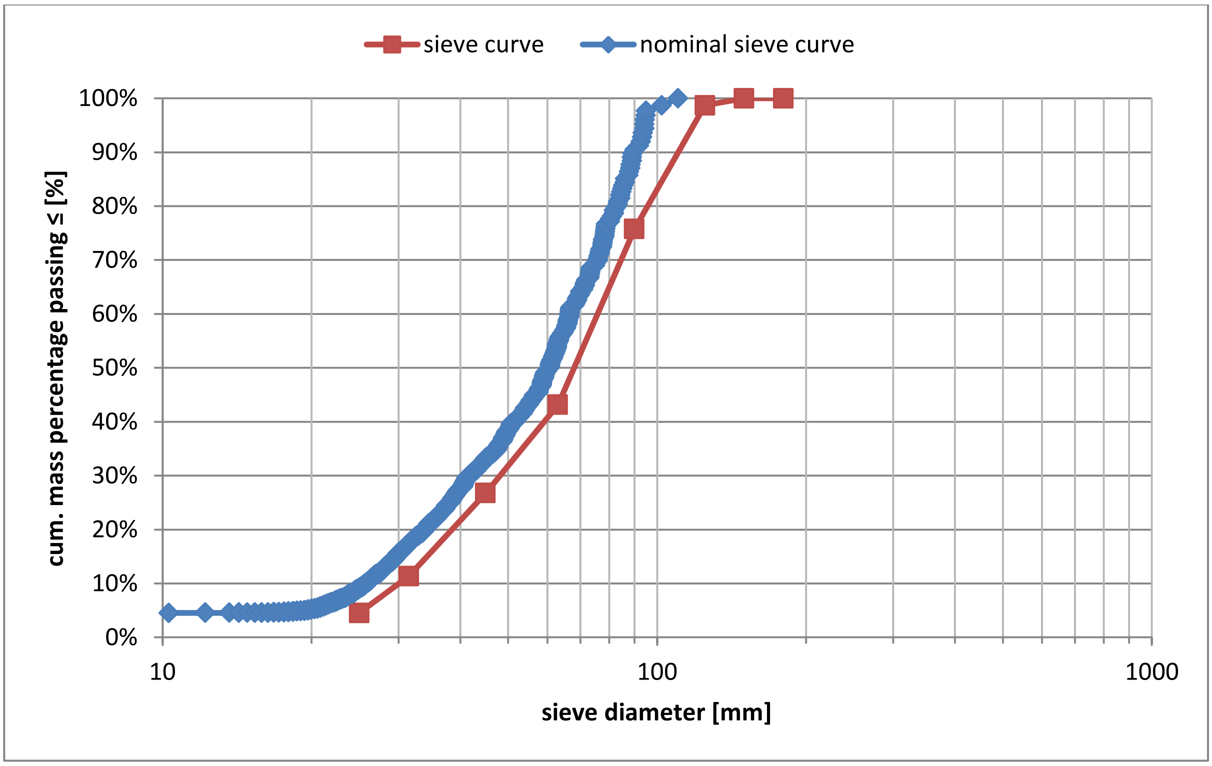


Figure D.2-24 - sieve curves 1-5 A-C

In Figure D.2-25 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the curves show great overlap, especially for the relatively small rocks (nominal diameter < approx. 50 mm). For the larger rocks the accuracy of the approximation decreases slightly, especially for rock with a nominal diameter over 90 mm. These diameters are overestimated by the product of shape factor and sieve diameter.

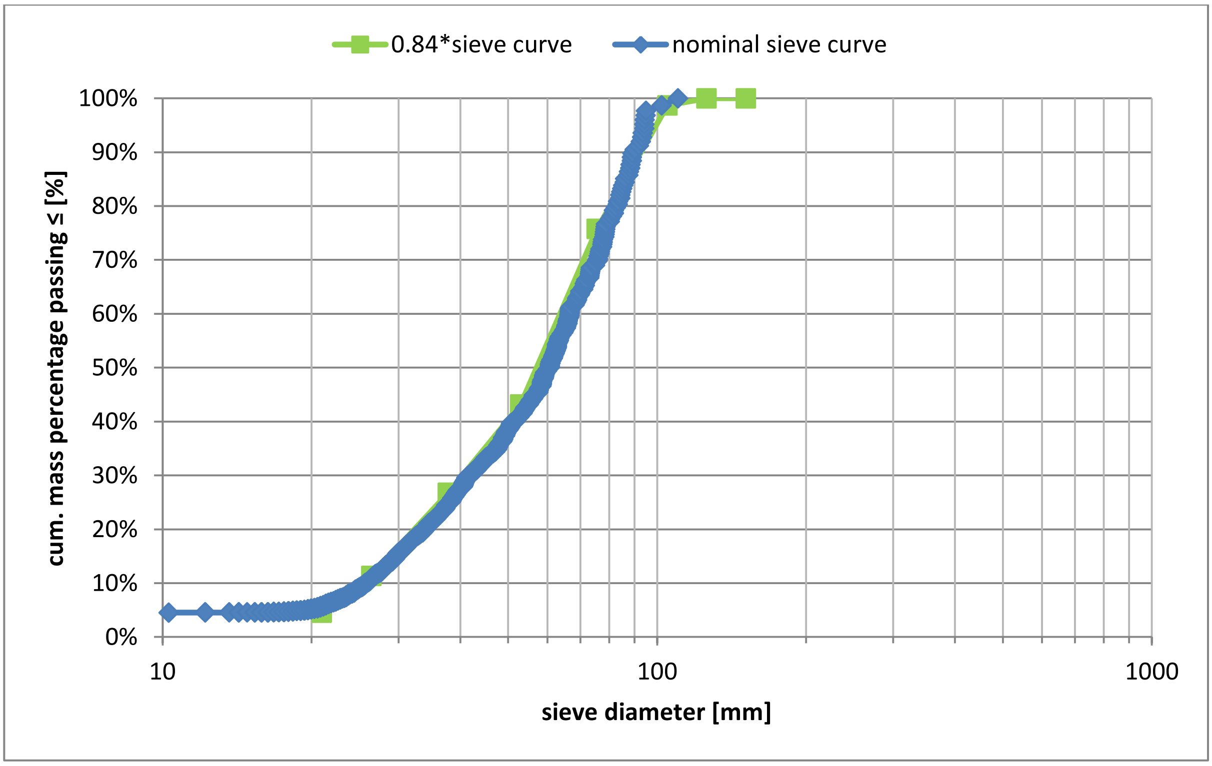


Figure D.2-25 - verification shape factor 1-5 A-C

D.2.1.4 Conclusions

The information gained on the shape factor of the 1-5 material is listed in Table D-100. It is concluded the value of the shape factor F_{50} – the value commonly applied in practice – is fluctuating between a value of 0.86-0.89 for the individual samples. The combined sample yields the value of 0.88 for F_{50}. Furthermore for each sample it is concluded the shape factor is not constant for none of the samples. The value for d_5 in sample B and C is cannot be obtained by interpolation. Since extrapolation of the tail of the sieve curve is considered rather arbitrary, these values have been left blank. Moreover, in general the value decreases considerably for the 98 cumulative mass percentage. Except from sample C the same holds the 90 cumulative mass percentage.

Table D-100 - shape factor 1-5

	Sample	A	B	C	A-C
ELL	dn5	40.905	25.577	13.702	19.376
	d5	44.596	-	-	25.441
	F5	0.917	-	-	0.762
NLL	dn15	56.292	31.137	22.183	29.696
	d15	63.068	36.576	27.082	34.692
	F15	0.893	0.851	0.819	0.856
MED	dn50	78.088	57.075	45.618	60.687
	d50	87.503	65.026	53.266	68.670
	F50	0.892	0.878	0.856	0.884
NUL	dn90	94.630	84.631	94.501	89.585
	d90	120.508	103.486	101.842	111.741
	F90	0.785	0.818	0.928	0.802
EUL	dn98	106.838	92.943	94.501	97.395
	d98	139.218	120.697	120.368	123.932
	F98	0.767	0.770	0.785	0.786

D.2.2 5+ Slovag

Origin: Wergeland Halsvik AS, Norway
Aggregate type: Basaltic rock
Shape type: Fresh

D.2.2.1 Sample A

Amount of rock: 107

Sieve test

Numerical information on the sieve test is given in Table D-101.

Table D-101 - sieve test results 5+ A

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
45-63	0.3	0.1	0.1
63-90	7.8	2.1	2.2
90-125	118.0	32.6	34.8
125-150	166.7	46.1	80.9
150-180	68.9	19.1	100.0
total	361.6	100.0	-

The resulting sieve curve is given in Figure D.2-26.

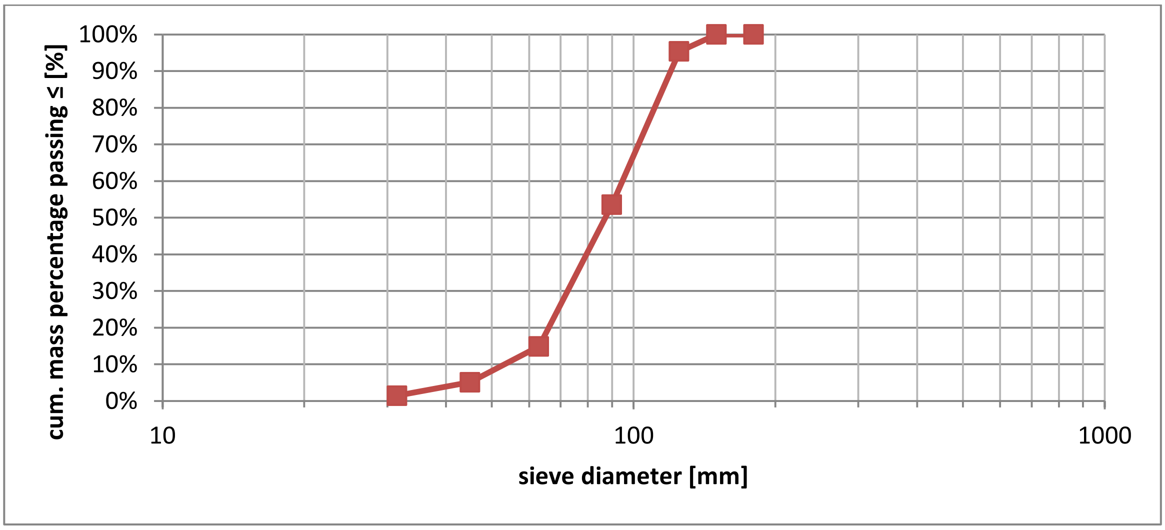


Figure D.2-26 - sieve curve 5+ A

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-102.

Table D-102 - Interpolated sieve diameters 5+ A

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	44.6
d10 (NLL)	54.0
d15	63.1
d25	70.1
d50 (MSD)	87.5
d60	95.4
d85	116.3
d90 (NUL)	120.5
d98 (EUL)	139.2

Grading width: d_{85}/d_{15} = 1.84. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-27 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

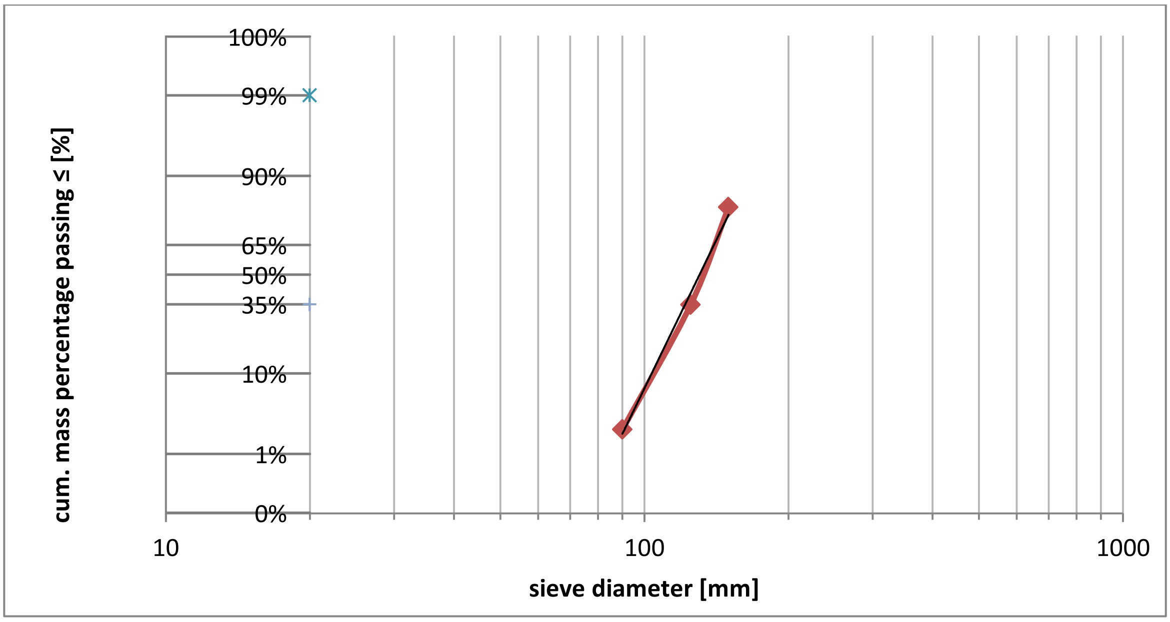


Figure D.2-27 - Gaussian sieve curve 5+ A

d_n-analysis

The nominal sieve curve including the nominal diameters calculated by the volumes determined according to the Archimedes method is given in Figure D.2-28.

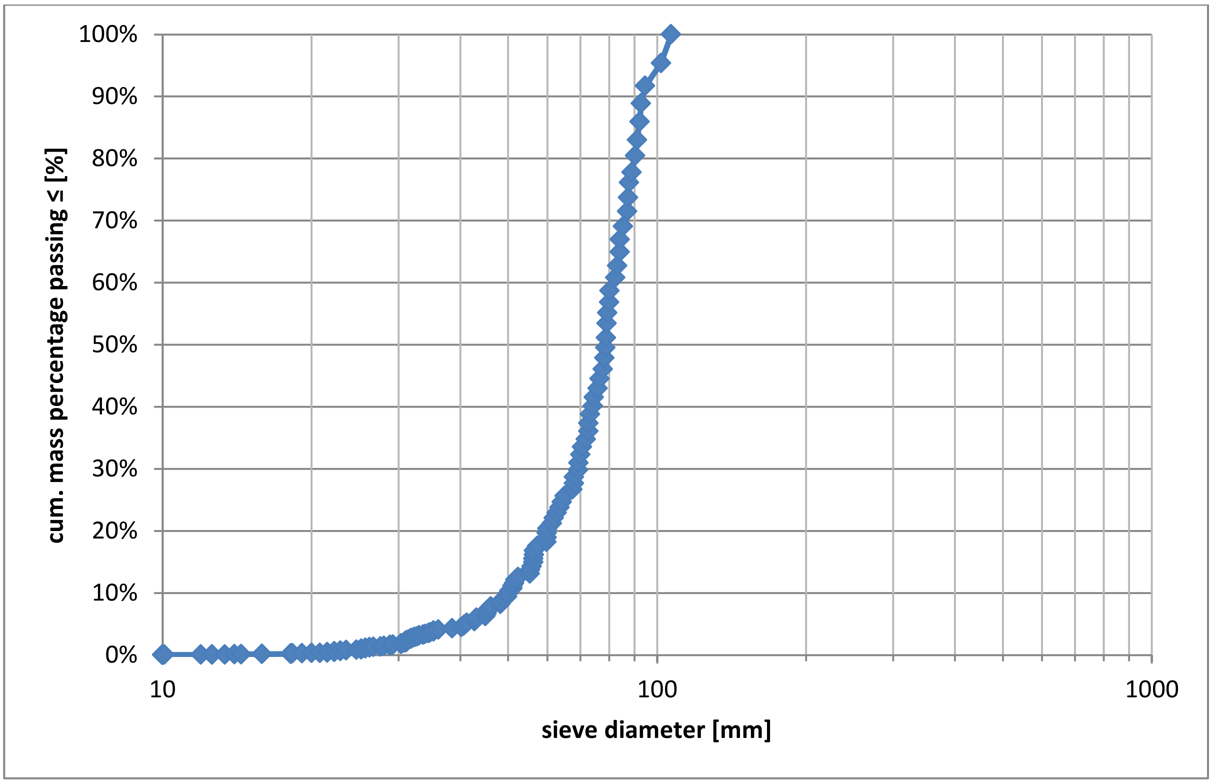


Figure D.2-28 - nominal sieve curve 5+ A

Again the impact of scattering densities is examined. In Figure D.2-29 the individual rock densities are presented.

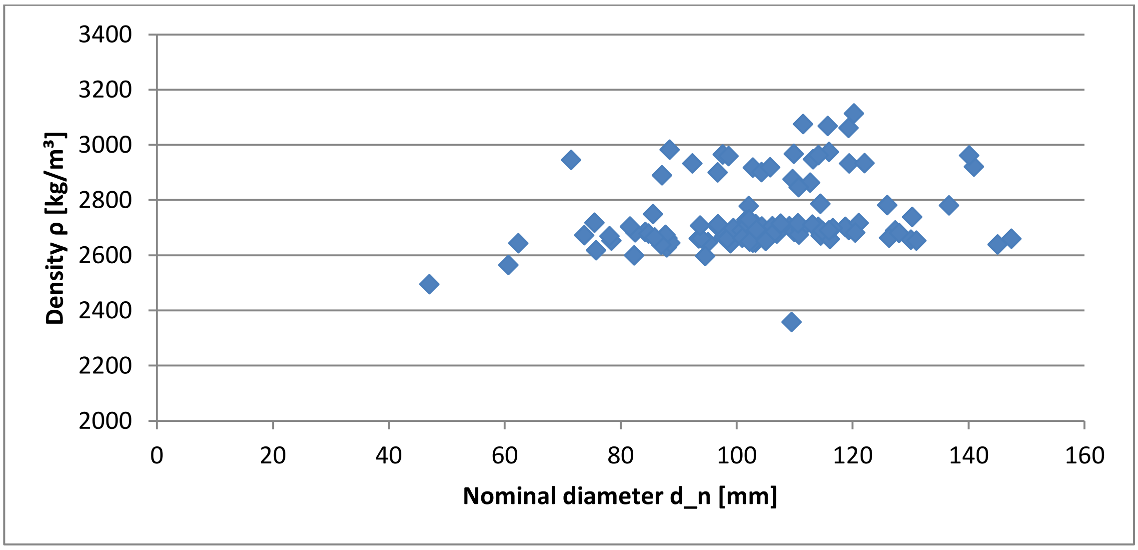


Figure D.2-29 - individual Archimedes rock densities 5+ A

The average of the densities is 2742 kg/m³, the median is 2696 kg/m³ and the modus is 2690 kg/m³. It is concluded a lot of scatter is present, in particular for the smaller rock. By application of a uniform density the nominal diameters are recalculated. The uniform

density is determined by the average density of the rocks in the 63-90 and 90-125 fractions and has a value of 2724 kg/m³.
Moreover the densities of the larger rocks (nominal diameter > approx. 70 mm) tend to concentrate in two distinct bands at values of approximately 2650 and 2950 kg/m³. The observed convergence can be explained by the occurrence of different rock types in the rock face. It is concluded the uniformity of the rock is considerably low. The influence of density scatter on the determination of the shape factor is however still based on the assumption of uniform density to yield results that can be compared with the results from the IJmuiden tests and analyses.

By application of the uniform density the nominal diameters are recalculated. The uniform density is determined by the average density of the rocks in the 63-90 and 90-125 fractions and has a value of 2742 kg/m³. The nominal sieve curve based on the recalculated nominal diameters is given in Figure D.2-30.

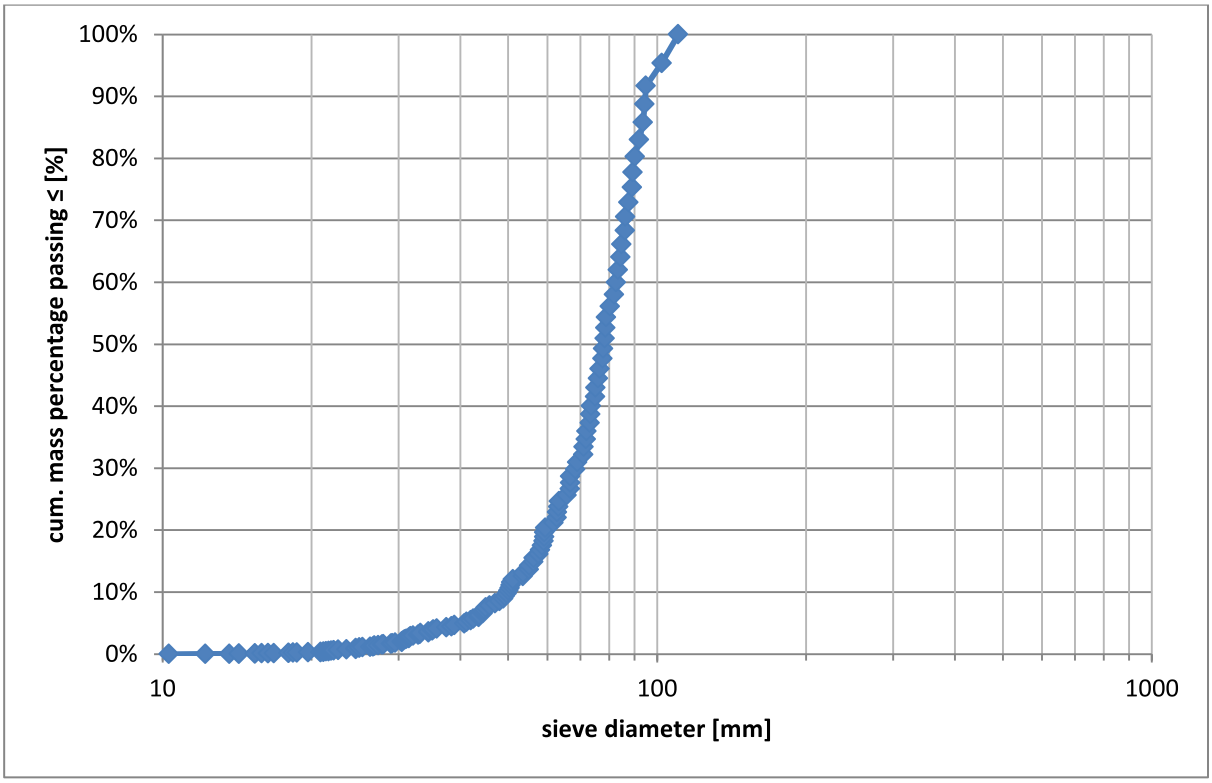


Figure D.2-30 - modified nominal sieve curve 5+ A

The observation of two distinct density bands can however not be ignored. Therefore the above analysis is redone by application of two distinct densities. These densities are determined on the basis of a subdivision of the rock in 63-90 and 90-125 fractions into normal density rock (Archimedes density < 2800 kg/m³) and high density rock (Archimedes density > 2800 kg/m³), see Figure D.2-31 and Figure D.2-32.

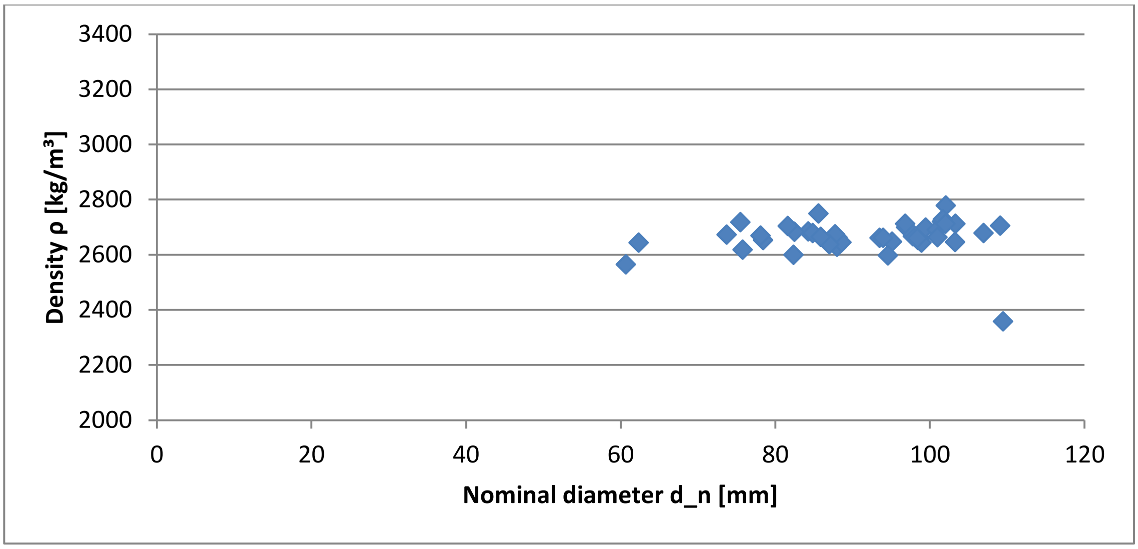


Figure D.2-31 – densities < 2800 kg/m³

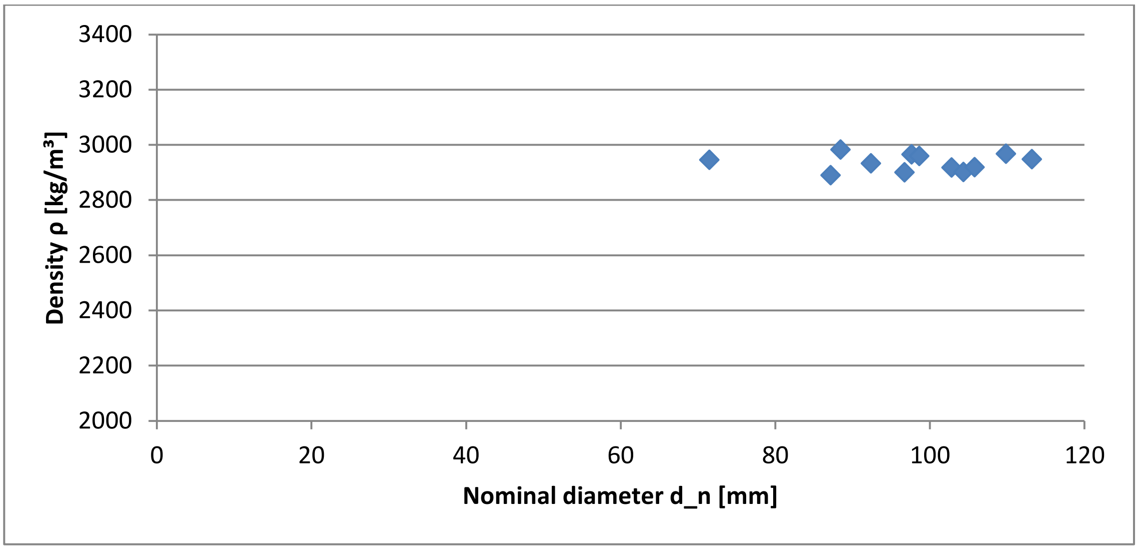


Figure D.2-32 - densities > 2800 kg/m³

The found averages of the normal density and high density rock are 2665 kg/m³ and 2935 kg/m³ respectively. To calculate the nominal diameters the value of 2665 kg/m³ is applied for all rocks having an Archimedes density below 2800 kg/m³. Accordingly the value of 2935 is applied for all rocks having an Archimedes density above 2800 kg/m³.

The resulting nominal sieve curve is given in Figure D.2-33.

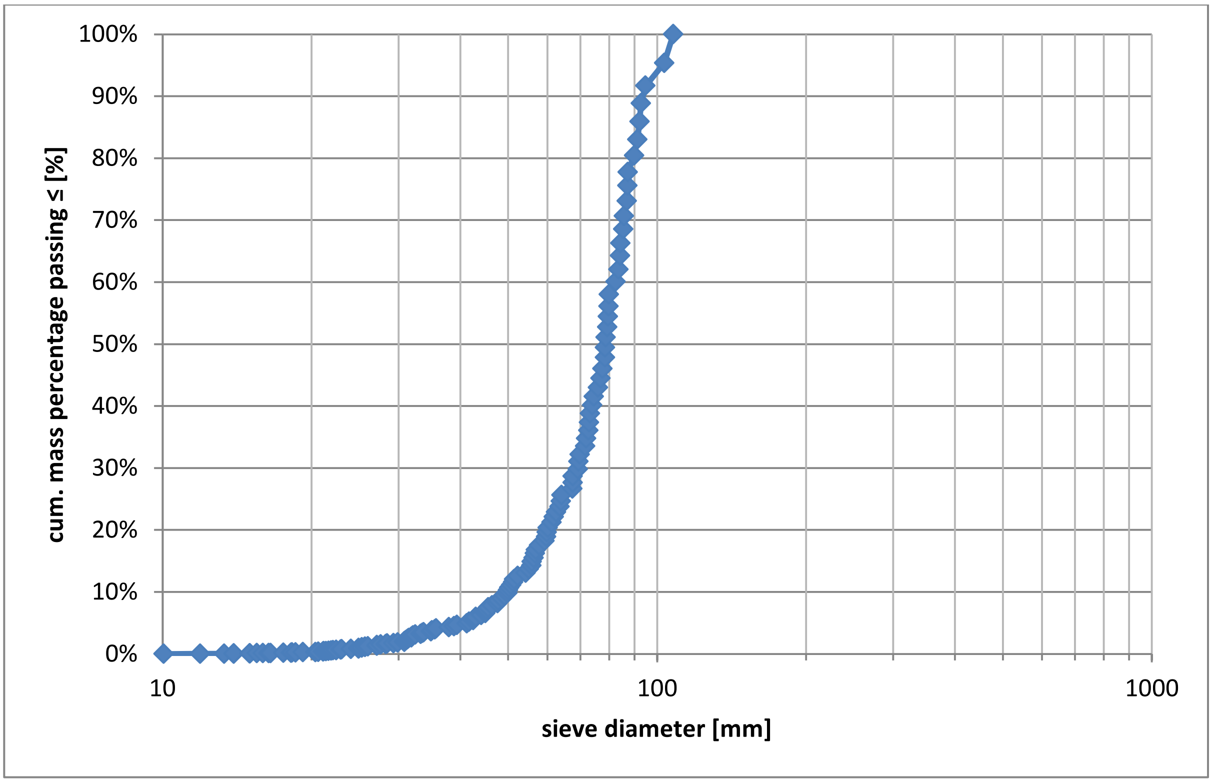


Figure D.2-33 - nominal sieve curve acc. to normal density and high density

In Table D-103 the interpolated nominal diameters based on both the Archimedes, modified and specific volumes are listed.

Table D-103 - comparison of dn-values acc. to Archimedes and modified volumes 5+ A

nominal diameter	acc. to Arc volumes	acc. Mod volumes	acc. to spec volumes
	[mm]	[mm]	[mm]
dn5	41.0	40.9	41.4
dn15	56.3	56.3	55.9
dn50	78.7	78.1	78.6
dn90	93.6	94.6	93.6
dn98	104.7	106.8	105.9

From Table D-122 it is concluded the differences in the nominal diameters found on basis of the three different methods are relatively small. In case of the median nominal diameter the largest difference is found between the value found by the Archimedes method and the modified method: 0.6 mm. This implies a relative error approximately of only 0.5 percent. It is therefore concluded the observed scatter in the densities do not cause the nominal diameters found by either method to be unrealistic. Therefore the nominal diameters on the basis of the Archimedes volumes are applied in this sample.

Shape factors F_x

The shape factors are given in Table D-104.

Table D-104 - shape factors 5+ A

nominal diameter				sieve diameter		shape factor			
[mm]	Arc	mod	spec	[mm]		[mm]	Arc	mod	spec
dn5	41.0	40.9	41.4	d5	44.6	F5	0.919	0.917	0.928
dn15	56.3	56.3	55.9	d15	63.1	F15	0.893	0.893	0.887
dn50	78.7	78.1	78.6	d50	87.5	F50	0.899	0.892	0.899
dn90	93.6	94.6	93.6	d90	120.5	F90	0.777	0.785	0.777
dn98	104.7	106.8	105.9	d98	139.2	F98	0.752	0.767	0.761

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.89-0.90, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-34.

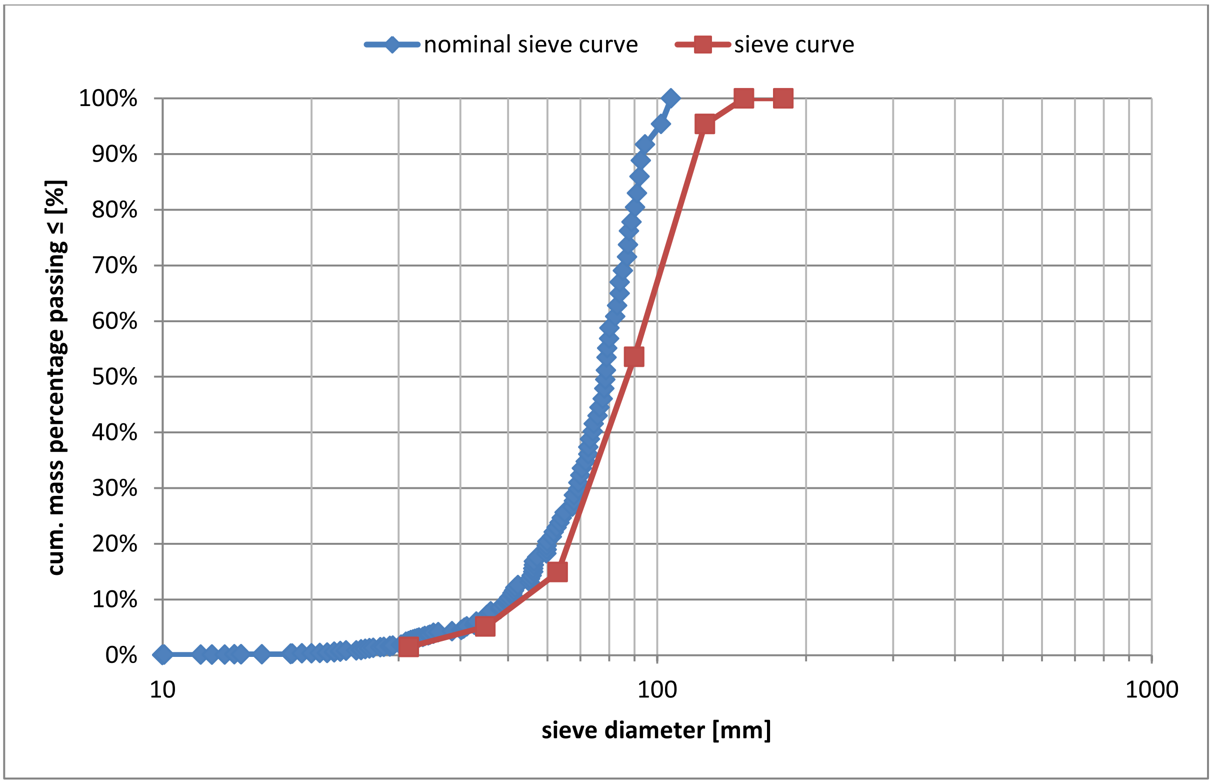


Figure D.2-34 - curves 1-5 A

In Figure D.2-35 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the product of shape factor and sieve diameter slightly underestimated the nominal diameter for rocks having a nominal diameter of 40 to 80 mm. Larger rocks is overestimated by the approximation.

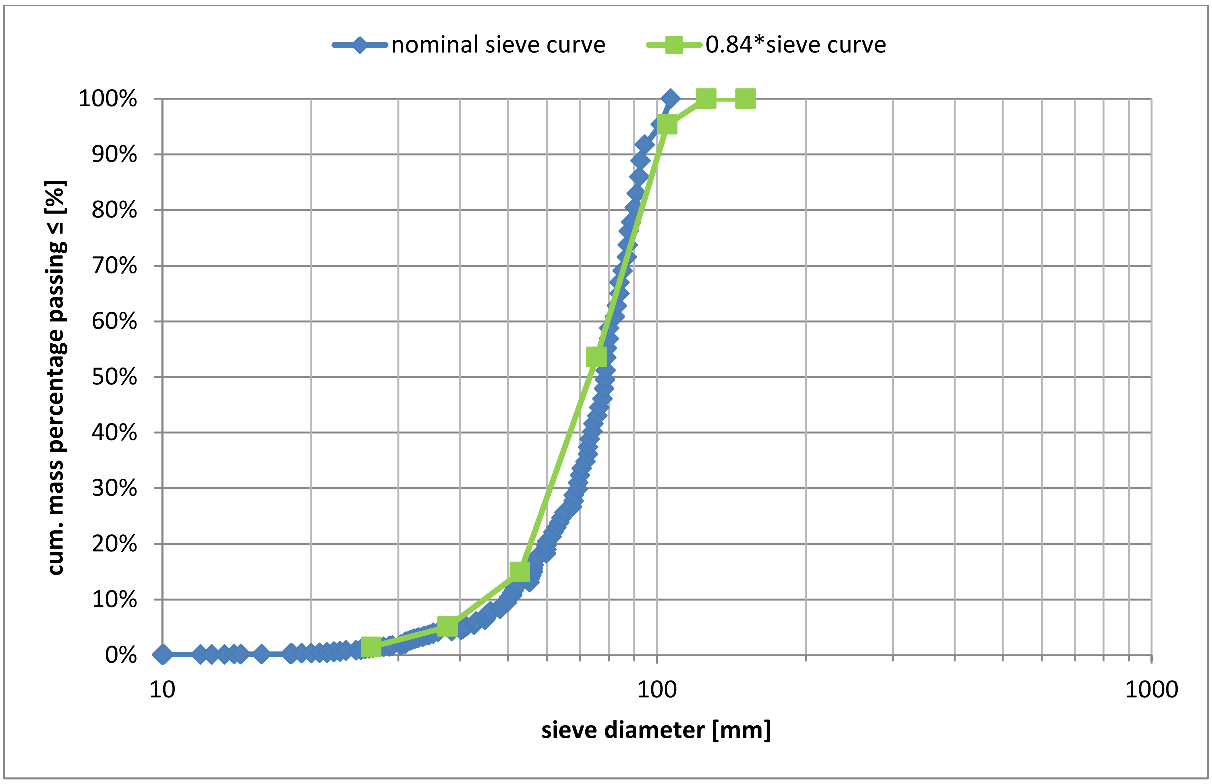


Figure D.2-35 - verification shape factor 5+ A

Shape test

In Table D-105 and Table D-106 an overview is given of the minimum, maximum and average values of the elongation and blockiness respectively.

Table D-105 – elongation 5+ A

	Elongation		
	minimum [-]	maximum [-]	average [-]
45-63	2.94	2.94	2.94
63-90	2.04	3.59	2.64
90-125	1.36	7.04	2.62
125-150	1.55	4.44	2.46
150-180	1.66	3.30	2.55
total	1.36	7.04	2.55

Table D-106 -blockiness 5+ A

	Blockiness		
	minimum [%]	maximum [%]	average [%]
45-63	32.62	32.62	32.62
63-90	37.36	53.85	44.70
90-125	34.97	60.02	46.76
125-150	29.61	72.87	44.63
150-180	38.82	64.90	44.93
total	29.61	72.87	45.47

For elongation the minimum and maximum value found are 1.36 and 7.04 respectively. The minima is rather constant over the fractions. The maxima tends to fluctuate severely. No significant trends are observed in the elongation values over the sieve fractions. Considering blockiness the minimum and maximum blockiness found are 11 respectively 65 percent approximately. 11 percent blockiness represents a very hollow shape, which is not found in the sample and therefore most probably the result of a measurement error. The average blockiness values over the fractions are relatively constant. It is concluded no significant trends are observed in elongation nor blockiness for this sample.

D.2.2.2 Sample B

Amount of rock: 103

Sieve test

Numerical information on the sieve test is given in Table D-107.

Table D-107 - sieve test results 5+ B

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤31.5	6.9	7.3	7.27
31.5-45	19.4	20.6	27.82
45-63	18.4	19.4	47.26
63-90	34.4	36.5	83.73
90-125	15.4	16.3	100.00
total	94.4	100.0	-

The resulting sieve curve is given in Figure D.2-36.

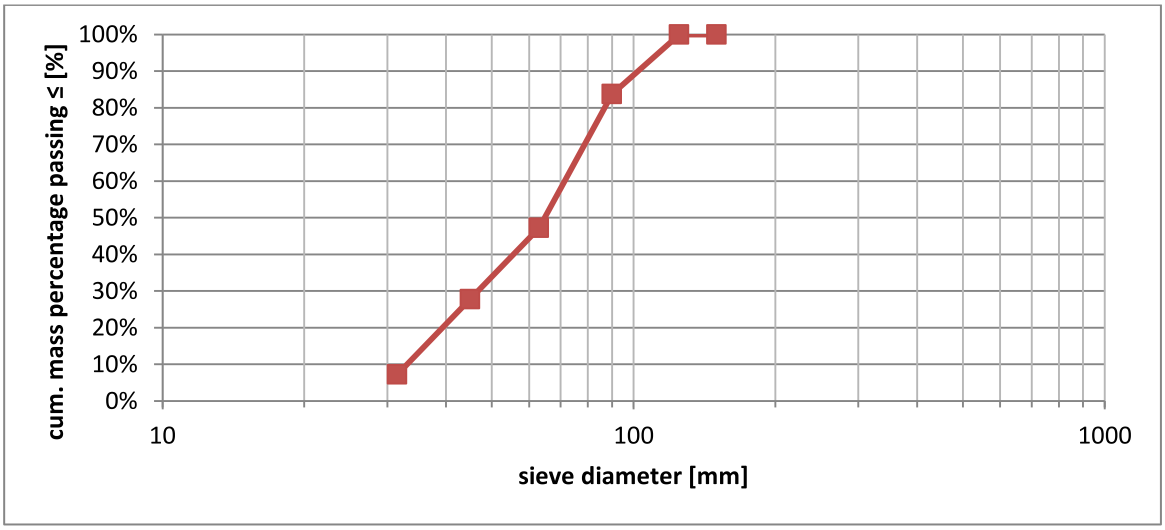


Figure D.2-36 - sieve curve 5+ B

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-108.

Table D-108 - Interpolated sieve diameters 5+ B

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	21.7
d10 (NLL)	33.3
d15	36.6
d25	43.1
d50 (MSD)	65.0
d60	72.4
d85	92.7
d90 (NUL)	103.5
d98 (EUL)	120.7

Grading width: d_{85}/d_{15} = 2.54. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-37 it is observed the samples mass distribution shows significant deviation over the sieve fractions from the expected normal distribution. Care should be taken during interpreting the interpolated sieve diameters.

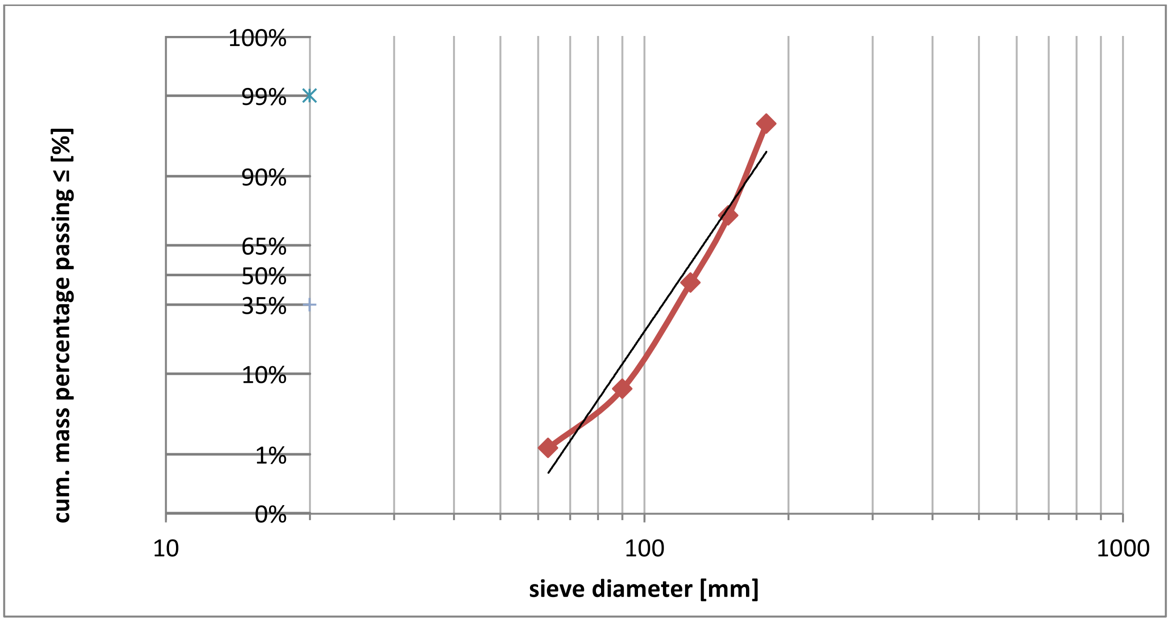


Figure D.2-37 - Gaussian sieve curve 5+ B

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2750 kg/m³. As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.2-38.

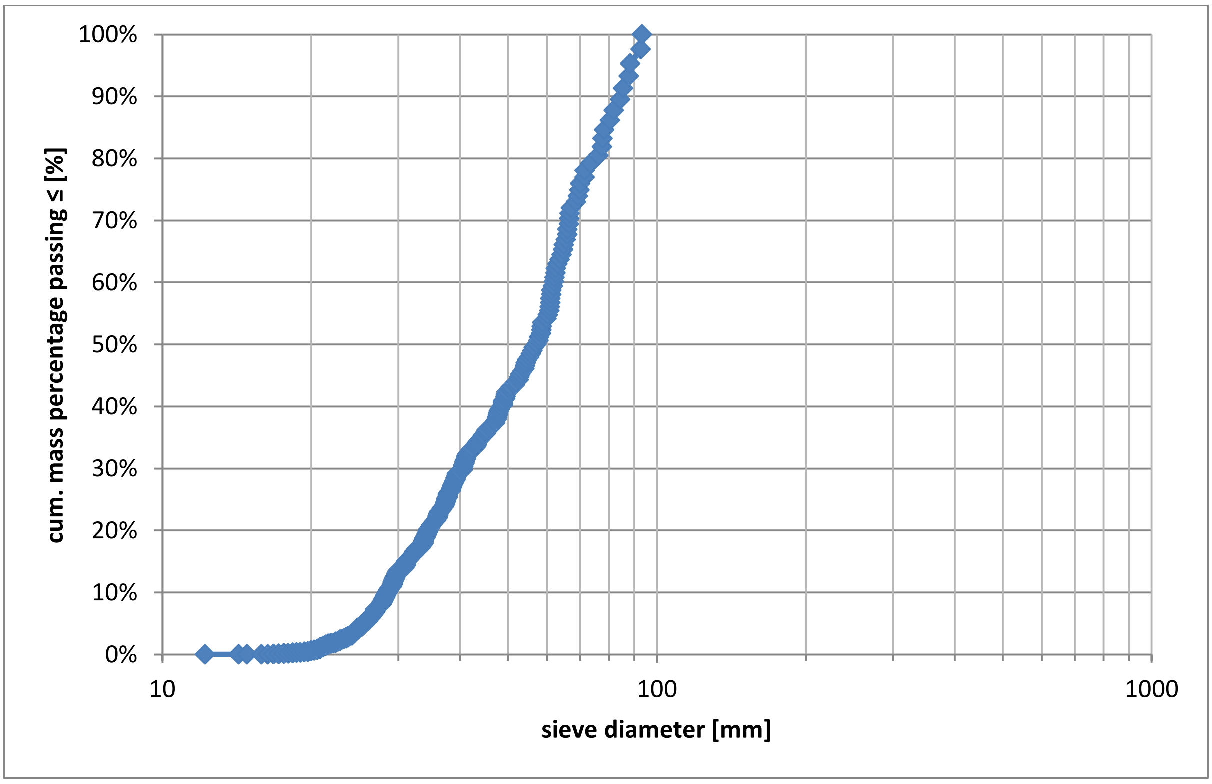


Figure D.2-38 - nominal sieve curve 5+ B

In Table D-109 nominal diameters interpolated from Figure D.2-38 have been listed.

Table D-109 - nominal diameters 5+ B

	nominal diameter
	[mm]
dn5	43.0
dn15	53.9
dn50	98.1
dn90	161.6
dn98	186.0

Shape factors F_x

The shape factors are given in Table D-110.

Table D-110 - shape factors 5+ B

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	43.0	d5	47.1	F5	0.913
dn15	53.9	d15	61.9	F15	0.871
dn50	98.1	d50	111.1	F50	0.883
dn90	161.6	d90	211.4	F90	0.764
dn98	186.0	d98	242.3	F98	0.768

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.88, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-39.

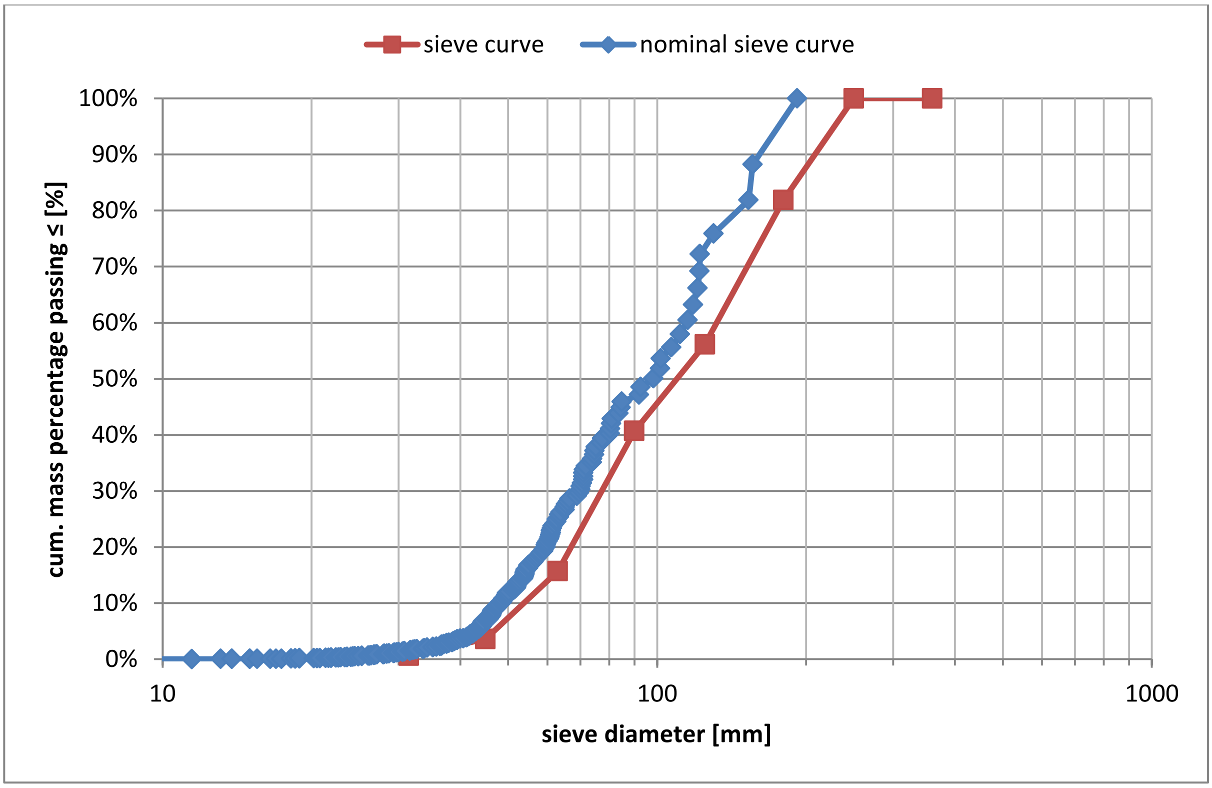


Figure D.2-39 - sieve curves 5+ B

In Figure D.2-40 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the nominal diameters are in general approximated rather well by the product of shape factor and sieve diameter. For larger rocks (nominal diameter > 120 mm) the accuracy however decreases slightly.

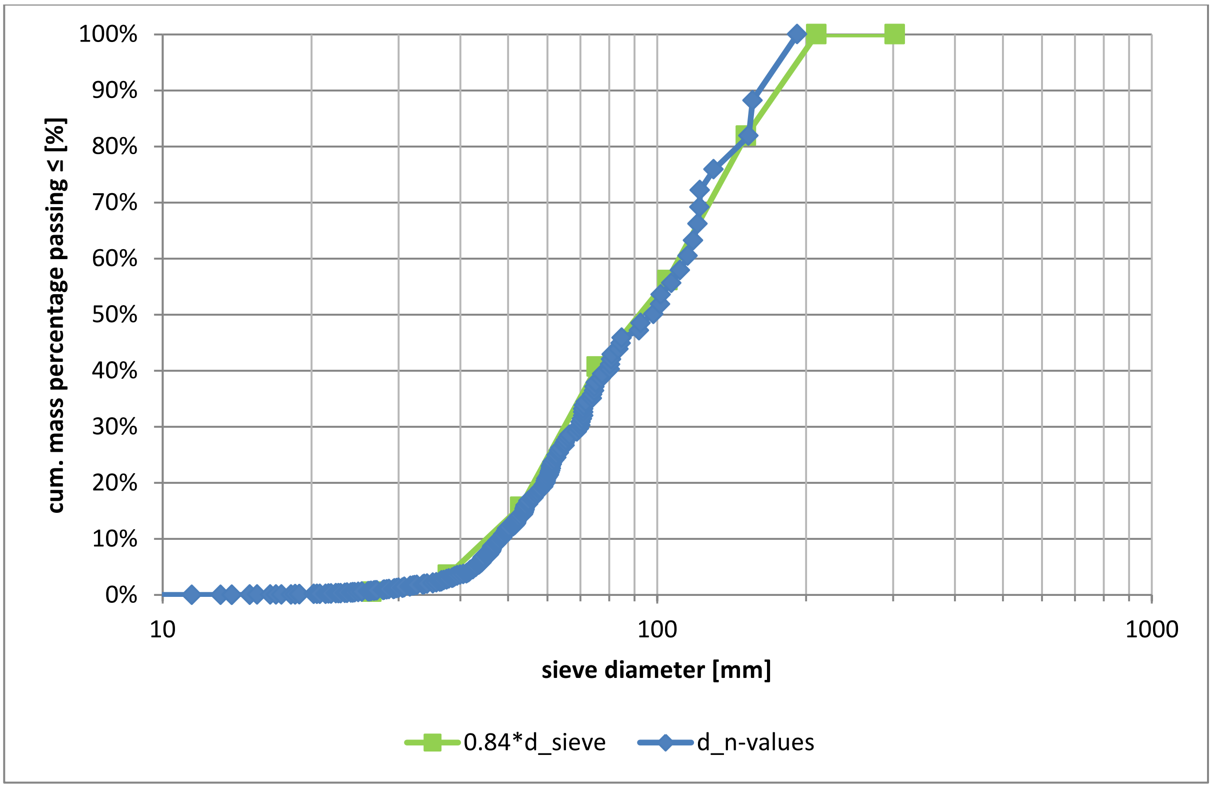


Figure D.2-40 - verification shape factor 5+ B

Sample C
Amount of rock: 152

Sieve test

Numerical information on the sieve test is given in Table D-111.

Table D-111 - sieve test results 5+ C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤25	12.9	11.7	11.70
25-31.5	11.4	10.3	22.01
31.5-45	21.5	19.5	41.46
45-63	20.5	18.6	60.05
63-90	27.4	24.8	84.89
90-125	16.7	15.1	100.00
total	110.3	100.0	-

The resulting sieve curve is given in Figure D.2-41.

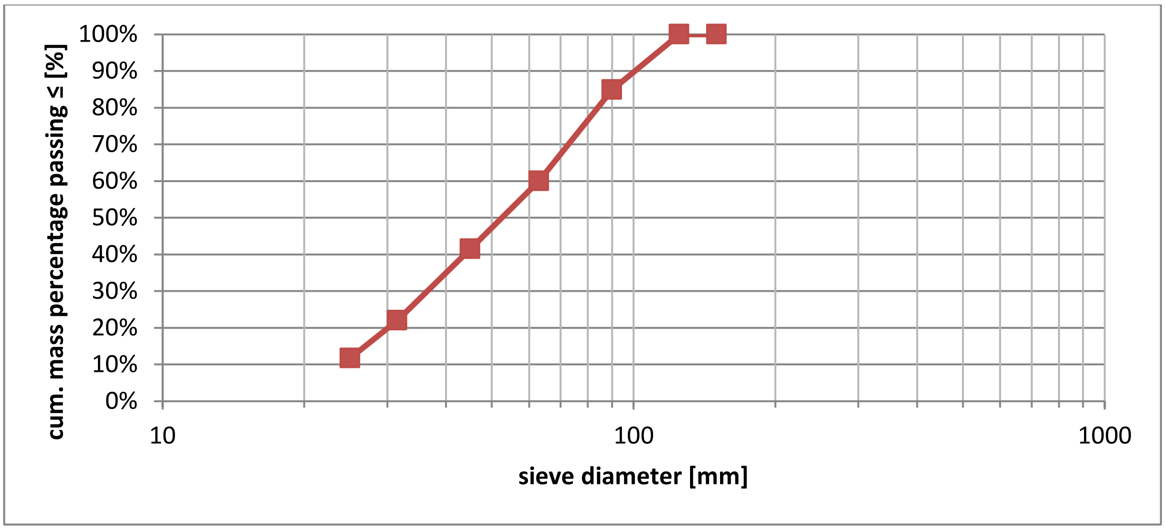


Figure D.2-41 - sieve curve 5+ C

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-112.

Table D-112 - Interpolated sieve diameters 5+ C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	-
d10 (NLL)	-
d15	27.1
d25	33.6
d50 (MSD)	53.3
d60	63.0
d85	90.3
d90 (NUL)	101.8
d98 (EUL)	120.4

Since more than 10 percent of the mass passed the smallest applied sieve, the sieve diameters associated with 5 and 10 cumulative mass percent could not be determined by interpolation. This problem can be overcome by application of an extrapolation technique. Since the uncertainties that would have introduced by extrapolation and its eventual effect on the determination of the shape factor this technique is not applied and the d_5 and d_{10} values are left blank.

Grading width: d_{85}/d_{15} = 3.33. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-42 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

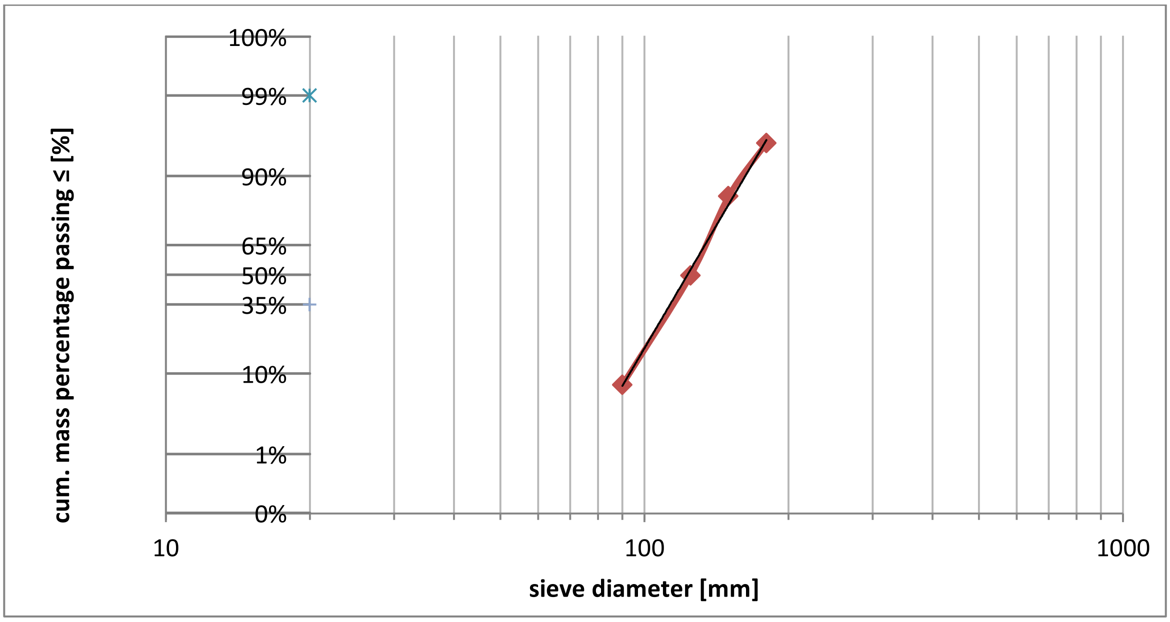


Figure D.2-42 - Gaussian sieve curve 5+ C

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2750 kg/m³. As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.2-43.

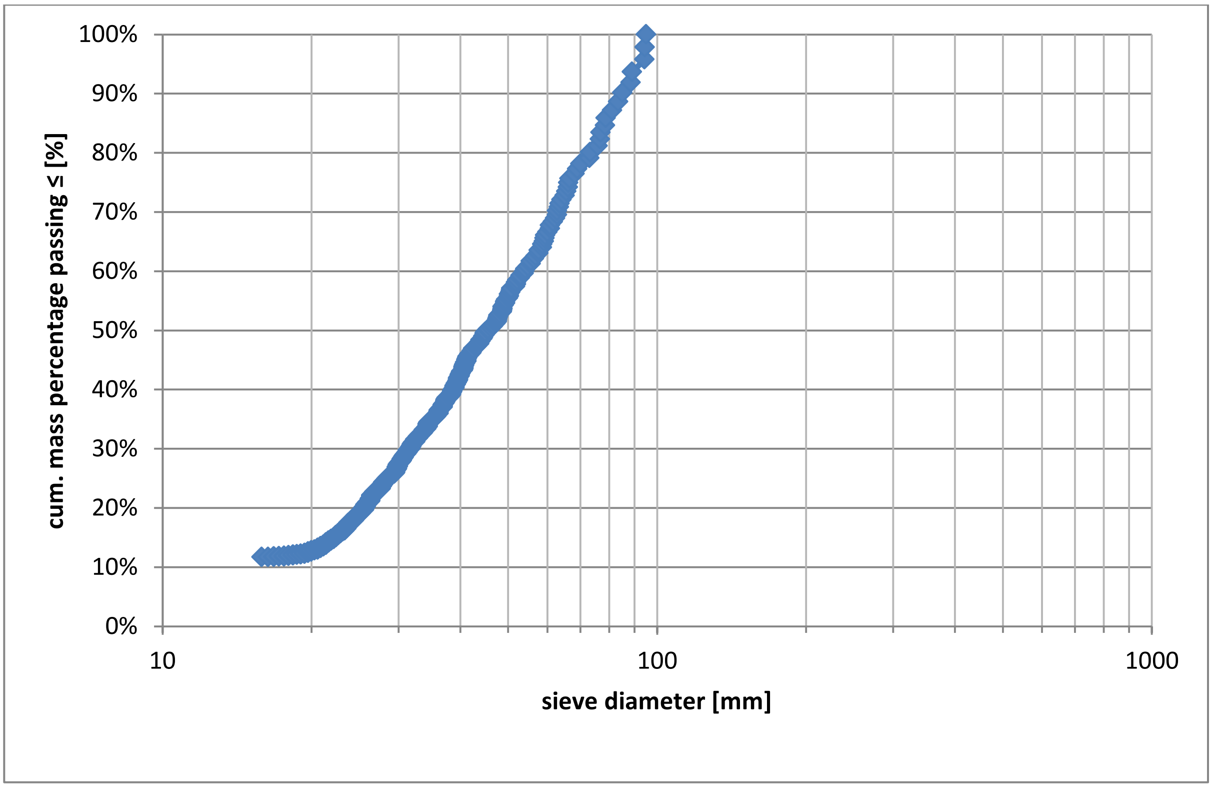


Figure D.2-43 - nominal sieve curve 5+ C

In Table D-113 nominal diameters interpolated from Figure D.2-43 have been listed.

Table D-113 - nominal diameters 5+ C

	nominal diameter
	[mm]
dn5	13.7
dn15	22.2
dn50	45.6
dn90	84.9
dn98	94.5

Shape factors F_x

The shape factors are given in Table D-114.

Table D-114 - shape factors 5+ C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	13.7	d5	-	F5	-
dn15	22.2	d15	27.1	F15	0.819
dn50	45.6	d50	53.3	F50	0.856
dn90	84.9	d90	101.8	F90	0.834
dn98	94.5	d98	120.4	F98	0.785

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.86, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-44.

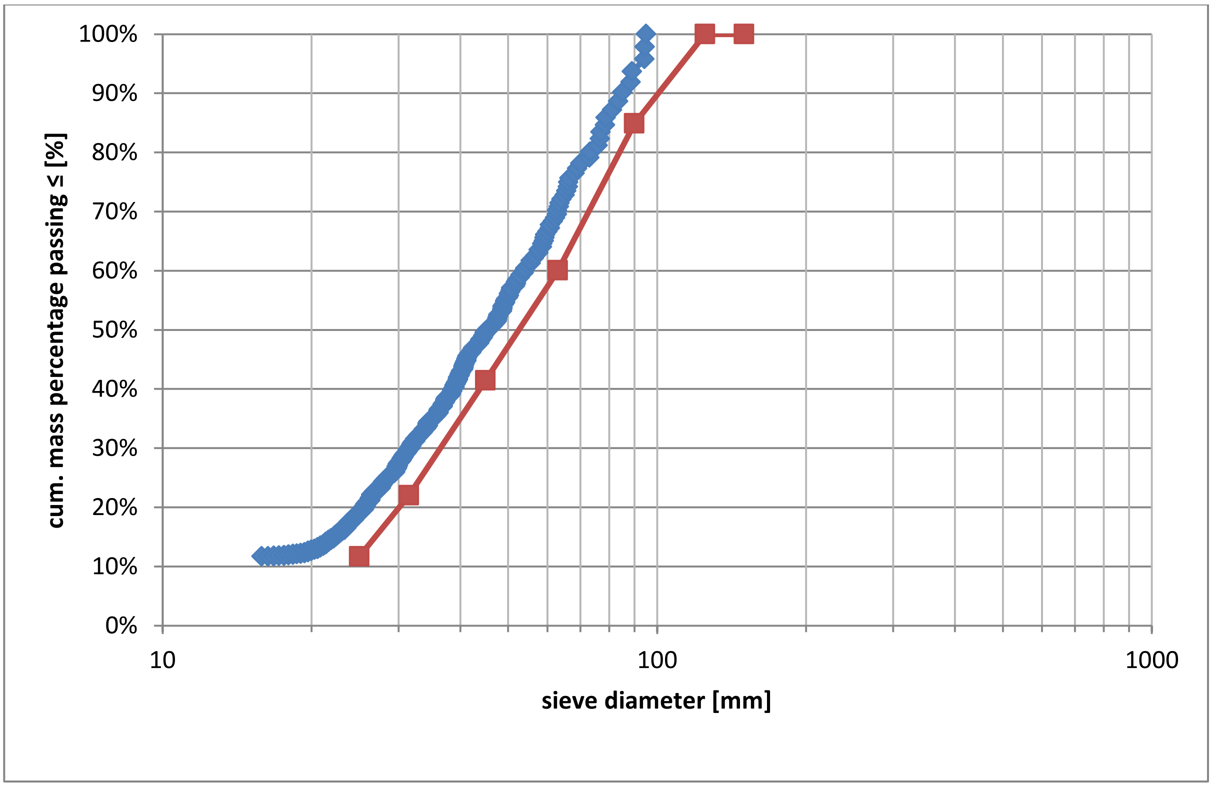


Figure D.2-44 - sieve curves 5+ C

In Figure D.2-45 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the nominal diameters are in general approximated rather well by the product of shape factor and sieve diameter. For larger rocks (nominal diameter > 120 mm) the accuracy however decreases slightly.

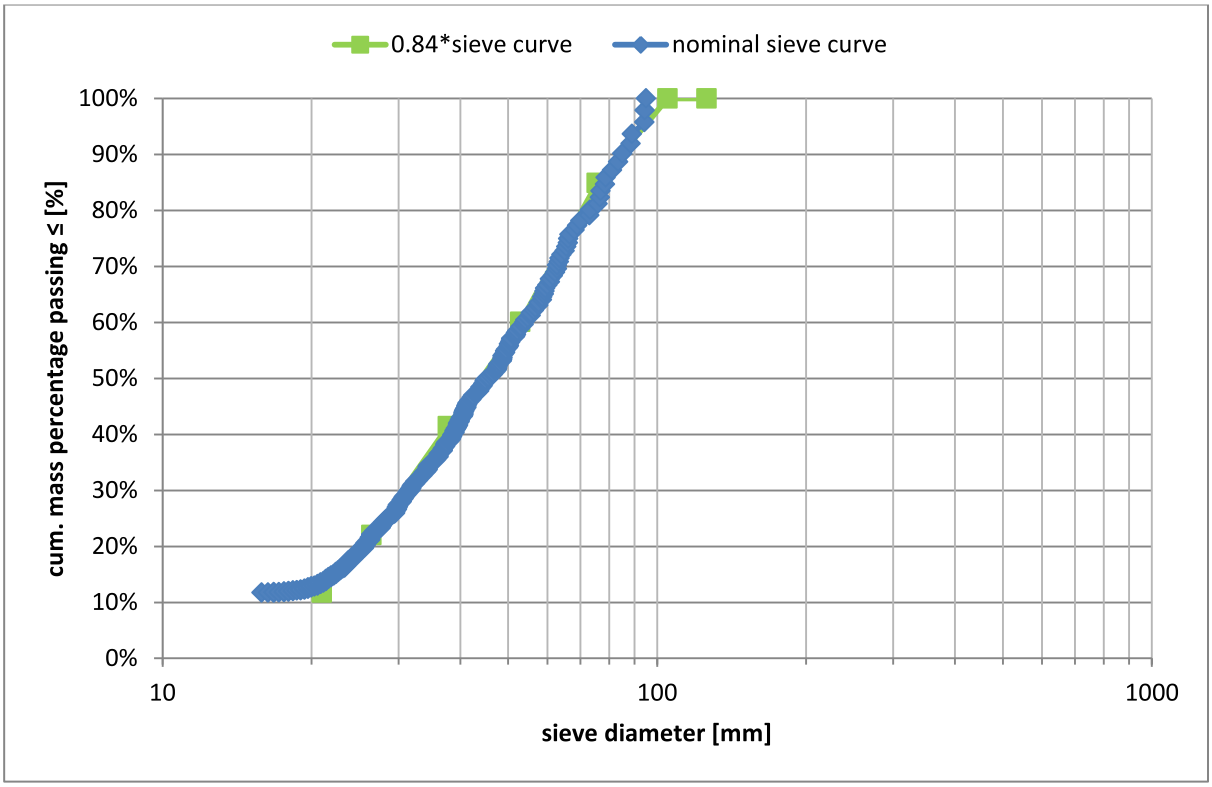


Figure D.2-45 - verification shape factor 5+ C

D.2.2.3 Sample A-C combined

Amount of rock: 362

The data represented in this sample is equivalent to the data of sample A-C together. It stressed that the results based on the combined sample is not equal to the average of the results of the separate samples.

Sieve test

Numerical information on the sieve test is given in Table D-115.

Table D-115 - sieve test results 5+ A-C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤25	12.9	4.5	4.5
25-31.5	19.4	6.8	11.4
31.5-45	43.8	15.4	26.8
45-63	46.7	16.4	43.2
63-90	92.6	32.6	75.7
90-125	65.3	23.0	98.7
125-150	3.7	1.3	100.0
total	284.4	100.0	-

The resulting sieve curve is given in Figure D.2-46.

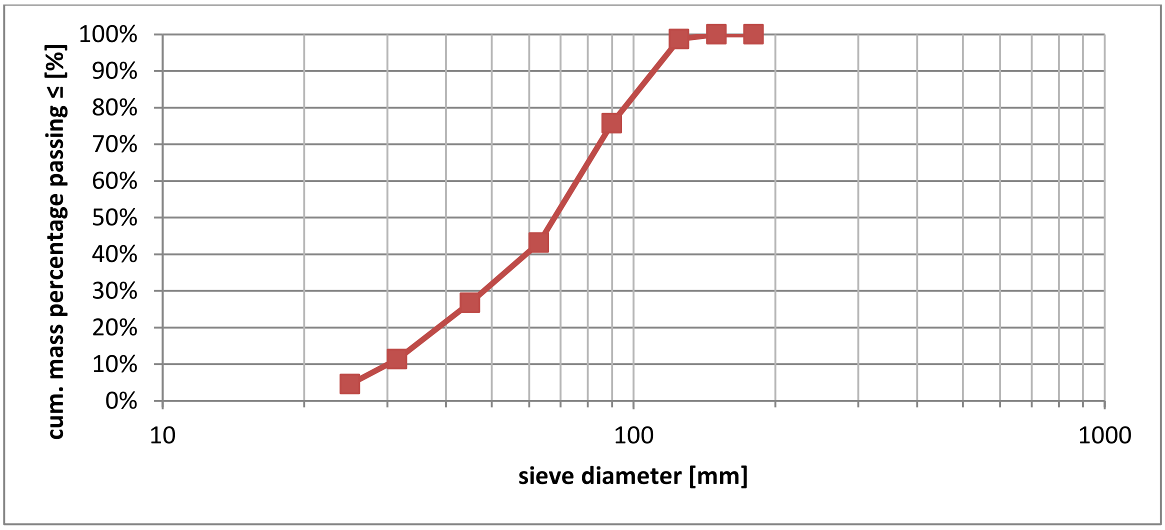


Figure D.2-46 - sieve curve 5+ A-C

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-116.

Table D-116 - Interpolated sieve diameters 5+ A-C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	25.44
d10 (NLL)	30.20
d15	34.69
d25	43.46
d50 (MSD)	68.67
d60	76.96
d85	104.12
d90 (NUL)	111.74
d98 (EUL)	123.93

Grading width: d_{85}/d_{15} = 3.00. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-47 it is observed the samples mass is rather normal distributed over the sieve fractions, yielding interpolated sieve diameters representative for the tested grading.

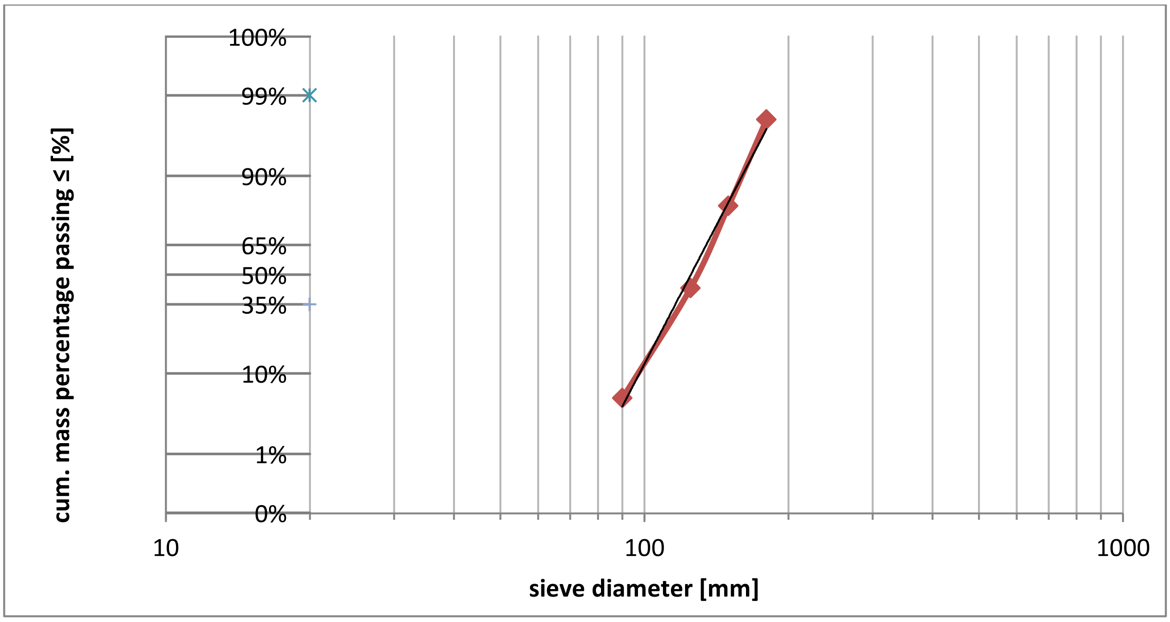


Figure D.2-47 - Gaussian sieve curve 5+ A-C

d_n-analysis

The volumes required to determine the nominal diameters are calculated by the quotient of mass and density. Also for sample A the nominal diameters this method is applied to assure uniform information. The resulting nominal sieve curve is given in Figure D.2-48.

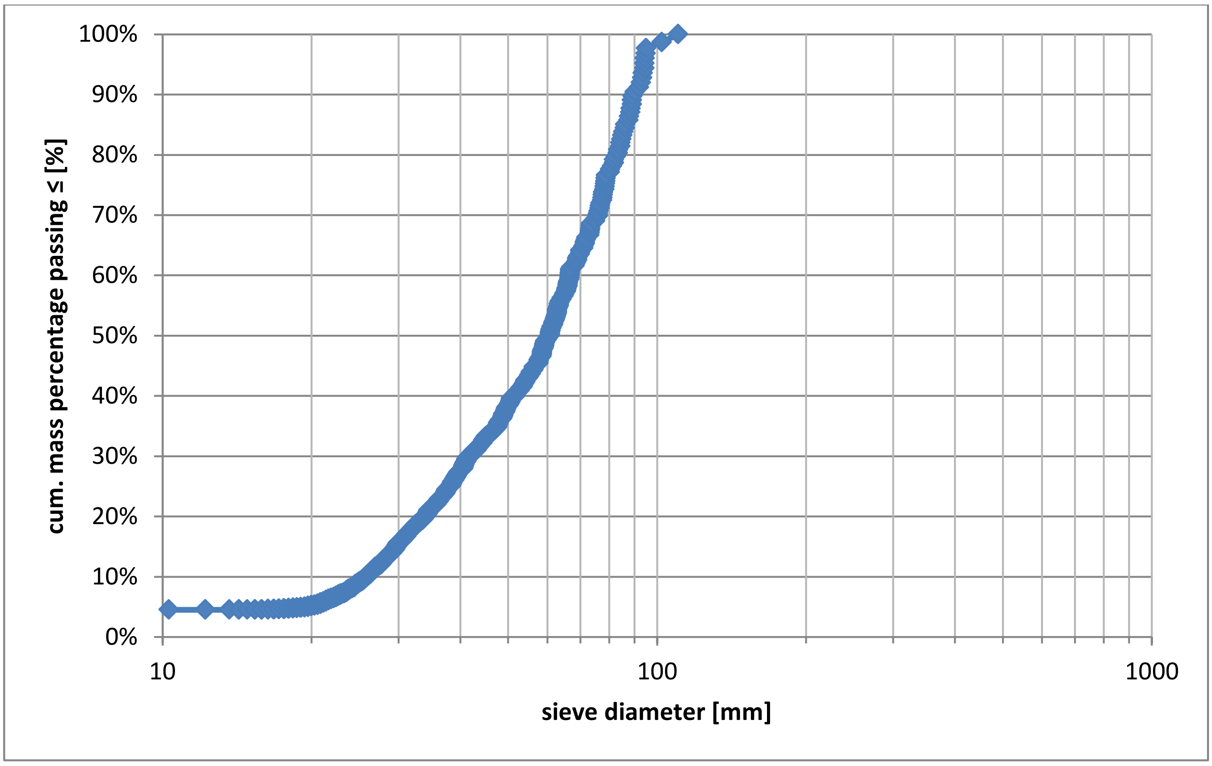


Figure D.2-48 - nominal sieve curve 5+ A-C

In Table D-117 nominal diameters interpolated from Figure D.2-48 have been listed.

Table D-117 - nominal diameters 5+ A-C

	nominal diameter [mm]
dn5	19.4
dn15	29.7
dn50	60.7
dn90	89.6
dn98	97.4

Shape factors F_x

The shape factors are given in Table D-118.

Table D-118 - shape factors 5+ A-C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	19.4	d5	25.4	F5	0.762
dn15	29.7	d15	34.7	F15	0.856
dn50	60.7	d50	68.7	F50	0.884
dn90	89.6	d90	111.7	F90	0.802
dn98	97.4	d98	123.9	F98	0.786

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.88, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-49.

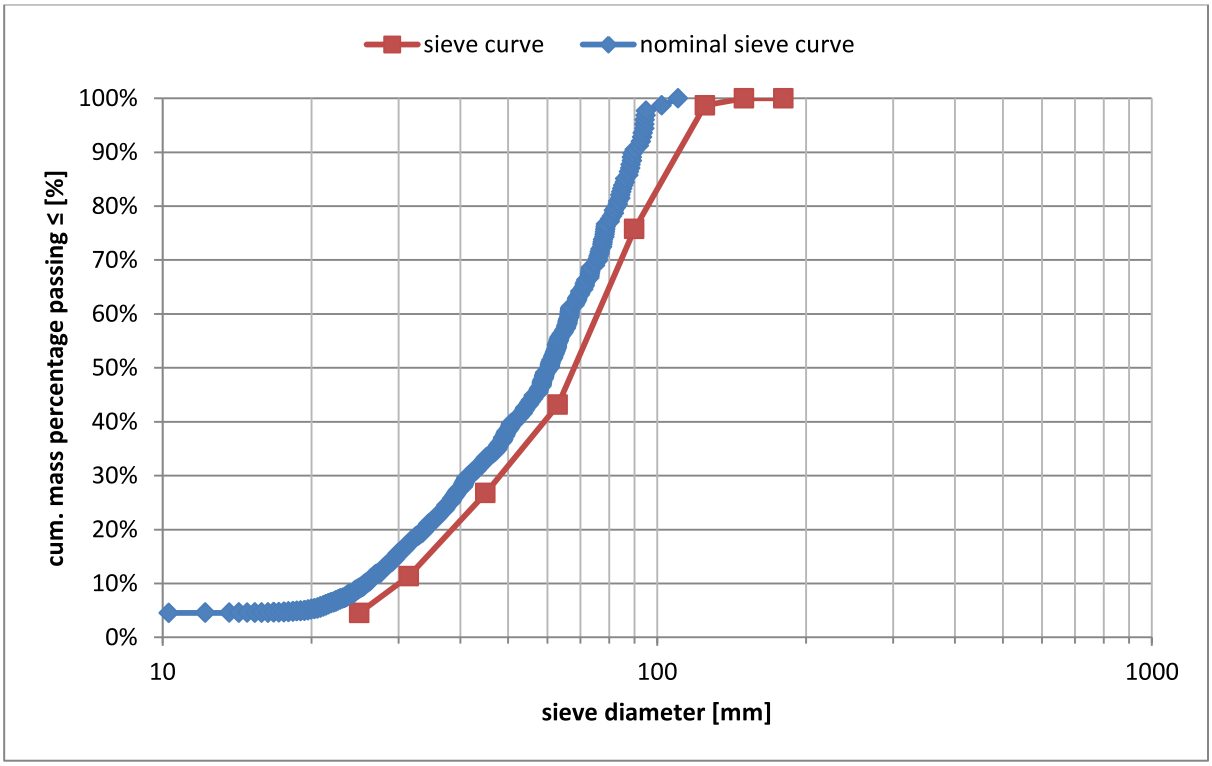


Figure D.2-49 - sieve curves 5+ A-C

In Figure D.2-50 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the curves show great overlap, especially for the relatively small rocks (nominal diameter < approx. 50 mm). For the larger rocks the accuracy of the approximation decreases slightly, especially for rock with a nominal diameter over 90 mm. These diameters are overestimated by the product of shape factor and sieve diameter.

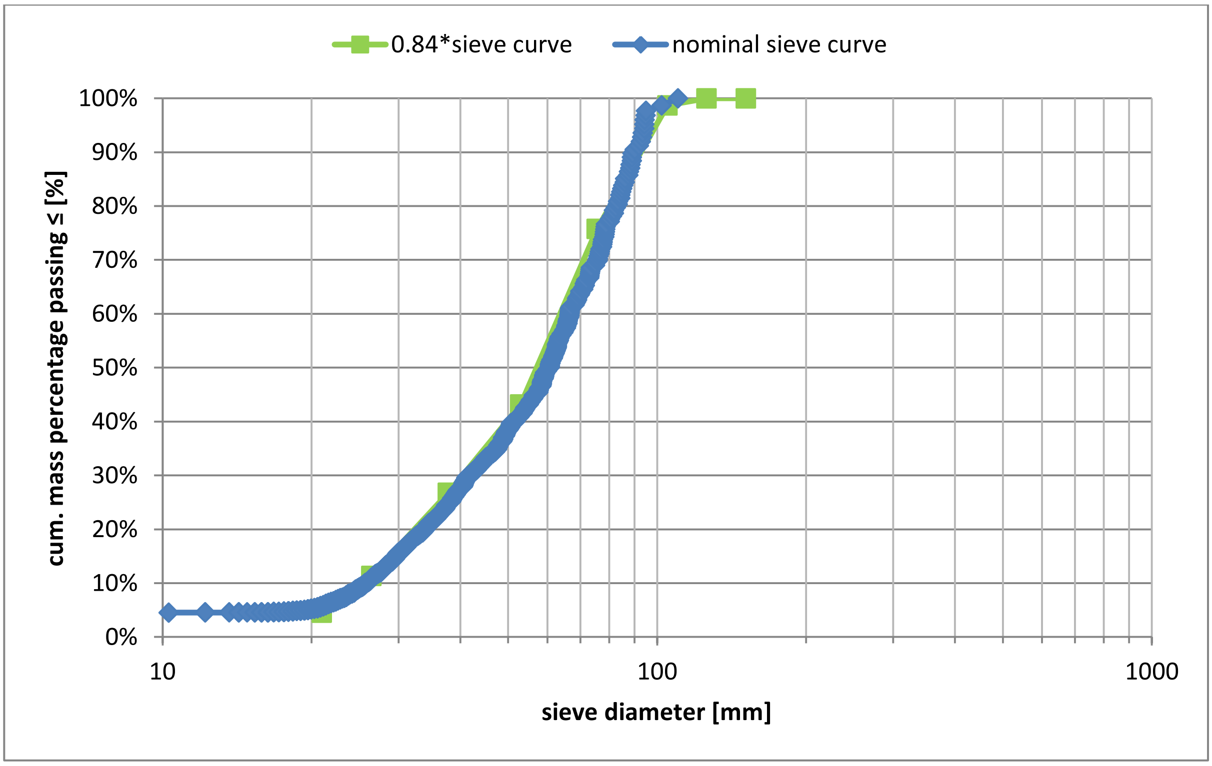


Figure D.2-50 - verification shape factor 5+ A-C

D.2.2.4 Conclusions

The information gained on the shape factor of the 5+ material is listed in Table D-119. It is concluded the value of the shape factor F_{50} – the value commonly applied in practice – is fluctuating between a value of 0.84-0.87 for the individual samples. The combined sample yields the value of 0.85 for F_{50}. Furthermore for each sample it is concluded the shape factor is not constant for none of the samples. Moreover, in general the value of considerably decreases for increasing rock size. For F_5 and F_{15} values between 0.91 and 95 are found. In contrary for F_{90} and F_{98} values between 0.84 and 0.75 are found.

Table D-119 - shape factor 5+

	Sample	A	B	C	A-C
ELL	dn5	85.367	76.290	75.581	79.221
	d5	92.980	80.769	79.645	87.474
	F5	0.918	0.945	0.949	0.906
NLL	dn15	97.301	88.200	87.002	90.845
	d15	103.708	97.211	96.107	98.872
	F15	0.938	0.907	0.905	0.919
MED	dn50	113.024	111.301	105.274	110.349
	d50	133.218	128.134	125.267	129.501
	F50	0.848	0.869	0.840	0.852
NUL	dn90	134.608	138.166	129.980	136.398
	d90	164.258	168.485	164.675	165.791
	F90	0.819	0.820	0.789	0.823
EUL	dn98	145.425	147.097	142.588	144.820
	d98	176.852	183.843	190.851	181.919
	F98	0.822	0.800	0.747	0.796

D.2.3 1-5+ Slovag - (1-5 - 5+ combined)

The conceptual 1-5+ grading results from the combination of the data from the 1-5 and 5+ gradings. The rock in sample 1-5+ A thus consists of the rock from sample 1-5 A and sample 5+ A.

Origin: Wergeland Halsvik AS, Norway
Aggregate type: Basaltic rock
Shape type: Fresh

D.2.3.1 Sample A

Amount of rock: 255

Sieve test

Numerical information on the sieve test is given in Table D-120.

Table D-120 - sieve test results 1-5+ A

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	1.162	0.3	0.26
31.5-45	2.908	0.7	0.92
45-63	8.061	1.8	2.75
63-90	38.583	8.7	11.49
90-125	151.271	34.3	45.77
125-180	170.392	38.6	84.38
180-250	68.919	15.6	100.00
total	441.3	100.0	-

The resulting sieve curve is given in Figure D.2-51.

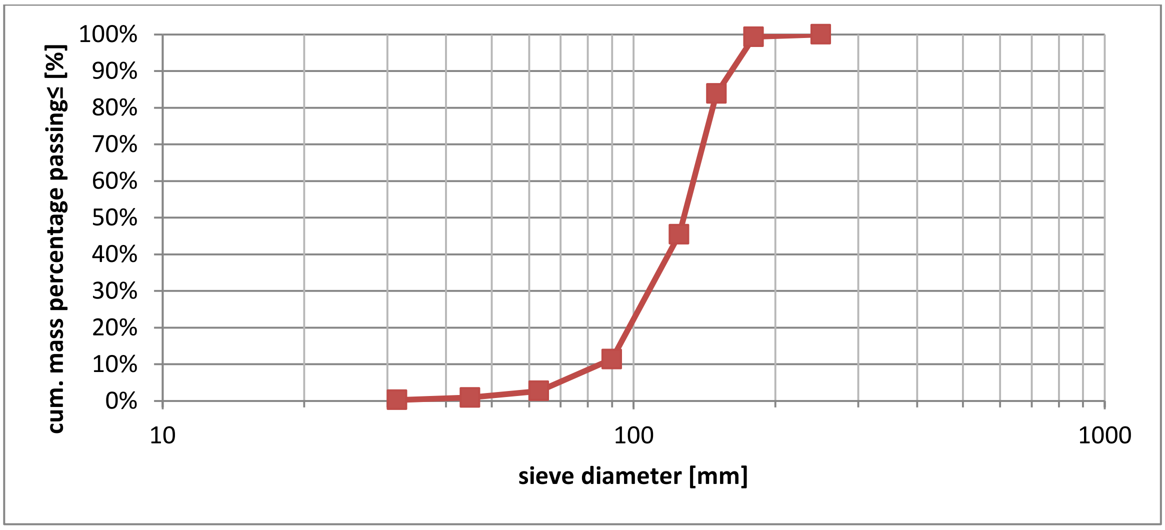


Figure D.2-51 - sieve curve 1-5+ A

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-121.

Table D-121 - Interpolated sieve diameters 1-5+ A

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	70.1
d10 (NLL)	85.6
d15	93.7
d25	104.0
d50 (MSD)	128.0
d60	134.5
d85	152.3
d90 (NUL)	161.9
d98 (EUL)	177.4

Grading width: d_{85}/d_{15} = 1.63. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-52 it is observed the samples mass distribution shows significant deviation over the sieve fractions from the expected normal distribution. Care should be taken during interpreting the interpolated sieve diameters.

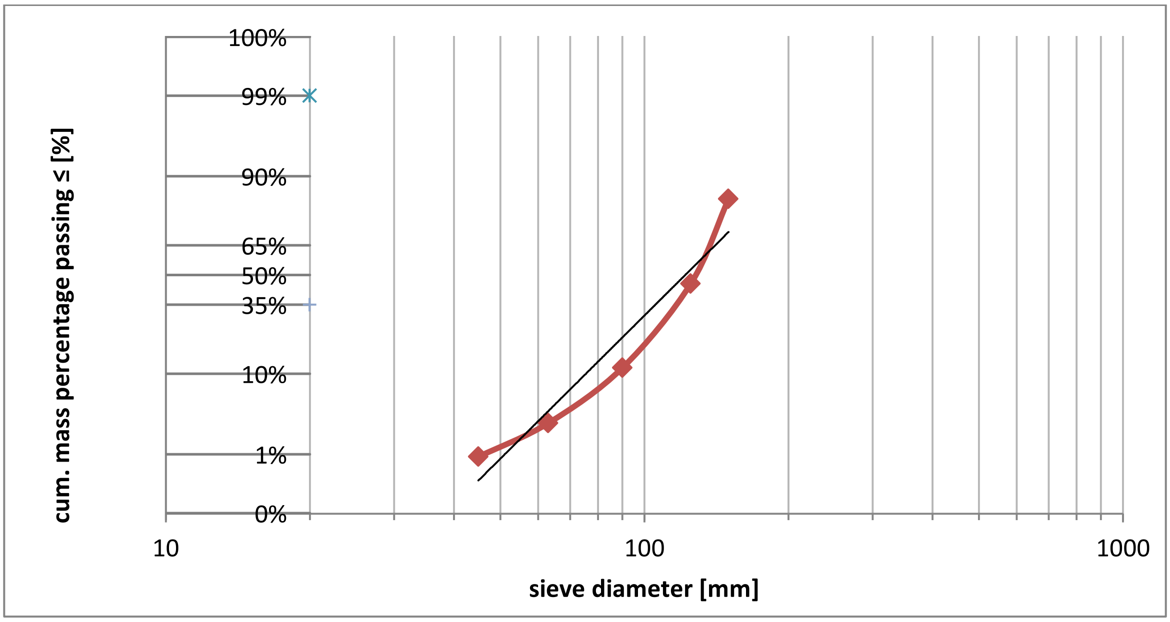


Figure D.2-52 - Gaussian sieve curve 1-5+ A

d_n-analysis

The nominal sieve curve including the nominal diameters calculated by the volumes determined according to the Archimedes method is given in Figure D.2-53.

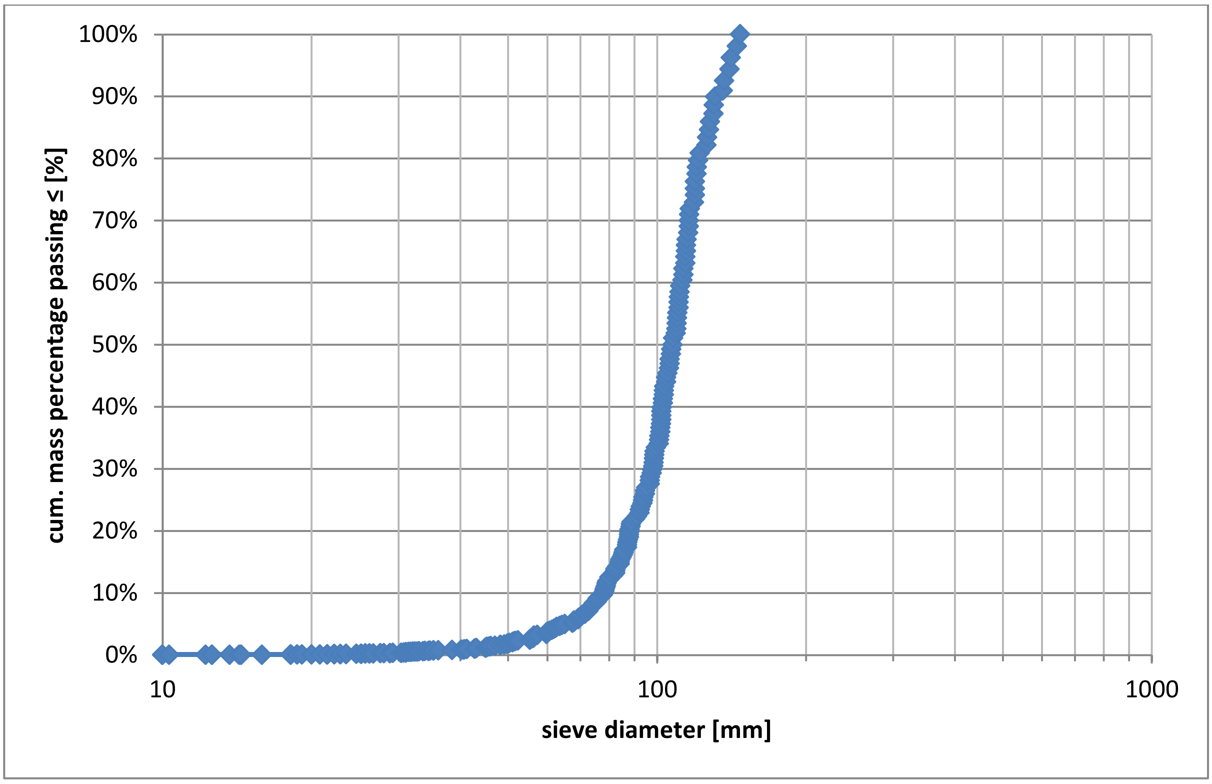


Figure D.2-53 - nominal sieve curve 1-5+ A

Again the impact of scattering densities is examined. In Figure D.2-54 the individual rock densities are plotted.

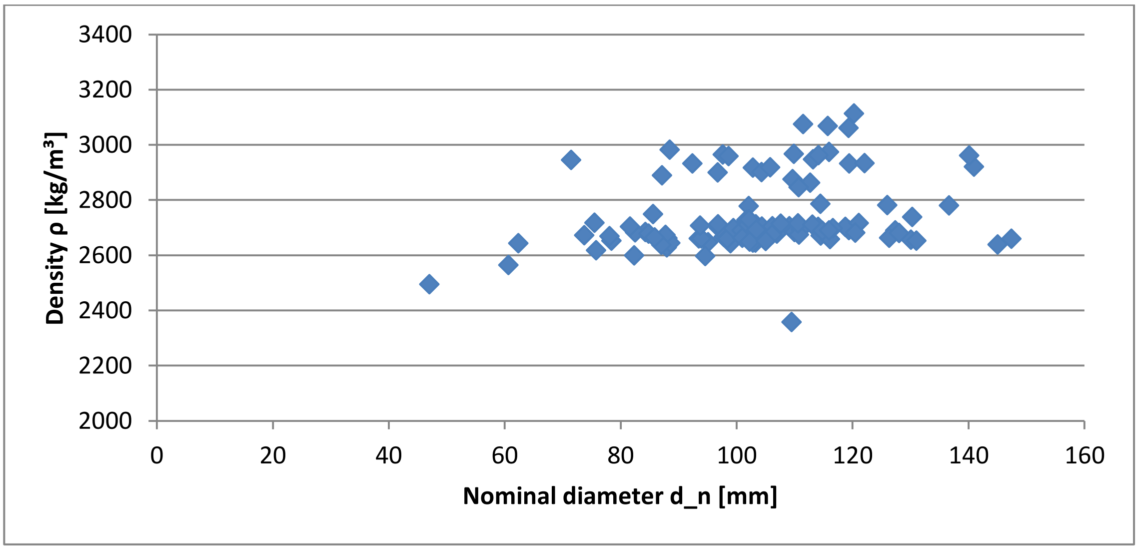


Figure D.2-54 - individual Archimedes rock densities 1-5+ A

The average of the densities is 2742 kg/m³, the median is 2696 kg/m³ and the modus is 2690 kg/m³. It is concluded a lot of scatter is present, in particular for the smaller rock. Moreover the densities of the larger rocks (nominal diameter > approx. 70 mm) tend to concentrate in two distinct bands at values of approximately 2650 and 2950 kg/m³. The observed convergence can be explained by the occurrence of different rock types in the rock face. It is concluded the uniformity of the rock is considerably low. The influence of density scatter on the determination of the shape factor is however still based on the assumption of uniform density to yield result that can be compared with the results from the IJmuiden tests and analyses.

By application of a uniform density the nominal diameters are recalculated. The uniform density is determined by the average density of the rocks in the 63-90 and 90-125 fractions and has a value of 2736 kg/m³. The nominal sieve curve based on the recalculated nominal diameters is given in Figure D.2-55.

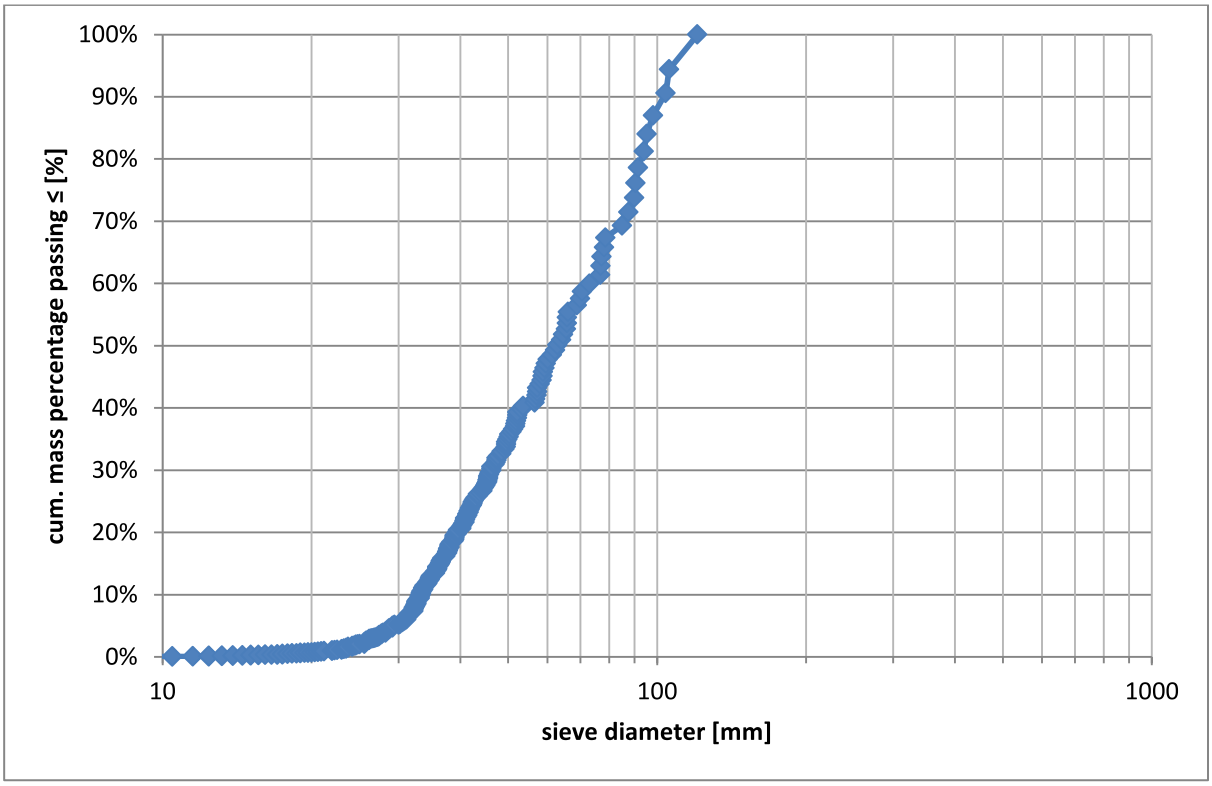


Figure D.2-55 - modified nominal sieve curve 1-5+ A

The observation of two distinct density bands can however not be ignored. Therefore the above analysis is redone by application of two distinct densities. These densities are determined on the basis of a subdivision of the rock in 63-90 and 90-125 fractions into normal density rock (Archimedes density < 2800 kg/m³) and high density rock (Archimedes density > 2800 kg/m³), see Figure D.2-56 and Figure D.2-57.

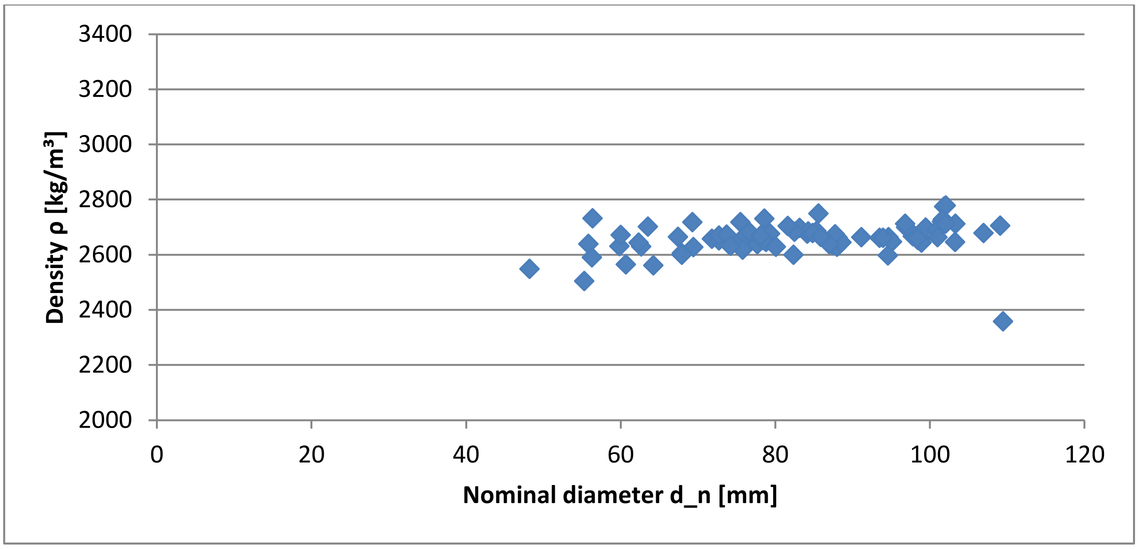


Figure D.2-56 – densities < 2800 kg/m³

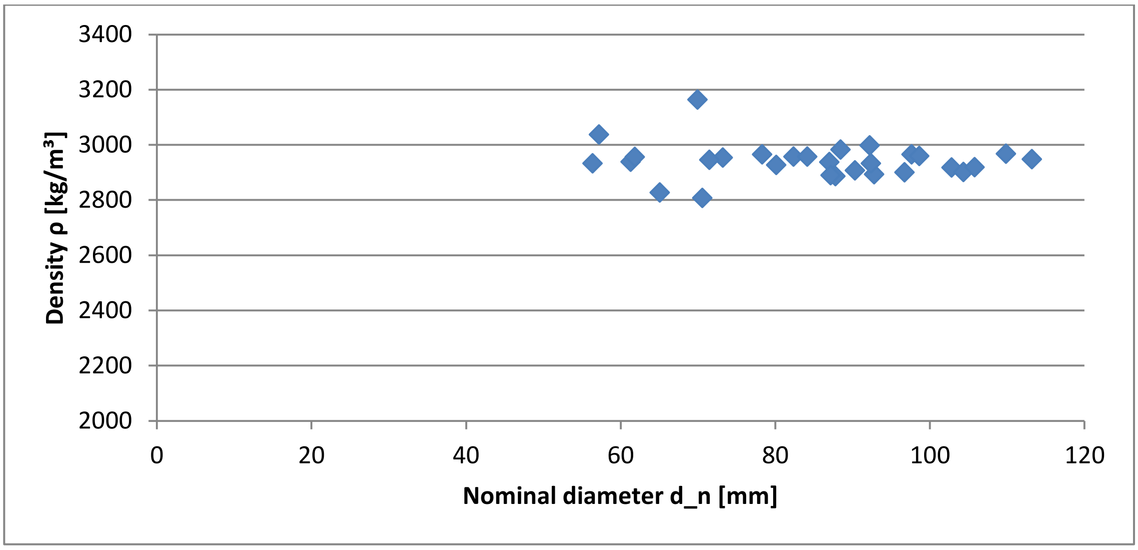


Figure D.2-57 - densities > 2800 kg/m³

The found averages of the normal density and high density rock are 2659 kg/m³ and 2940 kg/m³ respectively. To calculate the nominal diameters the value of 2659 kg/m³ is applied for all rocks having an Archimedes density below 2800 kg/m³. Accordingly the value of 2940 is applied for all rocks having an Archimedes density above 2800 kg/m³.

The resulting nominal sieve curve is given in Figure D.2-58.

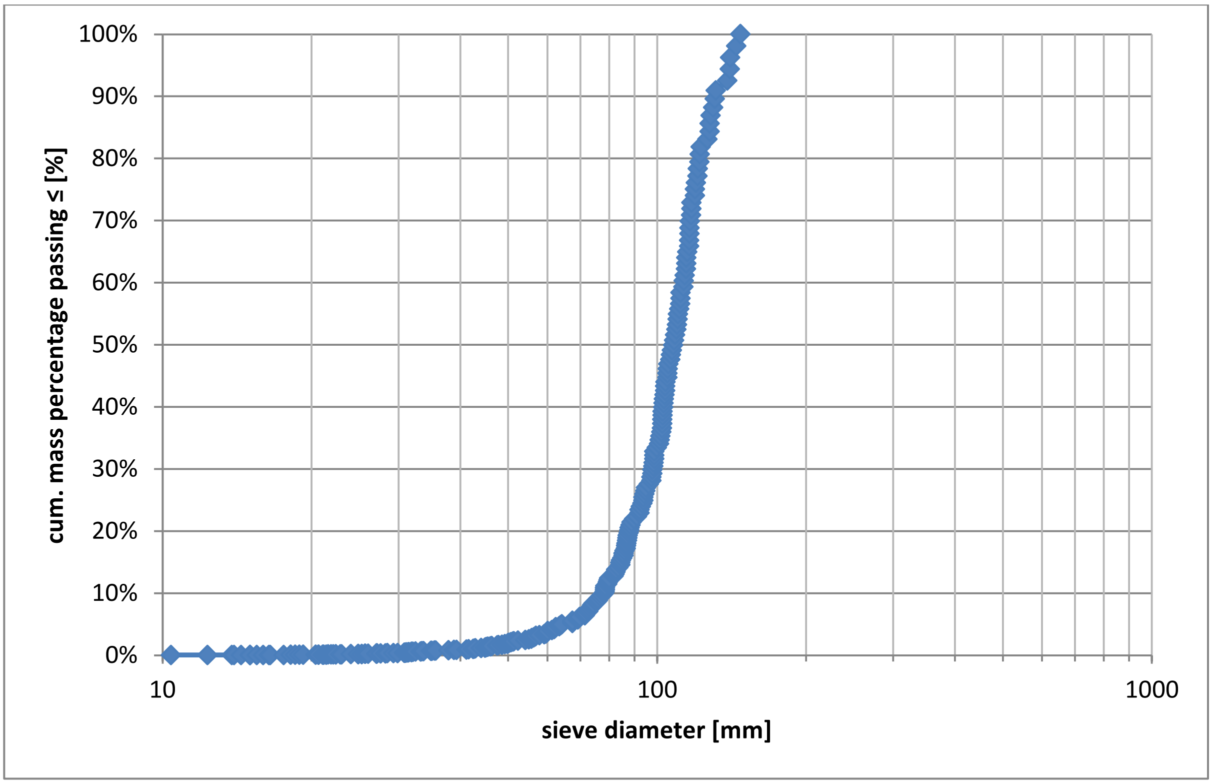


Figure D.2-58 - nominal sieve curve acc. to normal density and high density

In Table D-122 the interpolated nominal diameters based on both the Archimedes, modified and specific volumes are listed.

Table D-122 - comparison of dn-values acc. to Archimedes and modified volumes 1-5+ A

nominal diameter	acc. to Archimedes volumes	acc. Modified volumes	acc. to spec volumes
	[mm]	[mm]	[mm]
dn5	65.6	66.0	65.0
dn15	84.2	84.4	84.4
dn50	107.6	108.2	107.9
dn90	131.3	129.9	131.2
dn98	144.9	144.1	144.6

From Table D-122 it is concluded the differences in the nominal diameters found on basis of the three different methods are relatively small. In case of the median nominal diameter the largest difference is found between the value found by the Archimedes method and the modified method: 0.6 mm. This implies a relative error approximately of only 0.5 percent. It is therefore concluded the observed scatter in the densities do not cause the nominal diameters found by either method to be unrealistic. Therefore the nominal diameters on the basis of the Archimedes volumes are applied in this sample.

Shape factors F_x

The shape factors are given in Table D-123.

Table D-123 - shape factors 1-5+ A

nominal diameter				sieve diameter		shape factor			
[mm]	Arc	mod	spec	[mm]		[mm]	Arc	mod	spec
dn5	65.6	66.0	65.0	d5	70.1	F5	0.937	0.942	0.927
dn15	84.2	84.4	84.4	d15	93.7	F15	0.898	0.901	0.901
dn50	107.6	108.2	107.9	d50	128.0	F50	0.841	0.846	0.844
dn90	131.3	129.9	131.2	d90	161.9	F90	0.811	0.802	0.810
dn98	144.9	144.1	144.6	d98	177.4	F98	0.817	0.812	0.815

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. For each method this trend is observed in a similar extent. For the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.84-0.85, which is practically equal to the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-59.

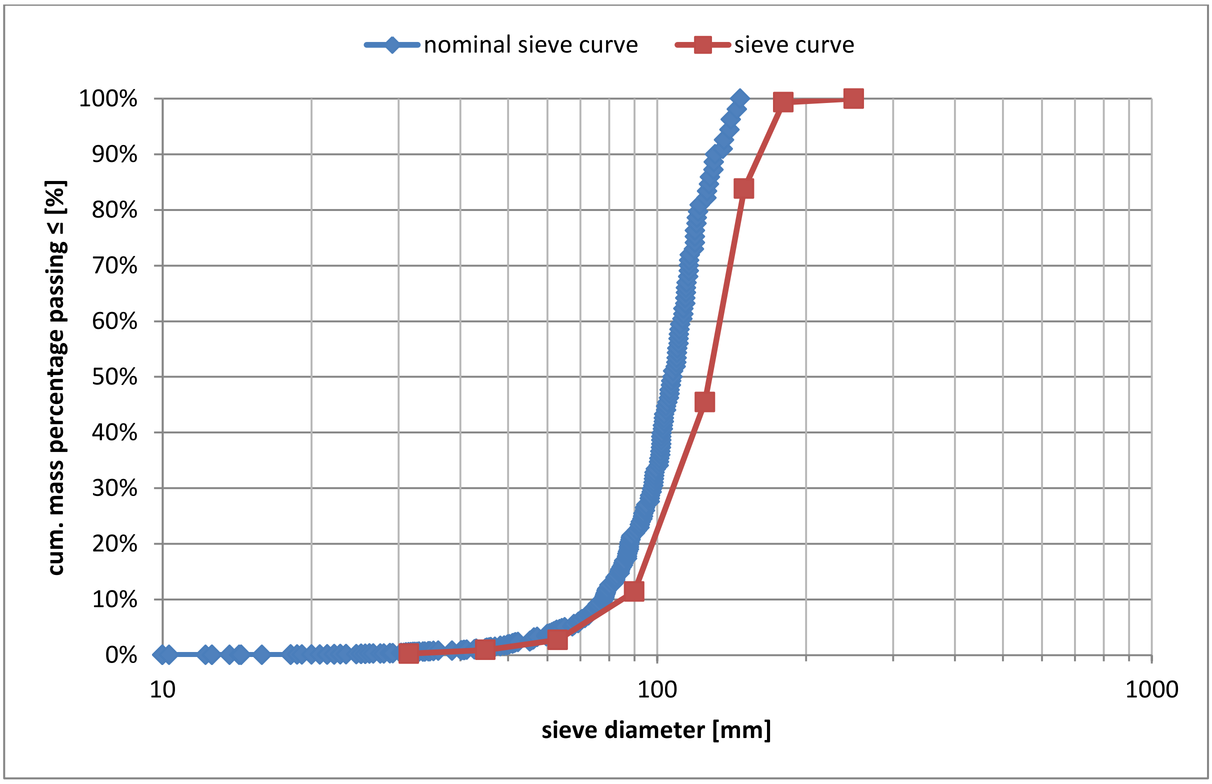


Figure D.2-59 - curves 1-5+ A

In Figure D.2-60 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that for small rocks the nominal diameters are approximated relatively poor by a value of 0.84 times the sieve curve. For the larger rocks (nominal diameter > approx. 100 mm) the nominal diameters are approximated rather well by the shape factor of 0.84 times the sieve diameters. Even for the largest rocks this observation holds.

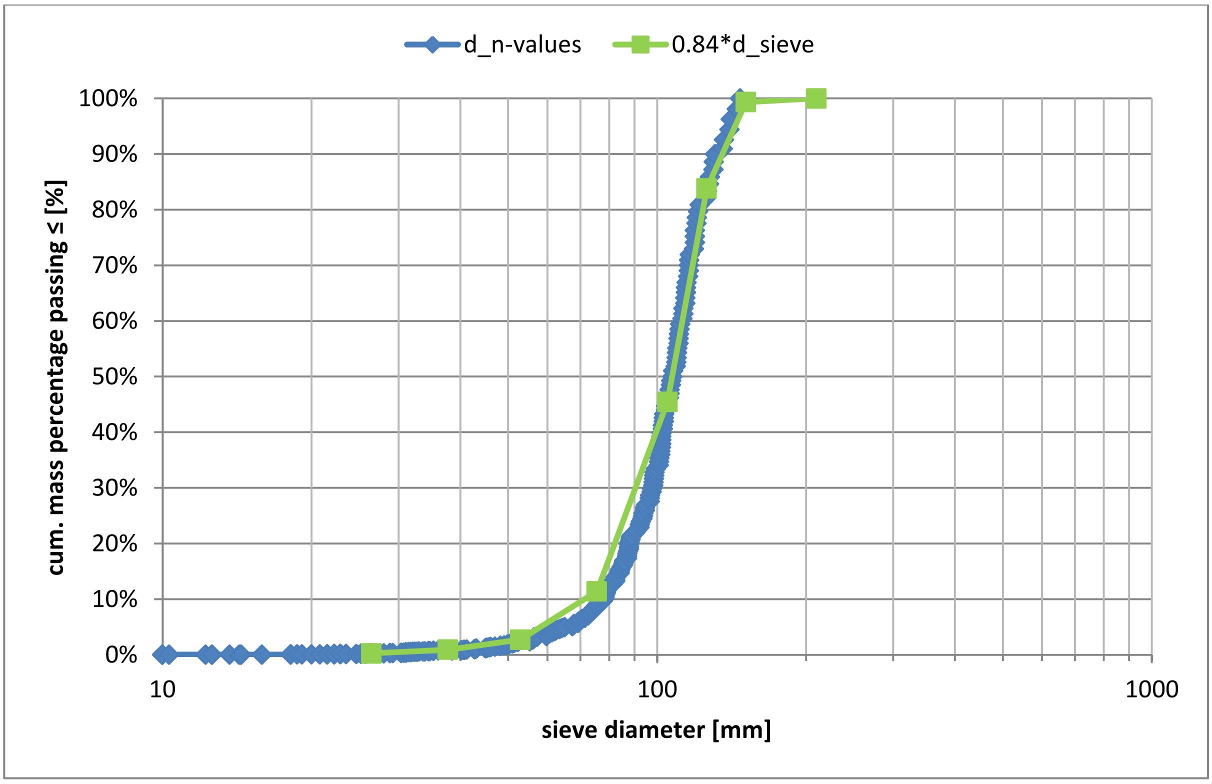


Figure D.2-60 - verification shape factor 1-5+ A

Shape test

In Table D-124 and Table D-125 an overview is given of the minimum, maximum and average values of the elongation and blockiness respectively.

Table D-124 - elongation 1-5+ A

	Elongation		
	minimum [-]	maximum [-]	average [-]
0-31.5	1.42	5.00	3.02
31.5-45	1.61	4.93	2.76
45-63	1.64	6.44	2.89
63-90	1.45	7.07	2.69
90-125	1.36	7.04	2.50
125-150	1.36	4.44	2.45
150-180	1.66	3.30	2.55
total	1.36	7.07	2.68

Table D-125 -blockiness 1-5+ A

	Blockiness		
	minimum [%]	maximum [%]	average [%]
0-31.5	11.25	65.06	44.64
31.5-45	29.86	63.49	44.14
45-63	30.09	53.02	41.60
63-90	28.66	62.05	41.10
90-125	31.15	59.76	44.91
125-150	29.48	72.55	44.75
150-180	38.33	63.09	46.02
total	11.25	72.53	43.85

The minimum elongation is relatively constant over the fractions, the absolute minimum observed is 1.36. The maximum value of elongation observed in the sample is 7.07, which is considered rather high. It is concluded the minima are relatively constant over the sieve fractions, in the maxima significant fluctuating is observed. A plausible cause may be that the 63-90 and 90-125 fractions contain more rocks. As a result the probability to find more extreme value statistically increases. However no trends in elongation are observed over the fractions. The average values found for elongation and blockiness considering all rocks are approximately 2.68 and 44 percent, which do agree with values normally found in practice. Considering blockiness also no significant trends are observed over the fractions.

Sample B

Amount of rock: 637

Sieve test

Numerical information on the sieve test is given in Table D-126.

Table D-126 - sieve test results 1-5+ B

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
0-31.5	6.866	1.8	1.84
31.5-45	19.401	5.2	7.05
45-63	21.782	5.8	12.90
63-90	50.348	13.5	26.41
90-125	123.962	33.3	59.68
125-150	88.803	23.8	83.52
150-180	54.533	14.6	98.15
180-250	6.887	1.8	100.00
total	372.6	100.0	-

The resulting sieve curve is given in Figure D.2-61.

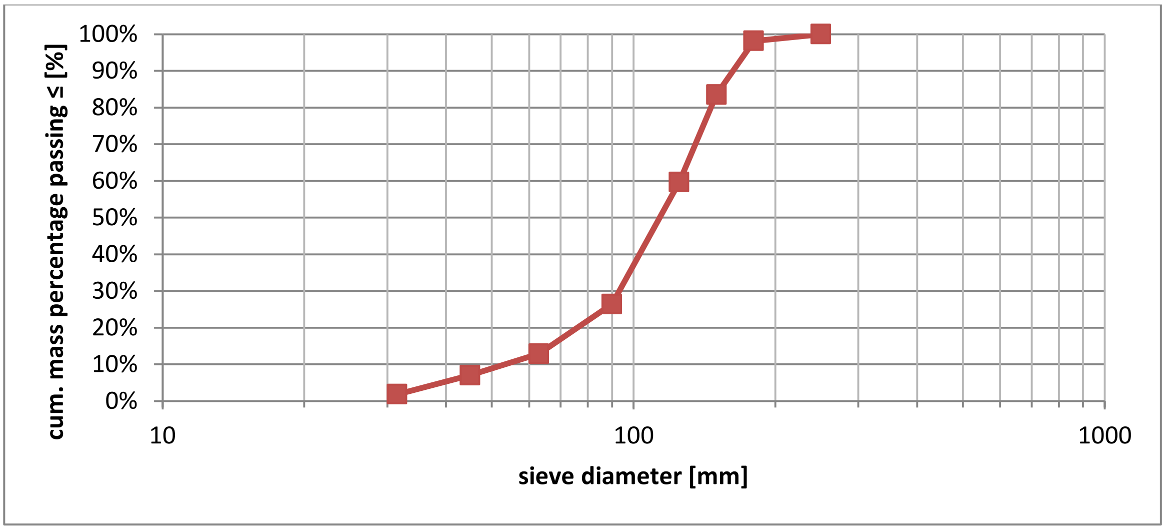


Figure D.2-61 - sieve curve 1-5+ B

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-127.

Table D-127 - Interpolated sieve diameters 1-5+ B

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	39.7
d10 (NLL)	54.1
d15	67.2
d25	87.2
d50 (MSD)	114.8
d60	125.3
d85	153.0
d90 (NUL)	163.3
d98 (EUL)	179.7

Grading width: d_{85}/d_{15} = 2.28. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-62 it is observed the samples mass distribution shows significant deviation over the sieve fractions from the expected normal distribution. Care should be taken during interpreting the interpolated sieve diameters.

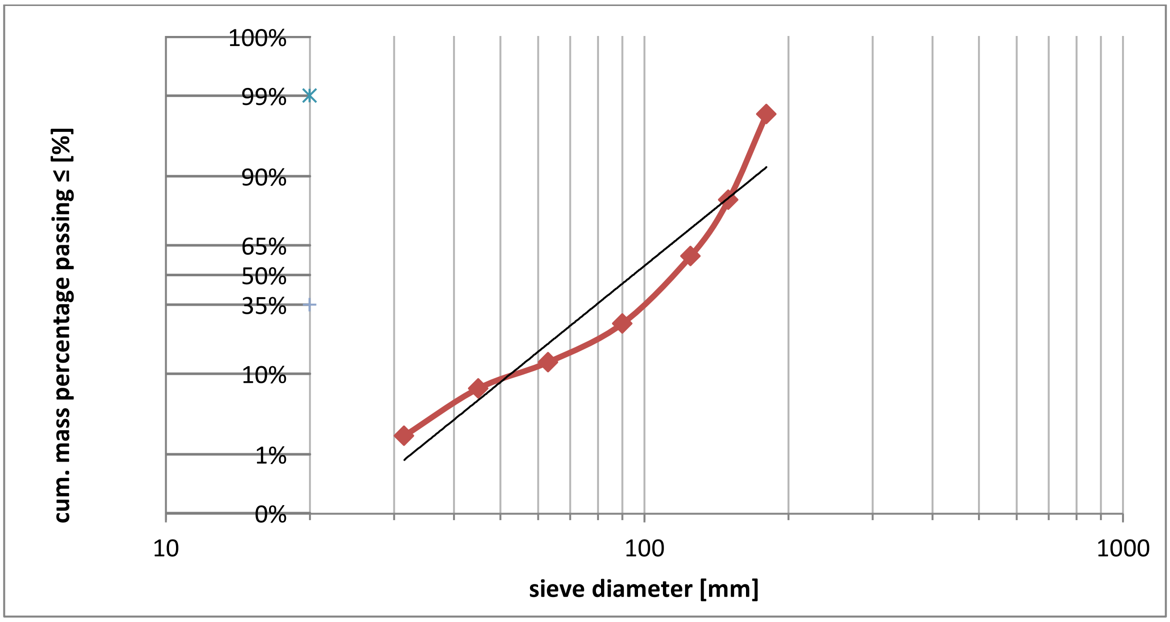


Figure D.2-62 - Gaussian sieve curve 1-5+ B

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2736 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.2-63.

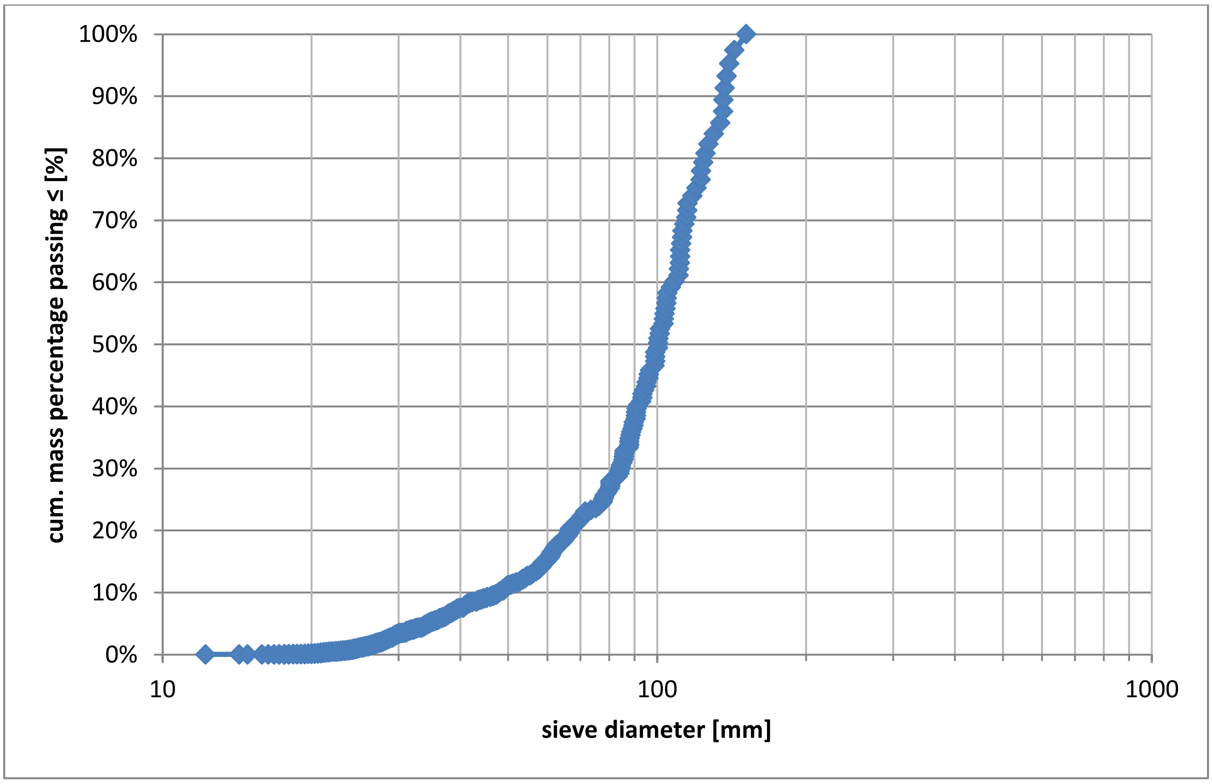


Figure D.2-63 - nominal sieve curve 1-5+ B

In Table D-128 nominal diameters interpolated from Figure D.2-63 have been listed.

Table D-128 - nominal diameters 1-5+ B

	nominal diameter
	[mm]
dn5	34.5
dn15	59.4
dn50	100.6
dn90	136.6
dn98	145.3

Shape factors F_x

The shape factors are given in Table D-129.

Table D-129 - shape factors 1-5+ B

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	34.5	d5	39.7	F5	0.870
dn15	59.4	d15	67.2	F15	0.884
dn50	100.6	d50	114.8	F50	0.876
dn90	136.6	d90	163.3	F90	0.836
dn98	145.3	d98	179.7	F98	0.808

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.88, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-64.

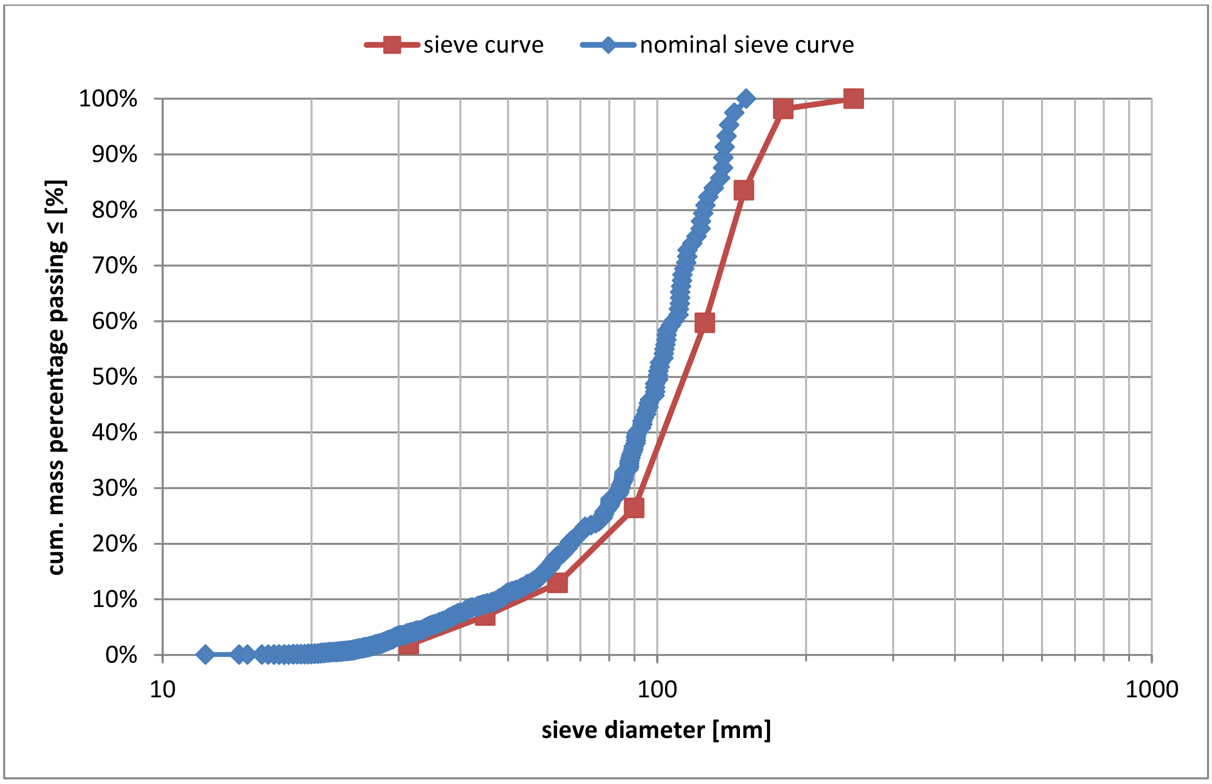


Figure D.2-64 - sieve curves 1-5+ B

In Figure D.2-65 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the nominal diameters are approximated rather well by a value of 0.84 times the sieve curve. Only for rocks that have a nominal diameter between 70 and 100 mm some small deviation is observed. Furthermore it is observed that the nominal diameter of the largest rock is considerably overestimated by multiplication of shape factor and sieve diameter.

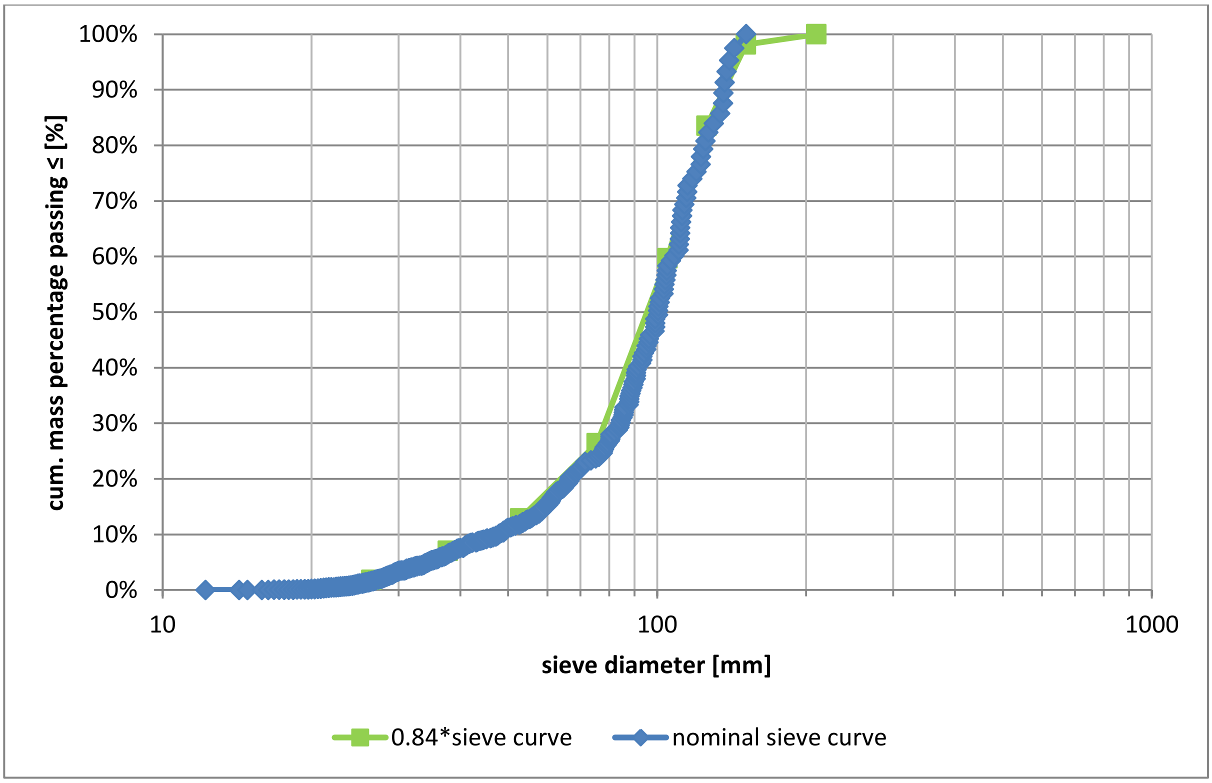


Figure D.2-65 - verification shape factor 1-5+ B

D.2.3.2 Sample C

Amount of rock: 861

Sieve test

Numerical information on the sieve test is given in Table D-130.

Table D-130 - sieve test results 1-5+ C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤25	12.903	2.9	2.89
25-31.5	11.377	2.5	5.43
31.5-45	21.46	4.8	10.24
45-63	22.831	5.1	15.35
63-90	50.917	11.4	26.74
90-125	157.81	35.3	62.06
125-150	117.717	26.3	88.41
150-180	37.071	8.3	96.71
180-250	14.711	3.3	100.00
total	446.8	100.0	-

The resulting sieve curve is given in Figure D.2-66.

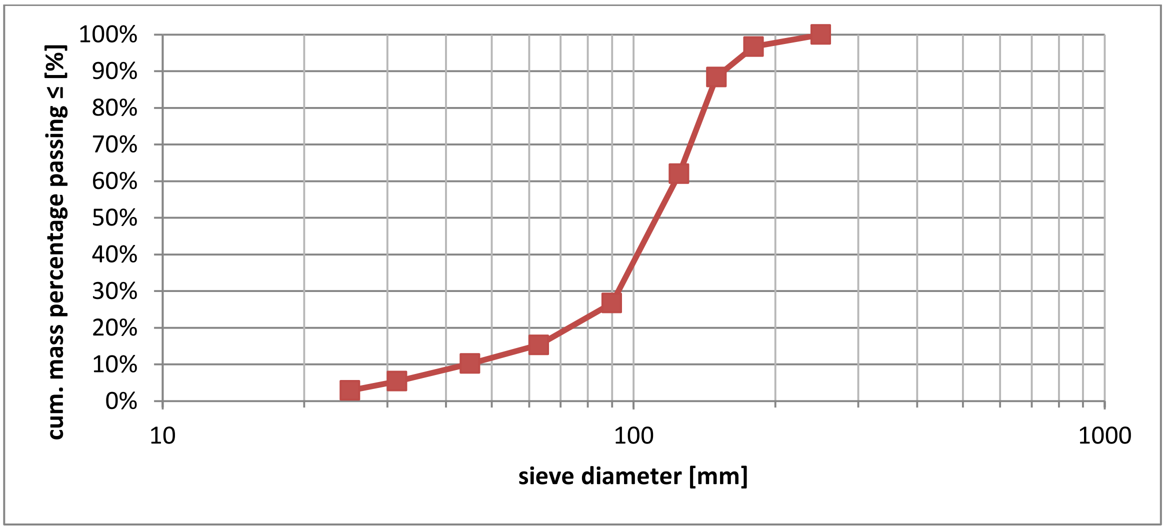


Figure D.2-66 - sieve curve 1-5+ B

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-131.

Table D-131 - Interpolated sieve diameters 1-5+ C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	30.4
d10 (NLL)	44.3
d15	61.8
d25	85.9
d50 (MSD)	113.1
d60	123.0
d85	146.8
d90 (NUL)	155.8
d98 (EUL)	207.5

Grading width: d_{85}/d_{15} = 2.38. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-67 it is observed the samples mass distribution shows significant deviation over the sieve fractions from the expected normal distribution. Care should be taken during interpreting the interpolated sieve diameters.

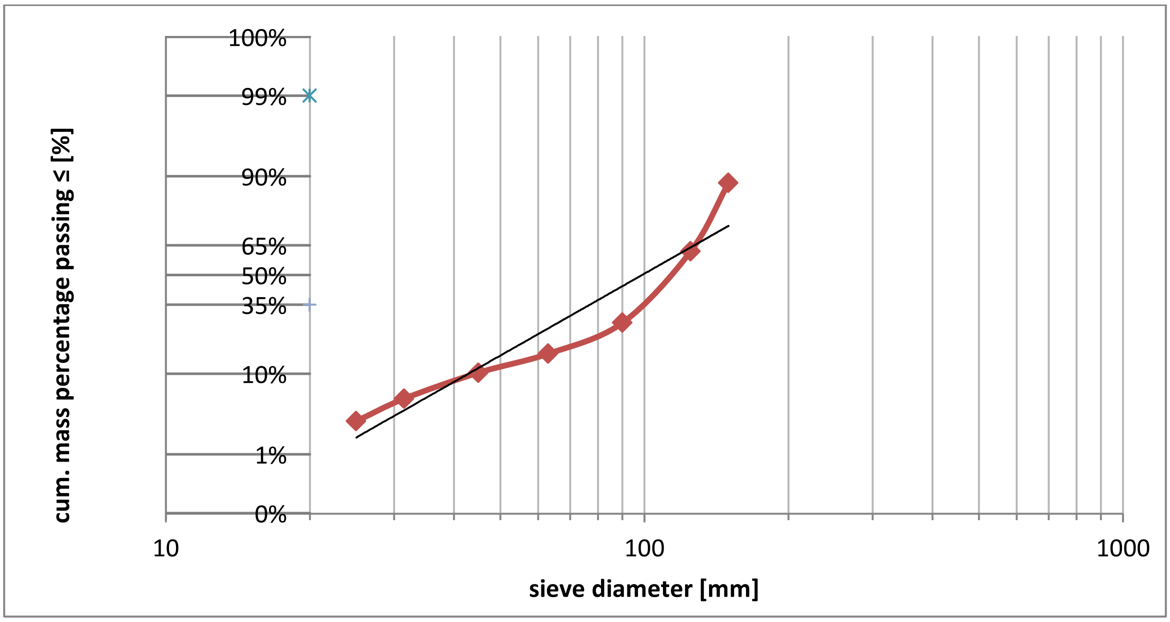


Figure D.2-67 - Gaussian sieve curve 1-5+ C

d_n-analysis

Since for this sample the submersion technique was not performed the volumes required to determine the nominal diameters are calculated by the quotient of mass and density. For the density the uniform density of sample A is applied: 2736 kg/m³ . As both samples are extracted from the same stockpile this is assumption is considered applicable. The resulting nominal sieve curve is given in Figure D.2-68.

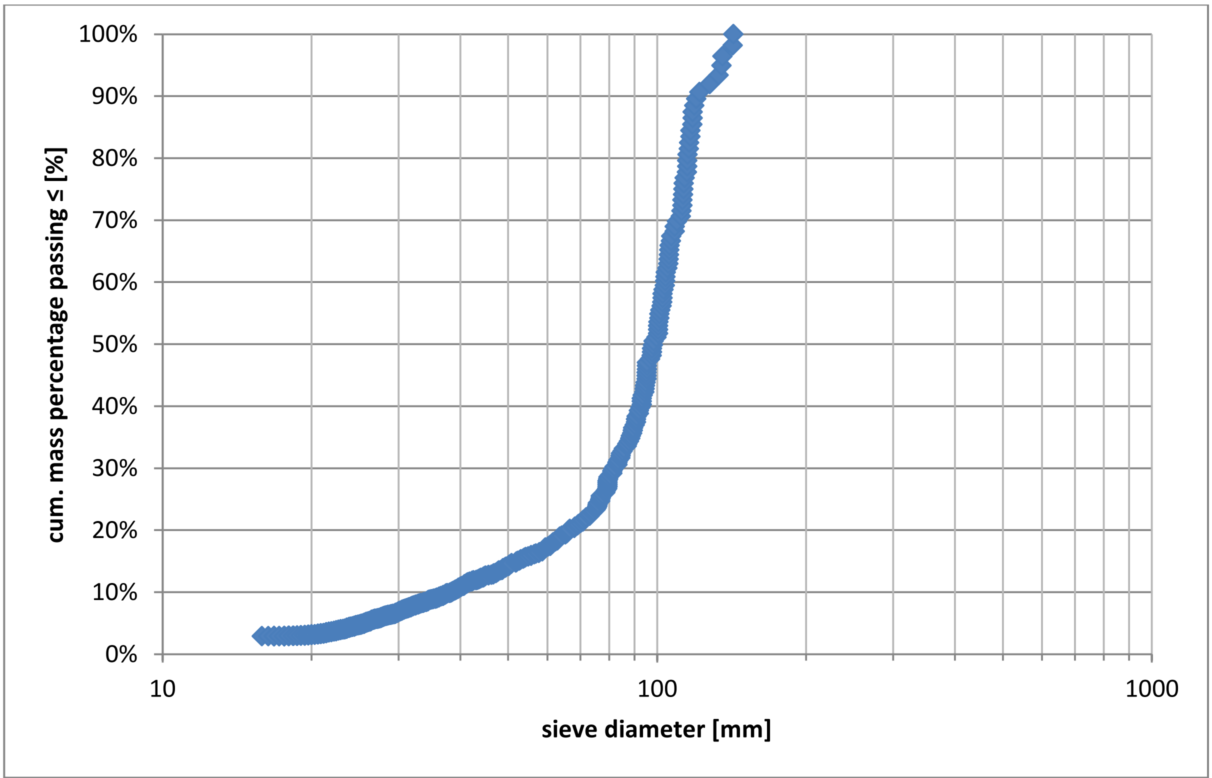


Figure D.2-68 - nominal sieve curve 1-5+ C

In Table D-132 nominal diameters interpolated from Figure D.2-69 have been listed.

Table D-132 - nominal diameters 1-5+ C

	nominal diameter [mm]
dn5	25.6
dn15	52.2
dn50	98.2
dn90	120.8
dn98	141.5

Shape factors F_x

The shape factors are given in Table D-133.

Table D-133 - shape factors 1-5+ C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	25.6	d5	30.4	F5	0.843
dn15	52.2	d15	61.8	F15	0.845
dn50	98.2	d50	113.1	F50	0.869
dn90	120.8	d90	155.8	F90	0.776
dn98	141.5	d98	207.5	F98	0.682

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.87, which is larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-69.

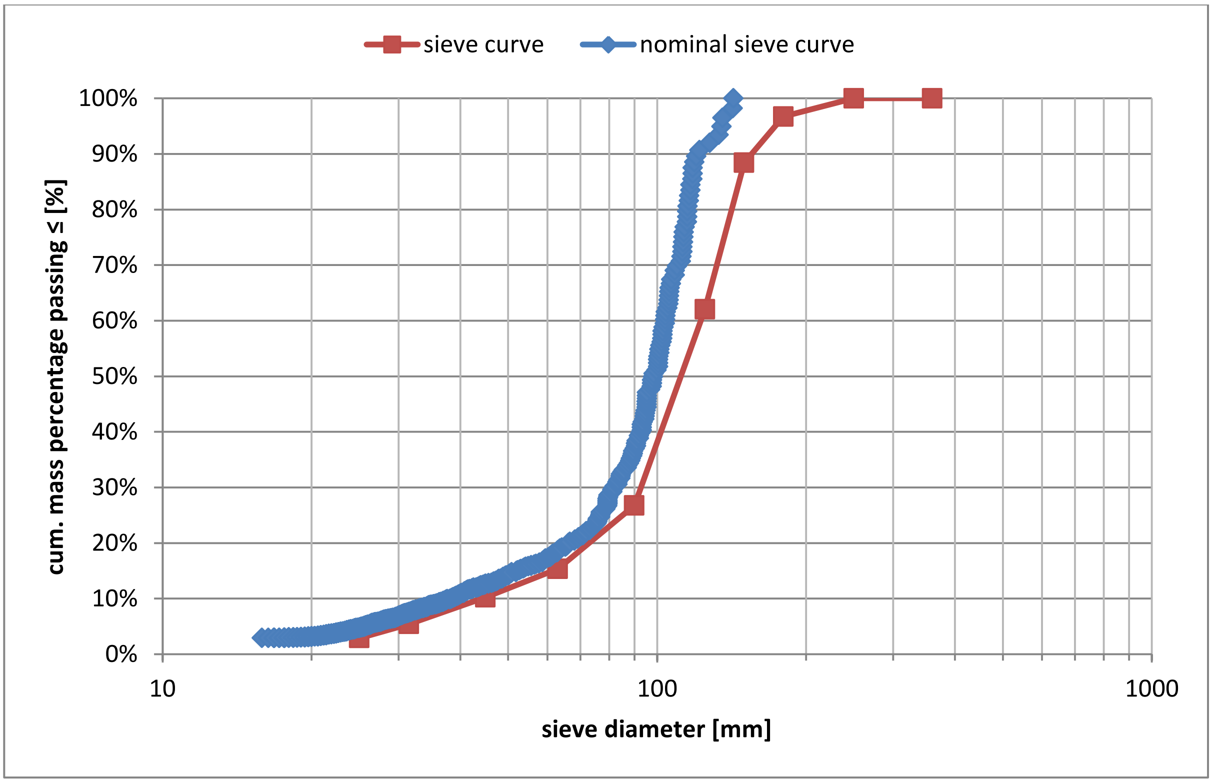


Figure D.2-69 - sieve curves 1-5+ C

In Figure D.2-70 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. It is concluded that the nominal diameters are approximated rather well by a value of 0.84 times the sieve curve. For rocks that have a nominal diameter between 60 and 100 mm only some small deviation is observed. Moreover it is observed that for the largest rocks (nominal diameter > 115 mm) the nominal diameter is continuously significantly overestimated by multiplication of shape factor and sieve diameter.

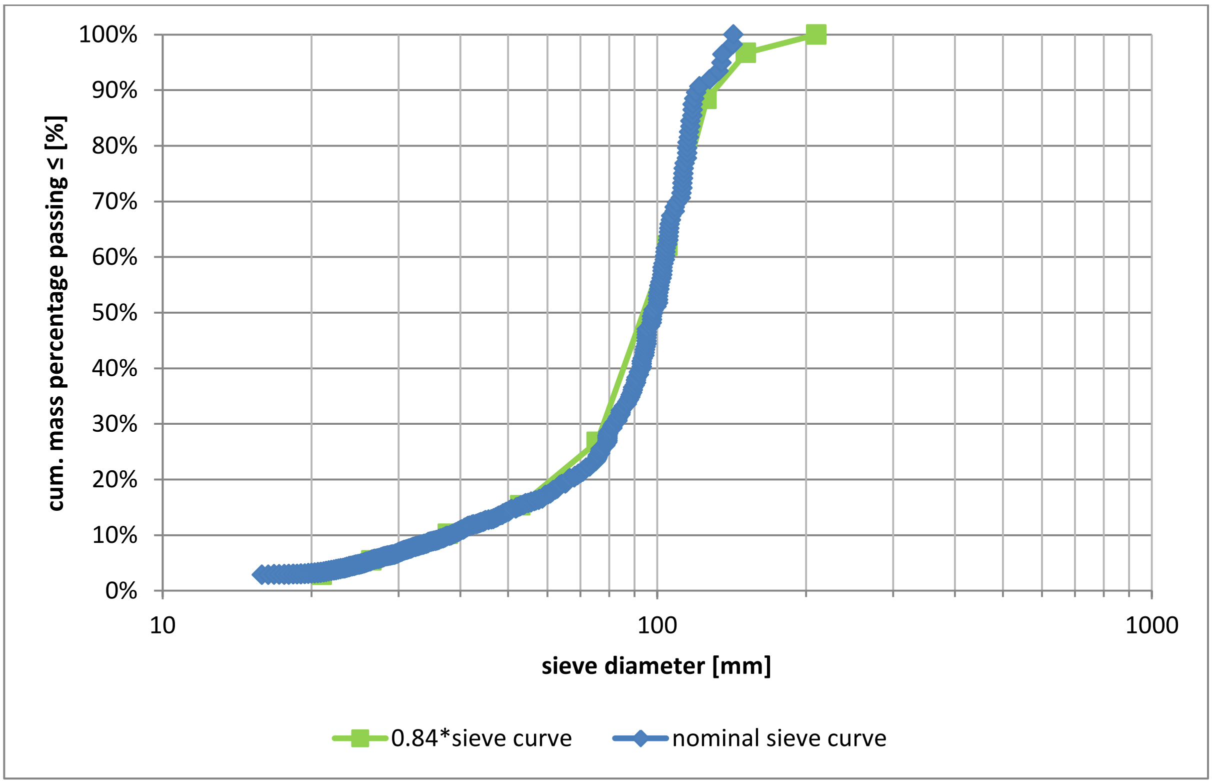


Figure D.2-70 - verification shape factor 1-5+ C

Sample A-C combined

Amount of rock: 1753

The data represented in this sample is equivalent to the data of sample A-C together. It stressed that the results based on the combined sample is not equal to the average of the results of the separate samples.

Sieve test

Numerical information on the sieve test is given in Table D-134.

Table D-134 - sieve test results 1-5+ A-C

fraction	mass	percentage	accum. percentage
[mm]	[kg]	[%]	[%]
≤25	12.903	1.0	1.02
25-31.5	19.405	1.5	2.56
31.5-45	43.769	3.5	6.03
45-63	52.674	4.2	10.21
63-90	139.848	11.1	21.31
90-125	433.043	34.4	55.66
125-150	376.912	29.9	85.55
150-180	160.523	12.7	98.29
180-250	21.598	1.7	100.00
total	1260.7	100.0	-

The resulting sieve curve is given in Figure D.2-71.

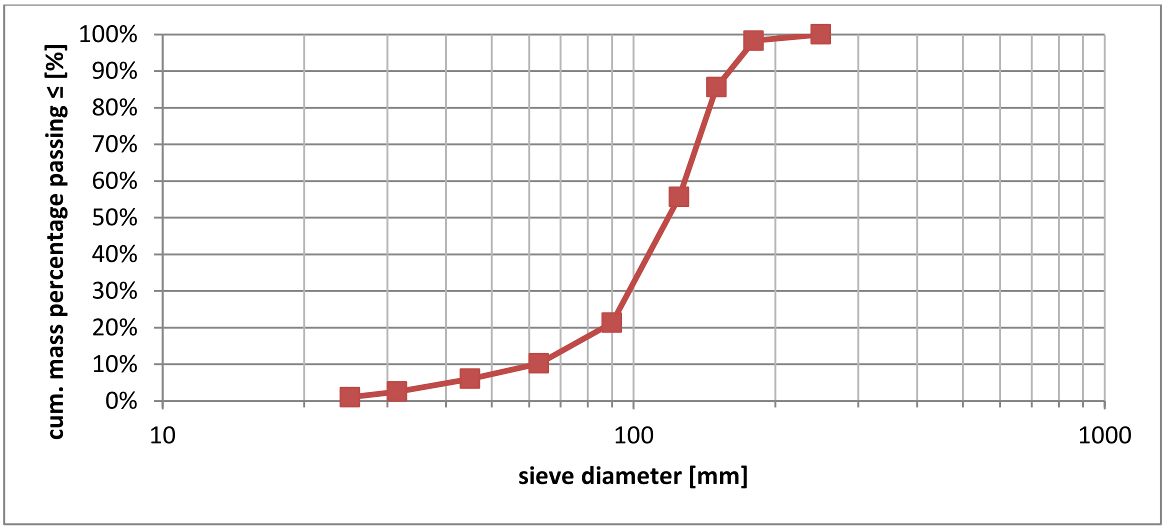


Figure D.2-71 - sieve curve 1-5+ A-C

Interpolated sieve diameters associated with certain cumulative mass passing percentages are listed in Table D-135.

Table D-135 - Interpolated sieve diameters 1-5+ A-C

interpolated sieve diameter	
d%	[mm]
d5 (ELL)	41.0
d10 (NLL)	62.1
d15	74.7
d25	93.8
d50 (MSD)	119.2
d60	128.6
d85	149.5
d90 (NUL)	160.5
d98 (EUL)	179.3

Grading width: d_{85}/d_{15} =2.00. Wide coarse grading according to the Rock Manual (2007).

From Figure D.2-72 it is observed the samples mass distribution shows significant deviation over the sieve fractions from the expected normal distribution. Care should be taken during interpreting the interpolated sieve diameters.

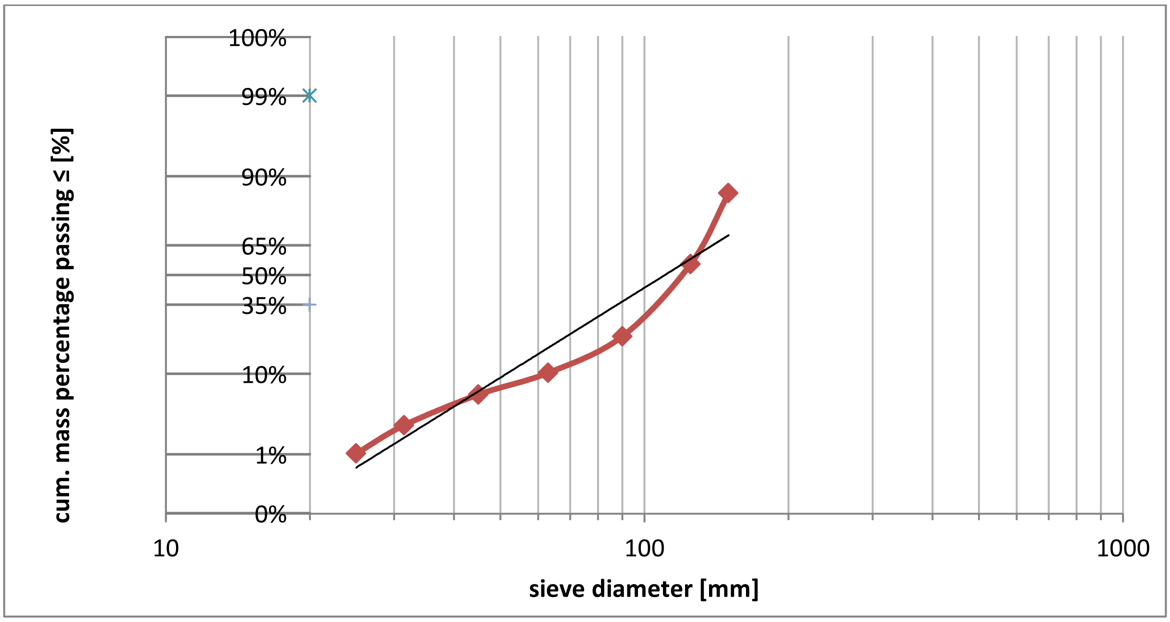


Figure D.2-72 - Gaussian sieve curve 1-5+ A-C

d_n-analysis

The volumes required to determine the nominal diameters are calculated by the quotient of mass and density. Also for sample A the nominal diameters this method is applied to assure uniform information. The resulting nominal sieve curve is given in Figure D.2-73.

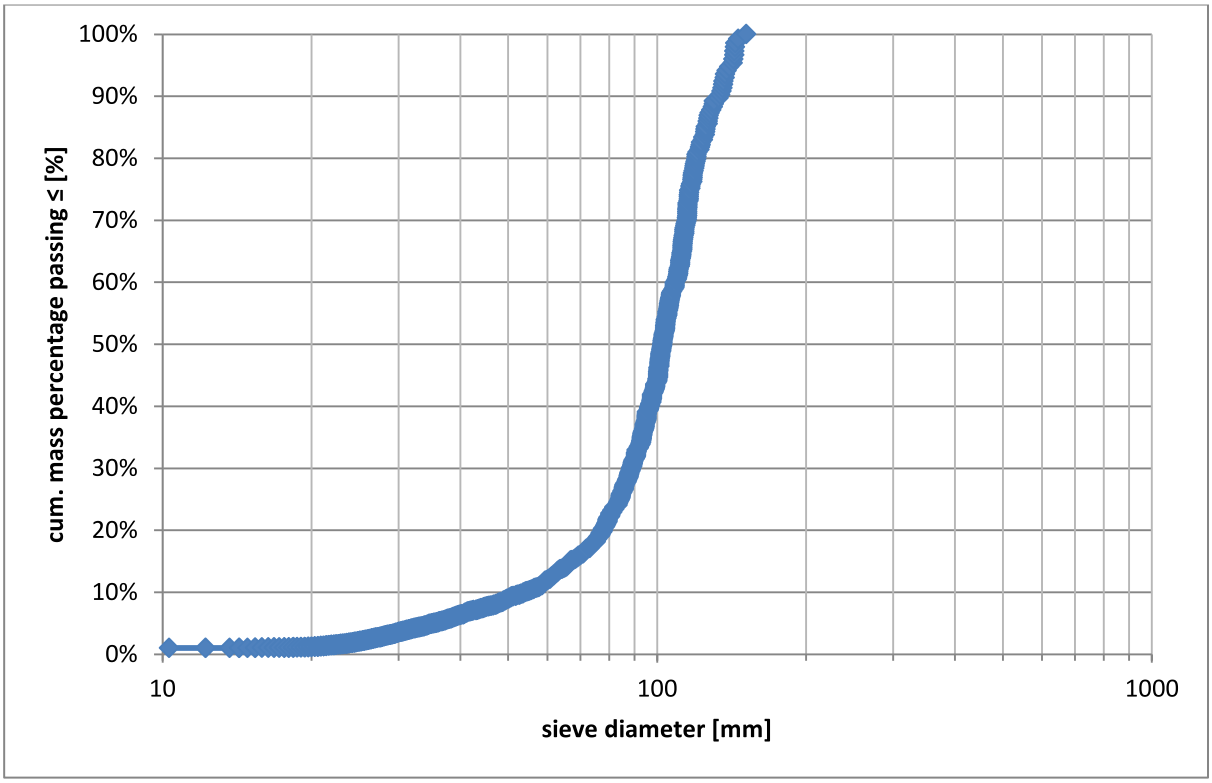


Figure D.2-73 - nominal sieve curve 1-5+ A-C

In Table D-136 nominal diameters interpolated from Figure D.2-73 have been listed.

Table D-136 - nominal diameters 2-8 A-E

	nominal diameter
	[mm]
dn5	35.4
dn15	66.8
dn50	102.6
dn90	133.8
dn98	143.9

Shape factors F_x

The shape factors are given in Table D-137.

Table D-137 - shape factors 1-5+ A-C

nominal diameter		sieve diameter		shape factor	
	[mm]		[mm]		[-]
dn5	35.4	d5	40.98	F5	0.863
dn15	66.8	d15	74.7	F15	0.895
dn50	102.6	d50	119.2	F50	0.861
dn90	133.8	d90	160.5	F90	0.834
dn98	143.9	d98	179.3	F98	0.803

It is concluded the shape factor is not constant for the sample. The shape factor tends to decrease for increasing rock size. Moreover the value of the shape factor associated with fifty percent mass passing - the shape factor in literature - has a value of 0.86, which is slightly larger than the commonly applied value of 0.84. The course of the nominal sieve curve and normal sieve curve relative to each other is presented in Figure D.2-74.

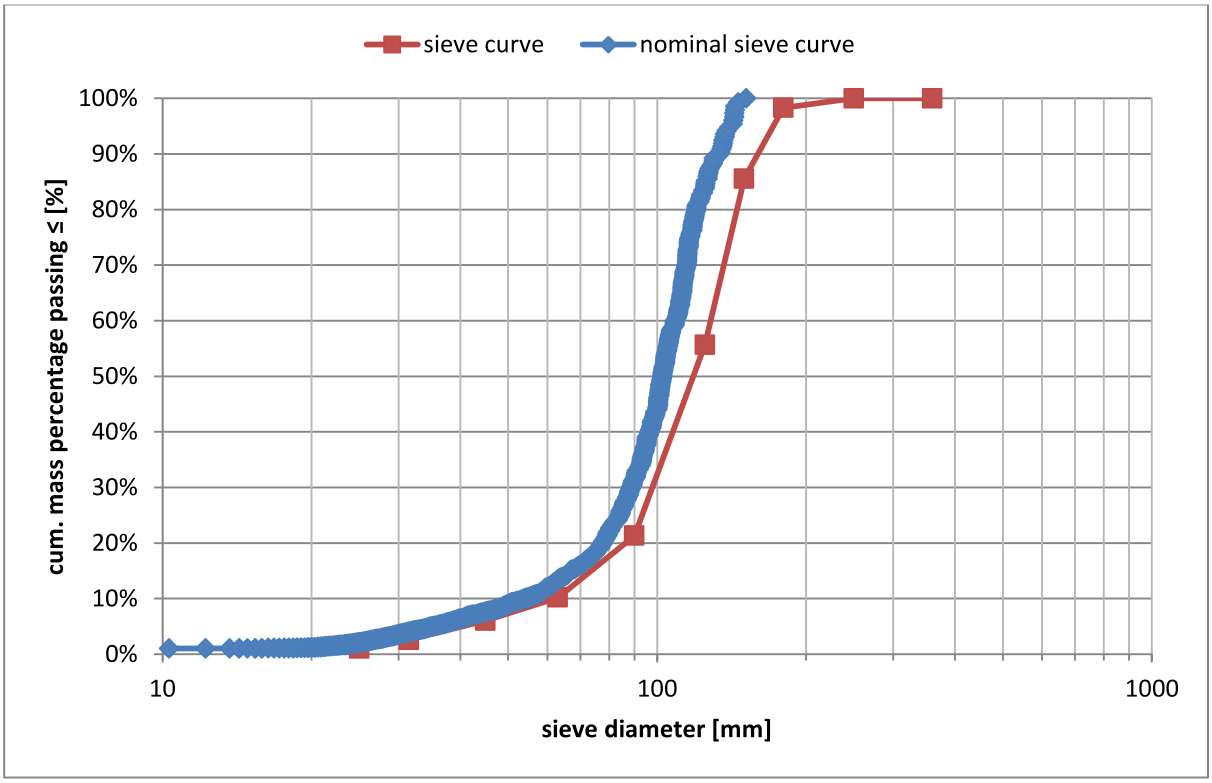


Figure D.2-74 - sieve curves 1-5+ A-C

In Figure D.2-75 the sieve diameters have been multiplied by a factor of 0.84 (in green). As a result the entire sieve curve is shifted to the left. For the rocks that have a nominal diameter between 60 and 100 mm are slightly underestimated by the approximation. Furthermore the largest few rocks are overestimated.

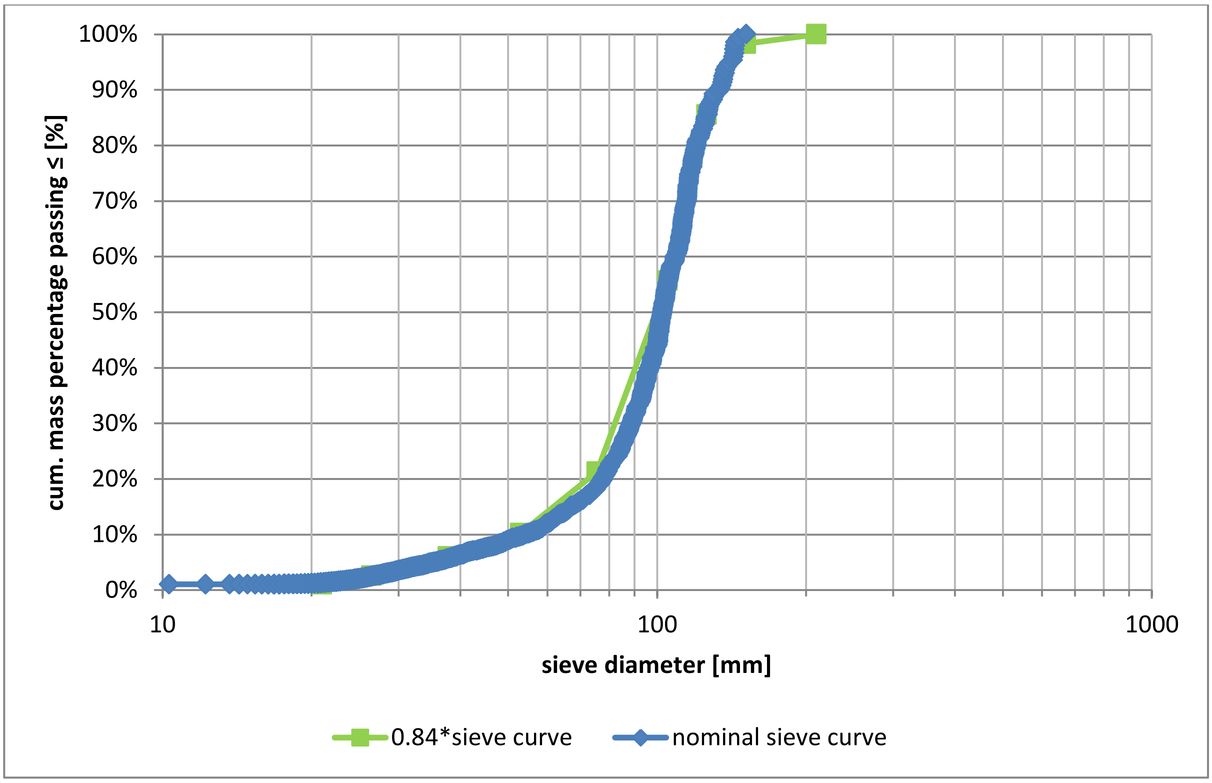


Figure D.2-75 - verification shape factor 1-5+ A-C

D.2.3.3 Conclusions

The information gained on the shape factor of the 5+ material is listed in Table D-138. It is concluded the value of the shape factor F_{50} – the value commonly applied in practice – is fluctuating between a value of 0.85-0.88 for the individual samples. The combined sample yields the value of 0.86 for F_{50}. Furthermore for each sample it is concluded the shape factor is not constant for none of the samples. Moreover, in general the value of considerably decreases for increasing rock size. For F_5 and F_{15} values between 0.84 and 94 are found. In contrary for F_{90} and F_{98} values between 0.84 and 0.68 are found.

Table D-138 - shape factor 1-5+

	Sample	A	B	C	A-C
ELL	dn5	66.011	34.517	25.617	35.362
	d5	70.053	39.685	30.392	40.977
	F5	0.942	0.870	0.843	0.863
NLL	dn15	84.372	59.419	52.202	66.824
	d15	93.683	67.203	61.777	74.652
	F15	0.901	0.884	0.845	0.895
MED	dn50	108.198	100.576	98.226	102.608
	d50	127.952	114.816	113.046	119.237
	F50	0.846	0.876	0.869	0.861
NUL	dn90	129.924	136.553	120.793	133.804
	d90	161.930	163.292	155.748	160.476
	F90	0.802	0.836	0.776	0.834
EUL	dn98	144.089	145.257	141.472	143.917
	d98	177.399	179.689	207.480	179.324
	F98	0.812	0.808	0.682	0.803

E. Virtual sieving

E.1 Concept

In appendix [A] the procedures of performing a sieve analysis are elaborated upon. It is explained a rock sample is sieved through a predefined set of sieves of standardized mesh widths. In contrast no such set is applied in virtual sieving. By application of the dimensions of the smallest enclosing box for each rock individually a virtual sieve diameter can be determined. This data has been acquired through shape tests, also elaborated upon in appendix [A].

The sieve diameter of an individual rock is defined as the dimension of the mesh width [m] of the smallest sieve the rock is able to pass. In general this dimension is found by more or less orientating the rock with its elongated axis perpendicular to the plane spanned by the sieve. In other words the cross section of the rock perpendicular to the elongated axis is to be fit to pass the sieve. Please note that during fitting it is allowed to rotate and even wriggle the rock to pass the sieve, on the condition the rock maintains its original shape. It is concluded that the maximum dimension of the smallest enclosing box [X] will not determine the sieve diameter. As a result the cross sectional plane spanned by the median and minimum dimensions, [Y] and [Z], orientated perpendicular to the maximum dimension [X] determine the sieve diameter. A database of the smallest enclosing boxes dimensions [X], [Y] and [Z] of over a thousand individual rocks has been acquired by the execution of a series of shape tests. Those dimensions can be used to determine the sieve diameter virtually. In fact the mesh width of the smallest sieve the rock is able to pass is fit around the plane spanned by the median and minimum dimensions [X] and [Y] of the smallest enclosing box.

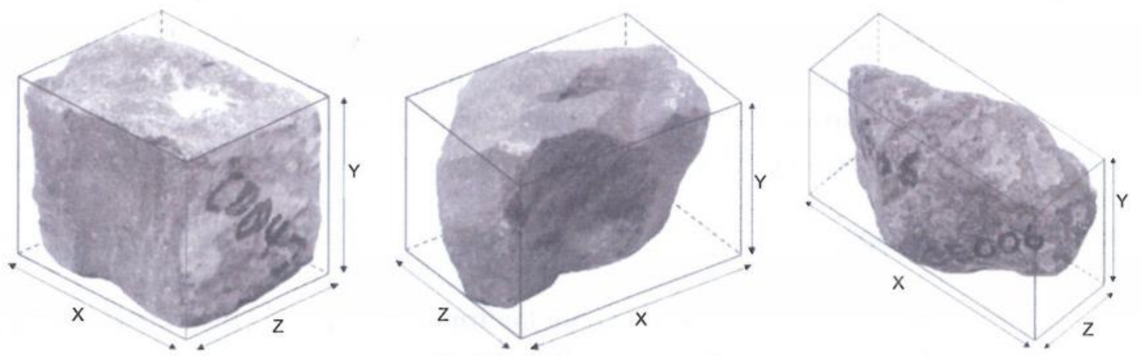


Figure E-1 - definition of rock dimensions X, Y and Z.

E.2 Mesh width formula

For relatively round as well as relatively cubic rock the dimensions Y and Z do have similar values. As a result, for such rock shapes, the smallest mesh width the rock is able to pass can be approximated by the value of Y and/or Z. It is concluded if $Y \approx Z$ then: $m = d_{vs} \approx Y \approx Z$. An example of virtually fitting a sieve around a relatively round rock is given in Figure E-2. The median and minimum dimensions [X] and [Z] of the rock as well as the virtual sieve diameter [d_{vs}] have been included.

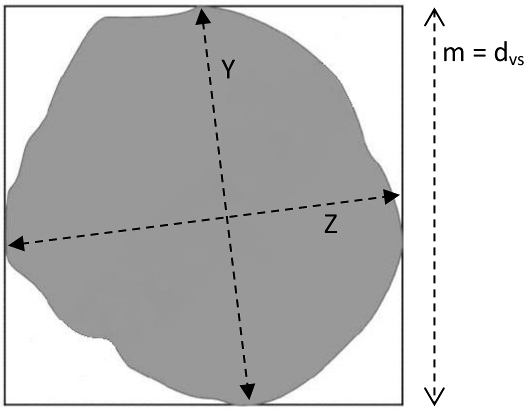


Figure E-2 - virtually sieving round rock

For rather flat rock the median dimension [Y] is a multitude of the minimum dimension [Z]. It therefore holds: $X > Y >> Z$. For such rock shapes the smallest sieve is generally found by orientating the Y dimension diagonally in the area of the virtual sieve. It is concluded that if $X > Y >> Z$, then: $m = d_{vs} \approx Y/\sqrt{2}$. An example of virtually fitting a sieve around a relatively flat rock is given in Figure E-3. The median and minimum dimensions [X] and [Y] of the rock as well as the virtual sieve diameter [d_{vs}] have been included.

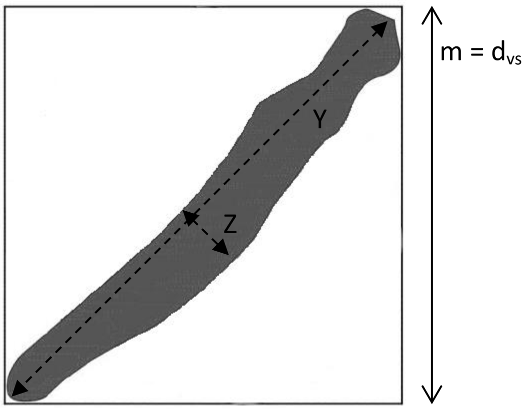


Figure E-3 - virtually sieving flat rock

By Verhagen (2014) equation [1] has been proposed to estimate the value of the virtual sieve diameter d_{vs} dependent on the median and minimum dimensions [Y] and [Z] of the smallest enclosing box.

$$d_{vs} \approx \frac{Y}{1 + 0.45 \cdot \left(1 - \frac{Z}{Y}\right)} \qquad [1]$$

Considering the formula, the factor 0.45 accounts for the 'obliqueness' of the rock in the virtual sieve. The influence of this factor is dependent on the 'flatness' of the rock, defined as the ratio of the minimum and median dimensions: Z/Y. For flat rock; Z<<Y, the term in between the brackets converges to 1, and thus d_{vs} converges to Y/1.45 ≈ Y/√2. For relatively round, cubic or rectanguloid shaped rock; Y ≈ Z, the term in between the brackets converges to 0. As a result the influence of the factor 0.45 vanishes from the equations and thus d_{vs} ≈ Y.

E.3 Individual shape factors

For each of the tested gradings on the rock in sample A, a series of shape tests has been performed. This has resulted in data on smallest enclosing box dimensions [X], [Y] and [Z] for over a thousand rocks, see appendix [C]. By application of equation [1] this data is used to calculated a set of virtual sieve diameters for each of the tested gradings. In appendix [D] for these rock the nominal diameters have also been calculated. The ratio of the virtual sieve diameter and nominal diameter of a rock yields the individual shape factor [1]. In paragraphs E.3.1 to E.3.5 for each tested grading those individual shape factors are presented and briefly discussed.

E.3.1 Sample A 22-90 mm

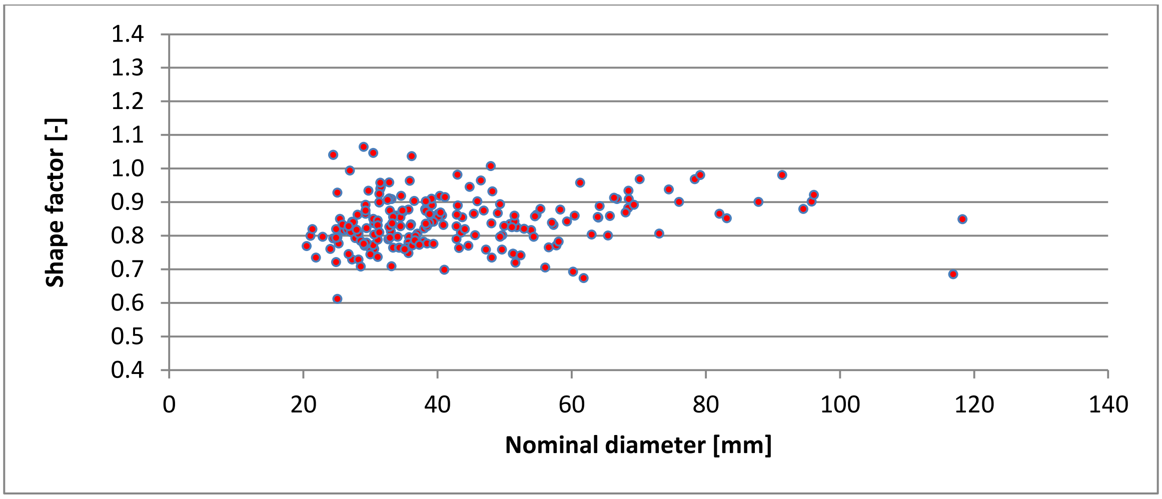


Figure E-4 - Individual shape factor 22-90 sample A

In Figure E-4 a lot of scatter is observed in the values of the individual shape factors. The minimum and maximum values found are 0.61 and 1.06 respectively. On average value the value of the individual shape factor is 0.839. Furthermore a standard deviation of 0.075 has been found. Moreover the bandwidth of the scatter slightly decreases for increasing nominal diameter. This observation is explained by the fact that in the grading the quantity of 'small-sized' rock is larger than the quantity of 'large-sized' rock. As a result the statistical probability of finding extreme individual shape factor values increases for decreasing rock size.

[1] Please note that in the derivation of the individual shape factors the grading of rock is not accounted for in contrary to the derivation of the 'common' shape factor by the application of median values for the nominal diameter and sieve diameter.

E.3.2 Sample A 2-5 inch

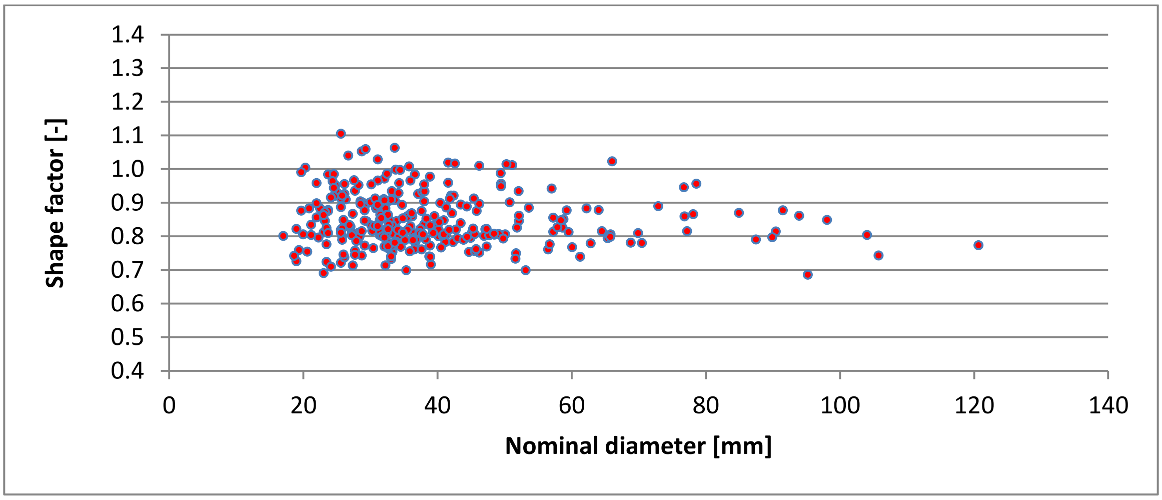


Figure E-5 - Individual shape factors 2-5 sample A

The scatter pattern observed in Figure E-5 is comparable to that observed in Figure E-4. The decrease of the bandwidth over the nominal diameter is even more pronounced. The minimum value found is 0.69; the maximum 1.10; the average is 0.847. The standard deviations is 0.078.

E.3.3 Sample A 2-8 inch

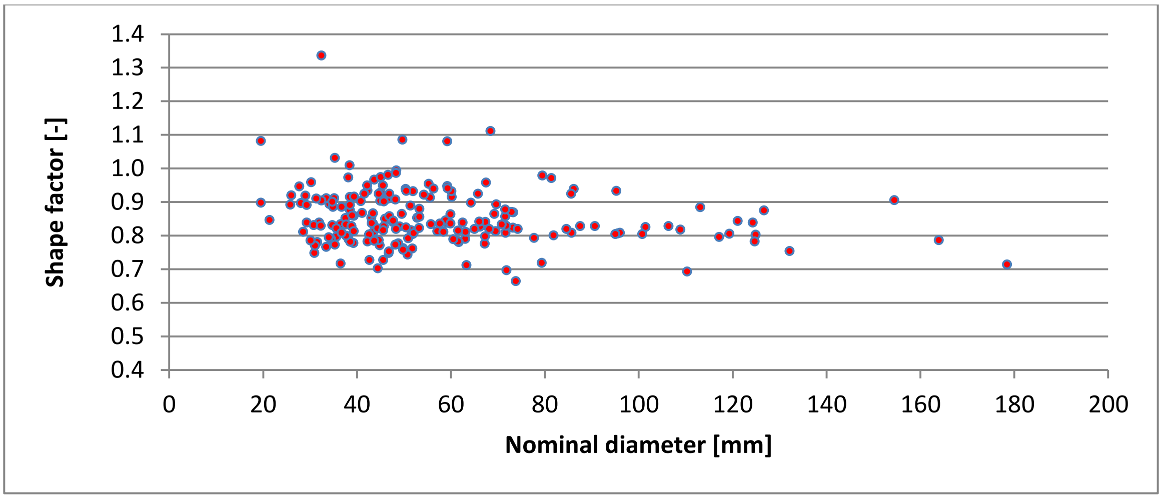


Figure E-6 - Individual shape factors 2-8 sample A

The scatter pattern observed in Figure E-6 is again comparable to those observed in Figure E-4 and Figure E-5; the bandwidth is slightly decreasing for increasing nominal diameter. The minimum, maximum and average individual shape factor values found are 0.66, 1.34 and 0.853 respectively. The standard deviation is 0.083.

E.3.4 **Sample A 1-5 inch**

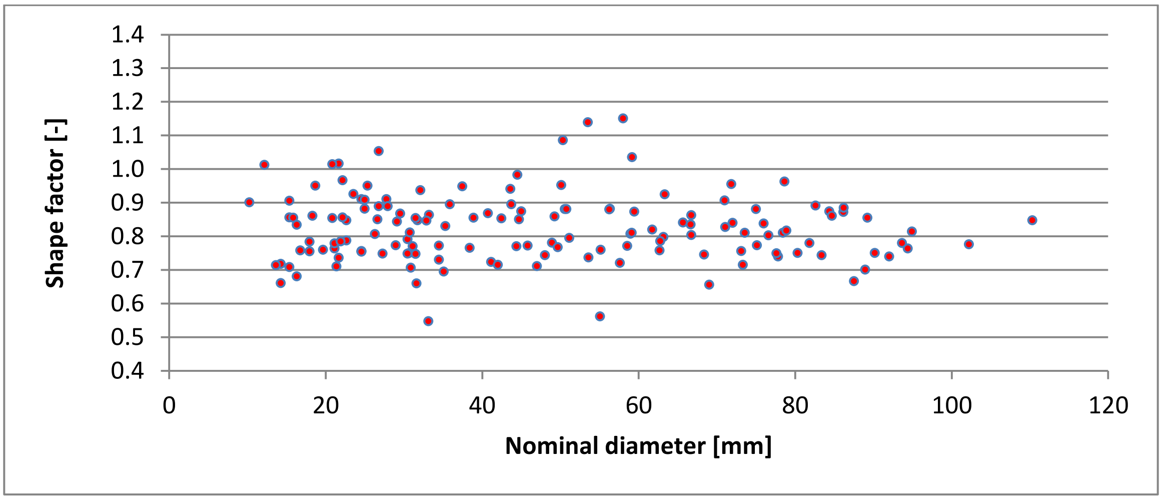


Figure E-7 - Individual shape factors 1-5 sample A

In the scatter pattern observed in Figure E-7 no explicit trends are discerned. The extreme individual shape factor values are found for 'median-sized' rock instead of 'small-sized' rock. This is explained by the fact that the quantity of rock is more equally distributed over the grading. As a result the statistical probability to find extreme values is more or less equal over the nominal diameter. The minimum value found is 0.55, the maximum 1.15 and the average 0.823. Furthermore the standard deviation is 0.098.

E.3.5 **Sample A 5+ inch**

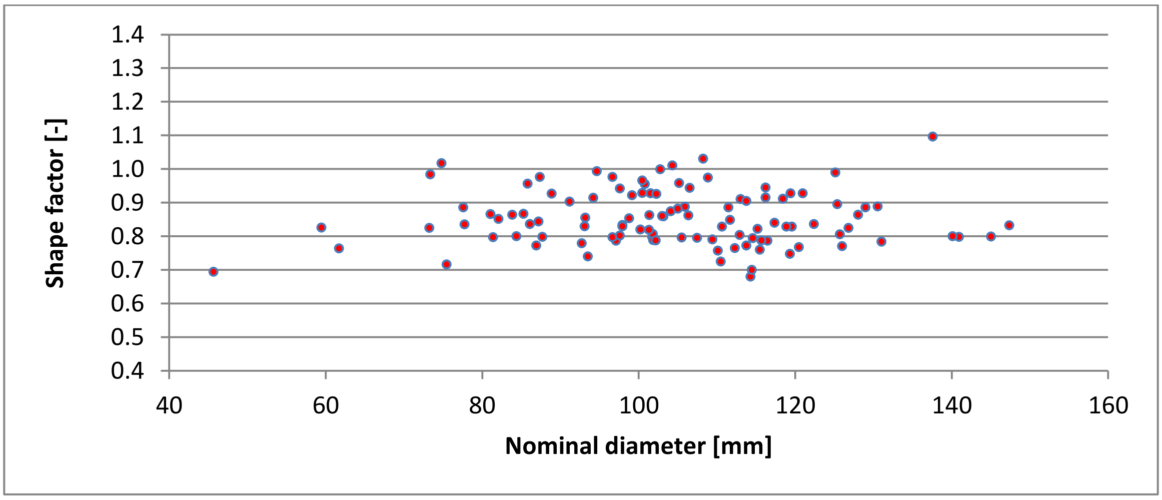


Figure E-8 - Individual shape factors 5+ sample A

The bandwidth of the scatter observed in Figure E-8 is practically constant over the nominal diameter. The pattern is more or less comparable to that observed in Figure E-7 and in contrast to those observed in Figure E-4, Figure E-5 and Figure E-6. The minimum, maximum and average values found are 0.68, 1.10 and 0.854 respectively. The standard deviation is 0.080.

E.3.6 Samples A combined

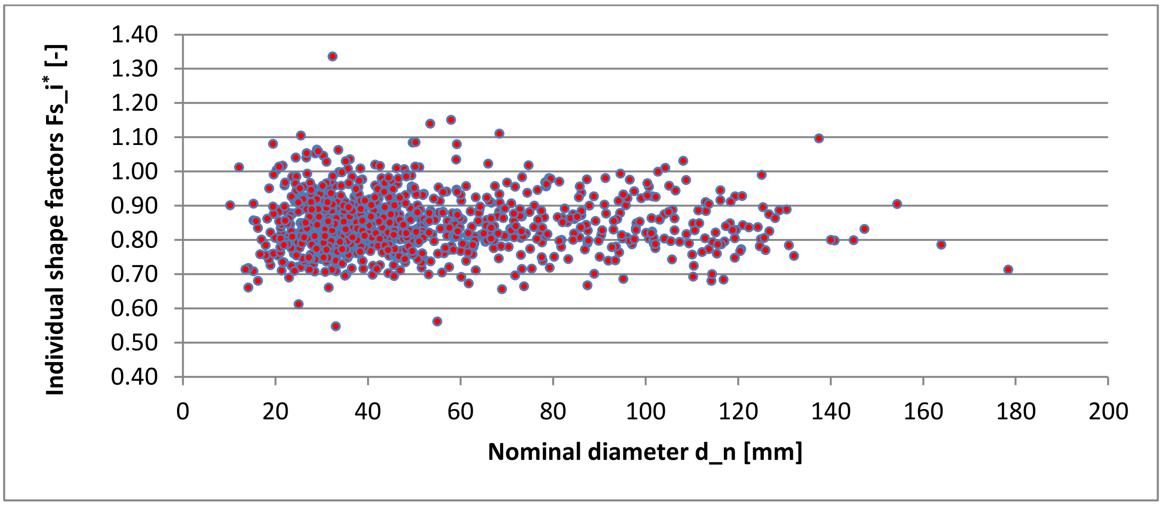


Figure E-9 - Individual shape factors samples A combined

In Figure E-9 the data from samples A of each tested grading has been combined. As a result 969 data points are included. The bandwidth of the observed scatter shows a slightly decrease over the nominal diameter. However for each nominal diameter value the spreading is relatively large. The average individual shape factor is 0.844. The standard deviation is 0.083. The minimum and maximum individual shape factor values are 0.55 and 1.33 respectively.

E.3.7 Conclusions

In Table E-1 the information on the individual shape factor found in paragraphs E.3.1 to 0 is listed.

Table E-1 - overview individual shape factor values

Sample	22-90 A	2-5 A	2-8 A	1-5 A	5+ A	Combined
F_{ind_ave}	0.839	0.847	0.853	0.823	0.854	0.844
St. Dev. σ	0.075	0.078	0.083	0.098	0.080	0.083
$F_{ind\_ave} + \sigma$	0.91	0.92	0.94	0.92	0.93	0.93
$F_{ind\_ave} - \sigma$	0.76	0.77	0.77	0.76	0.77	0.76
F_{ind_min}	0.61	0.69	0.66	0.55	0.68	0.55
F_{ind_max}	1.06	1.10	1.33	1.15	1.10	1.33

- The average value of the individual shape factor for each of the tested gradings approximates the value of 0.84. This value is practically in accordance with shape factor values found on the basis of the cumulative mass percentages of a grading.
- Within a sample the spreading of the shape factor is relatively large. The standard deviation is approximately 10 percent of the average individual shape factor.
- The individual shape factor may exceed the value of 1.0. In section 0 a theoretical explanation has been given.

E.4 Geometrics and the individual shape factor

In 0 a great variety is observed in the values of the individual shape factors. Also values larger than 1.0 are found. This means the nominal diameter exceeds the virtual sieve diameter. In other words the redistributed cubic volume in order to calculate the nominal diameter is unable to pass the virtual sieve. This is only possible for elongated, blocky rock. Assuming a constant virtual sieve diameter, blockiness can only increase as a result of increasing rock volume within the boundaries of the enclosing box volume. As a consequence the nominal diameter of the rock is also increasing. Since the virtual sieve diameter was kept constant an increase of blockiness results in an increase of the individual shape factor. Besides blockiness also elongation is expected to be of influence on the value of the shape factor. In order to assess the influence of elongation different shapes having 100% blockiness are examined. These are three specific rectanguloids, which consist of a square (e·e) base plane with perpendicular height h. For h < e the rectanguloid is referred to as *short*, for h > e the rectanguloid is referred to as *long*. A special rectanguloid is found by h = e. In this case a cube is yielded: all edges are of equal length. In this section the theoretical limits of the individual shape factor of those idealized geometrically perfect rectanguloids are assessed. Moreover, also the geometrically perfect sphere has been studied here.

E.4.1 Cube

The nominal diameter of any arbitrarily shaped rock is defined as the dimension of the edge of the perfectly cubic shaped body of equal volume. For a cubic rock the nominal diameter is thus to be measured directly by the dimension of the edge. The virtual sieve diameter of any arbitrarily shaped rock is defined as the dimension of the smallest mesh width of a square sieve[2] that the rock is able to pass. The virtual sieve diameter of a cubic rock thus equals the edge of the cube and is also to be measured directly by the dimension of the edge. It is concluded both the nominal diameter and virtual sieve diameter are determined by the dimension of the edge of the cube, and thus: $e_c = m = d_n = d_{vs}$, see also Figure E-10. As a result the ratio of the nominal diameter and virtual sieve diameter - the individual shape factor - for a perfectly cubic shaped rock equals 1.0.

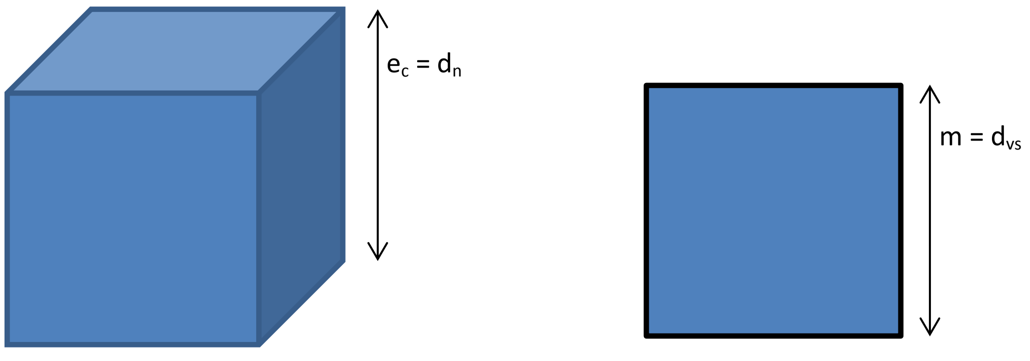


Figure E-10 - nominal diameter and virtual sieve diameter of a cube

[2] Rectangular sieves are assumed throughout the entire analysis.

E.4.2 Infinitely short rectanguloid

A perfectly rectanguloid shape having an infinitely short perpendicular dimension theoretically results in a square plane. Since this shape has no body it has no volume and thus the nominal diameter of an infinitely short rectanguloid shape equals zero. The infinitely short rectanguloid will pass the smallest virtual sieve when diagonally orientated in the sieve. As a result the virtual sieve diameter equals the dimension of the edge of the square base plane divided by a factor of √2; $m = d_{vs} = e_{sbp}/\sqrt{2}$, see also Figure E-11. However, since the value of the nominal diameter equals zero the value of the individual shape factor equals zero, regardless the value of the virtual sieve diameter.

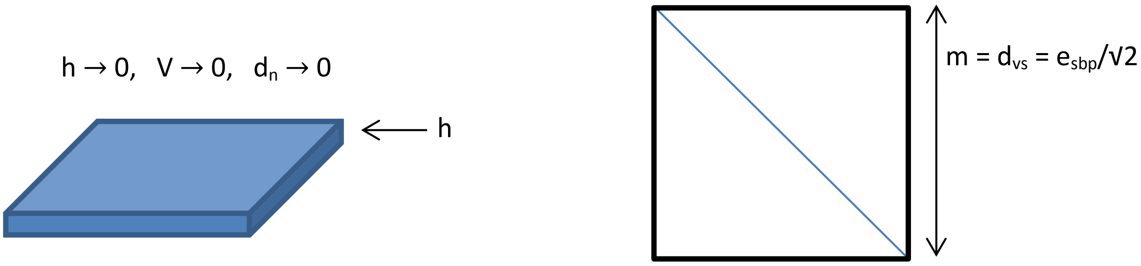


Figure E-11 - nominal diameter and virtual sieve diameter of an infinitely short rectanguloid

E.4.3 Infinitely long rectanguloid

A perfectly rectanguloid shape having an infinitely long perpendicular dimension theoretically results in a body of infinite volume. As a result the value of the nominal diameter of an infinitely long rectanguloid shape is infinite. The virtual sieve diameter of the infinitely short rectanguloid equals the edge of the square base plane; $m = d_{vs} = e_{sbp}$. However, since the value of the nominal diameter equals infinity the value of the individual shape factor is infinite, regardless the value of the virtual sieve diameter.

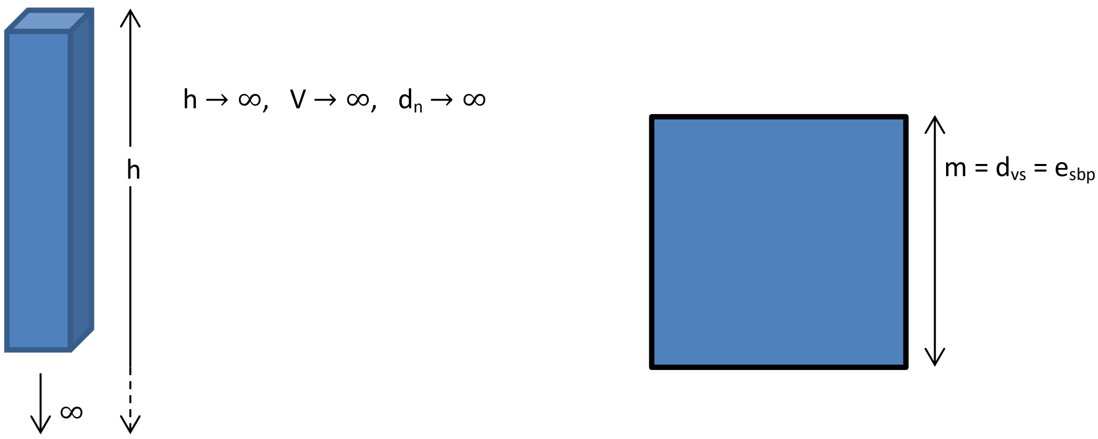


Figure E-12 - nominal diameter and virtual sieve diameter of an infinitely long rectanguloid

E.4.4 Sphere

The body of a perfect sphere is characterized by a single diameter value d_s. The nominal diameter of the sphere is calculated by the cubic root of the volume of the sphere. The volume of a sphere is given by $(\pi /6) \cdot d_s^3$. The cubic root yields a nominal diameter of $0.8060 \cdot d_s$. Furthermore from Figure E-13 it is concluded the virtual sieve diameter of a sphere equals the diameter of the sphere. As a result the individual shape factor of a sphere is equal to 0.8060, regardless the value of the sphere diameter.

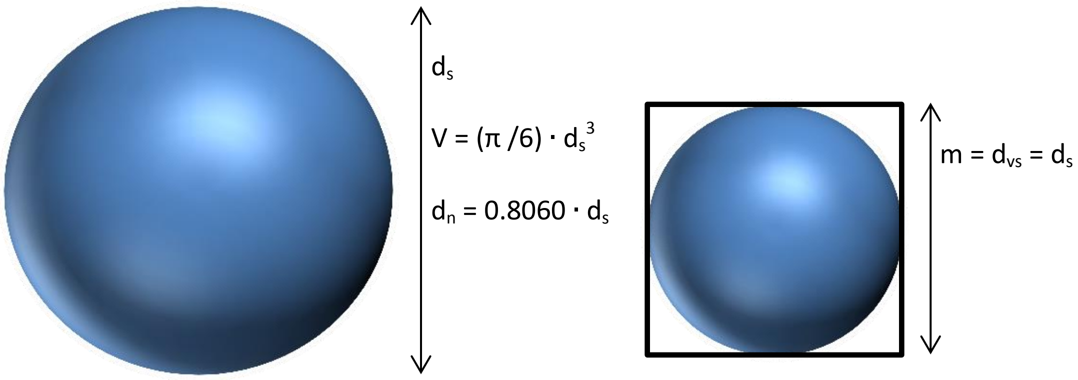
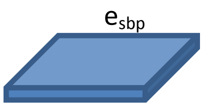
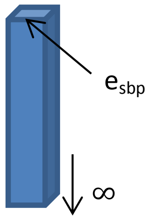
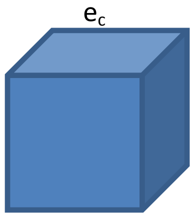
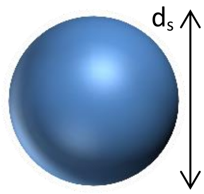


Figure E-13 - nominal diameter and virtual sieve diameter of a sphere

E.4.5 Limits of the individual shape factor

In paragraphs E.4.1 to 0 the nominal diameter as well as the virtual sieve diameter of four typically theoretical rock shapes have been examined. The results yield insight in the limits for the value of the shape factor. In Table E-2 an overview of the information can be found.

Table E-2 - volumes, nominal and virtual sieve diameter and individual shape factor of idealized geometrical shapes.

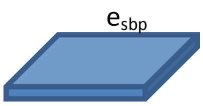
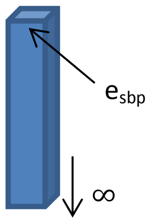
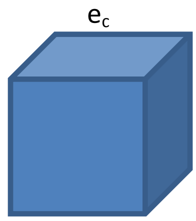
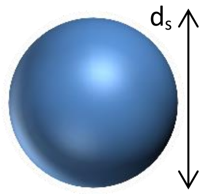
	Infinite short rectangulaoid	Infinite long rectangulaoid	Cube	Sphere
				
V [mm^3]	→ 0	→ ∞	e_c^3	$(\pi/6) \cdot d_s^3$
d_n [mm]	→ 0	→ ∞	e_c	$\sqrt[3]{(\pi/6)} \cdot d_s$
d_{vs} [mm]	→ $e_{sbp}/\sqrt{2}$	→ e_{sbp}	e_c	d_s
F_{ind} [-]	→ 0	→ ∞	1	$\sqrt[3]{(\pi/6)} \approx 0.81$

From Table E-2 it is observed that the theoretical lower limit for the individual shape factor is zero; the upper limit is infinite. Those limit values however are associated with shapes that do not occur in reality. Highly elongated or flat rock shapes, such as the infinitely short and long rectanguloid respectively will break into 'less extreme' or 'more compact' rock shapes. The resulting bodies tend to have more cubical and/or spherical shapes, for which the individual shape factor value converges to 1.0. Still those latter are idealized perfectly geometrical bodies, in fact only providing an indication for the value of the shape factor. Nonetheless the assessed shapes have provided valuable insight in both the theoretical and practical limits of the shape factor and thus the influence of shape on the value of the shape factor in reality.

E.4.6 Blockiness and Elongation

Both the infinitely *short* and *long* rectanguloids do have 100% blockiness. Also, both rectanguloids do have an infinite LT ratio. However note that in case of the infinitely short rectanguloid this is caused by an infinitely small thickness. In contrary, in case of the infinitely long rectanguloid this is caused by the infinitely large length. For both the cube and sphere the LT ratio is 1. Furthermore the cube has 100% blockiness; in contrast the sphere has a blockiness of π/6 ≈ 50%. In Table E-3 the data on blockiness and elongation for each of the idealized geometrically perfect shapes is listed, again the value s of the individual shape factor have been included.

Table E-3 - length, thickness, blockiness and individual shape factor of idealized geometrical shapes

	Infinite short rectanguloid	**Infinite long rectanguloid**	**Cube**	**Sphere**
				
L [mm]	$e_{sbp} \cdot \sqrt{2}$	→ ∞	$e_c \cdot \sqrt{3}$	d
T [mm]	→ 0	e_{sbp}	e_c	d
L/T [mm]	→ ∞	→ ∞	√3	1
BLC [%]	→ 0	100	100	π/6 · 100
F_{ind} [-]	→ 0	→ ∞	1	$\sqrt[3]{(\pi/6)} \approx 0.81$

E.5 Synthesis

According to Table E-3 it is concluded the individual shape factor may exceed the value of 1.0 if and only if the length of the shape exceeds e·√3, i.e.: for *long* rectanguloids. Furthermore it can be concluded the value of the individual shape factor decreases for decreasing blockiness. In paragraph E.5.1 the individual shape factor of *short* rectanguloids is assessed in more detail. Furthermore, the individual shape factor of 'non 100% blocky'-shapes is elaborated upon in more detail in paragraph E.5.2.

E.5.1 Finitely short rectanguloid

Consider a short rectanguloid. The dimension p, perpendicular to the square base plane, has a finite value and is described as a fraction of the dimension of the square base plane edge e. As a result p can be denoted by e/x, with $1 \le x \le e$, as is depicted in Figure E-14. The resulting length L of a short rectanguloid can be calculated by the equation: $e \cdot \sqrt{(2+(1/x^2))}$. Since $x \ge 1$, the term $2+(1/x)^2$ per definition is equal to or smaller than 3. As a consequence the individual shape factor for a short rectanguloid having a finite perpendicular dimension will never exceed the value of 1.0.

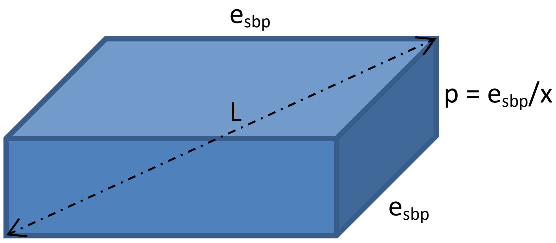


Figure E-14 - short rectanguloid having a finite perpendicular dimension

E.5.2 Capsules

Consider the capsule shapes depicted in Figure E-15. These shapes can be imagined as *long* rectanguloid shapes having rounded edges, i.e.: 'non 100% blocky'-shapes. For capsule shapes having a length significantly larger than e·√3 the individual shape factor may exceed the value of 1.0, despite their rounded edges.

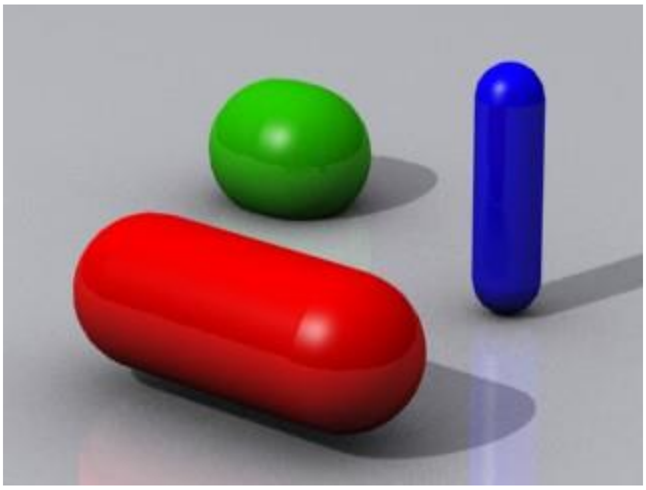


Figure E-15 - capsule shapes

By decreasing the dimension of the longitudinal axis of the capsule shape a sphere can be obtained. By doing so, the blockiness and thus individual shape factor decreases. (Constant virtual sieve diameter). Decreasing the dimension of the longitudinal axis even further **or** decreasing the lateral axis of the capsule results in flattened shapes. (Virtual sieve diameter decreases). Flattened shapes can be considered as *short* rectanguloids. For such shapes it has already been concluded the shape factor cannot exceed the value of 1.0. According to Table E-3 the value of the individual shape factor for short rectanguloids is also decreasing for decreasing length and/or blockiness. Disregarding surface irregularities capsule shapes very well represent natural rock shapes.

E.6 Conclusions

- For a constant virtual sieve diameter d_{vs}, the value of the individual shape factor increases for increasing blockiness.
- For a constant virtual sieve diameter d_{vs}, the value of the individual shape factor increases for increasing elongation.
- The value of the individual shape factor may exceed the value of 1.0 if and only if the length of the shape is larger than $e \cdot \sqrt{3}$.
- The value of the individual shape factor may exceed the value of 1.0 despite non 100% blockiness.
- The value of the individual shape factor does not take into account the variety of shapes and sizes within a grading in contrast to the shape factor derived on the basis of the cumulative mass percentages of a grading.

E.7 Data: Individual shape factor values

E.7.1 Sample 22-90 A

d_n	d_vs	d_s	d_vs / d_s	F_ind
21.12	26.43	31.5	0.84	0.80
34.51	41.69	45	0.93	0.83
33.86	39.44	45	0.88	0.86
29.34	33.93	45	0.75	0.86
34.08	42.82	45	0.95	0.80
27.30	37.50	45	0.83	0.73
33.08	40.74	45	0.91	0.81
27.13	33.27	45	0.74	0.82
32.73	41.53	45	0.92	0.79
33.19	36.56	45	0.81	0.91
32.84	36.09	45	0.80	0.91
36.12	43.35	45	0.96	0.83
28.28	38.82	45	0.86	0.73
30.46	29.13	31.5	0.92	1.05
25.11	27.07	31.5	0.86	0.93
21.94	29.87	31.5	0.95	0.73
24.50	30.97	31.5	0.98	0.79
29.04	27.31	31.5	0.87	1.06
25.50	30.03	31.5	0.95	0.85
26.07	31.99	31.5	1.02	0.81
21.40	26.12	31.5	0.83	0.82
24.50	23.55	31.5	0.75	1.04
20.54	26.74	31.5	0.85	0.77
24.91	34.55	31.5	1.10	0.72
22.93	28.80	31.5	0.91	0.80
39.22	44.05	45	0.98	0.89
37.95	48.57	45	1.08	0.78
40.17	46.49	45	1.03	0.86
33.86	39.45	45	0.88	0.86
28.12	32.65	45	0.73	0.86
28.59	40.42	45	0.90	0.71
30.60	40.27	45	0.89	0.76
31.51	33.58	45	0.75	0.94
31.38	34.97	45	0.78	0.90
29.34	32.93	45	0.73	0.89
29.34	33.58	45	0.75	0.87
29.91	39.13	45	0.87	0.76
39.13	43.05	45	0.96	0.91
34.61	37.70	45	0.84	0.92
26.61	32.60	45	0.72	0.82
32.96	37.70	45	0.84	0.87
36.21	34.97	45	0.78	1.04
34.92	40.12	45	0.89	0.87
27.80	35.09	45	0.78	0.79
36.59	40.55	45	0.90	0.90
35.73	47.81	45	1.06	0.75
31.64	33.49	45	0.74	0.94
40.94	49.24	45	1.09	0.83
40.41	44.00	45	0.98	0.92
37.06	46.03	45	1.02	0.81
35.73	40.76	45	0.91	0.88
24.07	31.69	45	0.70	0.76
31.38	33.98	45	0.76	0.92
35.83	45.04	45	1.00	0.80
24.91	30.43	45	0.68	0.82
26.96	27.15	45	0.60	0.99
39.30	46.25	45	1.03	0.85
25.11	41.06	45	0.91	0.61
29.77	31.89	45	0.71	0.93
35.73	45.87	45	1.02	0.78
33.42	43.77	45	0.97	0.76
34.51	40.42	45	0.90	0.85
30.60	36.58	45	0.81	0.84
38.21	43.51	45	0.97	0.88
30.05	40.42	45	0.90	0.74
38.30	42.45	45	0.94	0.90
32.84	34.29	45	0.76	0.96
40.71	47.37	45	1.05	0.86
33.42	39.07	45	0.87	0.86
33.19	46.85	45	1.04	0.71
33.30	40.09	45	0.89	0.83
29.48	35.88	45	0.80	0.82
30.46	35.85	45	0.80	0.85
35.92	37.31	45	0.83	0.96
28.28	35.09	45	0.78	0.81
34.29	44.92	45	1.00	0.76
30.46	39.49	45	0.88	0.77
31.13	42.28	45	0.94	0.74
31.13	39.56	45	0.88	0.79
27.30	32.49	45	0.72	0.84
32.84	39.77	45	0.88	0.83
27.30	32.60	45	0.72	0.84
31.13	36.87	45	0.82	0.84
41.16	45.04	45	1.00	0.91
28.59	36.51	45	0.81	0.78
27.47	32.70	45	0.73	0.84

27.13	33.49	45	0.74	0.81
30.60	38.14	45	0.85	0.80
35.53	46.44	45	1.03	0.77
32.96	41.55	45	0.92	0.79
27.96	34.22	45	0.76	0.82
25.88	31.12	45	0.69	0.83
29.19	37.94	45	0.84	0.77
29.48	37.85	45	0.84	0.78
25.31	32.60	45	0.72	0.78
25.11	31.63	45	0.70	0.79
34.82	39.82	45	0.88	0.87
24.50	23.55	45	0.52	1.04
32.61	36.00	45	0.80	0.91
36.02	43.45	45	0.97	0.83
33.30	39.85	45	0.89	0.84
26.79	35.98	45	0.80	0.74
36.31	47.12	45	1.05	0.77
24.91	31.39	45	0.70	0.79
31.13	37.50	45	0.83	0.83
26.79	32.36	45	0.72	0.83
31.38	34.90	45	0.78	0.90
31.51	32.93	45	0.73	0.96
29.04	37.50	45	0.83	0.77
31.38	38.79	45	0.86	0.81
50.86	61.00	63	0.97	0.83
47.98	47.69	63	0.76	1.01
54.82	63.59	63	1.01	0.86
49.72	62.11	63	0.99	0.80
51.86	62.92	63	1.00	0.82
54.01	66.18	63	1.05	0.82
43.54	53.85	63	0.85	0.81
58.35	66.51	63	1.06	0.88
40.17	46.94	63	0.75	0.86
49.36	55.29	63	0.88	0.89
52.96	64.63	63	1.03	0.82
42.87	54.30	63	0.86	0.79
45.45	52.58	63	0.83	0.86
42.87	51.83	63	0.82	0.83
49.67	65.53	63	1.04	0.76
38.47	49.59	63	0.79	0.78
43.74	51.19	63	0.81	0.85
42.94	49.84	63	0.79	0.86
38.30	43.89	63	0.70	0.87
43.00	43.85	63	0.70	0.98
51.29	68.78	63	1.09	0.75
44.64	58.03	63	0.92	0.77
51.53	61.24	63	0.97	0.84
38.04	46.32	63	0.74	0.82
46.52	48.26	63	0.77	0.96
41.09	58.85	63	0.93	0.70
48.25	51.83	63	0.82	0.93
44.83	47.44	63	0.75	0.94
46.92	53.68	63	0.85	0.87
36.78	46.09	63	0.73	0.80
47.26	62.39	63	0.99	0.76
34.40	45.04	63	0.71	0.76
51.53	60.01	63	0.95	0.86
45.63	57.01	63	0.90	0.80
39.46	50.92	63	0.81	0.77
40.48	46.62	63	0.74	0.87
36.69	46.68	63	0.74	0.79
39.46	46.94	63	0.75	0.84
43.28	56.72	63	0.90	0.76
38.80	46.38	63	0.74	0.84
49.36	62.03	63	0.98	0.80
48.09	57.53	63	0.91	0.84
50.02	60.40	63	0.96	0.83
38.47	46.49	63	0.74	0.83
54.57	63.65	63	1.01	0.86
37.33	48.37	63	0.77	0.77
44.13	53.92	63	0.86	0.82
51.15	62.03	63	0.98	0.82
48.14	65.56	63	1.04	0.73
51.34	68.87	63	1.09	0.75
45.99	51.02	63	0.81	0.90
49.05	56.60	63	0.90	0.87
57.33	68.94	63	1.09	0.83
38.89	45.05	63	0.72	0.86
35.13	46.31	63	0.74	0.76
43.07	48.44	63	0.77	0.89
38.30	45.87	63	0.73	0.83
63.02	78.55	90	0.87	0.80
73.12	90.81	90	1.01	0.81
70.18	72.53	90	0.81	0.97
65.75	76.63	90	0.85	0.86
60.24	87.10	90	0.97	0.69
74.52	79.55	90	0.88	0.94
61.83	91.90	90	1.02	0.67
56.64	74.07	90	0.82	0.76
57.10	68.18	90	0.76	0.84
66.81	73.53	90	0.82	0.91
76.07	84.51	90	0.94	0.90
68.56	75.51	90	0.84	0.91
64.05	75.09	90	0.83	0.85
57.79	75.01	90	0.83	0.77

91.42	93.26	90	1.04	0.98
78.39	81.00	90	0.90	0.97
63.96	74.79	90	0.83	0.86
54.40	68.37	90	0.76	0.80
82.10	95.00	90	1.06	0.86
79.20	80.83	90	0.90	0.98
68.45	77.65	90	0.86	0.88
58.13	74.37	90	0.83	0.78
61.30	64.08	90	0.71	0.96
55.40	63.01	90	0.70	0.88
60.52	70.47	90	0.78	0.86
68.08	78.37	90	0.87	0.87
52.41	70.74	90	0.79	0.74
66.38	72.75	90	0.81	0.91
69.35	77.85	90	0.87	0.89
64.23	72.39	90	0.80	0.89
65.49	81.88	90	0.91	0.80
51.67	71.88	90	0.80	0.72
59.36	70.55	90	0.78	0.84
56.12	79.65	90	0.88	0.70
68.53	73.41	90	0.82	0.93
94.60	107.67	125	0.86	0.88
118.34	139.50	125	1.12	0.85
83.17	97.69	125	0.78	0.85
95.82	106.36	125	0.85	0.90
87.92	97.73	125	0.78	0.90
96.19	104.45	125	0.84	0.92
116.95	170.96	180	0.95	0.68
		>1?	30	6
		% >1	14.35	2.87

E.7.2 **Sample 2-5 A**

d_n	d_vs	d_s	d_vs / d_s	F_ind
20.94	23.72	31.5	0.75	0.88
25.62	35.56	31.5	1.13	0.72
27.77	29.71	31.5	0.94	0.93
24.19	26.43	31.5	0.84	0.92
23.04	28.42	31.5	0.90	0.81
26.38	29.01	31.5	0.92	0.91
22.04	25.75	31.5	0.82	0.86
26.74	25.71	31.5	0.82	1.04
26.19	28.30	31.5	0.90	0.93
24.82	26.09	31.5	0.83	0.95
25.62	23.19	31.5	0.74	1.10
26.19	27.42	31.5	0.87	0.96
20.34	20.26	31.5	0.64	1.00
25.03	26.91	31.5	0.85	0.93
25.62	31.29	31.5	0.99	0.82
23.74	24.13	31.5	0.77	0.98
25.62	28.06	31.5	0.89	0.91
23.74	27.05	31.5	0.86	0.88
22.30	28.03	31.5	0.89	0.80
23.74	27.13	31.5	0.86	0.88
24.61	26.79	31.5	0.85	0.92
24.61	25.00	31.5	0.79	0.98
22.55	25.56	31.5	0.81	0.88
23.51	32.49	31.5	1.03	0.72
22.04	24.56	31.5	0.78	0.90
23.28	26.71	31.5	0.85	0.87
21.22	25.45	31.5	0.81	0.83
19.02	26.21	31.5	0.83	0.73
20.64	27.38	31.5	0.87	0.75
19.02	23.16	31.5	0.74	0.82
19.37	25.54	31.5	0.81	0.76
24.40	25.31	31.5	0.80	0.96
18.66	25.16	31.5	0.80	0.74
23.28	27.52	31.5	0.87	0.85
20.02	24.86	31.5	0.79	0.81
23.04	26.71	31.5	0.85	0.86
19.70	22.50	31.5	0.71	0.88
23.51	30.32	31.5	0.96	0.78
25.62	28.90	31.5	0.92	0.89
23.51	28.52	31.5	0.91	0.82
21.22	26.40	31.5	0.84	0.80
19.70	19.89	31.5	0.63	0.99
22.04	23.00	31.5	0.73	0.96
17.07	21.32	31.5	0.68	0.80
24.61	26.09	31.5	0.83	0.94
17.07		31.5		
17.49		31.5		
20.94		31.5		
17.90		31.5		
13.19		31.5		
12.41		31.5		
17.49		31.5		
16.62		31.5		
16.14		31.5		
12.41		31.5		
12.41		31.5		
12.41		31.5		
9.14		31.5		
10.47		31.5		
17.49		31.5		
15.10		31.5		
17.90		31.5		
19.02		31.5		
18.29		31.5		
11.52		31.5		
11.52		31.5		
12.41		31.5		
14.52		31.5		
15.10		31.5		
15.64		31.5		
15.10		31.5		
17.49		31.5		
15.10		31.5		
18.29		31.5		
17.49		31.5		
20.64		31.5		
13.88		31.5		
15.10		31.5		
12.41		31.5		
16.14		31.5		
15.64		31.5		
15.10		31.5		
12.41		31.5		
13.19		31.5		
10.47		31.5		
14.52		31.5		
13.19		31.5		
13.88		31.5		
12.41		31.5		
13.88		31.5		
13.88		31.5		

12.41		31.5		
12.41		31.5		
9.14		31.5		
11.52		31.5		
12.41		31.5		
23.51		31.5		
38.90	50.40	45	1.12	0.77
31.40	39.09	45	0.87	0.80
36.67	37.28	45	0.83	0.98
35.60	41.43	45	0.92	0.86
33.35	41.28	45	0.92	0.81
38.04	45.55	45	1.01	0.84
34.99	44.05	45	0.98	0.79
33.80	33.88	45	0.75	1.00
42.09	45.69	45	1.02	0.92
36.00	43.42	45	0.96	0.83
36.00	37.28	45	0.83	0.97
34.35	35.87	45	0.80	0.96
33.58	36.51	45	0.81	0.92
38.30	48.47	45	1.08	0.79
34.67	42.71	45	0.95	0.81
33.91	40.15	45	0.89	0.84
30.05	33.35	45	0.74	0.90
32.16	33.12	45	0.74	0.97
41.65	40.86	45	0.91	1.02
35.80	35.54	45	0.79	1.01
33.46	36.22	45	0.80	0.92
31.14	32.27	45	0.72	0.97
37.14	40.12	45	0.89	0.93
46.26	45.85	45	1.02	1.01
33.69	37.12	45	0.82	0.91
37.78	40.55	45	0.90	0.93
32.65	41.81	45	0.93	0.78
32.28	45.27	45	1.01	0.71
32.04	35.21	45	0.78	0.91
36.00	41.53	45	0.92	0.87
28.88	32.11	45	0.71	0.90
33.35	44.27	45	0.98	0.75
33.23	39.86	45	0.89	0.83
36.48	45.13	45	1.00	0.81
27.26	33.70	45	0.75	0.81
32.88	38.79	45	0.86	0.85
25.82	32.29	45	0.72	0.80
31.53	38.84	45	0.86	0.81
33.23	35.60	45	0.79	0.93
29.48	34.90	45	0.78	0.84
26.19	35.54	45	0.79	0.74
34.78	43.06	45	0.96	0.81
26.56	31.95	45	0.71	0.83
31.79	39.77	45	0.88	0.80
28.41	35.54	45	0.79	0.80
30.19	36.28	45	0.81	0.83
30.33	37.16	45	0.83	0.82
32.65	42.72	45	0.95	0.76
34.35	42.91	45	0.95	0.80
32.16	41.78	45	0.93	0.77
28.26	35.56	45	0.79	0.79
28.26	34.88	45	0.78	0.81
32.28	36.58	45	0.81	0.88
32.40	39.46	45	0.88	0.82
28.41	35.56	45	0.79	0.80
34.78	38.93	45	0.87	0.89
34.13	41.67	45	0.93	0.82
42.66	42.00	45	0.93	1.02
36.29	42.27	45	0.94	0.86
24.19	34.09	45	0.76	0.71
33.12	44.69	45	0.99	0.74
27.43	38.47	45	0.85	0.71
42.44	46.12	45	1.02	0.92
29.18	32.93	45	0.73	0.89
28.73	35.24	45	0.78	0.82
37.69	43.05	45	0.96	0.88
33.12	45.22	45	1.00	0.73
31.40	35.00	45	0.78	0.90
31.14	30.30	45	0.67	1.03
36.77	46.94	45	1.04	0.78
32.88	36.32	45	0.81	0.91
40.21	50.26	45	1.12	0.80
32.28	37.47	45	0.83	0.86
27.77	36.67	45	0.81	0.76
31.14	37.48	45	0.83	0.83
38.90	39.82	45	0.88	0.98
0.00	40.74	45	0.91	0.00
33.46	43.03	45	0.96	0.78
33.69	31.70	45	0.70	1.06
32.76	39.26	45	0.87	0.83
37.51	45.63	45	1.01	0.82
30.88	34.97	45	0.78	0.88
28.73	27.31	45	0.61	1.05
35.19	44.65	45	0.99	0.79
34.24	36.87	45	0.82	0.93
30.61	36.84	45	0.82	0.83
34.46	34.56	45	0.77	1.00
31.40	37.08	45	0.82	0.85
33.12	36.47	45	0.81	0.91

32.40	37.57	45	0.83	0.86
35.60	41.55	45	0.92	0.86
35.60	43.49	45	0.97	0.82
25.82	31.37	45	0.70	0.82
38.13	40.86	45	0.91	0.93
33.91	43.27	45	0.96	0.78
33.35	43.20	45	0.96	0.77
39.65	47.65	45	1.06	0.83
38.04	39.86	45	0.89	0.95
28.57	31.63	45	0.70	0.90
30.19	31.65	45	0.70	0.95
32.53	32.99	45	0.73	0.99
29.18	34.48	45	0.77	0.85
32.16	35.48	45	0.79	0.91
30.74	33.70	45	0.75	0.91
29.18	33.26	45	0.74	0.88
28.57	31.89	45	0.71	0.90
31.53	36.52	45	0.81	0.86
34.56	44.99	45	1.00	0.77
32.53	40.05	45	0.89	0.81
29.18	37.82	45	0.84	0.77
28.73	38.69	45	0.86	0.74
30.47	39.85	45	0.89	0.76
25.82	32.70	45	0.73	0.79
31.14	37.50	45	0.83	0.83
36.19	41.69	45	0.93	0.87
32.16	40.42	45	0.90	0.80
32.65	39.77	45	0.88	0.82
32.65	37.81	45	0.84	0.86
28.26	29.68	45	0.66	0.95
25.62	31.62	45	0.70	0.81
32.65	42.37	45	0.94	0.77
27.60	28.56	45	0.63	0.97
27.43	33.91	45	0.75	0.81
30.88	34.88	45	0.78	0.89
33.69	43.15	45	0.96	0.78
25.82	28.03	45	0.62	0.92
29.33	27.71	45	0.62	1.06
23.04	33.41	45	0.74	0.69
27.09	32.70	45	0.73	0.83
27.26	33.99	45	0.76	0.80
26.01	34.88	45	0.78	0.75
26.01	30.66	45	0.68	0.85
31.66	37.08	45	0.82	0.85
31.14	34.88	45	0.78	0.89
27.77	37.31	45	0.83	0.74
27.43	31.65	45	0.70	0.87
23.74	29.34	45	0.65	0.81
24.19	26.43	45	0.59	0.92
26.92	32.29	45	0.72	0.83
27.93	35.56	45	0.79	0.79
0.00	34.22	45	0.76	0.00
46.26	61.63	63	0.98	0.75
48.53	60.31	63	0.96	0.80
43.48	51.86	63	0.82	0.84
45.17	55.77	63	0.89	0.81
50.16	62.25	63	0.99	0.81
49.54	51.84	63	0.82	0.96
52.15	55.83	63	0.89	0.93
49.17	60.97	63	0.97	0.81
53.21	76.14	63	1.21	0.70
49.85	62.85	63	1.00	0.79
38.82	52.50	63	0.83	0.74
51.77	69.11	63	1.10	0.75
52.20	61.75	63	0.98	0.85
42.37	54.11	63	0.86	0.78
49.49	50.12	63	0.80	0.99
44.98	56.60	63	0.90	0.79
45.48	49.87	63	0.79	0.91
51.68	70.48	63	1.12	0.73
40.44	45.00	63	0.71	0.90
51.20	50.61	63	0.80	1.01
47.20	57.53	63	0.91	0.82
35.40	50.63	63	0.80	0.70
46.97	58.68	63	0.93	0.80
36.58	46.02	63	0.73	0.79
34.88	43.03	63	0.68	0.81
44.73	59.41	63	0.94	0.75
45.60	60.35	63	0.96	0.76
43.48	48.62	63	0.77	0.89
41.36	51.43	63	0.82	0.80
40.83		63		
49.54	52.26	63	0.83	0.95
39.40	48.24	63	0.77	0.82
36.86	46.66	63	0.74	0.79
45.78	60.13	63	0.95	0.76
42.80	52.23	63	0.83	0.82
57.06	60.63	63	0.96	0.94
47.76	59.51	63	0.94	0.80
41.21	52.67	63	0.84	0.78
36.58	48.10	63	0.76	0.76
40.83	50.87	63	0.81	0.80
43.00	54.14	63	0.86	0.79
38.39	45.04	63	0.71	0.85
40.21	49.03	63	0.78	0.82

51.92	62.91	63	1.00	0.83
45.60	56.55	63	0.90	0.81
42.23	48.63	63	0.77	0.87
41.36	46.69	63	0.74	0.89
45.35	55.10	63	0.87	0.82
39.07	54.57	63	0.87	0.72
33.12	44.79	63	0.71	0.74
53.65	60.64	63	0.96	0.88
47.37	61.59	63	0.98	0.77
40.98	50.85	63	0.81	0.81
39.57	46.02	63	0.73	0.86
44.40	50.00	63	0.79	0.89
45.90	52.45	63	0.83	0.88
37.32	46.09	63	0.73	0.81
40.98	48.36	63	0.77	0.85
40.29	47.86	63	0.76	0.84
41.87	45.96	63	0.73	0.91
48.48	60.05	63	0.95	0.81
40.60	52.94	63	0.84	0.77
36.39	46.18	63	0.73	0.79
41.80	51.04	63	0.81	0.82
43.95	55.68	63	0.88	0.79
37.42	46.29	63	0.73	0.81
44.47	55.76	63	0.89	0.80
37.87	47.25	63	0.75	0.80
37.87	46.98	63	0.75	0.81
50.31	49.63	63	0.79	1.01
50.81	56.41	63	0.90	0.90
41.65	43.45	63	0.69	0.96
46.26	51.62	63	0.82	0.90
47.37	57.65	63	0.92	0.82
38.99	46.85	63	0.74	0.83
39.40	48.69	63	0.77	0.81
38.04	42.09	63	0.67	0.90
38.99	52.80	63	0.84	0.74
37.69	49.57	63	0.79	0.76
35.90	47.52	63	0.75	0.76
34.88	40.90	63	0.65	0.85
78.64	82.24	90	0.91	0.96
78.16	90.30	90	1.00	0.87
57.30	67.01	90	0.74	0.86
56.55	74.37	90	0.83	0.76
64.07	72.95	90	0.81	0.88
65.44	82.44	90	0.92	0.79
57.30	70.48	90	0.78	0.81
66.09	64.63	90	0.72	1.02
56.79	73.17	90	0.81	0.78
69.94	86.40	90	0.96	0.81
76.76	81.21	90	0.90	0.95
77.28	94.77	90	1.05	0.82
58.70	71.08	90	0.79	0.83
70.54	90.51	90	1.01	0.78
58.85	69.24	90	0.77	0.85
65.83	81.72	90	0.91	0.81
65.80	82.46	90	0.92	0.80
76.87	89.53	90	0.99	0.86
61.32	83.05	90	0.92	0.74
72.96	82.07	90	0.91	0.89
60.11	78.38	90	0.87	0.77
62.29	70.57	90	0.78	0.88
58.44	68.94	90	0.77	0.85
64.57	79.24	90	0.88	0.81
59.29	67.57	90	0.75	0.88
62.90	80.74	90	0.90	0.78
52.20	60.64	90	0.67	0.86
57.91	70.08	90	0.78	0.83
68.86	88.18	90	0.98	0.78
59.61	73.39	90	0.82	0.81
87.51	110.74	125	0.89	0.79
93.99	109.19	125	0.87	0.86
85.01	97.81	125	0.78	0.87
98.15	115.73	125	0.93	0.85
91.52	104.39	125	0.84	0.88
90.51	111.18	125	0.89	0.81
89.94	112.81	125	0.90	0.80
120.72	156.23	180	0.87	0.77
95.27	138.93	180	0.77	0.69
104.12	129.53	180	0.72	0.80
105.81	142.52	180	0.79	0.74
		# >1?	21	14
		% >1	6.82	4.56

E.7.3 **Sample 2-8 A**

d_n	d_vs	d_s	d_vs / d_s	F_ind
28.11	31.37	31.5	1.00	0.90
26.06	28.37	31.5	0.90	0.92
27.79	29.39	31.5	0.93	0.95
21.39	25.31	31.5	0.80	0.85
19.60	18.14	31.5	0.58	1.08
19.60	21.85	31.5	0.69	0.90
34.17	38.28	45	0.85	0.89
29.33	35.00	45	0.78	0.84
38.19	39.28	45	0.87	0.97
40.84	45.31	45	1.01	0.90
38.53	42.15	45	0.94	0.91
35.21	38.69	45	0.86	0.91
38.28	48.55	45	1.08	0.79
35.71	44.85	45	1.00	0.80
34.49	43.69	45	0.97	0.79
33.51	36.83	45	0.82	0.91
32.48	24.32	45	0.54	1.34
42.29	45.33	45	1.01	0.93
29.03	31.62	45	0.70	0.92
31.62	40.54	45	0.90	0.78
30.98	41.44	45	0.92	0.75
32.48	35.96	45	0.80	0.90
38.53	44.05	45	0.98	0.87
34.06	42.89	45	0.95	0.79
38.53	43.27	45	0.96	0.89
38.45	38.14	45	0.85	1.01
31.99	38.20	45	0.85	0.84
30.85	37.16	45	0.83	0.83
36.58	43.89	45	0.98	0.83
32.36	39.07	45	0.87	0.83
25.87	29.03	45	0.65	0.89
34.91	39.45	45	0.88	0.88
30.31	31.65	45	0.70	0.96
31.37	34.48	45	0.77	0.91
33.51	43.77	45	0.97	0.77
41.58	45.00	45	1.00	0.92
31.11	40.46	45	0.90	0.77
35.31	34.29	45	0.76	1.03
29.33	32.96	45	0.73	0.89
28.58	35.25	45	0.78	0.81
30.18	38.46	45	0.85	0.78
37.58	44.14	45	0.98	0.85
34.80	38.69	45	0.86	0.90
37.76	45.35	45	1.01	0.83
41.14	47.48	45	1.06	0.87
34.80	41.90	45	0.93	0.83
46.78	62.58	63	0.99	0.75
48.44	48.77	63	0.77	0.99
49.13	59.44	63	0.94	0.83
43.59	53.82	63	0.85	0.81
53.33	60.71	63	0.96	0.88
39.36	45.87	63	0.73	0.86
49.89	65.47	63	1.04	0.76
43.45	52.02	63	0.83	0.84
55.61	60.95	63	0.97	0.91
52.89	62.04	63	0.98	0.85
43.12	50.63	63	0.80	0.85
39.28	50.56	63	0.80	0.78
44.99	49.87	63	0.79	0.90
43.19	51.68	63	0.82	0.84
43.72	45.27	63	0.72	0.97
51.88	64.60	63	1.03	0.80
44.87	58.27	63	0.92	0.77
44.43	54.11	63	0.86	0.82
51.55	63.23	63	1.00	0.82
46.02	54.20	63	0.86	0.85
50.44	53.80	63	0.85	0.94
42.22	44.50	63	0.71	0.95
36.58	51.07	63	0.81	0.72
50.93	64.34	63	1.02	0.79
54.33	59.03	63	0.94	0.92
48.87	62.95	63	1.00	0.78
47.68	56.75	63	0.90	0.84
59.30	54.92	63	0.87	1.08
46.49	51.19	63	0.81	0.91
44.68	56.87	63	0.90	0.79
48.33	59.00	63	0.94	0.82
49.59	57.42	63	0.91	0.86
52.11	64.60	63	1.03	0.81
46.95	54.76	63	0.87	0.86
68.50	61.68	63	0.98	1.11
42.71	53.50	63	0.85	0.80
48.39	49.12	63	0.78	0.99
59.26	62.59	63	0.99	0.95
46.95	50.84	63	0.81	0.92
53.33	62.38	63	0.99	0.85
42.64	53.13	63	0.84	0.80
51.97	55.83	63	0.89	0.93
50.54	54.20	63	0.86	0.93
48.23	53.22	63	0.84	0.91
45.12	46.38	63	0.74	0.97

48.23	62.50	63	0.99	0.77
45.12	48.63	63	0.77	0.93
51.41	57.89	63	0.92	0.89
45.54	48.00	63	0.76	0.95
45.67	62.88	63	1.00	0.73
42.29	54.11	63	0.86	0.78
46.67	47.65	63	0.76	0.98
43.45	50.21	63	0.80	0.87
39.44	43.12	63	0.68	0.91
55.33	58.03	63	0.92	0.95
49.74	45.87	63	0.73	1.08
46.84	62.27	63	0.99	0.75
38.62	49.44	63	0.78	0.78
35.71	43.49	63	0.69	0.82
36.76	41.57	63	0.66	0.88
39.03	45.44	63	0.72	0.86
45.79	55.43	63	0.88	0.83
42.71	58.83	63	0.93	0.73
45.79	50.85	63	0.81	0.90
45.67	56.04	63	0.89	0.81
47.74	56.60	63	0.90	0.84
43.72	55.77	63	0.89	0.78
38.87	46.98	63	0.75	0.83
37.76	47.27	63	0.75	0.80
39.36	48.47	63	0.77	0.81
44.68	48.36	63	0.77	0.92
36.76	45.55	63	0.72	0.81
35.31	45.75	63	0.73	0.77
44.49	63.38	63	1.01	0.70
60.25	65.91	90	0.73	0.91
63.08	79.89	90	0.89	0.79
63.18	77.96	90	0.87	0.81
67.28	86.79	90	0.96	0.78
81.42	83.95	90	0.93	0.97
81.93	102.40	90	1.14	0.80
86.21	91.95	90	1.02	0.94
73.27	89.04	90	0.99	0.82
71.64	83.69	90	0.93	0.86
57.19	70.41	90	0.78	0.81
61.73	79.21	90	0.88	0.78
73.32	84.42	90	0.94	0.87
55.78	66.96	90	0.74	0.83
69.58	85.71	90	0.95	0.81
65.83	71.28	90	0.79	0.92
72.99	83.95	90	0.93	0.87
69.32	80.28	90	0.89	0.86
79.56	81.35	90	0.90	0.98
56.34	59.98	90	0.67	0.94
71.64	81.71	90	0.91	0.88
66.26	80.28	90	0.89	0.83
64.35	71.72	90	0.80	0.90
69.68	78.14	90	0.87	0.89
67.41	80.25	90	0.89	0.84
71.72	88.81	90	0.99	0.81
67.33	84.53	90	0.94	0.80
60.14	64.59	90	0.72	0.93
59.23	70.74	90	0.79	0.84
61.57	75.66	90	0.84	0.81
63.37	89.09	90	0.99	0.71
58.94	69.79	90	0.78	0.84
67.53	70.56	90	0.78	0.96
53.29	64.87	90	0.72	0.82
58.47	72.18	90	0.80	0.81
59.97	69.50	90	0.77	0.86
62.58	74.67	90	0.83	0.84
61.57	78.74	90	0.87	0.78
71.86	86.71	90	0.96	0.83
59.93	71.79	90	0.80	0.83
59.34	63.10	90	0.70	0.94
50.49	61.32	90	0.68	0.82
51.83	68.17	90	0.76	0.76
50.83	68.45	90	0.76	0.74
65.10	79.53	90	0.88	0.82
68.21	83.33	90	0.93	0.82
49.84	65.86	90	0.73	0.76
66.09	78.61	90	0.87	0.84
60.56	76.81	90	0.85	0.79
57.69	69.09	90	0.77	0.83
108.94	133.34	125	1.07	0.82
95.57	118.64	125	0.95	0.81
95.27	102.20	125	0.82	0.93
96.03	118.96	125	0.95	0.81
71.91	103.33	125	0.83	0.70
101.49	123.14	125	0.99	0.82
90.71	109.58	125	0.88	0.83
100.85	125.52	125	1.00	0.80
124.37	148.51	125	1.19	0.84
87.60	105.89	125	0.85	0.83
77.74	98.12	125	0.78	0.79
95.07	118.32	125	0.95	0.80
70.85	85.14	125	0.68	0.83
85.78	106.23	125	0.85	0.81
85.70	92.76	125	0.74	0.92
84.64	103.39	125	0.83	0.82
73.85	111.26	125	0.89	0.66

74.26	90.70	125	0.73	0.82
79.40	110.56	125	0.88	0.72
154.49	170.76	180	0.95	0.90
132.18	175.51	180	0.98	0.75
119.39	148.41	180	0.82	0.80
124.97	155.87	180	0.87	0.80
117.16	147.35	180	0.82	0.80
110.40	159.42	180	0.89	0.69
124.79	159.73	180	0.89	0.78
113.15	128.06	180	0.71	0.88
126.75	144.99	180	0.81	0.87
121.12	143.76	180	0.80	0.84
106.39	128.51	180	0.71	0.83
164.01	208.72	250	0.83	0.79
178.50	250.47	250	1.00	0.71
		# >1?	17	7
		% >1	8.46	3.48

E.7.4 **Sample 1-5 A**

d_n	d_vs	d_s	d_vs / d_s	F_ind
24.62	32.60	31.5	1.03	0.76
24.62	32.58	31.5	1.03	0.76
33.25	38.52	31.5	1.22	0.86
22.67	26.74	31.5	0.85	0.85
25.39	26.73	31.5	0.85	0.95
22.67	28.80	31.5	0.91	0.79
29.56	34.08	31.5	1.08	0.87
26.82	25.46	31.5	0.81	1.05
25.01	28.36	31.5	0.90	0.88
23.57	25.46	31.5	0.81	0.93
19.70	25.93	31.5	0.82	0.76
16.34	24.03	31.5	0.76	0.68
27.79	30.54	31.5	0.97	0.91
21.15	27.71	31.5	0.88	0.76
17.99	23.82	31.5	0.76	0.76
21.68	21.33	31.5	0.68	1.02
24.62	27.05	31.5	0.86	0.91
20.87	24.45	31.5	0.78	0.85
21.15	27.17	31.5	0.86	0.78
21.42	30.15	31.5	0.96	0.71
22.18	25.93	31.5	0.82	0.86
18.71	19.69	31.5	0.62	0.95
25.01	27.52	31.5	0.87	0.91
21.68	29.47	31.5	0.94	0.74
21.93	27.96	31.5	0.89	0.78
22.18	22.95	31.5	0.73	0.97
17.99	22.95	31.5	0.73	0.78
26.82	30.15	31.5	0.96	0.89
20.87	20.58	31.5	0.65	1.01
15.38	16.99	31.5	0.54	0.91
15.38	21.72	31.5	0.69	0.71
16.34	19.59	31.5	0.62	0.83
14.28	21.62	31.5	0.69	0.66
12.21	12.06	31.5	0.38	1.01
15.38	17.96	31.5	0.57	0.86
10.30	11.43	31.5	0.36	0.90
15.88	18.58	31.5	0.59	0.85
14.28	19.90	31.5	0.63	0.72
13.66	19.14	31.5	0.61	0.71
16.79	22.16	31.5	0.70	0.76
18.36	21.32	31.5	0.68	0.86
44.55	45.35	45	1.01	0.98
30.63	40.86	45	0.91	0.75
32.91	38.87	45	0.86	0.85
31.75	37.48	45	0.83	0.85
35.31	42.52	45	0.94	0.83
30.50	38.56	45	0.86	0.79
31.51	36.89	45	0.82	0.85
30.89	43.75	45	0.97	0.71
33.14	60.58	45	1.35	0.55
37.51	39.56	45	0.88	0.95
27.95	31.44	45	0.70	0.89
32.11	34.29	45	0.76	0.94
29.14	34.55	45	0.77	0.84
31.63	47.92	45	1.06	0.66
31.51	42.16	45	0.94	0.75
30.50	40.74	45	0.91	0.75
34.51	47.25	45	1.05	0.73
40.75	46.94	45	1.04	0.87
35.88	40.09	45	0.89	0.90
30.76	37.92	45	0.84	0.81
50.36	46.40	45	1.03	1.09
29.00	37.50	45	0.83	0.77
31.14	40.42	45	0.90	0.77
34.51	44.69	45	0.99	0.77
24.62	32.65	45	0.73	0.75
26.30	32.60	45	0.72	0.81
27.31	36.52	45	0.81	0.75
26.65	31.32	45	0.70	0.85
50.60	57.42	63	0.91	0.88
59.19	57.20	63	0.91	1.03
42.50	49.85	63	0.79	0.85
45.86	59.36	63	0.94	0.77
58.03	50.46	63	0.80	1.15
56.36	63.90	63	1.01	0.88
44.43	57.70	63	0.92	0.77
51.16	64.36	63	1.02	0.79
41.19	56.90	63	0.90	0.72
43.61	46.38	63	0.74	0.94
50.12	52.62	63	0.84	0.95
44.73	52.62	63	0.84	0.85
53.55	47.01	63	0.75	1.14
42.03	58.79	63	0.93	0.71
58.56	75.94	63	1.21	0.77
48.93	62.65	63	0.99	0.78
48.06	64.63	63	1.03	0.74
45.03	51.50	63	0.82	0.87
38.92	45.50	63	0.72	0.86
50.79	57.69	63	0.92	0.88
35.11	50.56	63	0.80	0.69
49.68	64.78	63	1.03	0.77

49.28	57.37	63	0.91	0.86
43.74	48.85	63	0.78	0.90
38.43	50.21	63	0.80	0.77
78.67	81.72	90	0.91	0.96
84.41	96.57	90	1.07	0.87
63.18	79.14	90	0.88	0.80
68.39	91.79	90	1.02	0.75
65.69	78.11	90	0.87	0.84
66.74	83.08	90	0.92	0.80
56.28	63.99	90	0.71	0.88
47.04	66.18	90	0.74	0.71
86.21	98.89	90	1.10	0.87
62.69	82.70	90	0.92	0.76
71.08	85.90	90	0.95	0.83
75.01	85.17	90	0.95	0.88
63.36	68.55	90	0.76	0.92
75.14	97.16	90	1.08	0.77
73.61	90.88	90	1.01	0.81
61.78	75.35	90	0.84	0.82
53.63	72.78	90	0.81	0.74
58.98	73.02	90	0.81	0.81
66.74	77.39	90	0.86	0.86
57.63	80.00	90	0.89	0.72
66.68	79.86	90	0.89	0.84
86.24	97.55	90	1.08	0.88
71.03	78.37	90	0.87	0.91
59.47	68.13	90	0.76	0.87
82.64	92.70	90	1.03	0.89
78.45	96.83	90	1.08	0.81
71.86	75.24	90	0.84	0.96
76.01	90.75	90	1.01	0.84
72.03	85.79	90	0.95	0.84
55.11	98.14	90	1.09	0.56
69.03	105.31	90	1.17	0.66
55.19	72.67	90	0.81	0.76
59.16	73.06	90	0.81	0.81
62.78	79.97	90	0.89	0.79
77.84	105.27	125	0.84	0.74
73.16	96.83	125	0.77	0.76
73.34	102.61	125	0.82	0.71
89.27	104.45	125	0.84	0.85
94.41	123.65	125	0.99	0.76
84.72	98.41	125	0.79	0.86
83.41	112.23	125	0.90	0.74
81.85	105.00	125	0.84	0.78
94.94	116.65	125	0.93	0.81
80.36	107.09	125	0.86	0.75
87.56	131.35	125	1.05	0.67
77.63	103.65	125	0.83	0.75
92.06	124.51	125	1.00	0.74
88.98	127.05	125	1.02	0.70
93.69	120.12	125	0.96	0.78
90.20	120.18	125	0.96	0.75
76.64	95.50	125	0.76	0.80
78.92	96.67	125	0.77	0.82
102.23	131.81	125	1.05	0.78
110.36	130.19	150	0.87	0.85
		# >1?	29	8
		% >1	19.59	5.41

E.7.5 **Sample 5+ A**

d_n	d_vs	d_s	d_vs / d_s	F_ind
45.70	65.86	63	1.05	0.69
74.82	73.55	90	0.82	1.02
87.41	89.55	90	1.00	0.98
81.10	93.68	90	1.04	0.87
73.40	74.64	90	0.83	0.98
59.47	72.06	90	0.80	0.83
61.74	80.91	90	0.90	0.76
73.26	88.83	90	0.99	0.82
103.18	120.20	125	0.96	0.86
105.21	109.82	125	0.88	0.96
86.96	112.69	125	0.90	0.77
97.96	117.55	125	0.94	0.83
87.73	109.90	125	0.88	0.80
102.77	102.85	125	0.82	1.00
116.26	123.07	125	0.98	0.94
94.22	103.10	125	0.82	0.91
97.65	103.66	125	0.83	0.94
97.97	118.19	125	0.95	0.83
87.23	103.41	125	0.83	0.84
106.56	112.93	125	0.90	0.94
97.13	123.53	125	0.99	0.79
83.89	97.16	125	0.78	0.86
92.78	119.19	125	0.95	0.78
101.56	109.55	125	0.88	0.93
96.68	99.08	125	0.79	0.98
94.68	95.34	125	0.76	0.99
100.84	105.64	125	0.85	0.95
96.69	121.26	125	0.97	0.80
97.62	121.78	125	0.97	0.80
82.11	96.50	125	0.77	0.85
85.86	89.80	125	0.72	0.96
88.91	95.95	125	0.77	0.93
75.47	105.41	125	0.84	0.72
99.18	107.63	125	0.86	0.92
104.35	103.32	125	0.83	1.01
98.80	115.80	125	0.93	0.85
86.11	103.02	125	0.82	0.84
84.39	105.55	125	0.84	0.80
100.50	104.10	125	0.83	0.97
102.30	110.55	125	0.88	0.93
85.29	98.41	125	0.79	0.87
100.48	108.22	125	0.87	0.93
113.06	124.20	125	0.99	0.91
101.76	127.56	125	1.02	0.80
100.24	122.22	125	0.98	0.82
91.18	101.04	125	0.81	0.90
101.40	117.50	125	0.94	0.86
77.77	93.11	125	0.74	0.84
101.88	129.22	125	1.03	0.79
81.44	102.14	125	0.82	0.80
77.61	87.68	125	0.70	0.89
108.26	105.05	125	0.84	1.03
108.87	111.72	125	0.89	0.97
93.23	109.03	125	0.87	0.86
93.12	112.25	125	0.90	0.83
106.38	123.40	125	0.99	0.86
119.62	144.36	150	0.96	0.83
119.42	128.81	150	0.86	0.93
113.78	125.79	150	0.84	0.90
109.45	138.58	150	0.92	0.79
101.83	126.32	150	0.84	0.81
110.69	133.70	150	0.89	0.83
122.42	146.43	150	0.98	0.84
118.90	143.46	150	0.96	0.83
104.13	119.07	150	0.79	0.87
111.69	131.60	150	0.88	0.85
137.60	125.57	150	0.84	1.10
101.34	123.74	150	0.82	0.82
118.46	129.97	150	0.87	0.91
102.23	129.80	150	0.87	0.79
126.85	153.85	150	1.03	0.82
110.15	145.56	150	0.97	0.76
113.79	147.35	150	0.98	0.77
103.04	119.91	150	0.80	0.86
93.55	126.45	150	0.84	0.74
114.60	144.39	150	0.96	0.79
110.50	152.57	150	1.02	0.72
112.94	140.48	150	0.94	0.80
115.22	140.27	150	0.94	0.82
105.94	119.38	150	0.80	0.89
125.43	140.14	150	0.93	0.90
130.56	147.00	150	0.98	0.89
120.99	130.40	150	0.87	0.93
125.77	156.13	150	1.04	0.81
117.41	139.86	150	0.93	0.84
112.33	147.01	150	0.98	0.76
125.17	126.45	150	0.84	0.99
129.00	145.61	150	0.97	0.89
116.48	148.14	150	0.99	0.79
105.52	132.57	150	0.88	0.80
114.31	168.10	150	1.12	0.68

116.26	127.01	150	0.85	0.92
107.49	135.29	150	0.90	0.79
115.49	152.00	150	1.01	0.76
111.52	125.95	150	0.84	0.89
105.05	119.20	150	0.79	0.88
126.01	163.68	180	0.91	0.77
147.41	177.22	180	0.98	0.83
114.47	163.70	180	0.91	0.70
140.99	176.69	180	0.98	0.80
115.73	147.07	180	0.82	0.79
120.52	157.13	180	0.87	0.77
140.14	175.19	180	0.97	0.80
119.36	159.76	180	0.89	0.75
128.08	148.31	180	0.82	0.86
145.07	181.52	180	1.01	0.80
131.07	167.20	180	0.93	0.78
		# >1?	10	4
		% >1	9.35	3.74

F. Elongation versus shape factor

F.1 Shape factor versus elongation

For each grading on sample A, shape tests have been performed. For each individual rock its length and thickness have been measured to calculate elongation. Per sample the average elongation has been calculated and is plot versus the factor in Figure F.1-1.

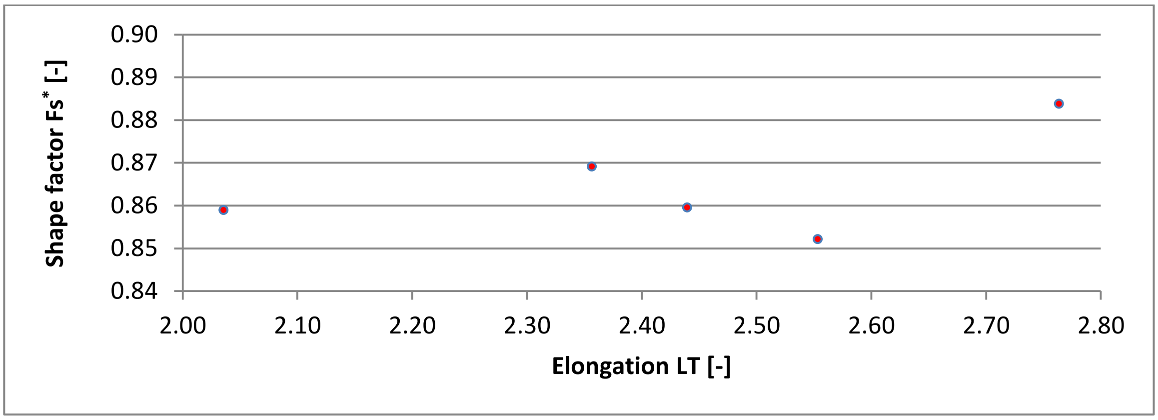


Figure F.1-1 - shape factor versus elongation for the 5 tested gradings

At first glance from Figure F.1-1 no clear relation can be discerned for the shape factor versus elongation. Considering the scatter, for increasing elongation either an increase or decrease in the value of the shape factor can be expected. In appendix [D] it is however concluded the shape factor calculated from a sample of approximately 200 rocks is not necessarily representative for the grading. From sample to sample deviations are observed in the value of the shape factor. To overcome this problem the data of the separate samples has been combined into A-E an sample and the shape factor has been recalculated on basis of approximately 1000 rocks. This approach has resulted in 'less extreme' or 'average[1]' values for the shape factor which is more reliable. In Figure F.1-2 the values of those 'average' shape factors have been plot again versus the average elongation.

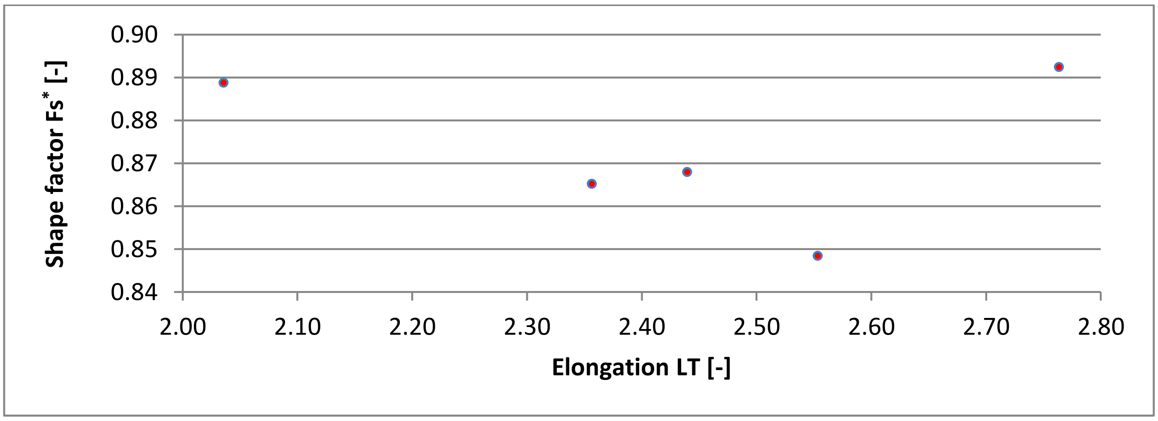


Figure F.1-2 'average' shape factor versus elongation

[1] These shape factor values have been calculated on the basis of the combined data of the separate samples. Taking the average shape factor value of the separate samples will yielded a different value.

Comparing Figure F.1-1 and Figure F.1-2 in particular the value of the shape factor of the leftmost data point (grading of on average least elongated rock) has significantly changed from approximately 0.86 to 0.89. The other four data points just slightly altered value; by less than 0.01. As a result, in general the scatter remains and no relation is expected on the basis of the present analysis.

It is stressed that shape tests have been performed on sample A of each grading only. The average elongation calculated on basis of sample A has been applied integrally to the combined sample A-E. As a result it has been assumed the average elongation of sample A is constant over the different samples. No information is however available on the validity of this assumption and thus the results should be handled with care.

F.2 **Individual shape factors versus elongation**

Besides length and thickness in the shape tests also the dimensions of the smallest enclosing box have been measured. By application of this data for each individual rock a virtual sieve diameter is determined. Furthermore for each individual rock the nominal diameter has been calculated. The ratio of the nominal diameter and virtual sieve diameter results in individual shape factors. For detailed information please consult appendix [E]. In this section for each of the gradings the calculated individual shape factors of sample A have been plot versus the elongation value of the associated individual rock. Moreover the linear regression line based on least squares has been added to the figures to visualize possible relations.

F.2.1 Sample 22-90 A

The average value of the individual shape factor is 0.839. The standard deviation of 0.075. The minimum and maximum value are 0.61 and 1.06 respectively. The average elongation value is 2.19. The standard deviation of 0.59. The minimum and maximum value are 1.00 and 5.29 respectively. It is concluded the data is rather scattered which is also observed in Figure F.2-1. Considering the bandwidth of the scatter, both the upper and lower limit of the shape factor value tend to increase for increasing elongation. Nonetheless the spreading of the data widens for increasing elongation. The equation for linear regression, given by Fs* = 0.0217 * LT + 0.7918 confirms this finding. For average elongated rock (LT = 2.19) the equation yields an individual shape factor value of 0.839. On the basis of sample 22-90 A, a weak but significant relation is expected for individual shape factor versus elongation.

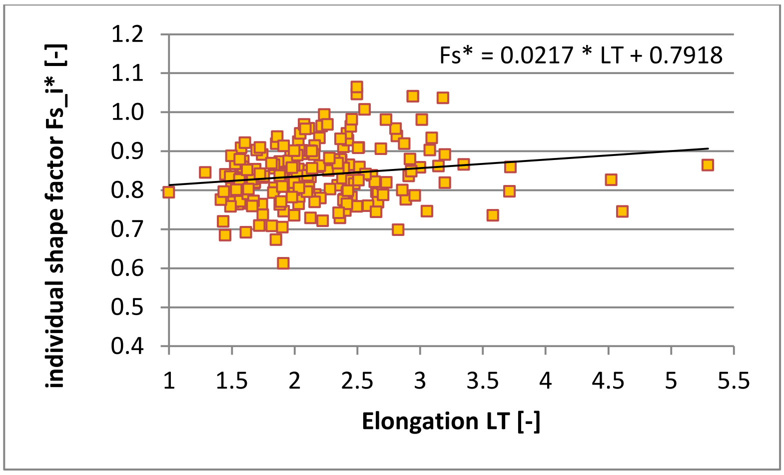


Figure F.2-1 - shape factor versus elongation 22-90 sample A

F.2.2 Sample 2-5 A

The average value of the individual shape factor is 0.847. The standard deviation of 0.078. The minimum and maximum value are 0.69 and 1.10 respectively. The average elongation value is 2.36. The standard deviation of 0.67. The minimum and maximum value are 1.00 and 5.5 respectively. It is concluded the data is rather scattered which is also observed in Figure F.2-2. In appendix [E] it has been found, the individual shape factor cannot exceed the value of 1.0 for rock that has an elongation value of 1.0. The upper left data point is thus considered unrealistic and neglected therefore. Considering the resulting bandwidth of the scatter, the upper limit tends to increase for increasing elongation. The lower limit is considered rather constant over elongation at an approximate value of 0.7. The spreading of the data thus widens for increasing elongation. The equation for linear regression is given by Fs* = 0.0043 * LT + 0.8364, which suggests a rather weak and insignificant relation between the individual shape factor and elongation. For average elongated rock (LT = 2.36) the equation yields an individual shape factor value of 0.847. On the basis of sample 2-5 A, no relation of significant importance is expected for individual shape factor versus elongation.

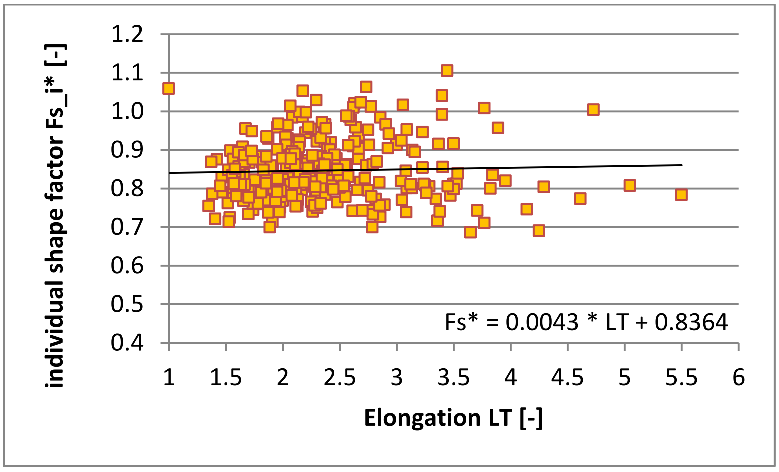


Figure F.2-2 - shape factor versus elongation 2-5 sample A

F.2.3 Sample 2-8 A

The average value of the individual shape factor is 0.853. The standard deviation of 0.083. The minimum and maximum value are 0.66 and 1.34 respectively. The average value of the elongation is 2.35. The standard deviation of 0.67. The minimum and maximum value are 1.24 and 4.68 respectively. It is concluded the data is rather scattered which is also observed in Figure F.2-3. Considering the bandwidth of the scatter, the upper limit tends to increase for increasing elongation. The lower limit is considered rather constant over elongation at an approximate value of 0.7. The spreading of the data thus widens for increasing elongation. The equation for linear regression is given by Fs* = 0.0192 * LT + 0.8076, which suggests a weak but significant relation between the individual shape factor and elongation. For average elongated rock (LT = 2.35) the equation yields an individual shape factor value of 0.853. On the basis of sample 2-8 A, a weak but significant relation is expected for individual shape factor versus elongation.

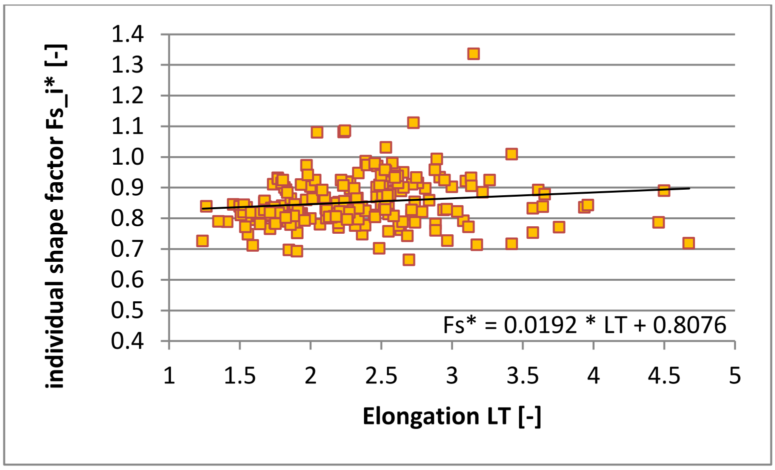


Figure F.2-3 - shape factor versus elongation 2-8 sample A

F.2.4 Sample 1-5 A

The average value of the individual shape factor is 0.823. The standard deviation of 0.098. The minimum and maximum value are 0.55 and 1.15 respectively. The average value of the elongation is 2.76. The standard deviation of 1.02. The minimum and maximum value are 1.38 and 7.07 respectively. It is concluded the data is rather scattered which is also observed in Figure F.2-4. Considering the bandwidth of the scatter, the upper limit tends to increase for increasing elongation. Disregarding the two minimum individual shape factor values, the lower limit is considered rather constant over elongation at an approximate value of 0.65. The spreading of the data thus widens for increasing elongation. The equation for linear regression is given by Fs* = 0.0169 * LT + 0.7766, which suggests a weak but significant relation between the individual shape factor and elongation. For average elongated rock (LT = 2.76) the equation yields an individual shape factor value of 0.823. On the basis of sample 1-5 A, a weak but significant relation is expected for individual shape factor versus elongation.

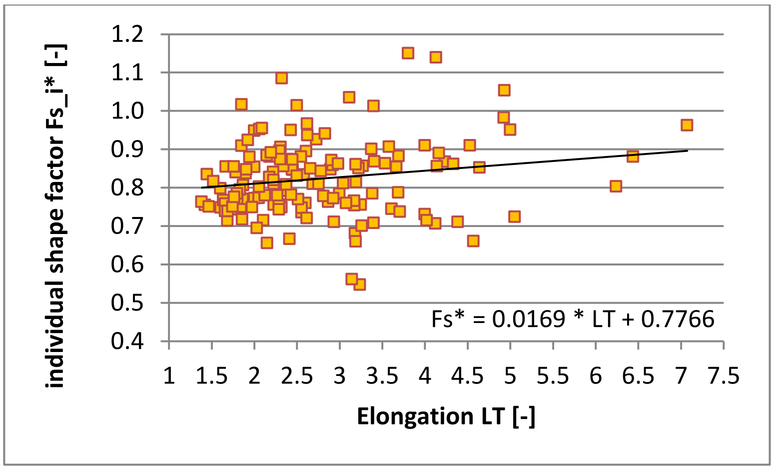


Figure F.2-4 - shape factor versus elongation 1-5 sample A

F.2.5 Sample 5+ A

The average value of the individual shape factor is 0.854. The standard deviation of 0.080. The minimum and maximum value are 0.68 and 1.10 respectively. The average value of the elongation is 2.55. The standard deviation of 0.80. The minimum and maximum value are 1.36 and 7.04 respectively. It is concluded the data is rather scattered which is also observed in Figure F.2-5. Considering the bandwidth of the scatter, the upper limit tends to increase for increasing elongation. The lower limit is considered rather constant over elongation at an approximate value of 0.7. The spreading of the data thus widens for increasing elongation. The equation for linear regression is given by Fs* = 0.018 * LT + 0.8086, which suggests a weak but significant relation between the individual shape factor and elongation. For average elongated rock (LT = 2.55) the equation yields an individual shape factor value of 0.855. On the basis of sample 5+ A, a weak but significant relation is expected for individual shape factor versus elongation.

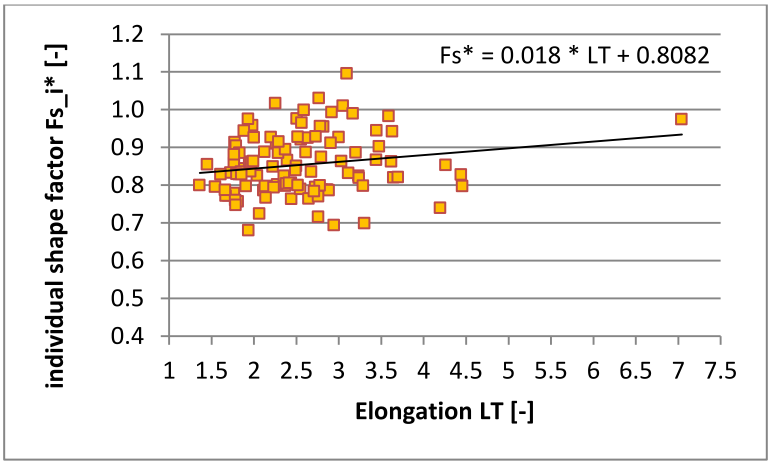


Figure F.2-5 - shape factor versus elongation 5+ sample A

F.2.6 Combined sample

The data of the above discussed samples has been combined in this paragraph. In Figure F.2-6 the individual shape factors have been plot versus the associated individual elongation value for 969 rocks. The average value of the individual shape factor is 0.844. The standard deviation is 0.083. The minimum and maximum value are 0.55 and 1.34 respectively. The average elongation value is 2.40. The standard deviation of 0.74. The minimum and maximum value are 1.00 and 7.07 respectively. It is concluded the data is rather scattered, which is also observed in Figure F.2-6. These findings logically are in line with the above observations. In F.2.2 it has been explained the upper left data point should be neglected. Considering the resulting bandwidths of the scatter, the upper limit tends to increase for increasing elongation. Disregarding the three minimum individual shape factor values, the lower limit is considered rather constant over elongation at an approximate value of 0.65. The equation for linear regression is given by Fs* = 0.0122 * LT + 0.8143, which suggests a weak but significant relation for the individual shape factor versus elongation. For average elongated rock (LT = 2.40) the equation yields an individual shape factor value of 0.844.

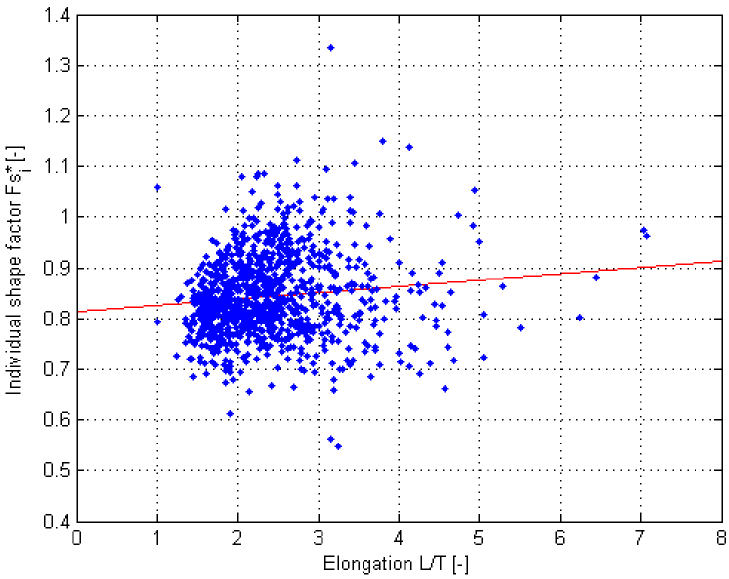


Figure F.2-6 - shape factor versus elongation, combined sample

F.3 Conclusion

The plots of the individual shape factors versus the associated individual elongation values have shown extensive scatter for each sample. Nonetheless the average value of the individual shape factors approaches the commonly applied value; 0.84-0.85 for each of the samples. For sample 2-8 A, a slightly smaller value has been found: 0.82. The standard deviation varies from 0.075 to 0.098 over the samples. This is approximately 10 percent of the average individual shape factor value, which is considered quite a large number.
The average elongation value ranges from 2.19 to 2.76. The standard deviation varies from 0.59 to 1.02 over the samples. This is approximately 25-40 percent of the average elongation values, which is considered a very large number. For overview the statistical findings have been tabulated in Table F.3-1.

Table F.3-1 - average and standard deviation of individual shape factor per sample

Sample	Average F [-]	st. dev.[2] F [-]	Average LT [-]	st. dev. LT [-]
22-90 A	0.839	0.075	2.19	0.59
1-5 A	0.847	0.078	2.76	1.02
2-5 A	0.853	0.083	2.36	0.67
2-8 A	0.823	0.098	2.35	0.61
5+ A	0.854	0.080	2.55	0.80
Combined	0.844	0.083	2.40	0.74

Regarding the bandwidth of the scatter, the upper limit significantly increases for increasing elongation in each of the samples. The lower limit is rather constant over elongation at an approximate value of 0.65-0.70 in four of the samples. In one sample (22-90 A) the lower limit slightly increases for increasing elongation. As a result for each of the samples the bandwidth of the scatter and thus the standard deviation[2] increases for increasing elongation. Those observations suggest a weak but significant relation between the individual shape factor and elongation. Moreover the linear regression equation for each of the five samples have confirmed this finding. The slope in each of the equations is positive, yielding increasing individual shape factor values for increasing elongation values. In Table F.3-3 the equations have been listed for overview. For specific elongation values, the individual shape factor value has been calculated by application of the formulae. The delta Δ represents the difference in the value of the individual shape factor in the elongation range of 1.5-3.5. 89 percent of all rock has an elongation value within this range.

Table F.3-2 - regression dependent on elongation per sample

Sample	Regression for F_s^*(LT)	1.5	2.0	2.5	3.0	3.5	Δ	LT_{ave}
22-90 A	0.0217 * LT + 0.7918	0.824	0.835	0.846	0.857	0.868	0.044	0.839
1-5 A	0.0169 * LT + 0.7766	0.802	0.810	0.818	0.827	0.836	0.034	0.823
2-5 A	0.0043 * LT + 0.8364	0.843	0.845	0.847	0.849	0.852	0.009	0.847
2-8 A	0.0192 * LT + 0.8076	0.836	0.846	0.856	0.865	0.875	0.039	0.853
5+ A	0.0180 * LT + 0.8086	0.836	0.845	0.854	0.863	0.872	0.036	0.855
Combined	0.0122 * LT + 0.8143	0.833	0.839	0.845	0.851	0.857	0.024	0.844

From Table F.3-2 it is concluded the value of the individual shape factor increases for increasing elongation for each of the samples. The largest increase of the individual shape factor over elongation in the range 1.5-3.5 is found for the sample 22-90 A: 0.044. The smallest increase is found for the sample 2-5 A: 0.009. No relation is observed in the rate of

[2] The standard deviation in fact increases for increasing diameter. The given value represents the 'overall' standard deviation derived on the basis of all available data.

increase over specific grading properties of the samples. Furthermore it is concluded the individual shape factor values found for the sample 1-5 A are significantly smaller compared with the values found for the other samples. A specific explanation cannot be given for this observation.

Applying the regression equations strictly, the value of the individual shape factor would be increasing for each subsequent increase of elongation. From the scatter however it can be clearly concluded that this concept does not hold in practice. In contrary, the value of the shape may considerably decrease for increasing elongation. To gain insight in the unpredictability for the rate of change of the individual shape factor value, the minimum and maximum values of the individual shape factor within small elongation ranges have been assessed. This has been done for the ranges 1.4-1.6, 1.9-2.1, 2.4-2.6, 2.9-3.1, and 3.4-3.6. In Table F.3-3 the results have been listed.

Table F.3-3 - minimum and maximum differences in elongation for specific elongation regions

Sample	$F_s^*{}_{ind}$ (LT: 1.4-1.6)		$F_s^*{}_{ind}$ (LT: 1.9-2.1)		$F_s^*{}_{ind}$ (LT: 2.4-2.6)		$F_s^*{}_{ind}$ (LT: 2.9-3.1)	
	min	max	min	max	min	max	min	max
22-90 A	0.68	0.91	0.61	0.97	0.75	1.06	0.75	1.04
1-5 A	0.75	0.84	0.69	0.96	0.67	1.01	0.71	0.87
2-5 A	0.71	0.90	0.71	0.98	0.76	0.99	0.77	1.02
2-8 A	0.71	0.85	0.69	1.08	0.70	1.03	0.73	0.93
5+ A	0.80	0.86	0.68	0.98	0.76	1.00	0.86	1.10
Combined	0.68	0.91	0.61	1.08	0.67	1.06	0.71	1.10

It is concluded on macro-scale[3] significant relation can be discerned between the value of the individual shape factor and the elongation value. *The value of the individual shape factor increases for increasing elongation.* The rate approximate is 0.015 on 1.0. On a micro-scale[3] this relation does not hold and should not be applied. The value of the individual shape factor fluctuates extensively over small elongation ranges due to the large standard deviation. As a result the above stated relation is weakened.

[3] macro-scale: all rock in a sample; micro-scale: two rock of subsequently increasing elongation.

For the combined sample, the data scatter, regression line and bandwidths of 1, 2 and 3 standard deviations have been plotted in Figure F.3-1.

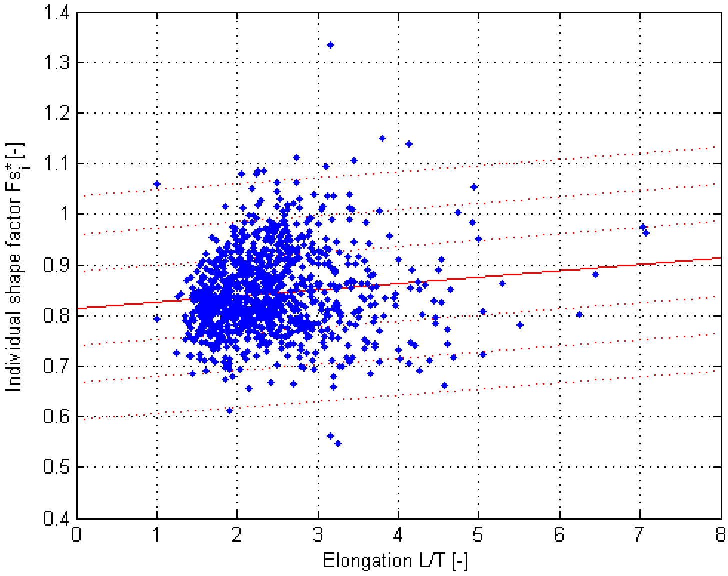


Figure F.3-1 - elongation regression equation and variance bandwidths of combined sample

G. Blockiness versus shape factor

G.1 Shape factor versus blockiness

For each grading on sample A shape tests have been performed. For each individual rock the dimensions of the smallest enclosing box have been measured to calculate blockiness. Per sample the average blockiness has been calculated and is plot versus the factor in Figure G.1-1.

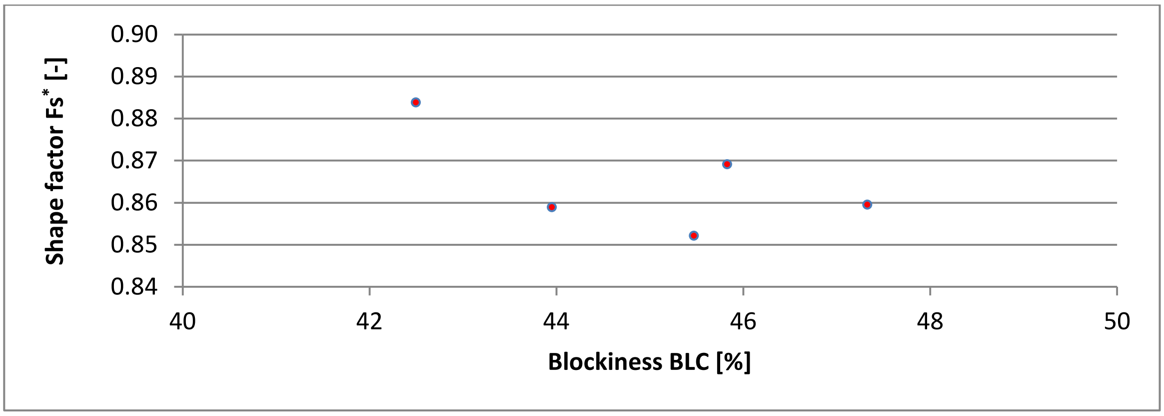


Figure G.1-1 - shape factor versus blockiness for the 5 tested gradings

At first glance from Figure G.1-1 no clear relation can be discerned for the shape factor versus blockiness. Considering the scatter, for increasing blockiness either an increase or decrease in the value of the shape factor can be expected. In appendix [D] it is however concluded the shape factor calculated from a sample of approximately 200 rocks is not necessarily representative for the grading. From sample to sample deviations are observed in the value of the shape factor. To overcome this problem the data of the separate samples has been combined into A-E an sample and the shape factor has been recalculated on basis of approximately 1000 rocks. This approach has resulted in 'less extreme' or 'average[1]' values for the shape factor which is more reliable. In Figure G.1-2 the values of those 'average' shape factors have been plot again versus the average blockiness.

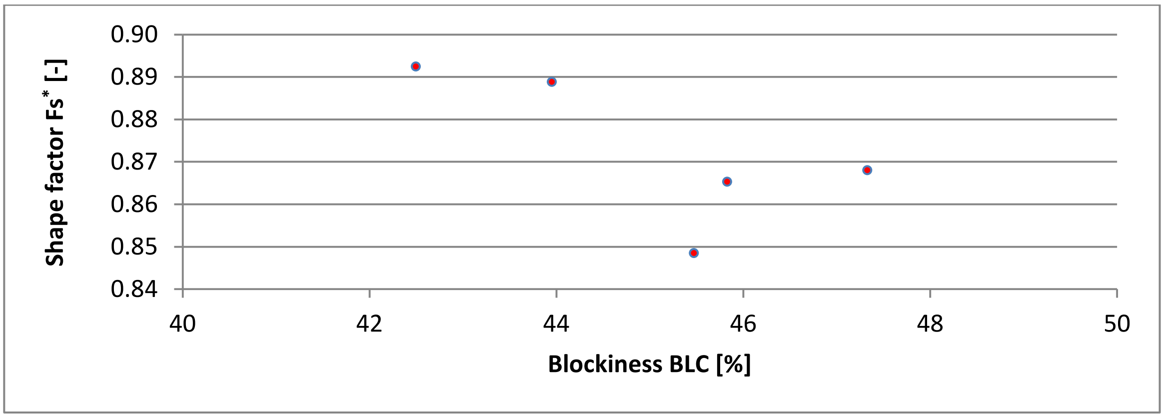


Figure G.1-2 - 'average' shape factor versus blockiness

Comparing Figure G.1-1 and Figure G.1-2 in particular the value of the shape factor of the second left data point (grading of on average second least blocky rock) has significantly changed from approximately 0.86 to 0.89. The other four data points just slightly altered value; by less than 0.01. As a result, in general the scatter remains and no relation is expected on the basis of the present analysis.

[1] These shape factor values have been calculated on the basis of the combined data of the separate samples. Taking the average shape factor value of the separate samples will yielded a different value.

It is stressed that shape tests have been performed on sample A of each grading only. The average blockiness calculated on basis of sample A has been applied integrally to the combined sample A-E. As a result it has been assumed the average blockiness of sample A is constant over the different samples. No information is however available on the validity of this assumption and thus the results should be handled with care.

G.2 Individual shape factors versus blockiness

By application of the dimensions of the smallest enclosing box for each individual rock a virtual sieve diameter is determined. Furthermore for each individual rock the nominal diameter has been calculated. The ratio of the nominal diameter and virtual sieve diameter results in individual shape factors. For detailed information please consult appendix [E]. In this section for each of the gradings the calculated individual shape factors of sample A have been plot versus the blockiness value of the associated individual rock. Moreover the linear regression line based on least squares has been added to the figures to visualize possible relations.

G.2.1 Sample 22-90 A

The average value of the individual shape factor is 0.839. The standard deviation of 0.075. The minimum and maximum value are 0.61 and 1.06 respectively. The average blockiness value is 45.2%. The standard deviation of 8.1%. The minimum and maximum value are 16.7% and 89.2% respectively. It is concluded the data is rather scattered which is also observed in Figure G.2-1. Considering the bandwidth of the scatter, both the upper and lower limit of the shape factor value tend to increase for increasing blockiness. The equation for linear regression, given by Fs* = 0.0044 * BLC + 0.6387 confirms this finding. For average blocky rock (BLC = 45.2%) the equation yields an individual shape factor value of 0.838. On the basis of sample 22-90 A, a weak but significant relation is expected for the individual shape factor versus blockiness.

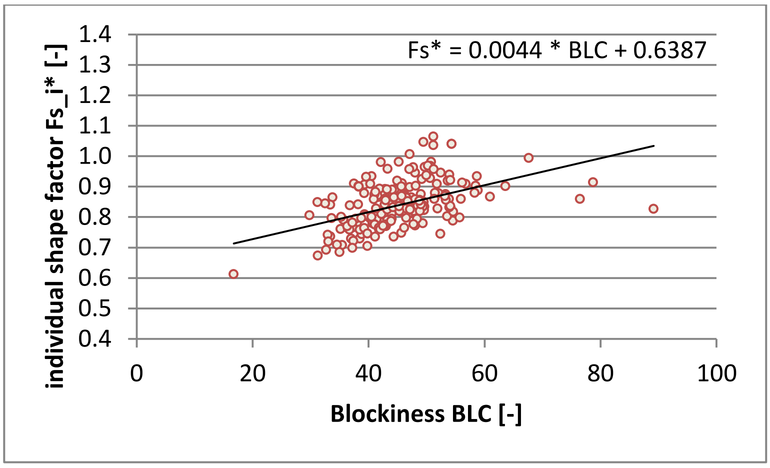


Figure G.2-1 - shape factor versus blockiness 22-90 sample A

G.2.2 Sample 2-5 A

The average value of the individual shape factor is 0.847. The standard deviation of 0.078. The minimum and maximum value are 0.69 and 1.10 respectively. The average blockiness value is 45.8%. The standard deviation of 7.1%. The minimum and maximum value are 26.3% and 65.1% respectively. It is concluded the data is rather scattered which is also observed in Figure G.2-2. Considering the resulting bandwidth of the scatter, the upper limit tends to increase for increasing blockiness. The lower limit is considered rather constant over blockiness at an approximate value of 0.7. The spreading of the data thus widens for increasing blockiness. The equation for linear regression is given by Fs* = 0.0058 * BLC + 0.5796, which suggests a weak but significant relation for the individual shape factor versus blockiness. For average blocky rock (BLC = 45.8%) the equation yields an individual shape factor value of 0.845. On the basis of sample 2-5 A, a weak but significant relation is expected for the individual shape factor versus blockiness.

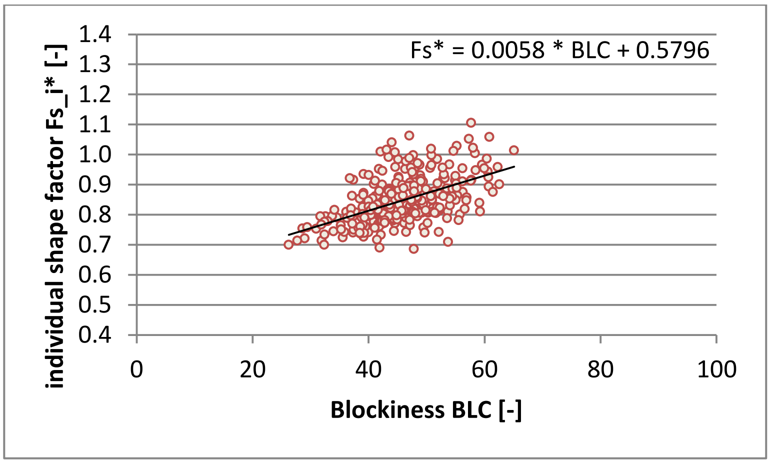


Figure G.2-2 - shape factor versus blockiness 2-5 sample A

G.2.3 Sample 2-8 A

The average value of the individual shape factor is 0.853. The standard deviation of 0.083. The minimum and maximum value are 0.66 and 1.34 respectively. The average blockiness value is 46.3%. The standard deviation of 8.9%. The minimum and maximum value are 29.6% and 96.5% respectively. It is concluded the data is rather scattered which is also observed in Figure G.2-3. Considering the bandwidth of the scatter, both the upper and lower limit of the shape factor value tend to increase for increasing blockiness. The equation for linear regression, given by Fs* = 0.0056 * BLC + 0.5932 confirms this finding. For average blocky rock (BLC = 46.3%) the equation yields an individual shape factor value of 0.852. On the basis of sample 2-8 A, a weak but significant relation is expected for the individual shape factor versus blockiness.

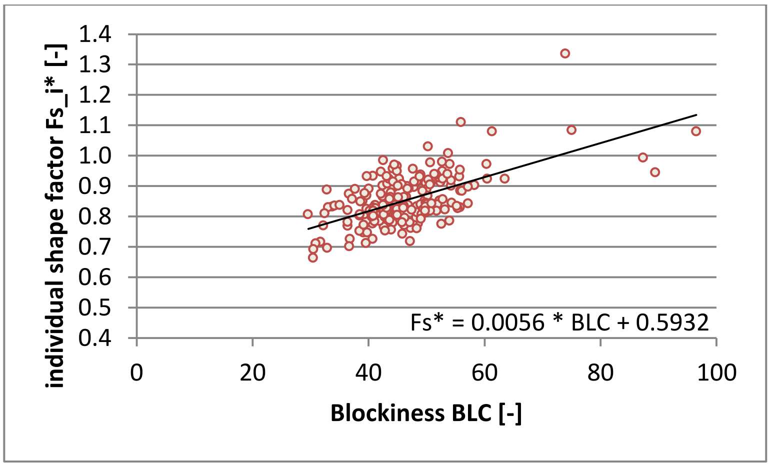


Figure G.2-3 - shape factor versus blockiness 2-8 sample A

G.2.4 Sample 1-5 A

The average value of the individual shape factor is 0.823. The standard deviation of 0.098. The minimum and maximum value are 0.55 and 1.15 respectively. The average blockiness value is 42.5%. The standard deviation of 7.9%. The minimum and maximum value are 11.2% and 64.8% respectively. It is concluded the data is rather scattered which is also observed in Figure G.2-4. Considering the resulting bandwidth of the scatter, the upper limit tends to increase for increasing blockiness. Disregarding the two minimum individual shape factor values, the lower limit is considered rather constant over blockiness at an approximate value of 0.65. The spreading of the data thus widens for increasing blockiness. The equation for linear regression is given by Fs* = 0.0037 * BLC + 0.6664, which suggests a weak but significant relation for the individual shape factor versus blockiness. For average blocky rock (BLC = 42.5%) the equation yields an individual shape factor value of 0.824. On the basis of sample 1-5 A, a weak but significant relation is expected for the individual shape factor versus blockiness.

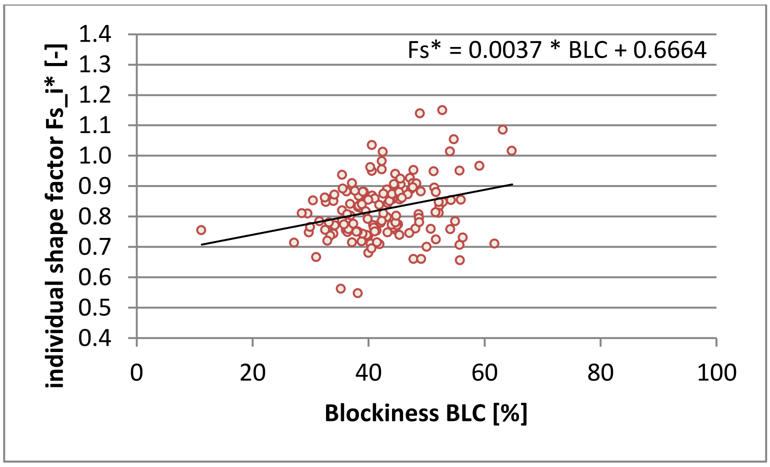


Figure G.2-4 - shape factor versus blockiness 1-5 sample A

G.2.5 Sample 5+ A

The average value of the individual shape factor is 0.854. The standard deviation of 0.080. The minimum and maximum value are 0.68 and 1.10 respectively. The average blockiness value is 45.5%. The standard deviation of 7.1%. The minimum and maximum value are 29.6% and 72.9% respectively. It is concluded the data is rather scattered which is also observed in Figure G.2-5. Considering the bandwidth of the scatter, both the upper and lower limit of the shape factor value tend to increase for increasing blockiness. The equation for linear regression, given by Fs* = 0.0060 * BLC + 0.5805 confirms this finding. For average blocky rock (BLC = 45.5%) the equation yields an individual shape factor value of 0.854. On the basis of sample 5+ A, a weak but significant relation is expected for the individual shape factor versus blockiness.

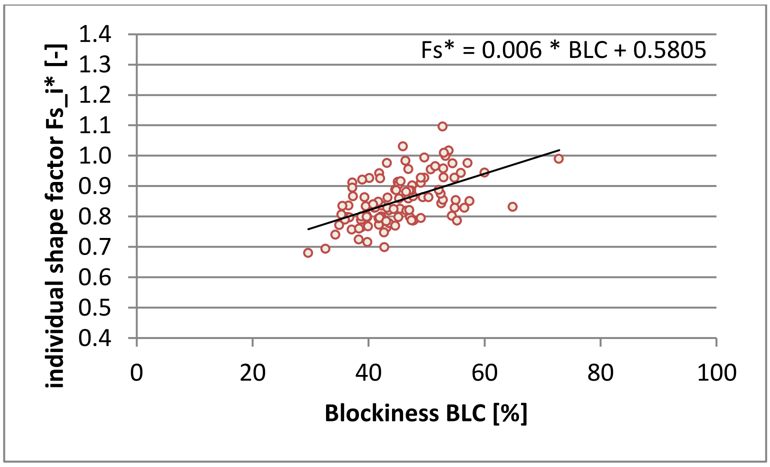


Figure G.2-5 - shape factor versus blockiness 5+ sample A

G.2.6 Combined sample

The data of the above discussed samples has been combined in this paragraph. In Figure G.2-6 the individual shape factors have been plot versus the associated individual blockiness value for 969 rocks. The average value of the individual shape factor is 0.844. The standard deviation is 0.083. The minimum and maximum value are 0.55 and 1.34 respectively. The average blockiness value is 45.2%. The standard deviation of 7.9%. The minimum and maximum value are 11.2% and 96.5% respectively. It is concluded the data is rather scattered, which is also observed in Figure G.2-6. These findings logically are in line with the above observations. Considering the bandwidths of the scatter, the upper limit tends to increase for increasing blockiness. Disregarding the three minimum individual shape factor values, the lower limit is considered rather constant over blockiness at an approximate value of 0.65. The equation for linear regression is given by Fs* = 0.0052 * BLC + 0.6086, which suggests a weak but significant relation for the individual shape factor versus blockiness. For average blocky rock (BLC = 45.2%) the equation yields an individual shape factor value of 0.844.

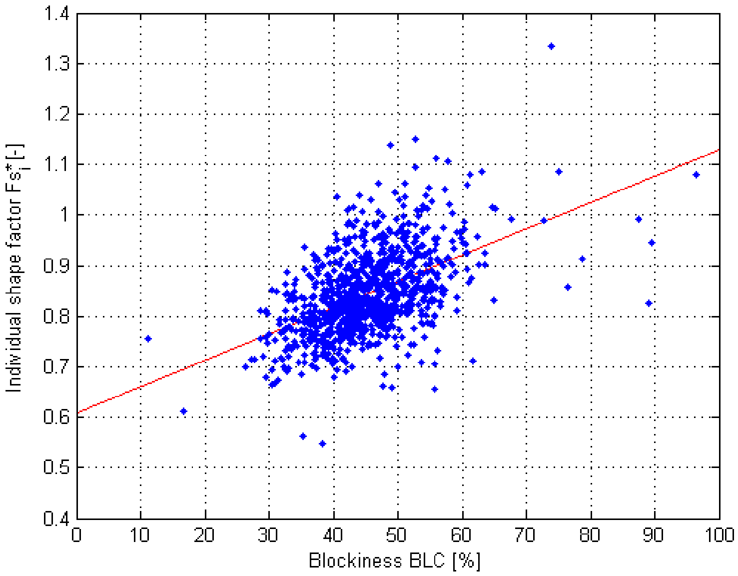


Figure G.2-6 - shape factor versus blockiness, combined sample

G.3 Conclusion

The plots of the individual shape factors versus the associated individual blockiness values have shown extensive scatter for each sample. Nonetheless the average value of the individual shape factors approaches the commonly applied value; 0.84-0.85 for each of the samples. For sample 2-8 A, a slightly smaller value has been found: 0.82. The standard deviation varies from 0.075 to 0.098 over the samples. This is approximately 10 percent of the average individual shape factor value, which is considered quite a large number.
The average blockiness value for most samples is approximately 45-46%. For the sample 1-5 A, a slightly smaller value has been found: 42.5%. The standard deviation varies from 7.1% to 8.9% over the samples. This is approximately 5-6 percent of the average blockiness values, which is considered a relatively moderate number. For overview these statistical findings have been tabulated in Table G.3-1.

Table G.3-1 - average and standard deviation of individual shape factor per sample

Sample	Average F [-]	st. dev.[2] F [-]	Average BLC [%]	st. dev. BLC [%]
22-90 A	0.839	0.075	45.2	8.1
1-5 A	0.847	0.078	42.5	7.9
2-5 A	0.853	0.083	45.8	7.1
2-8 A	0.823	0.098	46.3	8.9
5+ A	0.854	0.080	45.5	7.1
Combined	0.844	0.083	45.2	7.9

Regarding the bandwidth of the scatter, the upper limit significantly increases for increasing blockiness in each of the samples. The lower limit is rather constant over blockiness at an approximate value of 0.65-0.70 in four of the samples. In one sample (22-90 A) the lower limit slightly increases for increasing blockiness. As a result for each of the samples the bandwidth of the scatter and thus the standard deviation[2] increases for increasing blockiness. Those observations suggest a weak but significant relation between the individual shape factor and blockiness. Moreover the linear regression equation for each of the five samples have confirmed this finding. The slope in each of the equations is positive, yielding increasing individual shape factor values for increasing blockiness values. In Table G.3-2 the equations have been listed for overview. For specific blockiness values, the individual shape factor value has been calculated by application of the formulae. The delta Δ represents the difference in the value of the individual shape factor in the blockiness range of 30%-60%. 95 percent of all rock has a blockiness value within this range.

Table G.3-2 regression dependent on blockiness per sample

Sample	Regression for F_s^*(BLC)	30%	40%	50%	60%	Δ	BLC_{ave}
22-90 A	Fs* = 0.0044 * BLC + 0.6387	0.771	0.815	0.859	0.903	0.132	0.838
1-5 A	Fs* = 0.0037 * BLC + 0.6664	0.777	0.814	0.851	0.888	0.111	0.824
2-5 A	Fs* = 0.0058 * BLC + 0.5796	0.754	0.812	0.870	0.928	0.174	0.845
2-8 A	Fs* = 0.0056 * BLC + 0.5932	0.761	0.817	0.873	0.929	0.168	0.852
5+ A	Fs* = 0.0060 * BLC + 0.5805	0.761	0.821	0.881	0.941	0.180	0.854
Combined	Fs* = 0.0052 * BLC + 0.6086	0.765	0.817	0.868	0.921	0.156	0.844

From Table G.3-2 it is concluded the value of the individual shape factor increases for increasing blockiness for each of the samples. The largest increase of the individual shape factor over blockiness in the range 30%-60% is found for the sample 5+ A: 0.180. The smallest increase is found for the sample 1-5 A: 0.111. No relation is observed in the rate of

[2] The standard deviation in fact increases for increasing diameter. The given value represents the 'overall' standard deviation derived on the basis of all available data.

increase over specific grading properties of the samples. Furthermore it is concluded the individual shape factor values found for the sample 1-5 A are significantly smaller compared with the values found for the other samples. A specific explanation cannot be given for this observation.

Applying the regression equations strictly, the value of the individual shape factor would be increasing for each subsequent increase of blockiness. From the scatter however it can be clearly concluded that this concept does not hold in practice. In contrary, the value of the shape may considerably decrease for increasing blockiness. To gain insight in the unpredictability for the rate of change of the individual shape factor value, the minimum and maximum values of the individual shape factor within small blockiness ranges have been assessed. This has been done for the ranges 28%-32%, 38%-42%, 48%-52% and 58%-32%. In Table G.3-3 the results have been listed.

Table G.3-3 variation of the individual shape factor versus blockiness

Sample	28-32% BLC		38-42% BLC		48-52% BLC		58-62% BLC	
	min	max	min	max	min	max	min	max
22-90 A	0.67	0.85	0.70	0.93	0.77	1.06	0.87	0.93
1-5 A	0.67	0.85	0.55	1.03	0.66	1.14	0.71	0.97
2-5 A	0.71	0.79	0.69	0.95	0.74	1.02	0.81	1.06
2-8 A	0.66	0.81	0.71	0.93	0.76	1.03	0.90	1.08
5+ A	0.68	0.68	0.72	0.94	0.79	0.99	0.94	0.94
Combined	0.66	0.85	0.55	1.03	0.66	1.14	0.74	1.08

It is concluded on macro-scale[3] a significant relation can be discerned between the value of the individual shape factor and the blockiness value. *The value of the individual shape factor increases for increasing blockiness.* The rate approximate is 0.05 on 10. On a micro-scale[3] this relation does not hold and should not be applied. The value of the individual shape factor fluctuates extensively over small blockiness ranges due to the large standard deviation. As a result the above stated relation is weakened.

[3] macro-scale: all rock in a sample; micro-scale: two rock of subsequently increasing blockiness.

For the combined sample, the data scatter, regression line and bandwidths of 1, 2 and 3 standard deviations have been plotted in Figure G.3-1.

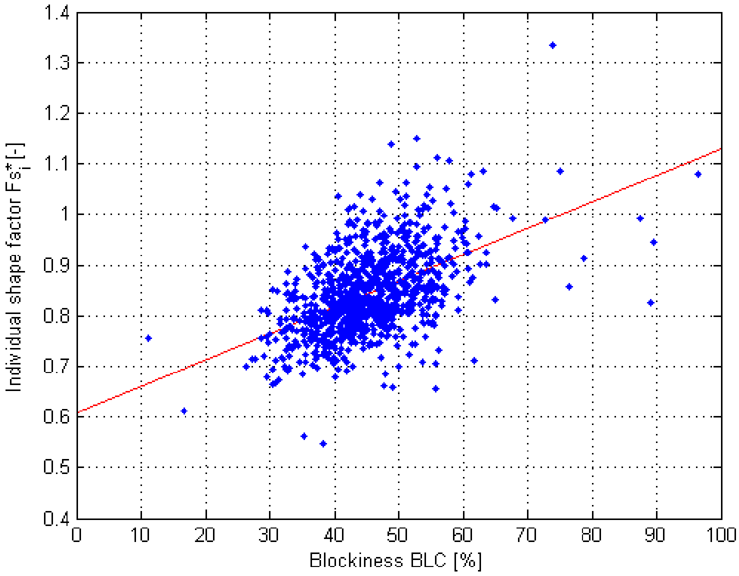
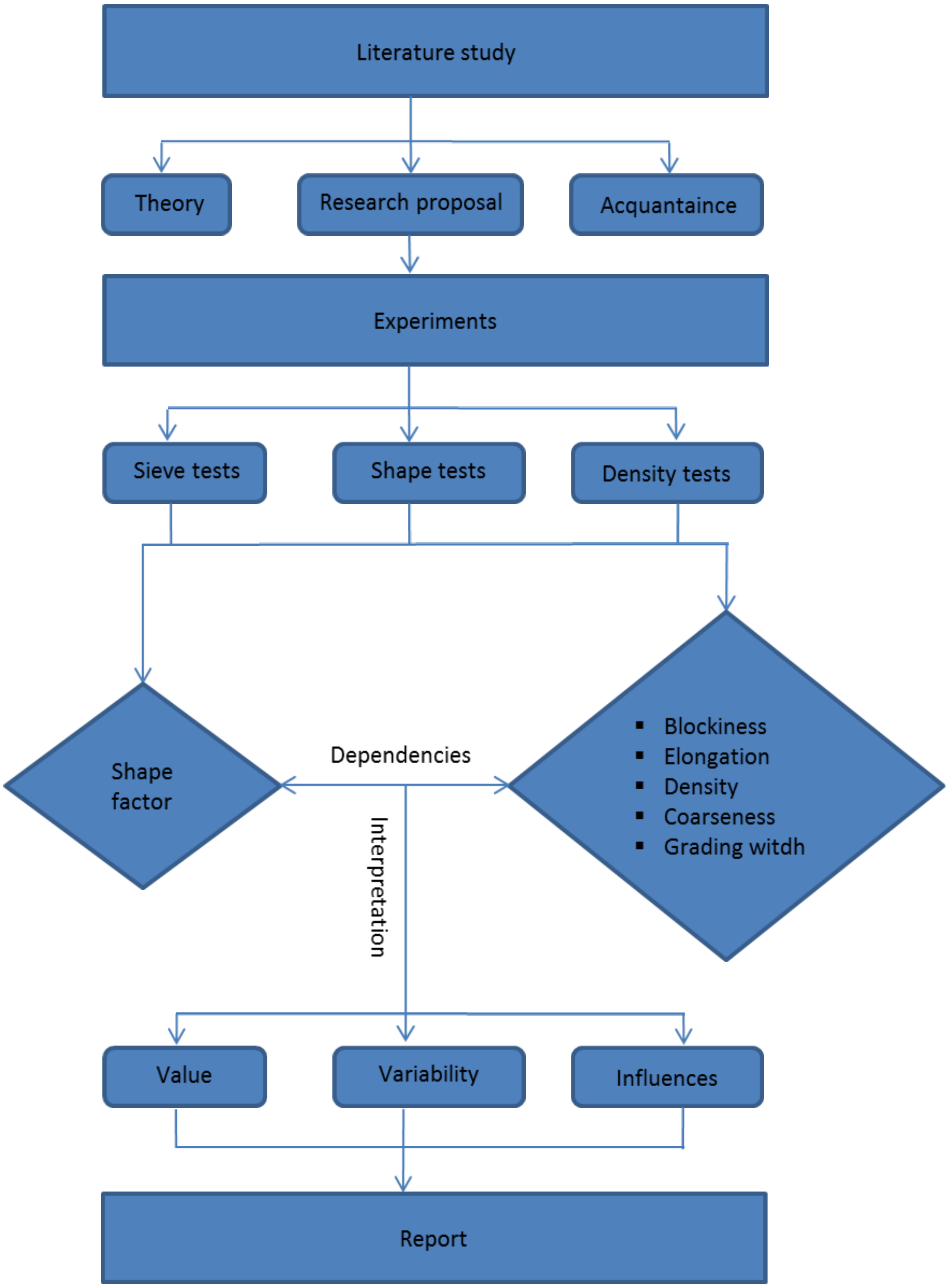


Figure G.3-1 - blockiness regression equation and variance bandwidths of combined sample

H. Flow chart


Literature study
Theory
Research proposal
Acquantaince
Experiments
Sieve tests
Shape tests
Density tests
Shape factor
Dependencies
Interpretation
Blockiness
Elongation
Density
Coarseness
Grading witdh
Value
Variability
Influences
Report