BRNO UNIVERSITY OF TECHNOLOGY

Z 7008

FACULTY OF CIVIL ENGINEERING
institute of building testing

FINAL REPORT ON THE RESULTS OF PRECISION EXPERIMENT

PROFICIENCY TESTING PROGRAM
Strenght and Elasticity of Hardened Concrete

ZZB 2018/2

Brno University of Technology
Proficiency testing provider at the SZK FAST
Veveří 95, Brno 602 00
Czech Republic

www.szk.fce.vutbr.cz

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Poskytovatel zkoušení způsobilosti při SZK FAST
Proficiency testing provider at the SZK FAST
Z 7008
Veveří 95
602 00 Brno
Czech Republic
szk.fce.vutbr.cz

Assoc. Prof. Ing. Tomáš Vymazal, Ph.D.
Head of the PT Provider, PTP coordinator

Ing. Petr Misák, Ph.D.
Coordinator of PTP results assessment

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1 Introduction and Important Contacts

In the year 2018, the Proficiency Testing Provider at the SZK FAST (PT Provider) initiated the Proficiency Testing Program (PTP) designated Strenght and Elasticity of Hardened Concrete whose aim was to verify and assess the conformity of test results across laboratories when testing hardened concrete.

The assessment of the results of the Proficiency Testing Program was carried out by a committee consisting of the following PT Provider employees:

Head of the PT Provider, PTP coordinator

doc. Ing. Tomáš Vymazal, Ph.D.
Brno University of Technology
Faculty of Civil Engineering
Institute of Building Testing
Veveří 95, Brno 602 00
Czech Republic
Tel.: +420 603 313 337
Email: Tomas.Vymazal@vutbr.cz

Coordinator of PTP result assessment PrZZ

Ing. Petr Misák, Ph.D.
Brno University of Technology
Faculty of Civil Engineering
Institute of Building Testing
Veveří 95, Brno 602 00
Czech Republic
Tel.: +420 774 980 255
Email: Petr.Misak@vutbr.cz

The subjects of proficiency testing were the following testing procedures:

1. **EN 12390-3** – Compressive strength of test specimens [1].
2. **EN 12390-5** – Flexural strength of test specimens [2].
3. **EN 12390-6** – Tensile splitting strength of test specimens [3].
4. **EN 12390-7** – Density of hardened concrete [4].
5. **ISO 1920-10** – Determination of static modulus of elasticity in compression [5].
6. **EN 12390-13** – method A – Determination of secant modulus of elasticity in compression [6].
7. **EN 12390-13** – method B – Determination of secant modulus of elasticity in compression [6].
8. **EN 12504-4, ČSN 731371** – Non-destructive testing of concrete [7], [8].
9. **ČSN 731373, EN 12504-2** – Determination of rebound number [9], [10].
10. **EN 1542, ČSN 736242** – Appendix B – Measurement of bond strength by pull-off [11], [12].

Testing procedures No 5 – 8 were not open due to low number of participants.

The supplier, BETOTECH s. r. o., was responsible for the preparation of hardened concrete for the PTP. Fresh concrete for the preparation of test samples was taken from one production batch prepared in accordance with methods stipulated in EN 206 [13]. Fresh concrete was poured into test molds, which were always of the same type, and after removal from the molds the test specimens were placed under identical conditions in storage rooms complying with the requirements for individual specifications.

The specimens were taken from the same production with the same production date. The test results from individual PTP participants were compared via a method involving the statistical analysis of all their results in a manner complying with ISO 5725-2 [14] and with EN ISO/IEC 17043 [15]. The outcome is the present final report summarizing the results of the interlaboratory comparison, including statistical evaluation.

30 laboratories from Europe took part in the program. In order to maintain the anonymity of the PTP, each laboratory was given an identification number that will be used henceforth in this document. An integral part of the present final report is a Certificate of Participation in the Proficiency Testing Program. It is unique for each participant and includes the participant's ID used in this report. The following chart shows the participation of laboratories in individual parts of the PTP.

Table 1: Participation of individual laboratories in the PTP (tests designated according to part 1)

ID / Testing method	1	2	3	4	5	6	7	8	9	10
065959	-	X	-	-	-	-	-	-	-	-
223144	X	-	-	X	-	-	-	-	X	-
360089	-	-	-	X	-	-	-	-	X	-
638307	X	X	-	X	-	-	-	-	-	-
953526	X	-	-	-	-	-	-	-	-	-
1d9468	X	-	-	X	-	-	-	-	-	-
2c694b	X	X	-	X	-	-	-	-	-	X
2ec0ad	X	-	-	X	-	-	-	-	-	-
341b60	X	-	-	X	-	-	-	-	-	-
3a3339	X	X	X	-	-	-	-	-	-	-
3c45a1	-	X	-	-	-	-	-	-	-	X
404e0a	X	X	-	X	-	-	-	-	-	-
47a8df	-	X	X	-	-	-	-	-	-	-
4e3829	X	-	X	X	-	-	-	-	X	X
5034d7	X	-	-	-	-	-	-	-	-	-
570e7a	X	X	X	X	-	-	-	-	X	X
5ae922	X	-	-	X	-	-	-	-	-	-
6d8f04	X	X	X	X	-	-	-	-	-	-
773e5d	-	-	-	-	-	-	-	-	X	X
9d28a2	X	-	-	-	-	-	-	-	-	-
a18ca8	X	-	-	X	-	-	-	-	-	-
b362c6	X	-	-	-	-	-	-	-	X	-
b998cc	X	-	-	X	-	-	-	-	-	-
cbf6fb	X	-	-	X	-	-	-	-	-	X
d099d8	X	-	-	X	-	-	-	-	-	-
da8a4c	X	-	-	-	-	-	-	-	-	-
e48ade	-	X	-	-	-	-	-	-	-	-
eb91d1	X	-	-	X	-	-	-	-	-	-
f00261	X	X	X	-	-	-	-	-	-	-
f56fc9	-	X	-	-	-	-	-	-	-	-

Table 2: List of participants (laboratories) – the order in the table does not correspond to the identification number in Table 1

Laboratory	Address	Accreditation number
"TRANSSTRY VARNA "AD	"HAN OMURTAG "№2, VARNA, + 359 9000, BULGARIA	-
BEST, a.s.	Lučice 87, Clumec nad Cidlinou, 50351, Česká republika	-
BETOTECH, s.r.o. - pracoviště Beroun	Beroun 660, Beroun, 26601, Česká republika	1195
BETOTECH, s.r.o. - pracoviště Brno	Jihlavská 51, Brno, 642 00, Česká republika	1195.3
BETOTECH, s.r.o. - pracoviště Cheb	Beroun 660, Beroun, 26601, Česká republika	1195
BETOTECH, s.r.o. - pracoviště Jindřichův Hradec	Beroun 660, Beroun, 26601, Česká republika	1195

Laboratory	Address	Accreditation number
BETOTECH, s.r.o. - pracoviště Klatovy	Beroun 660, Beroun, 26601, Česká republika	1195
BETOTECH, s.r.o. - pracoviště Most	Beroun 660, Beroun, 26601, Česká republika	1195
BETOTECH, s.r.o. - pracoviště Trutnov	Beroun 660, Beroun, 26601, Česká republika	1195
BETOTECH, s.r.o., zkušební laboratoř Ostrava	Beroun 660, BEROUN 2, 266 01, Česká republika	1195.2
Cement Hranice, akciová společnost - betonářská laboratoř	Bělotínská 288, Hranice I - Město, 75301, Czech Republic	1284
CEMEX Czech Republic, s.r.o.	Semtín 102, Pardubice, 53354, Česká republika	1302
CSS d.o.o.	Savska cesta 144a, Zagreb, 10000, CROATIA	1106 HAA
EUROVIA Services, s.r.o.	PO BOX 207, Praha 6, 160 41, Česká republika	1170
Institute for Materials Testing JSC Belgrade	Bulevar vojvode Mišića 43, Belgrade, 11000, Serbia	-
Koncept CB spol. s r.o.	nám. Švabinského 961/10, České Budějovice, 370 08, Česká republika	1534
QUALIFORM SLOVAKIA s.r.o. - org. složka - pracoviště Praha	Lesní 693, Bílovice nad Svitavou, 66401, Česká republika	S-301
QUALIFORM SLOVAKIA s.r.o. - organizační složka - pracoviště Olomouc	Lesní 693, Bílovice nad Svitavou, 66401, Česká republika	S-301
QUALIFORM SLOVAKIA s.r.o. , Pracovisko 02 Svit	Pasienková 9 D, Bratislava, 82106, Slovenská republika	154/S-301
Ředitelství silnic a dálnic ČR	Rebešovická 40, Brno-Chrlice, 643 00, Česká republika	1072
STACHEMA Bratislava a.s., Skúšobné laboratórium STACHEMA	Rovinka 411, Rovinka, 900 41, Slovenská republika	S-275
STACHEMA CZ s.r.o., Zkušební laboratoř, Pracoviště 1	Hasičská 1, Zibohlavy, Kolín, 280 02, Česká republika	L 1433
Stavební fakulta, ČVUT v Praze	Thákurova 7/2077, Praha, 266 29, Czech republic	L1048
STROYCONTROL 2003 LTD	Kostenec Str 12, Sofia Bulgaria, 1612, Bulgaria	182/LI
TPA ČR, s.r.o.	Vrbenská 1821/31, České Budějovice, 370 06, Česká republika	1181
TPA EOOD CTC SOFIA	Rezbarska 7 str., Sofia, 1510, Bulgaria	-
UAB "Konstrukcijų bandymo centras"	J. Basanavičiaus str. 160 D-2, Šiauliai, LT-76128, Lithuania	LA013
Universität für Bodenkultur Wien	Peter-Jordan-Str. 82, Wien - Vienna, 1190, Austria	-
University of Technology - TVFA	Inffeldgasse 24, Graz, 8010, Austria	-
ZAPA beton a.s.	ZAPA beton a.s. , PO BOX č. 31, Klatovská tř. 127, Plzeň 20, 320 81, Česká republika	1439

2 Procedures used in the Statistical Analysis of Laboratory Results

To describe the accuracy of measuring methods, the terms trueness and precision are used. Trueness refers to the closeness to congruity between the arithmetic mean of a high number of test results and a real or accepted reference value. Precision means the closeness to congruity between test results. The necessity to consider precision is based on the fact that tests generally do not yield the same results even though they are supposed to be carried out on the same material and under the same conditions. This is caused by accidental errors that are impossible to avoid. These errors represent an integral part of every testing procedure and we are unable to control them fully. The comparative analysis of laboratory data does not focus on assessing the trueness of test results, but first and foremost on their precision. Results are thus compared with one another and not with any reference value or real value.

The basis of the statistical analysis is a critical data assessment complying with ISO 5725-2 [14], i.e. the determination of dubious and outlying values, and other irregularities. This assessment is carried out using mainly Grubbs' and Cochran's tests (numerical evaluation) as well as Mandel's statistics (graphical evaluation). Other observed statistical parameters are interlaboratory dispersion, repeatability dispersion, reproducibility dispersion and related characteristics of repeatability and reproducibility. The outcome of PTP is to assess the performance of participating laboratories in compliance with EN ISO/IEC 17043 [15], consisting of the determination of relative values and their uncertainties and a final comparison with the test results of PTP participants.

A prerequisite for using these methods is the unimodal probability distribution of measured data. Furthermore, p will stand for the number of participating laboratories marked by the index A prerequisite for using these methods is the unimodal probability distribution of measured data. Furthermore, p will stand for the number of participating laboratories marked by the index $i = 1, \dots, p$, each of which carried out n number of tests., each of which carried out n number of tests.

2.1 The Numerical Procedure for Determining Outliers

To determine outliers, two basic statistical tests are used. One of them is Cochran's C test, which tests interlaboratory variabilities (in cases when the number of measurements of one quantity in one laboratory > 2) and is used first. If this test marks one participant's results as outlying, the laboratory is excluded and the test repeated. The second test (Grubbs' test) is first and foremost a test of interlaboratory variability and we can also employ it if Cochran's test raises the suspicion that only one of the test results is to blame for the high interlaboratory dispersion. Both tests assume a balanced experiment, i.e. the number of tests at one laboratory for the determination of one quantity must be constant.

When determining divergent or outlying values, three situations can occur:

- If the test statistic is within or equal to 5% of the critical value, the tested entity is considered to be *correct*;
- If the test statistic diverges from the critical value by more than 5%, but is within or equal to 1% of the critical value, the tested entity is considered to be *divergent*;
- If the test statistic diverges from the critical value by more than 1%, the tested entity is considered to be *outlying*.

2.1.1 Cochran's test

The Cochran's C statistic is given by the equation:

$$C = \frac{s_{max}^2}{\sum_{i=1}^{p} s_i^2} \tag{1}$$

where s_{max} is the highest sample standard deviation, s_i are sample standard deviations determined according to the results from all laboratories and p means the number of laboratories participating in the PT program.

The sample standard deviation is determined from the equation

$$s_i = \sqrt{\frac{1}{n_i - 1} \sum_{k=1}^{n_i} (y_k - \bar{y})^2}, \tag{2}$$

where n_i is the number of test results from the determination of one quantity in i-th laboratory, y_k is the k-th value and $\bar{y_i}$ is the average value measured in the i-th laboratory. If only two results were measured for the relevant quantity, we can use the simplified equation:

$$s_i = \frac{|y_1 - y_2|}{\sqrt{2}}. \tag{3}$$

2.1.2 Grubbs' test – One Outlying Observation

From the given set of x_i data for $i = 1, 2, ..., p$, ordered upward according to size, Grubbs' statistic G_p is calculated in order to use Grubbs' test to determine whether the largest observation is an outlier:

$$G_p = \frac{x_p - \bar{x}}{s}, \tag{4}$$

whereby $\bar{x}$ is the arithmetic mean of the observed feature. The observed feature can be the average value of the quantity determined within the laboratory. Furthermore, s is a sample standard deviation of the observed feature, which in this case is a standard deviation calculated for all the laboratories.

For significance testing of the smallest observation the test statistic is calculated:

$$G_p = \frac{\bar{x} - x_p}{s}. \tag{5}$$

2.2 Mandel's Statistics

In order to determine data consistency, two values called Mandel's h and k statistics were used. These indicators are commonly used for the graphical evaluation of laboratories in a similar way to a description of variability.

2.2.1 Interlaboratory Consistency Statistic h

For each laboratory, the interlaboratory consistency statistic h was evaluated according to the formula

$$h_i = \frac{\bar{y_i} - \bar{\bar{y}}}{\sqrt{\frac{1}{p-1}\sum_{i=1}^{p_j}\left(\bar{y_i} - \bar{\bar{y}}\right)}}, \tag{6}$$

where $\bar{y_i}$ is the average value for the i-th laboratory, $\bar{\bar{y}}$ is the arithmetic mean of all values and p is the number of laboratories. The values of the h_i statistics were plotted on graphs.

2.2.2 Intralaboratory Consistency Statistic k

The intralaboratory consistency statistic k is calculated from the equation

$$k_i = \frac{s_i\sqrt{p}}{\sqrt{\sum_{i=1}^{p} s_i^2}}, \tag{7}$$

where s_i is a sample standard deviation of values measured at the i-th laboratory. Just as with h statistics, the k values are plotted on graphs.

Study of the graphs displaying h and k values may indicate that certain laboratories show a significantly different ordering of results than other studied laboratories. This is caused by a permanently large and/or permanently small dispersion of results or extreme averages of results across all levels.

2.3 Calculation of Variances Estimates

After the elimination of outliers (of laboratories), we can proceed to the calculation of basic variability characteristics, i.e. repeatability dispersion, interlaboratory dispersion and reproducibility dispersion. These characteristics are stated in the form of standard deviations, i.e. after extracting the root. It is advantageous when the variability characteristics and the observed quantity are of the same physical dimensions.

2.3.1 Repeatability Variance

$$s_r^2 = \frac{\sum_{i=1}^{p}(n_i - 1)s_i^2}{\sum_{i=1}^{p}(n_i - 1)} \tag{8}$$

2.3.2 Interlaboratory Variance

$$s_L^2 = \frac{s_d^2 - s_r^2}{\bar{\bar{n}}}, \tag{9}$$

where

$$s_d^2 = \frac{1}{p-1}\sum_{i=1}^{p} n_i \left(\bar{y_i} - \bar{\bar{y}}\right)^2 \tag{10}$$

and

$$\bar{\bar{n}} = \frac{1}{p-1}\left[\sum_{i=1}^{p} n_i - \frac{\sum_{i=1}^{p} n_i^2}{\sum_{i=1}^{p} n_i}\right]. \tag{11}$$

2.3.3 Reproducibility Variance

$$s_R^2 = s_r^2 + s_L^2, \tag{12}$$

where s_r^2 is repeatability variance and s_l^2 is interlaboratory variance.

2.4 Repeatability and Reproducibility

Repeatability expresses the fact that the difference between two test results from the same sample from tests carried out by the same person at the same facility and within the shortest time interval possible will not exceed the repeatability value r on average more than once in 20 cases if the method is employed in the common and correct manner.

The repeatability value is expressed by the relation

$$r = 2,8 s_r, \tag{13}$$

where $s_r = \sqrt{s_r^2}$ stands for the standard deviation of repeatability.

Reproducibility expresses the fact that the reproducibility value R for test results from one sample obtained in the shortest time interval possible by two persons who used their own devices will not differ on average more than once in 20 cases if the method is employed in the common and correct manner.

The reproducibility value is expressed by the relation

$$R = 2,8 s_R, \tag{14}$$

where $s_R = \sqrt{s_R^2}$ stands for the standard deviation of reproducibility.

2.5 Assigned Values

The PT Provider will ensure the determination of assigned value X and its uncertainty for every PTP. Assigned values are always only imparted to PTP participants after they have submitted their PTP results so that they cannot obtain any benefit from the premature revelation of the values.

The assigned values are determined by the PT Provider as consensual values derived from the results of participants in compliance with Appendix B of EN ISO/IEC 17043 [15] using the statistical methods described in ISO 13528 [16] and ISO 5725-5 [17]. The assigned value X is therefore determined as a robust estimate of the average value x^* (the A algorithm mentioned in [16] and [17]):

Initial values x^* and s^* (robust standard deviation) are calculated as

$$x^* = \text{median } x_i, \tag{15}$$

$$s^* = 1,483 \cdot \text{median}\,|x_i - x^*|\,, \tag{16}$$

where $i = 1, \ldots, p$. The values of x^* and s^* are then processed as follows. First, $\varphi = 1,5 \cdot s^*$ is computed. For every x_i $(i = 1, \ldots, p)$ value, the following is calculated

$$x_i^* = \begin{cases} x^* - \varphi & \text{if } x_i < x^* - \varphi, \\ x^* + \varphi & \text{if } x_i > x^* + \varphi, \\ x_i & \text{in other cases.} \end{cases} \tag{17}$$

New values of x^* and s^* are calculated from the following equations

$$x^* = \sum_{i=1}^{p} \frac{x_i^*}{p}, \tag{18}$$

$$s^* = 1,134 \cdot \sqrt{\sum_{i=1}^{p} \frac{(x_i^* - x^*)^2}{p-1}}. \tag{19}$$

Robust estimates are derived by iteration until the estimate changes between calculations become small.

The standard uncertainty u_X of an assigned value determined in this manner is calculated from the relation

$$u_X = 1,25 \cdot \frac{s^*}{\sqrt{p}}. \tag{20}$$

In the case of a small number of PTP participants, the PT Provider sets the assigned values as consensual values obtained from expert participants who have proven their competence to determine the measured quantity that is the subject of testing.

Furthermore, if the number of participants is small $(4\ p\ 20)$, the PT Provider can consider determining the relative values by using what is called **Horn's method**. This method consists in the determination of so-called pivots used as a basis for estimating location and variability. First, the assessed data are ordered upwards. The low pivot is then determined from the equation

$$x_D = x_{(H)}, \tag{21}$$

where H is an ordinal index given by the equation $H = \frac{\text{int}\left(\frac{p+1}{2}\right)}{2}$ or $H = \frac{\text{int}\left(\frac{p+1}{2}+1\right)}{2}$.

The upper pivot is then determined from the equation

$$x_H = x_{p+1-H}. \tag{22}$$

Using Horn's method, the assigned value is determined as a location estimate, i.e. as the so-called pivot half sum:

$$x^* = \frac{x_D + x_H}{2}. \tag{23}$$

The variability estimate is determined as the so-called pivot range

$$R_L = x_H - x_D \tag{24}$$

and the uncertainty of an assigned value calculated in this way is determined as a 95% interval estimate of the mean value

$$u_X = R_L \cdot t_{L;0,95}(p), \tag{25}$$

where $t_{L;0,95}(p)$ is the $(1-\alpha)$ quantile of the T_L probability distribution with p degrees of freedom.

2.6 Calculation of Performance Statistics

Proficiency test results often need to be transformed into performance statistics in order to aid interpretation and to allow comparison with defined objectives. The aim is to express the divergence from the assigned value in a way that enables its comparison with performance criteria. In compliance with the EN ISO/IEC 17043 standard [15], the performance of participating laboratories is evaluated according to the so-called z-score and ζ-score (zeta-score).

For every non-outlying laboratory (participant), the z-score is calculated according to the equation

$$z_i = \frac{|\bar{x}_i - x^*|}{s^*}. \tag{26}$$

ζ-score is calculated using the equation

$$\zeta_i = \frac{|\bar{x}_i - x^*|}{\sqrt{u_i^2 + u_X^2}}, \tag{27}$$

where u_i is a combined standard uncertainty of the i-th laboratory. Combined standard measurement uncertainties can be arrived at by dividing the extended uncertainty U by the extension coefficient k, which for normal probability division has the value $k = 2$. If the participant does not state the extended measurement uncertainty in their test result protocol, it is impossible to determine the ζ-score. For more about measurement uncertainties see document [18].

The following scales are applied for the z-score and ζ-score (to simplify the matter, only the z-score is shown):

$$z\text{-score} = \begin{cases} |z| \leq 2 & \text{shows that the laboratory performance is } \textbf{satisfactory} \text{ and generates no signal;} \\ 2 \leq |z| \leq 3 & \text{shows that the laboratory performance is } \textbf{questionable} \text{ and generates an action signal;} \\ 3 \leq |z| & \text{shows that the laboratory performance is } \textbf{unsatisfactory} \text{ and generates an action signal.} \end{cases} \tag{28}$$

3 Conclusions of the Statistical Analysis

The present report summarizes the results of the Proficiency Testing Program Strenght and Elasticity of Hardened Concrete (PT Program) organized by the PT Provider at the SZK FAST. 30 participants (laboratories) took part in the PT Program. The program focused on ordinary standardized testing of hardened concrete with emphasis on its strength and elasticity. The test results are evaluated separately for each testing procedure examined. An evaluation of statistical characteristics is included in the Appendix, as well as test results and graphic presentations.

The most significant outcome of the PT Program is the so-called z-score and ζ-score (zeta-score).These characteristics assess the performance of individual participants by comparing it with the assigned value and measurement uncertainties. The assigned value and its uncertainty were determined according to the procedures stated in the section 2.6. z-score and ζ-score are compared with limit values (see part 2.6). The resulting ζ-score values are not taken into account during the final evaluation of the performance of participants as they are to a considerable degree dependent on the values of the measurement uncertainties of the assessed institutions.

3.1 EN 12390-3 – Compressive strength of test specimens

The test results are shown together with graphic presentation and evaluated statistical characteristics in part 1 of the Appendix. A numerical critical evaluation (Grubbs' and Cochran's test) did not indicate any exceedance of critical values.

Graphical determination of the consistency of laboratories (Mandel's statistics) has shown an exceedance of the critical value in the test results from some participants. The exceedance of the critical values of Mandel's statistics does not indicate that the results of the laboratories concerned are wrong; it only suggests minor inconsistencies. None of the participants were therefore excluded.

The assigned value and its uncertainty was determined using the A algorithm (ISO 13258 [16]). The limit value $z - score = 2$ was exceeded in the case of participant **eb91d1**. The performance of these participants was rated as **questionable**. The results of all other participants did not exceed the limit value of $z - score = 2$ and thus can be rated as **satisfactory**.

3.2 EN 12390-5 – Flexural strength of test specimens

The test results are shown together with graphic presentation and evaluated statistical characteristics in part 2 of the Appendix.

The numerical critical evaluation of the test results using Cochran's test has shown that results of participant 065959 exceeded the 1% critical value. A more detailed analysis has revealed that the outlying variability of these participants was caused by two test result only; after its removal the critical values of Cochran's test were no longer exceeded. Participant No. 065959 was not therefore excluded. Numerical critical evaluation of the test results using Grubbs' test shown that results of participants exceeded the 5% critical value. The test results of this participant were considered to be divergent.

Graphical determination of the consistency of laboratories (Mandel's statistics) has shown an exceedance of the critical value in the test results from some participants. The exceedance of the critical values of Mandel's statistics does not indicate that the results of the laboratories concerned are wrong; it only suggests minor inconsistencies. None of the participants were therefore excluded.

The assigned value and its uncertainty was determined using the A algorithm (ISO 13258 [16]). The limit value $z - score = 3$ was exceeded in the case of participant **47a8df**. The performance of these participants was rated as **unsatisfactory**.The results of all other participants did not exceed the limit value of $z - score = 2$ and thus can be rated as **satisfactory**.

3.3 EN 12390-6 – Tensile splitting strength of test specimens

The test results are shown together with graphic presentation and evaluated statistical characteristics in part 3 of the Appendix. The graphical and numerical critical evaluation did not indicate any exceedance of critical values.

The assigned value and its uncertainty was determined using the A algorithm (ISO 13258 [16]). The limit value $z - score = 2$ was exceeded in the case of participant **f00261**. The performance of this participant was rated as **questionable**. The results of all other participants did not exceed the limit value of $z - score = 2$ and thus can be rated as **satisfactory**.

3.4 EN 12390-7 – Density of hardened concrete

The test results are shown together with graphic presentation and evaluated statistical characteristics in part 4 of the Appendix. A numerical critical evaluation (Grubbs' and Cochran's test) did not indicate any exceedance of critical values.

Graphical determination of the consistency of laboratories (Mandel's statistics) has shown an exceedance of the critical value in the test results from some participants. The exceedance of the critical values of Mandel's statistics does not indicate that the results of the laboratories concerned are wrong; it only suggests minor inconsistencies. None of the participants were therefore excluded.

The assigned value and its uncertainty was determined using the A algorithm (ISO 13258 [16]). The results of all participants did not exceed the limit value of $z - score = 2$ and thus can be rated as **satisfactory**.

3.5 ISO 1920-10 – Determination of static modulus of elasticity in compression

This part of PT program was not open due to low number of participants.

3.6 EN 12390-13 – method A – Determination of secant modulus of elasticity in compression

This part of PT program was not open due to low number of participants.

3.7 EN 12390-13 – method B – Determination of secant modulus of elasticity in compression

This part of PT program was not open due to low number of participants.

3.8 EN 12504-4, ČSN 731371 – Non-destructive testing of concrete

This part of PT program was not open due to low number of participants.

3.9 ČSN 731373, EN 12504-2 – Determination of rebound number

The test results are shown together with graphic presentation and evaluated statistical characteristics in part 9 of the Appendix.

The numerical critical evaluation of the test results using Cochran's test has shown that results of participant 773e5d exceeded the 5% critical value. A more detailed analysis has revealed that the outlying variability of these participants was caused by two test result only; after its removal the critical values of Cochran's test were no longer exceeded. Participant 773e5d was not therefore excluded. Numerical critical evaluation of the test results using Grubbs' test shown that results of participant 570e7a exceeded the 5% critical value. The test results of this participant were considered to be divergent.

Graphical determination of the consistency of laboratories (Mandel's statistics) has shown an exceedance of the critical value in the test results from some participants. The exceedance of the critical values of Mandel's statistics does not indicate that the results of the laboratories concerned are wrong; it only suggests minor inconsistencies. None of the participants were therefore excluded.

The assigned value and its uncertainty was determined using the A algorithm (ISO 13258 [16]). The limit value $z - score = 3$ was exceeded in the case of participant No **570e7a**. The performance of this participant was rated as **unsatisfactory**. The results of all other participants did not exceed the limit value of $z - score = 2$ and thus can be rated as **satisfactory**.

3.10 EN 1542, ČSN 736242 – Appendix B – Measurement of bond strength by pull-off

The test results are shown together with graphic presentation and evaluated statistical characteristics in part 10 of the Appendix. The graphical and numerical critical evaluation did not indicate any exceedance of critical values.

The assigned value and its uncertainty was determined using the A algorithm (ISO 13258 [16]). The results of all participants did not exceed the limit value of $z - score = 2$ and thus can be rated as **satisfactory**.

References

[1] EN 12390-3. *Testing hardened concrete - Part 3: Compressive strength of test specimens*. 2009.

[2] EN 12390-5. *Testing hardened concrete - Part 5: Flexural strength of test specimens*. 2009.

[3] EN 12390-6. *Testing hardened concrete - Part 6: Tensile splitting strength of test specimens*. 2010.

[4] EN 12390-7. *Testing hardened concrete - Part 7: Density of hardened concrete*. 2009.

[5] ISO 1920-10. *Testing of concrete - Part 10: Determination of static modulus of elasticity in compression*. 2016.

[6] EN 12390-13. *Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression*. 2014.

[7] EN 12504-4. *Testing concrete - Part 4: Determination of ultrasonic pulse velocity*. 2005.

[8] ČSN 731371. *Non-destructive testing of concrete - Method of ultrasonic pulse testing of concrete*. 2011.

[9] ČSN 731373. *Non-destructive testing of concrete - Determination of compressive strength by hardness testing methods*. 2011.

[10] EN 12504-2. *Testing concrete in structures - Part 2: Non-destructive testing - Determination of rebound number*. 2013.

[11] EN 1542. *Products and systems for the protection and repair of concrete structures - Test methods - Measurement of bond strength by pull-off*. 2000.

[12] ČSN 736242. *Design and construction of pavements on road bridges*. 2010.

[13] EN 206. *Concrete - Specification, performance, production and conformity*. 2014.

[14] ISO 5725-2. *Accuracy (trueness and precision) of measurement methods and results - Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*. 1997.

[15] EN ISO/IEC 17043. *Conformity assessment - General requirements for proficiency testing*. 2010.

[16] ISO 13 528. *Statistical methods for use in proficiency testing by interlaboratory comparisons*. 2005.

[17] ISO 5725-5. *Accuracy (trueness and precision) of measurement methods and results - Part 5: Alternative methods for the determination of the precision of a standard measurement method*. 1999.

[18] EA 4/02. *Vyjadřování nejistot měření při kalibracích*. 2000.

1 Appendix – EN 12390-3 – Compressive strength of test specimens

1.1 Test results

Table 3: Test results - ordered by average value. Outliers are marked by star. u_X - extended uncertainty of measurement; $\bar{x}$ - average value; s_0 - sample standard deviation; V_X - variation coefficient

ID	Test results			u_X	$\bar{x}$	s_0	V_X
of participant	[N/mm^2]			[N/mm^2]	[N/mm^2]	[N/mm^2]	[%]
eb91d1	28.1	26.5	28.0	0.5	27.5	0.9	3.26
6d8f04	28.2	28.8	29.0	-	28.7	0.4	1.45
da8a4c	28.3	29.0	29.9	2.6	29.1	0.8	2.76
953526	29.2	29.6	30.5	1.0	29.8	0.7	2.24
341b60	29.4	30.8	29.5	0.9	29.9	0.8	2.61
cbf6fb	29.5	30.6	29.7	0.4	29.9	0.6	1.96
570e7a	30.1	31.3	29.7	1.6	30.4	0.8	2.74
4e3829	30.6	30.6	30.2	1.7	30.5	0.2	0.76
404e0a	31.2	28.8	32.2	1.4	30.7	1.7	5.69
638307	31.1	30.8	30.7	1.9	30.9	0.2	0.67
9d28a2	30.4	31.3	31.9	0.9	31.2	0.7	2.34
b362c6	33.0	30.2	30.6	-	31.3	1.5	4.84
3a3339	30.4	33.2	30.5	1.6	31.4	1.6	5.06
f00261	30.4	32.5	31.3	1.4	31.4	1.1	3.36
2c694b	31.6	31.1	31.6	1.7	31.4	0.3	0.92
2ec0ad	31.3	32.0	31.2	1.1	31.5	0.4	1.38
a18ca8	31.6	31.2	31.8	1.0	31.5	0.3	0.97
223144	31.3	30.8	32.7	1.3	31.6	1.0	3.12
5034d7	32.0	32.2	31.7	1.2	32.0	0.3	0.79
5ae922	31.4	31.9	32.8	0.8	32.0	0.7	2.21
d099d8	32.9	31.3	33.6	2.1	32.6	1.2	3.62
1d9468	34.1	32.4	32.5	0.4	33.0	1.0	2.89
b998cc	33.4	33.8	33.1	0.4	33.4	0.4	1.05

1.2 The Numerical Procedure for Determining Outliers

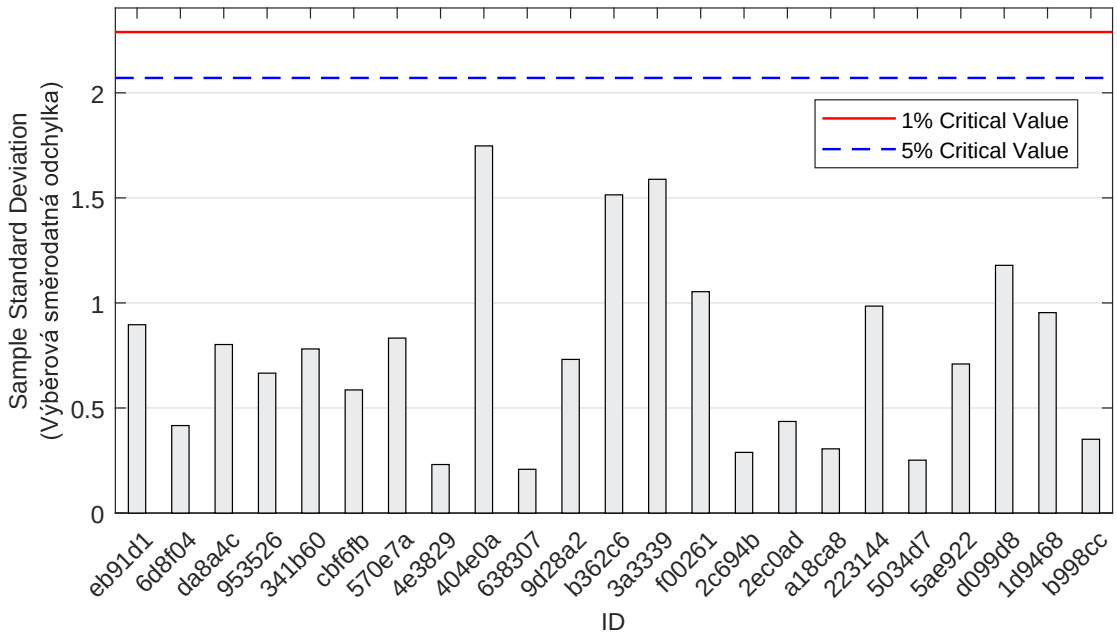

Figure 1: **Cochran's test** - sample standard deviations: 1% critical value - red color; 5% critical value - blue color

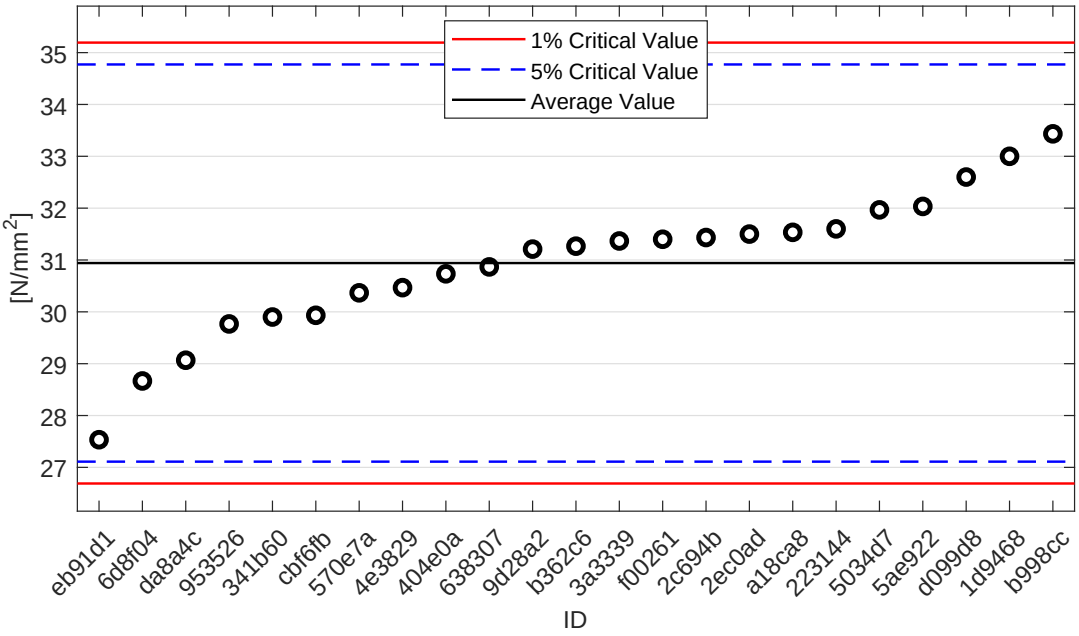

Figure 2: **Grubbs' test** - average values: 1% critical value - red color; 5% critical value - blue color

1.3 Mandel's Statistics

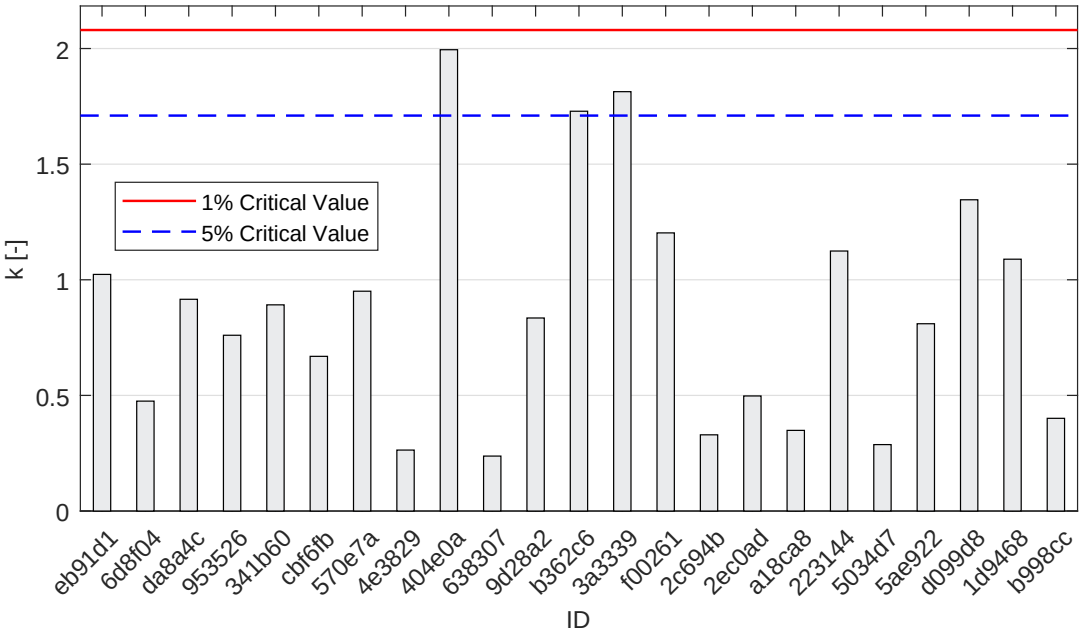

Figure 3: Intralaboratory Consistency Statistic k: 1% critical value - red color; 5% critical value - blue color

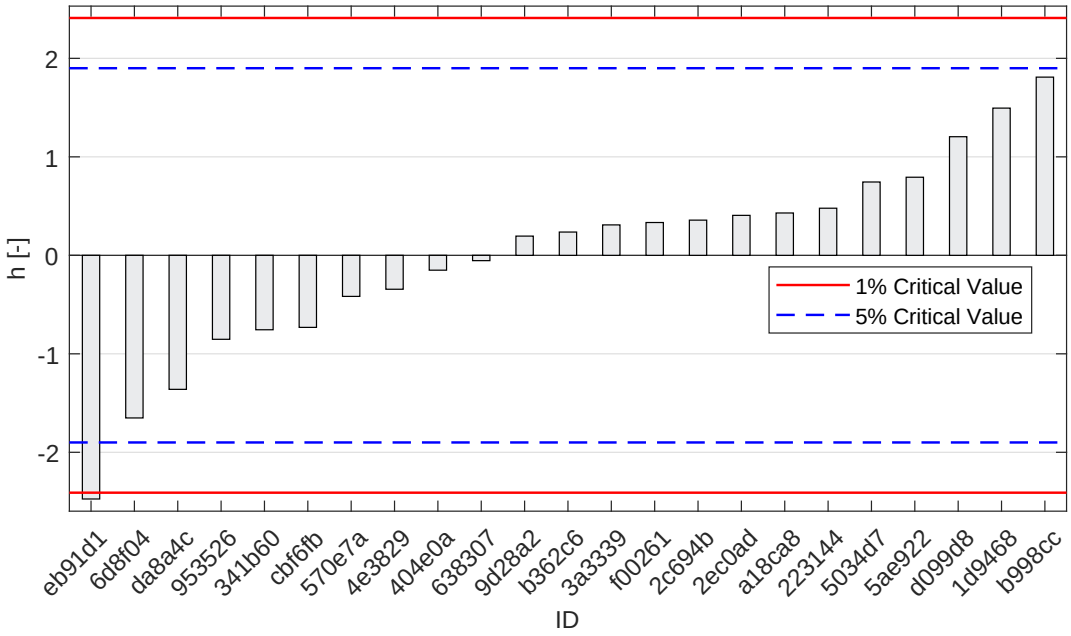

Figure 4: Interlaboratory Consistency Statistic h: 1% critical value - red color; 5% critical value - blue color

1.4 Calculation of Performance Statistics

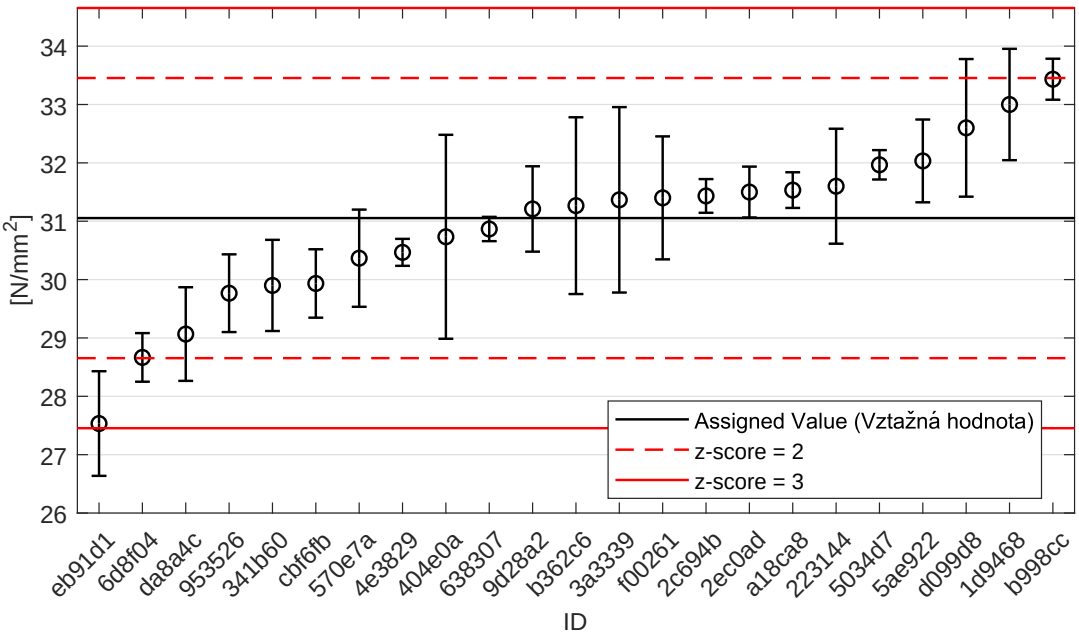

Figure 5: Average values and sample standard deviations

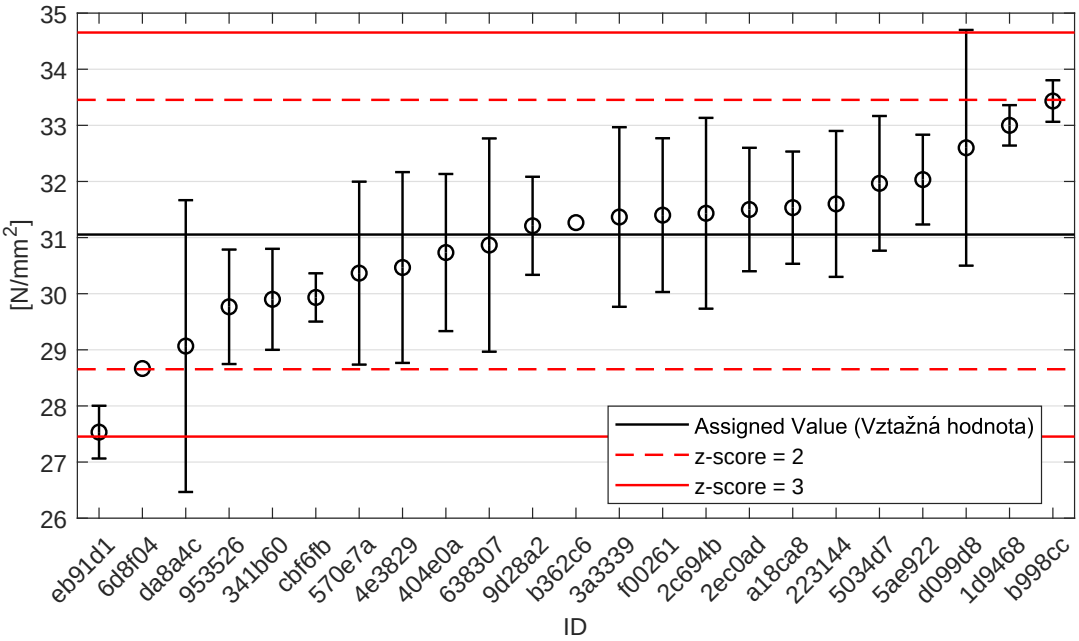

Figure 6: Average values and extended uncertainties of measurement

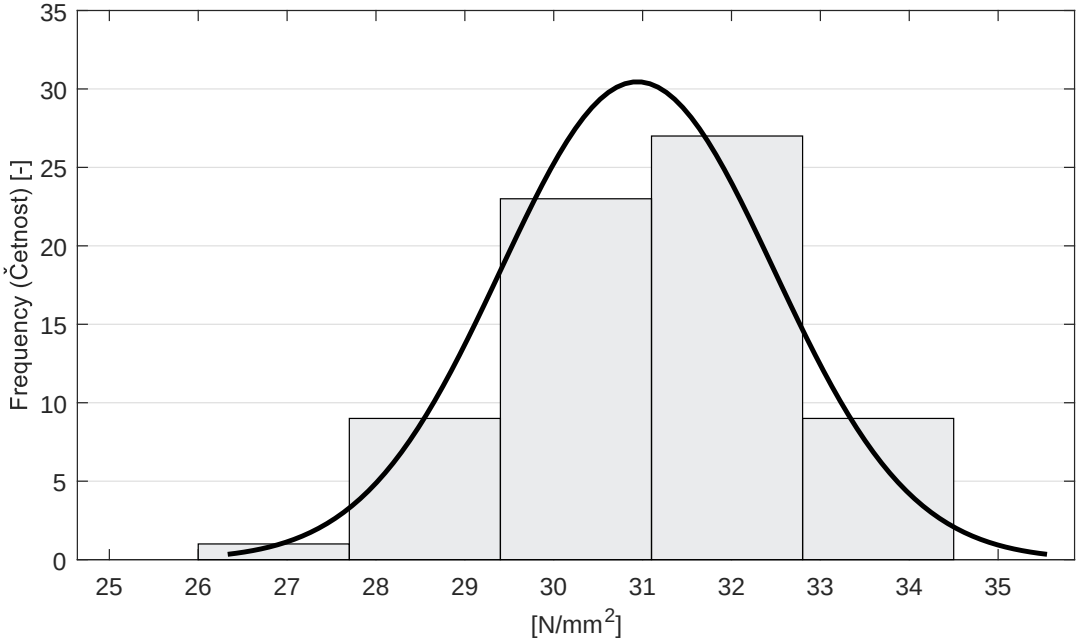

Figure 7: Histogram of all test results

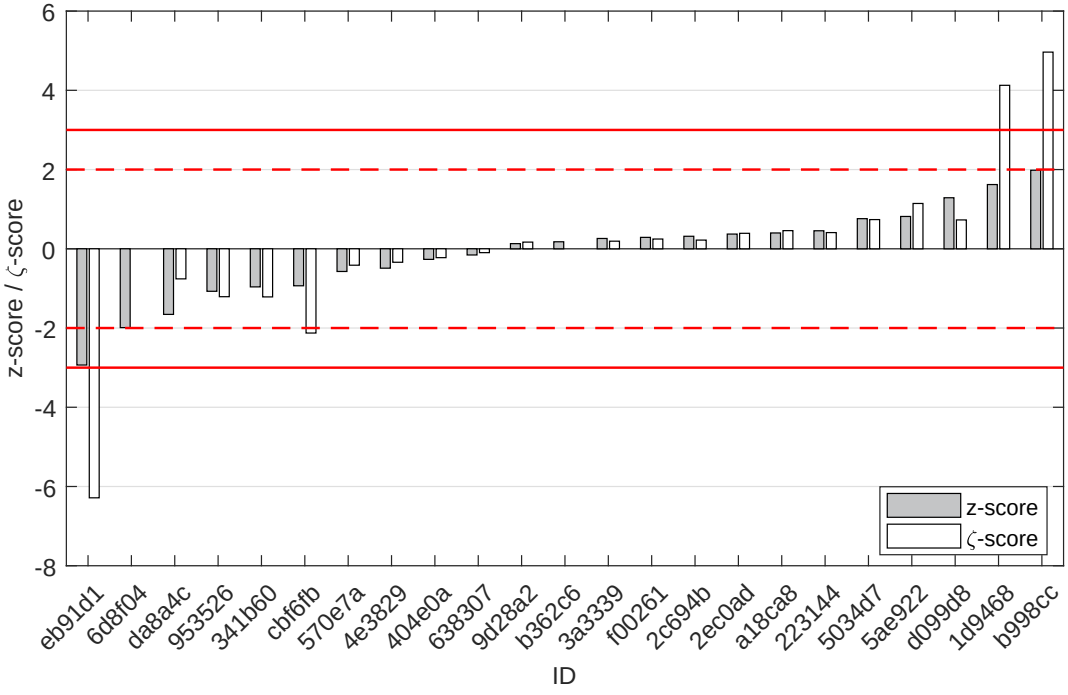

Figure 8: z-score and ζ-score

Table 4: z-score and ζ-score

ID	z-score [-]	ζ-score [-]
eb91d1	-2.93	-6.29
6d8f04	-1.99	-
da8a4c	-1.66	-0.76
953526	-1.07	-1.21
341b60	-0.96	-1.21
cbf6fb	-0.93	-2.13
570e7a	-0.57	-0.41
4e3829	-0.49	-0.34
404e0a	-0.27	-0.22
638307	-0.16	-0.10
9d28a2	0.13	0.17
b362c6	0.18	-
3a3339	0.26	0.19
f00261	0.29	0.25
2c694b	0.32	0.22
2ec0ad	0.37	0.39
a18ca8	0.40	0.46
223144	0.46	0.41
5034d7	0.76	0.74
5ae922	0.82	1.14
d099d8	1.29	0.73
1d9468	1.62	4.13
b998cc	1.98	4.96

2 Appendix – EN 12390-5 – Flexural strength of test specimens

2.1 Test results

Table 5: Test results - ordered by average value. Outliers are marked by star. u_X - extended uncertainty of measurement; $\bar{x}$ - average value; s_0 - sample standard deviation; V_X - variation coefficient

ID of participant	Test results [N/mm^2]			u_X [N/mm^2]	$\bar{x}$ [N/mm^2]	s_0 [N/mm^2]	V_X [%]
3c45a1	4.3	4.6	4.7	0.1	4.5	0.2	3.86
2c694b	4.4	4.3	5.0	1.2	4.6	0.4	8.29
f00261	4.5	4.7	4.6	0.1	4.6	0.1	1.85
e48ade	4.9	5.0	4.8	0.3	4.9	0.1	2.04
638307	4.9	5.1	5.3	0.3	5.1	0.2	3.92
6d8f04	5.0	5.0	5.3	-	5.1	0.2	3.40
3a3339	5.1	5.4	5.5	0.2	5.3	0.2	3.90
570e7a	5.9	6.0	5.5	0.7	5.8	0.3	4.40
065959	6.7*	5.3	5.7	1.9	5.9	0.7	12.22
f56fc9	6.0	6.2	6.2	0.3	6.1	0.1	1.88
404e0a	6.8	6.1	6.3	0.1	6.4	0.4	5.63
47a8df	8.3	8.2	8.4	0.3	8.3	0.1	1.20

2.2 The Numerical Procedure for Determining Outliers

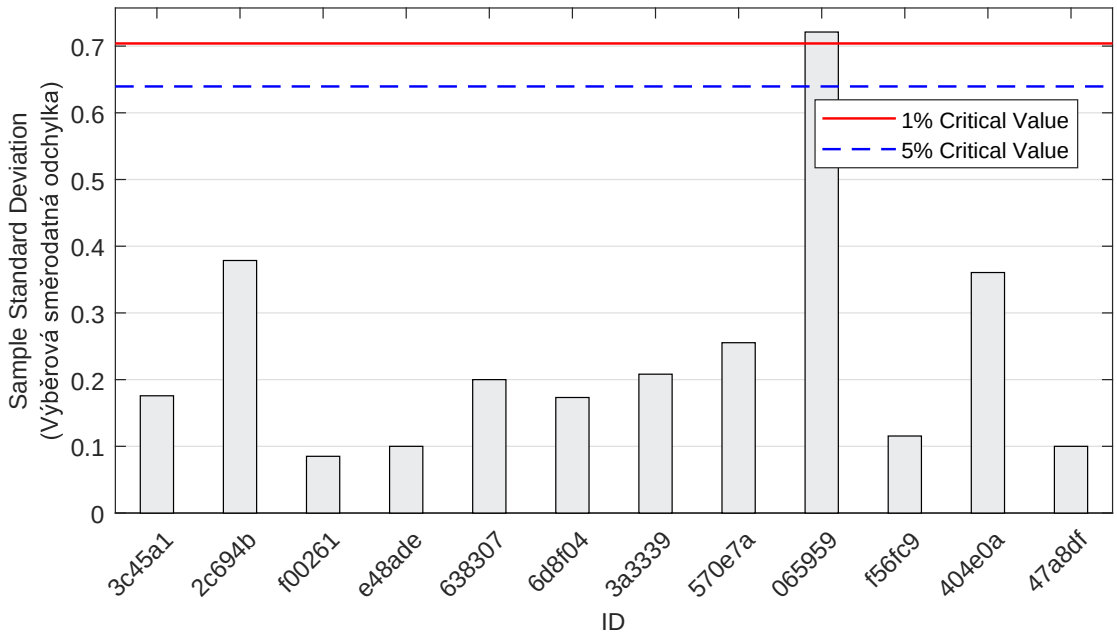

Figure 9: **Cochran's test** - sample standard deviations: 1% critical value - red color; 5% critical value - blue color

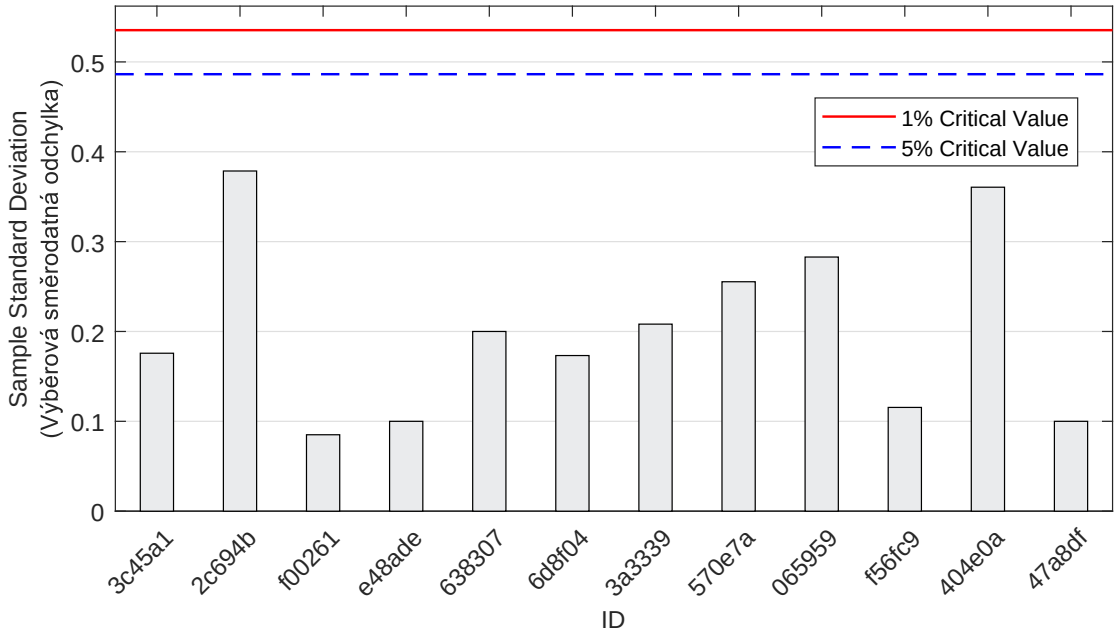

Figure 10: **Cochran's test** - sample standard deviations without outliers: 1% critical value - red color; 5% critical value - blue color

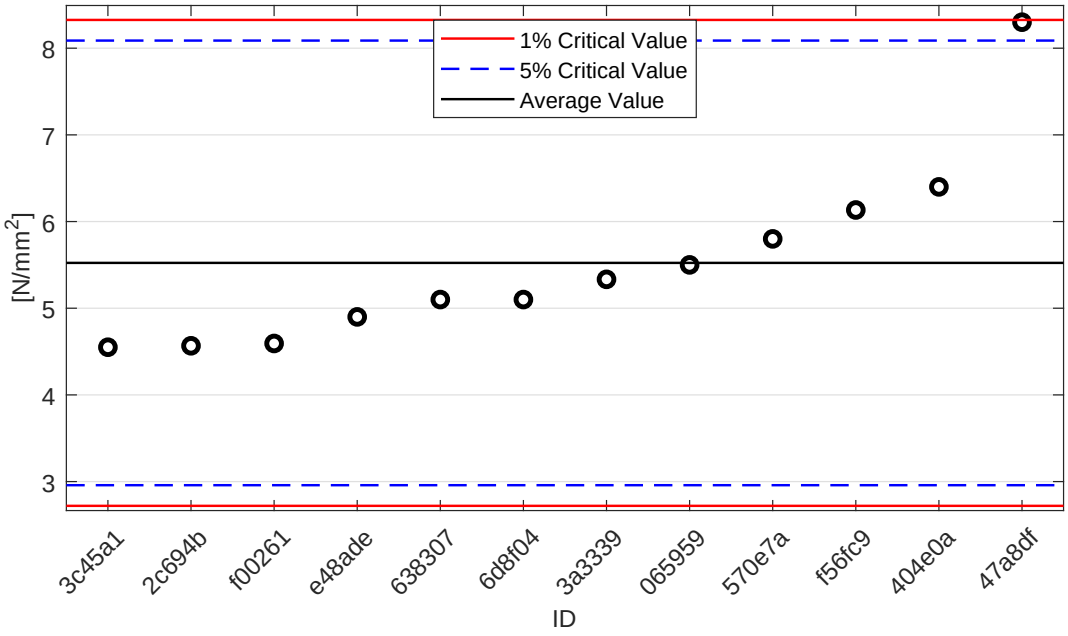

Figure 11: **Grubbs' test** - average values: 1% critical value - red color; 5% critical value - blue color

2.3 Mandel's Statistics

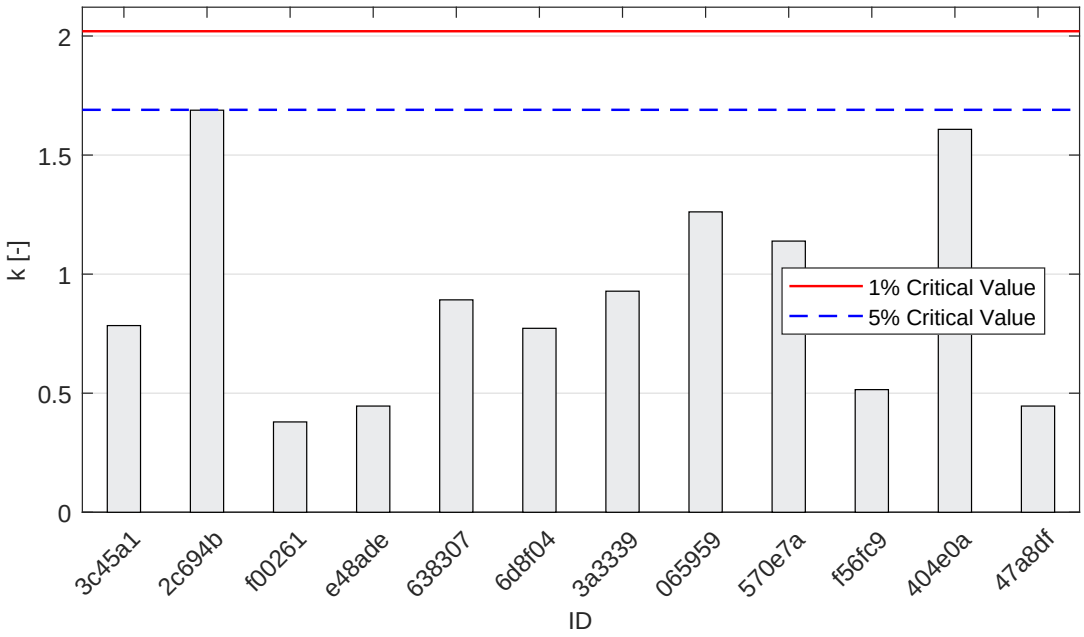

Figure 12: Intralaboratory Consistency Statistic k: 1% critical value - red color; 5% critical value - blue color

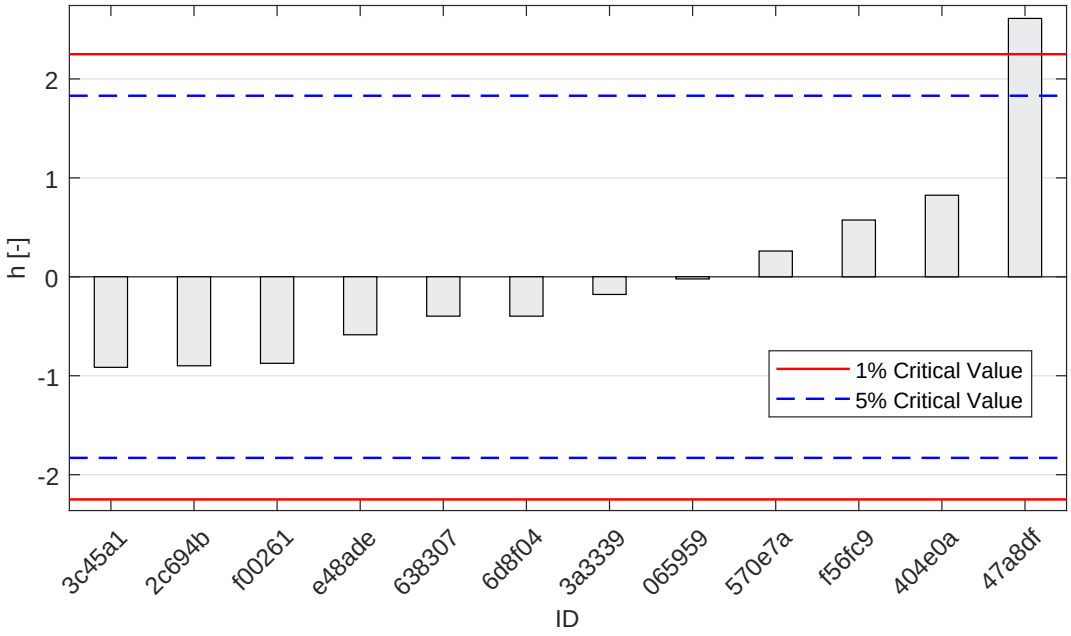

Figure 13: Interlaboratory Consistency Statistic *h*: 1% critical value - red color; 5% critical value - blue color

2.4 Calculation of Performance Statistics

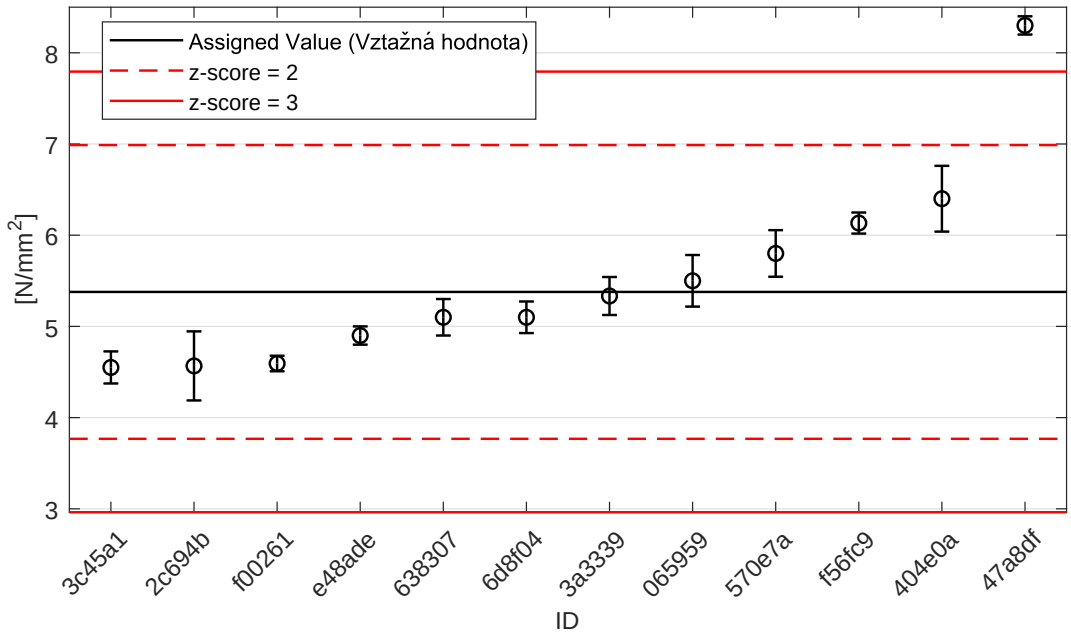

Figure 14: Average values and sample standard deviations

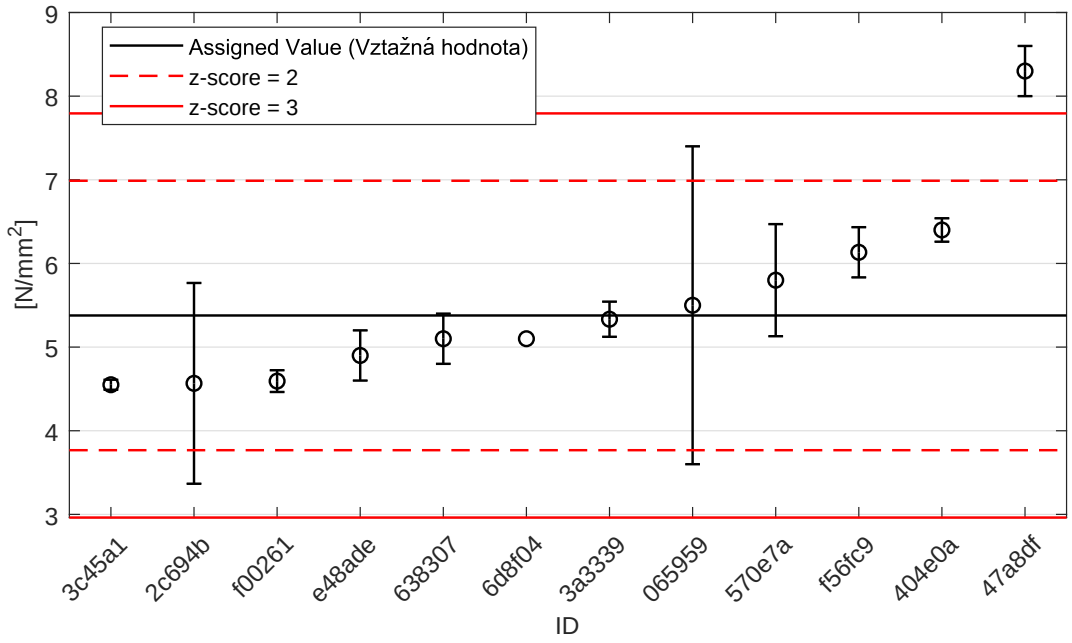

Figure 15: Average values and extended uncertainties of measurement

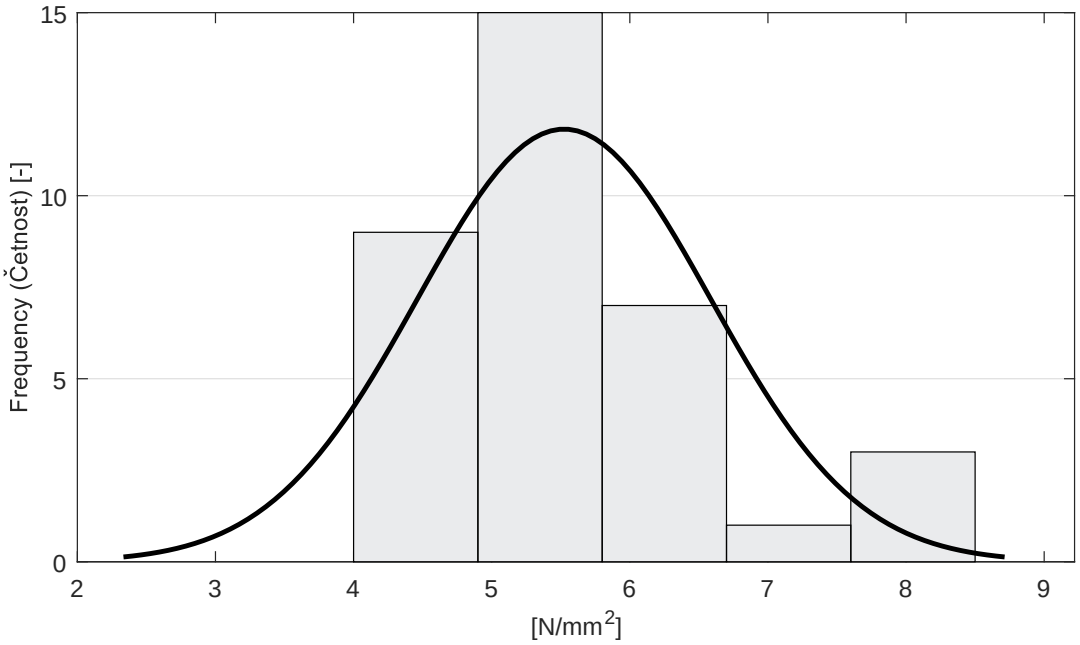

Figure 16: Histogram of all test results

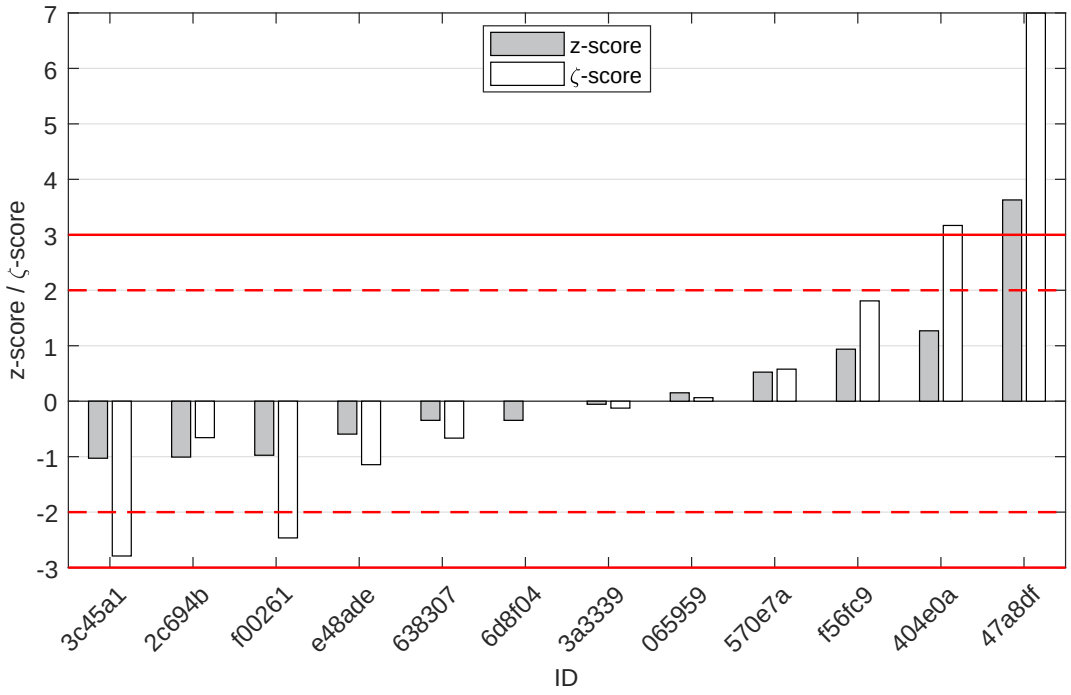

Figure 17: z-score and ζ-score

Table 6: z-score and ζ-score

ID	z-score [-]	ζ-score [-]
3c45a1	-1.03	-2.79
2c694b	-1.01	-0.66
f00261	-0.97	-2.46
e48ade	-0.59	-1.14
638307	-0.35	-0.67
6d8f04	-0.35	-
3a3339	-0.06	-0.12
065959	0.15	0.06
570e7a	0.52	0.58
f56fc9	0.94	1.81
404e0a	1.27	3.17
47a8df	3.63	7.00

3 Appendix – EN 12390-6 – Tensile splitting strength of test specimens

3.1 Test results

Table 7: Test results - ordered by average value. Outliers are marked by star. u_X - extended uncertainty of measurement; $\bar{x}$ - average value; s_0 - sample standard deviation; V_X - variation coefficient

ID of participant	Test results [N/mm^2]			u_X [N/mm^2]	$\bar{x}$ [N/mm^2]	s_0 [N/mm^2]	V_X [%]
f00261	3.12	2.68	2.84	0.15	2.88	0.22	7.73
570e7a	3.15	3.05	2.95	0.19	3.05	0.10	3.28
6d8f04	3.20	3.25	3.30	-	3.25	0.05	1.54
47a8df	3.25	3.35	3.15	0.20	3.25	0.10	3.08
4e3829	3.24	3.46	3.21	0.15	3.30	0.14	4.13
3a3339	3.55	3.10	3.45	0.24	3.37	0.24	7.02

3.2 The Numerical Procedure for Determining Outliers

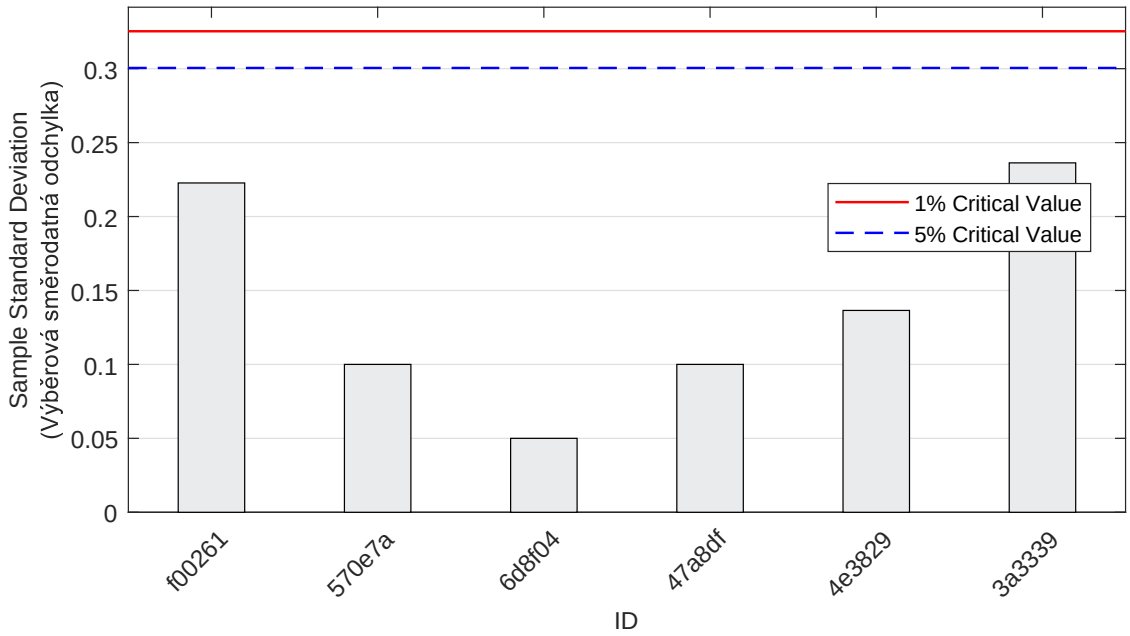

Figure 18: **Cochran's test** - sample standard deviations: 1% critical value - red color; 5% critical value - blue color

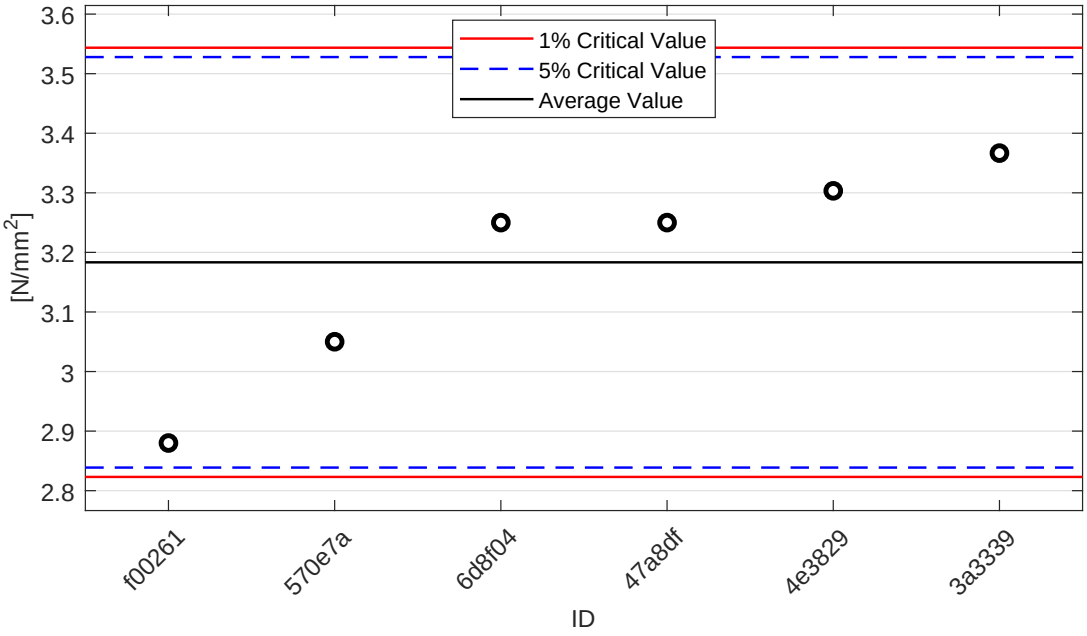

Figure 19: **Grubbs' test** - average values: 1% critical value - red color; 5% critical value - blue color

3.3 Mandel's Statistics

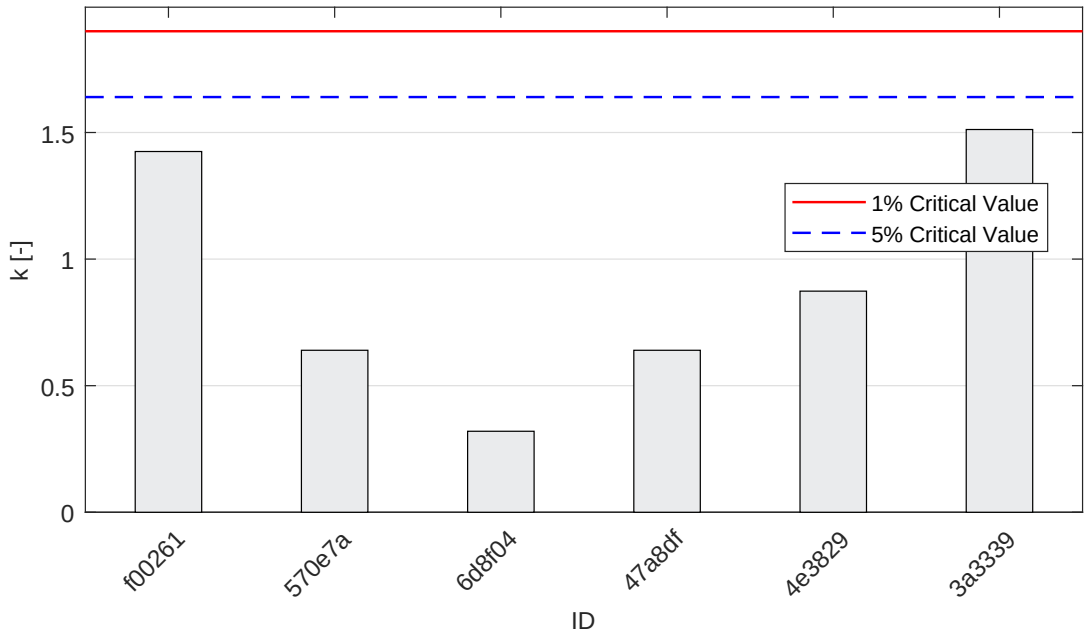

Figure 20: Intralaboratory Consistency Statistic k: 1% critical value - red color; 5% critical value - blue color

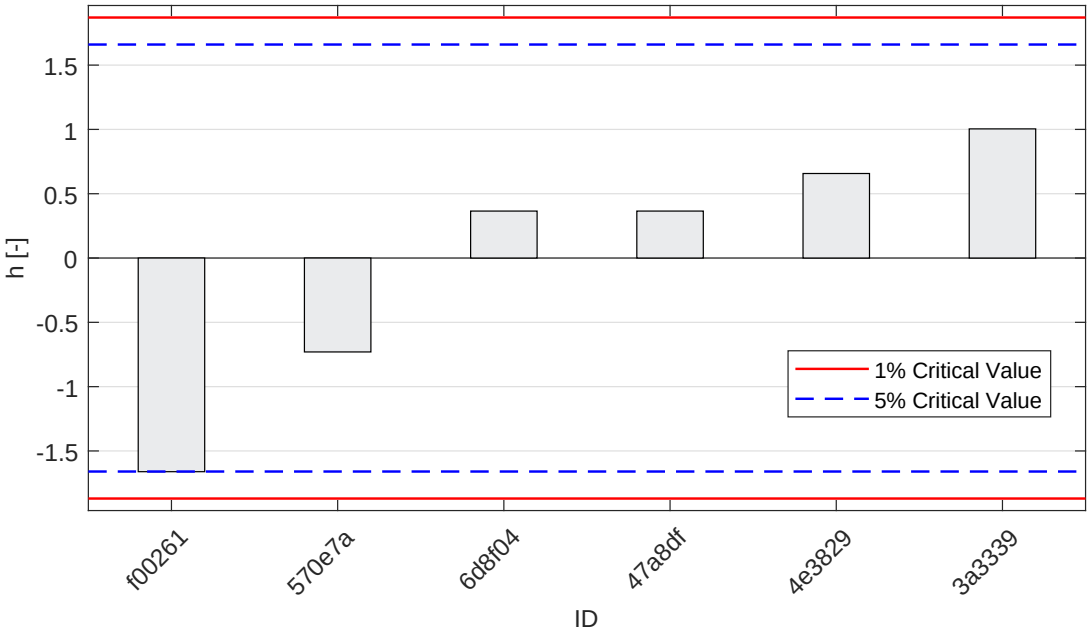

Figure 21: Interlaboratory Consistency Statistic *h*: 1% critical value - red color; 5% critical value - blue color

3.4 Calculation of Performance Statistics

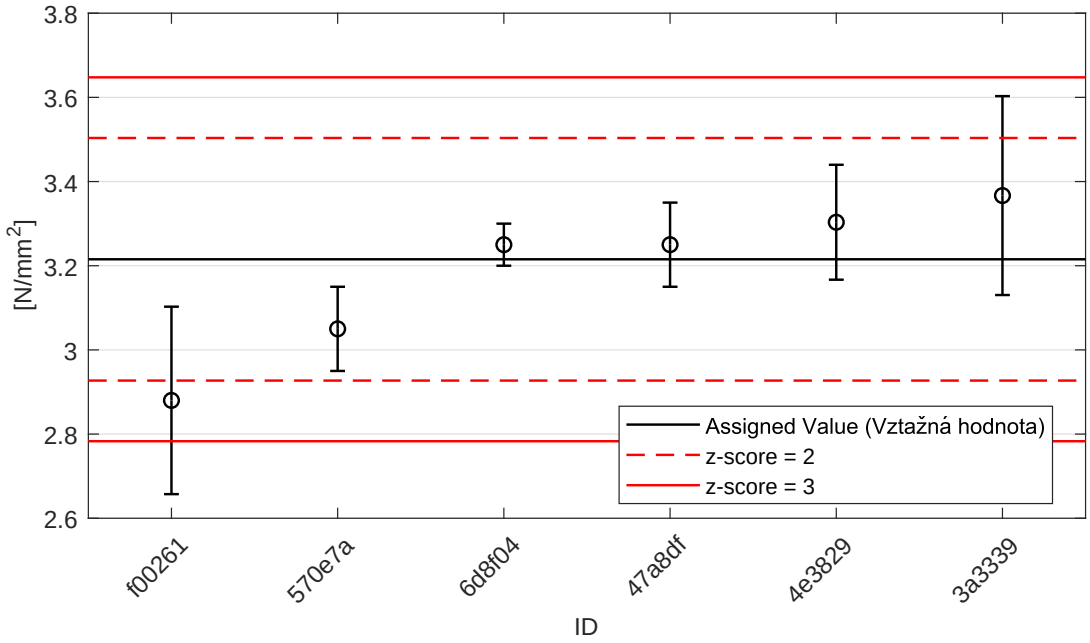

Figure 22: Average values and sample standard deviations

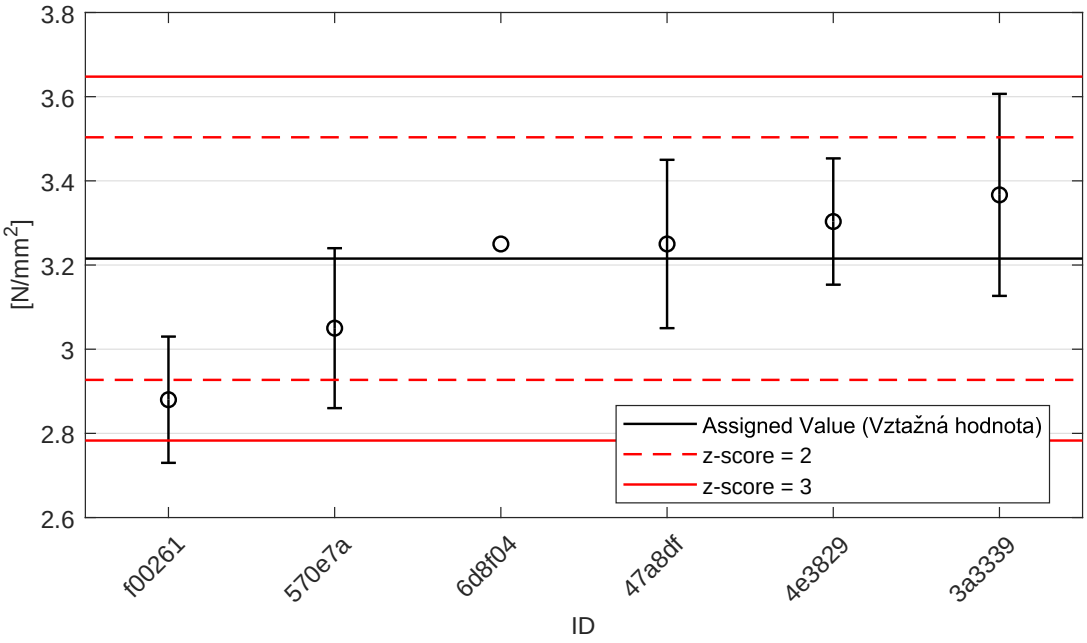

Figure 23: Average values and extended uncertainties of measurement

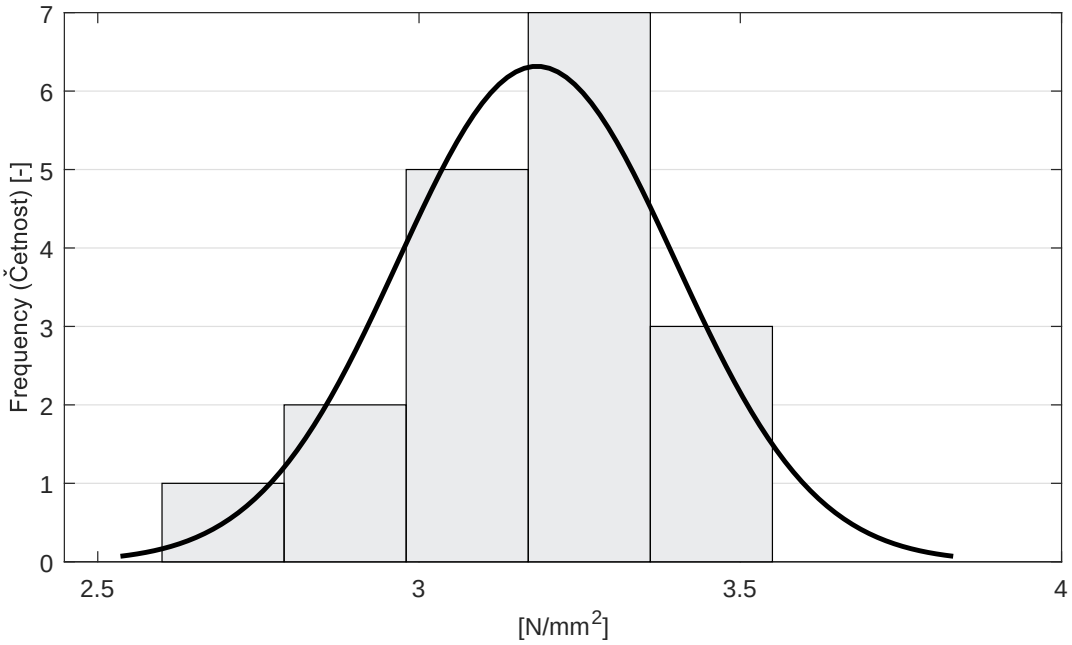

Figure 24: Histogram of all test results

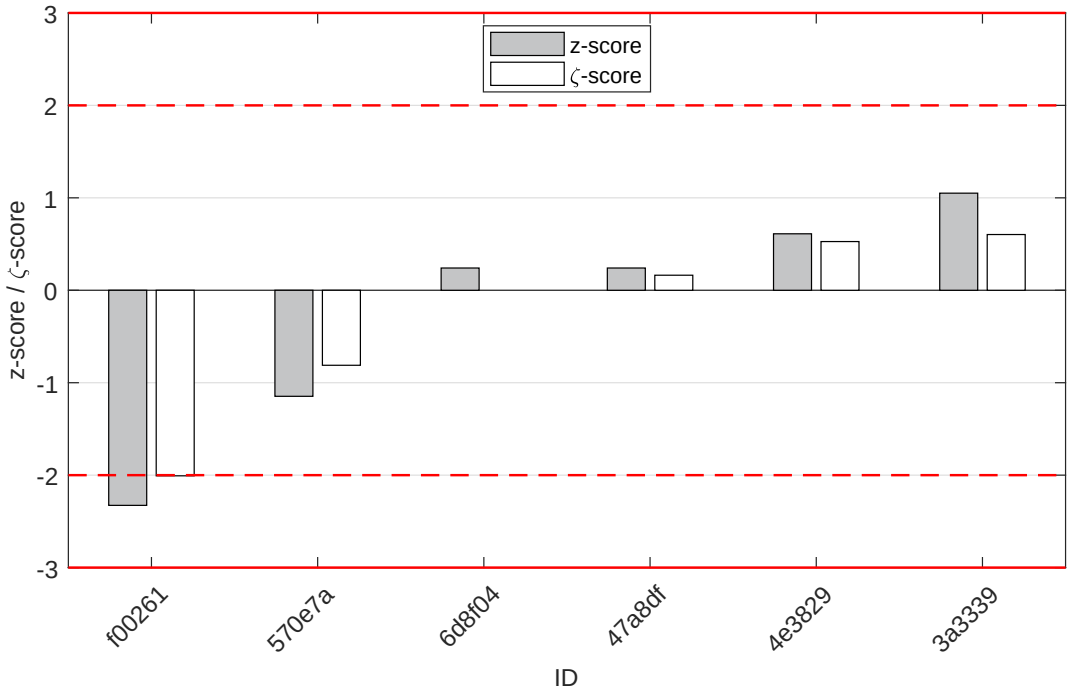

Figure 25: z-score and ζ-score

Table 8: z-score and ζ-score

ID	z-score [-]	ζ-score [-]
f00261	-2.33	-2.01
570e7a	-1.15	-0.81
6d8f04	0.24	-
47a8df	0.24	0.16
4e3829	0.61	0.53
3a3339	1.05	0.60

4 Appendix – EN 12390-7 – Density of hardened concrete

4.1 Test results

Table 9: Test results - ordered by average value. Outliers are marked by star. u_X - extended uncertainty of measurement; $\bar{x}$ - average value; s_0 - sample standard deviation; V_X - variation coefficient

ID	Test results			u_X	$\bar{x}$	s_0	V_X
of participant	[kg/m^3]			[kg/m^3]	[kg/m^3]	[kg/m^3]	[%]
341b60	2264	2275	2275	7	2271	6	0.28
2c694b	2270	2270	2280	20	2273	6	0.25
404e0a	2280	2290	2270	8	2280	10	0.44
223144	2280	2280	2290	10	2283	6	0.25
570e7a	2290	2270	2290	10	2283	12	0.51
4e3829	2290	2270	2290	10	2283	12	0.51
6d8f04	2290	2280	2290	-	2287	6	0.25
eb91d1	2274	2289	2301	32	2288	14	0.59
638307	2300	2280	2290	10	2290	10	0.44
360089	2300	2290	2290	100	2293	6	0.25
cbf6fb	2310	2300	2300	4	2303	6	0.25
5ae922	2310	2300	2310	32	2307	6	0.25
2ec0ad	2310	2300	2310	11	2307	6	0.25
1d9468	2320	2300	2310	23	2310	10	0.43
b998cc	2290	2320	2320	23	2310	17	0.75
a18ca8	2320	2300	2320	32	2313	12	0.50
d099d8	2330	2330	2320	40	2327	6	0.25

4.2 The Numerical Procedure for Determining Outliers

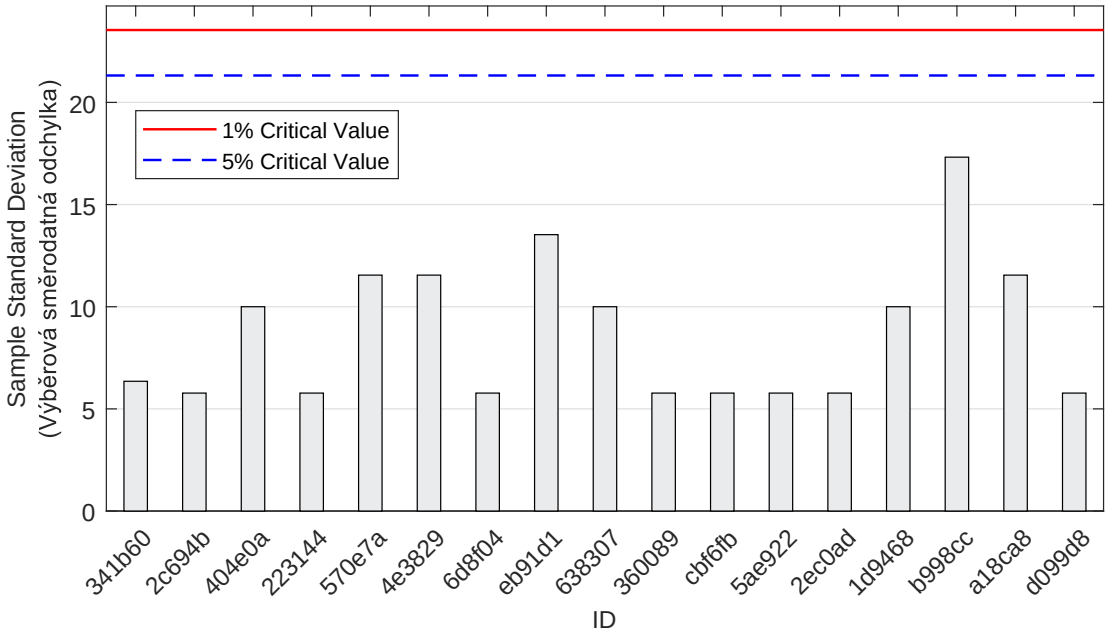

Figure 26: **Cochran's test** - sample standard deviations: 1% critical value - red color; 5% critical value - blue color

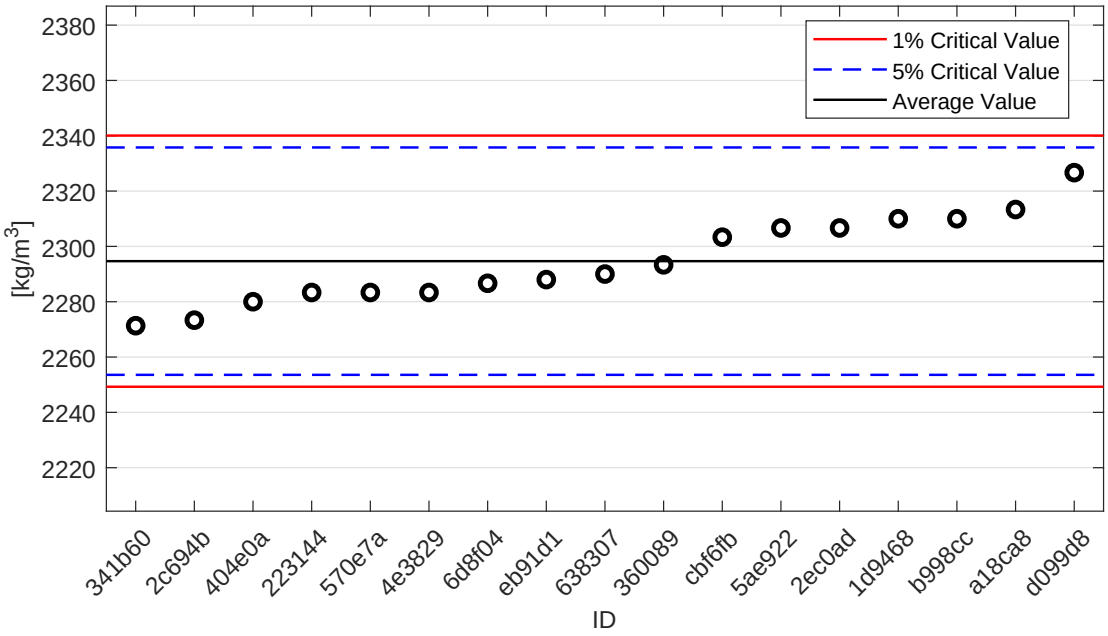

Figure 27: **Grubbs' test** - average values: 1% critical value - red color; 5% critical value - blue color

4.3 Mandel's Statistics

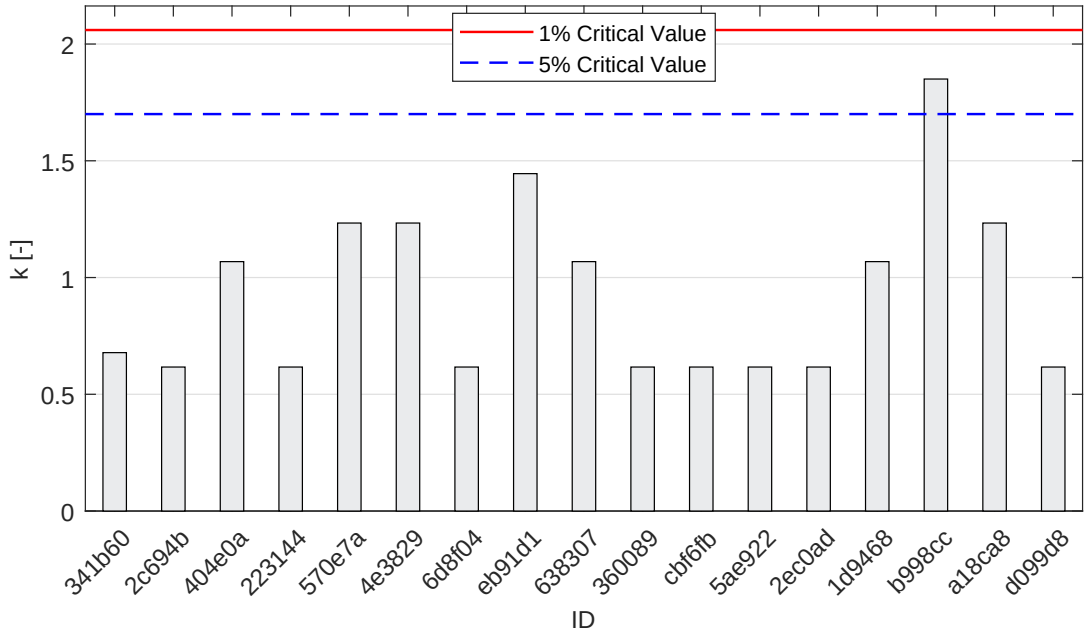

Figure 28: Intralaboratory Consistency Statistic k: 1% critical value - red color; 5% critical value - blue color

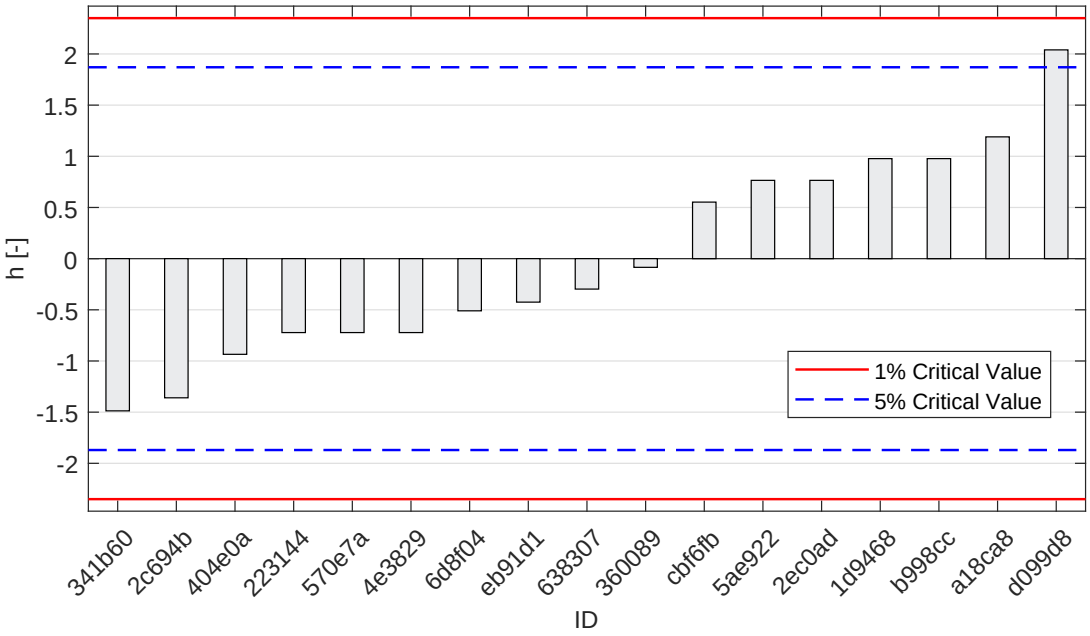

Figure 29: Interlaboratory Consistency Statistic h: 1% critical value - red color; 5% critical value - blue color

4.4 Calculation of Performance Statistics

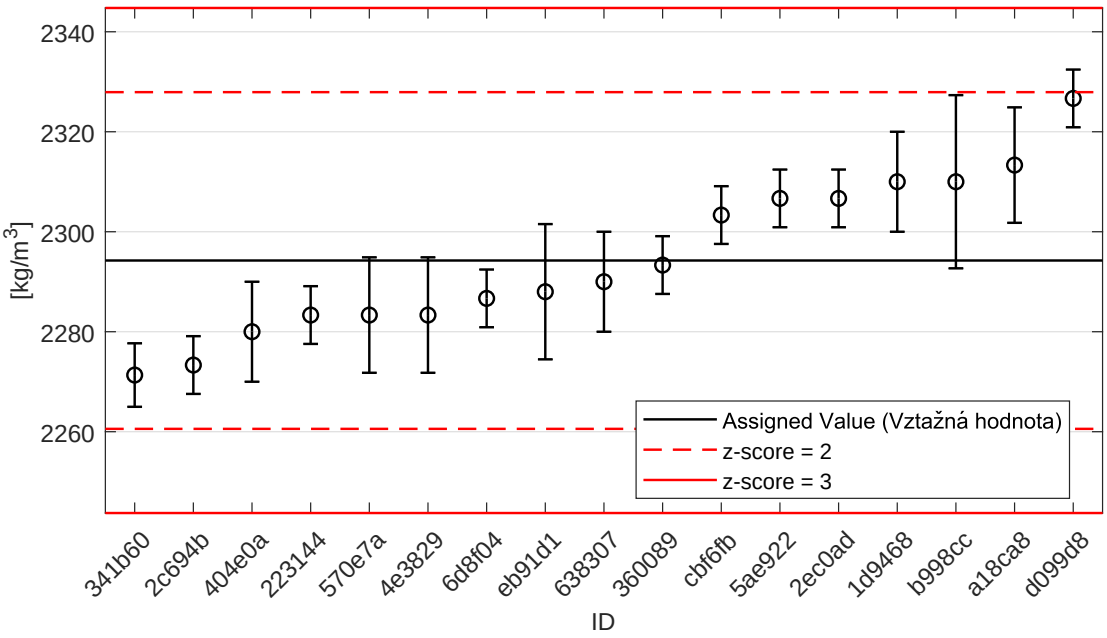

Figure 30: Average values and sample standard deviations

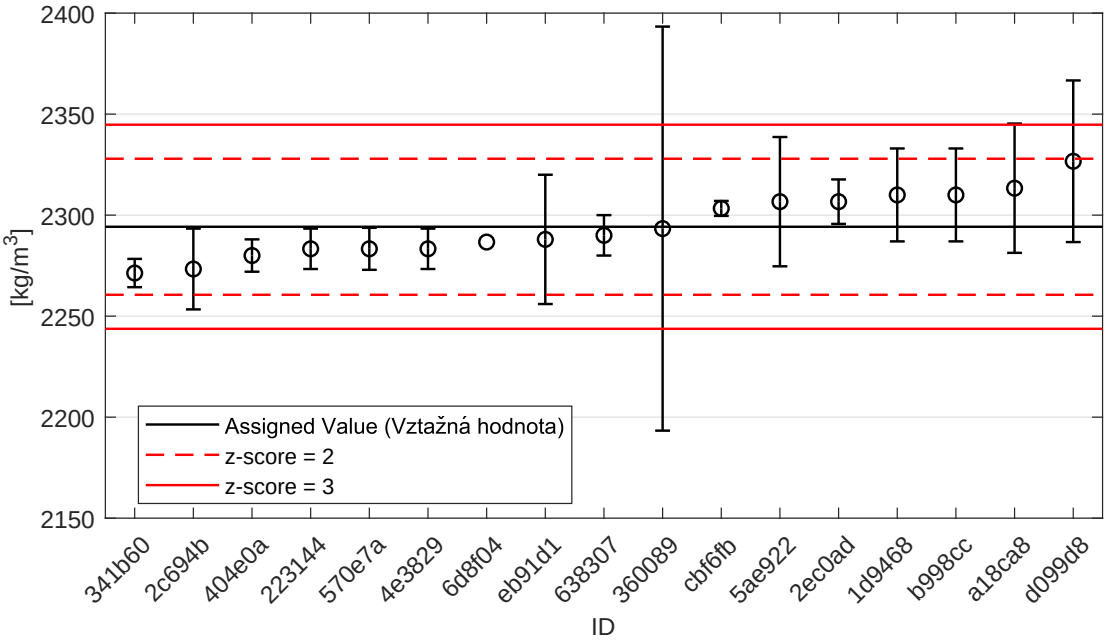

Figure 31: Average values and extended uncertainties of measurement

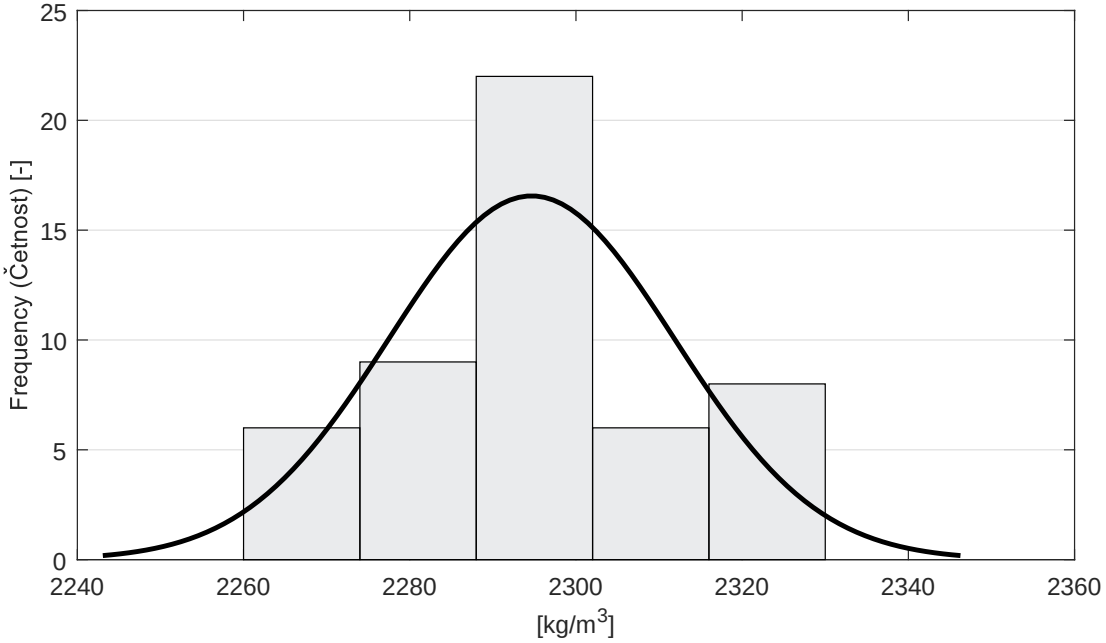

Figure 32: Histogram of all test results

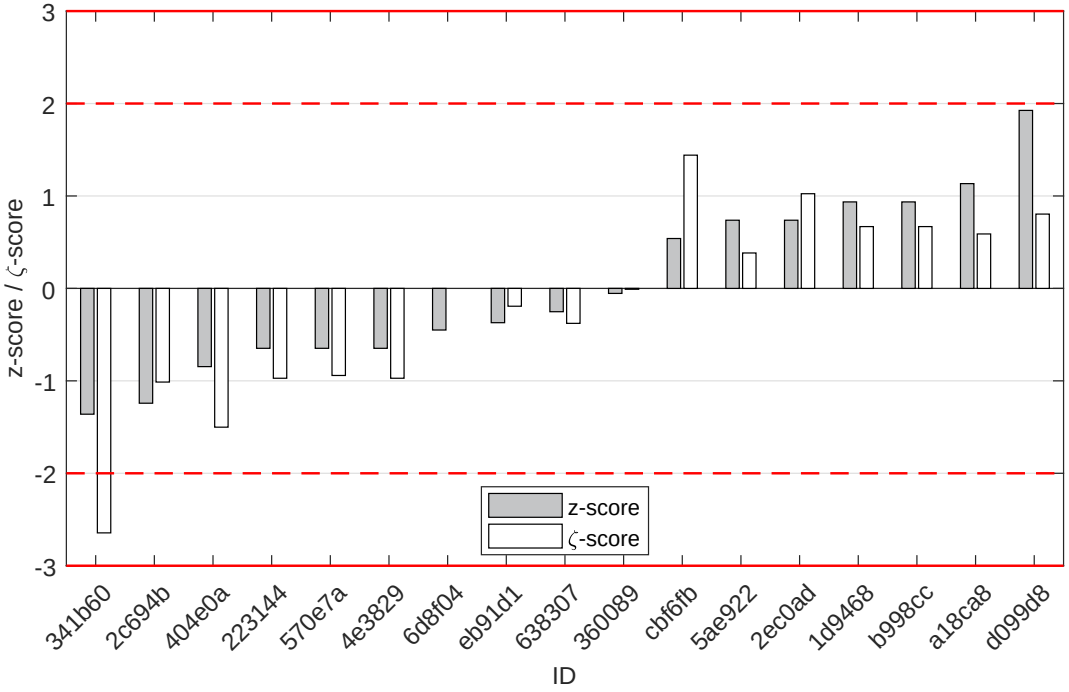

Figure 33: z-score and ζ-score

Table 10: z-score and ζ-score

ID	z-score [-]	ζ-score [-]
341b60	-1.36	-2.64
2c694b	-1.24	-1.01
404e0a	-0.85	-1.50
223144	-0.65	-0.97
570e7a	-0.65	-0.94
4e3829	-0.65	-0.97
6d8f04	-0.45	-
eb91d1	-0.37	-0.19
638307	-0.25	-0.38
360089	-0.05	-0.01
cbf6fb	0.54	1.44
5ae922	0.74	0.38
2ec0ad	0.74	1.02
1d9468	0.94	0.67
b998cc	0.94	0.67
a18ca8	1.13	0.59
d099d8	1.93	0.80

5 Appendix – ISO 1920-10 – Determination of static modulus of elasticity in compression

This part of PT program was not open due to low number of participants.

6 Appendix – EN 12390-13, method A – Determination of secant modulus of elasticity in compression

This part of PT program was not open due to low number of participants.

7 Appendix – EN 12390-13, method B – Determination of secant modulus of elasticity in compression

This part of PT program was not open due to low number of participants.

8 Appendix – EN 12504-4, ČSN 731371 – Non-destructive testing of concrete

This part of PT program was not open due to low number of participants.

9 Appendix – ČSN 731373, EN 12504-2 – Determination of rebound number

9.1 Test results

Table 11: Test results - ordered by average value. Outliers are marked by star. u_X - extended uncertainty of measurement; $\bar{x}$ - average value; s_0 - sample standard deviation; V_X - variation coefficient

ID of participant	Test results [-]			u_X [-]	$\bar{x}$ [-]	s_0 [-]	V_X [%]
570e7a	20	19	20	3	20	1	2.94
4e3829	31	29	30	2	30	1	3.33
223144	32	31	32	2	32	1	1.82
360089	34	34	35	5	34	1	1.68
b362c6	36	36	35	-	35	1	1.76
773e5d	35	35	39*	4	36	2	6.24

9.2 The Numerical Procedure for Determining Outliers

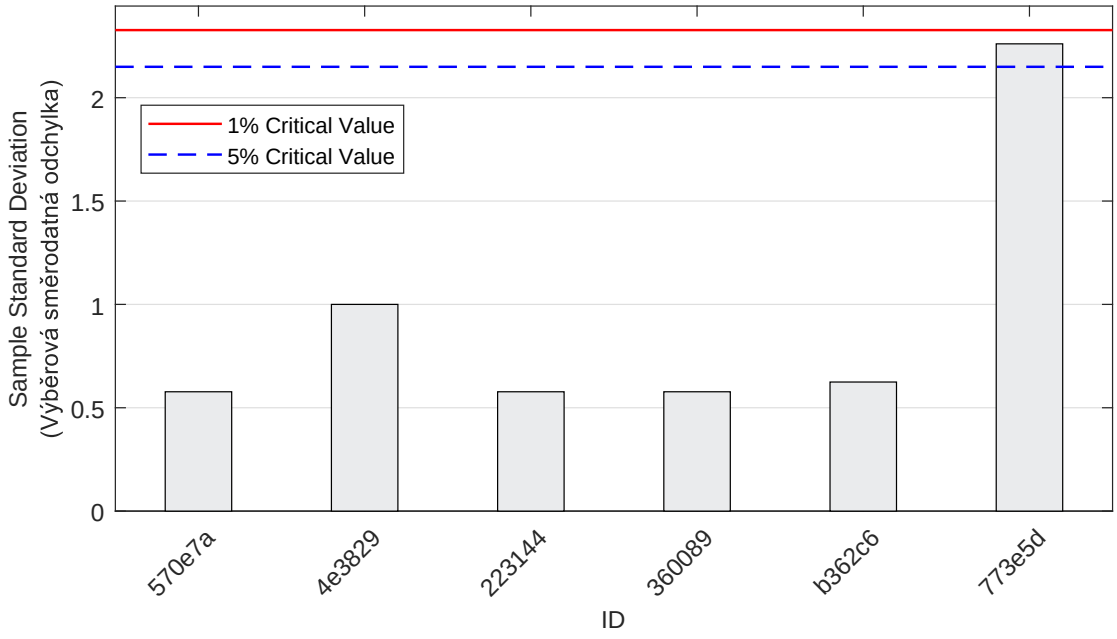

Figure 34: **Cochran's test** - sample standard deviations: 1% critical value - red color; 5% critical value - blue color

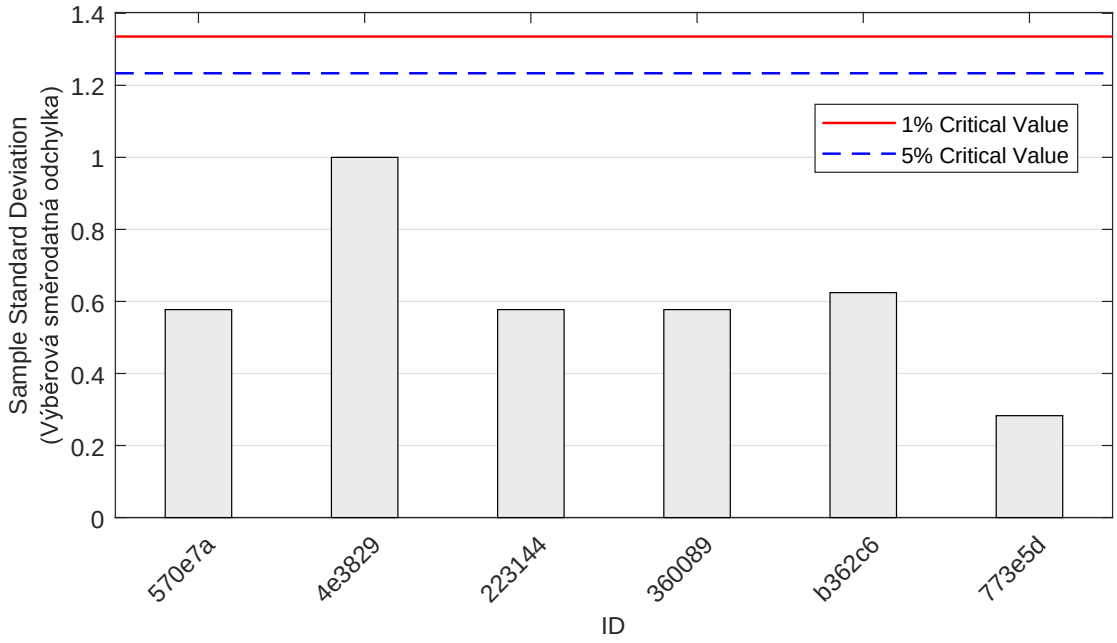

Figure 35: **Cochran's test** - sample standard deviations without outliers: 1% critical value - red color; 5% critical value - blue color

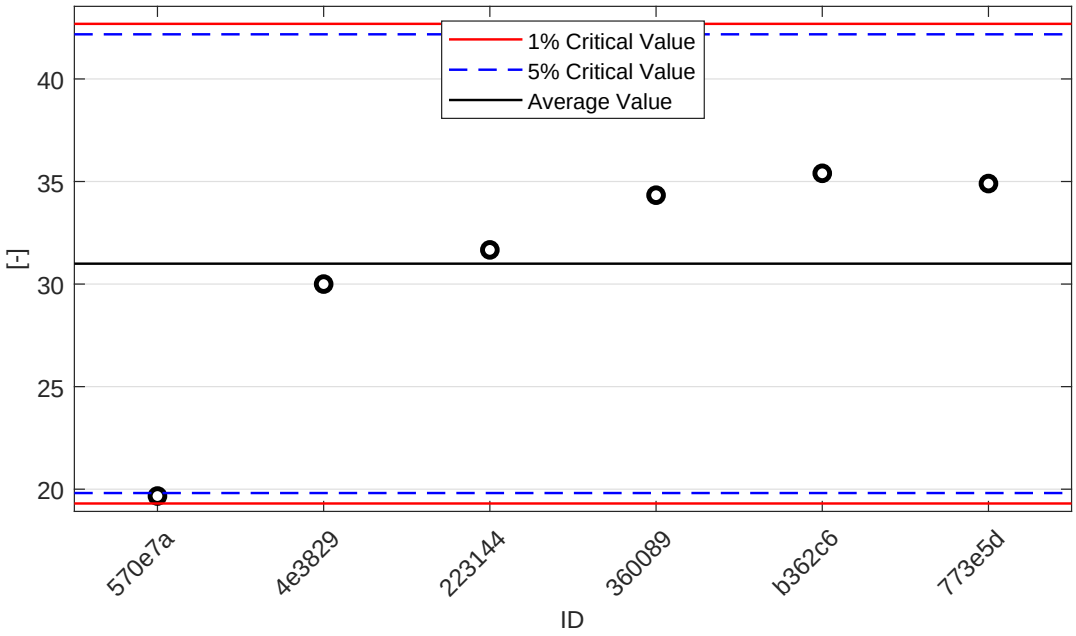

Figure 36: **Grubbs' test** - average values: 1% critical value - red color; 5% critical value - blue color

9.3 Mandel's Statistics

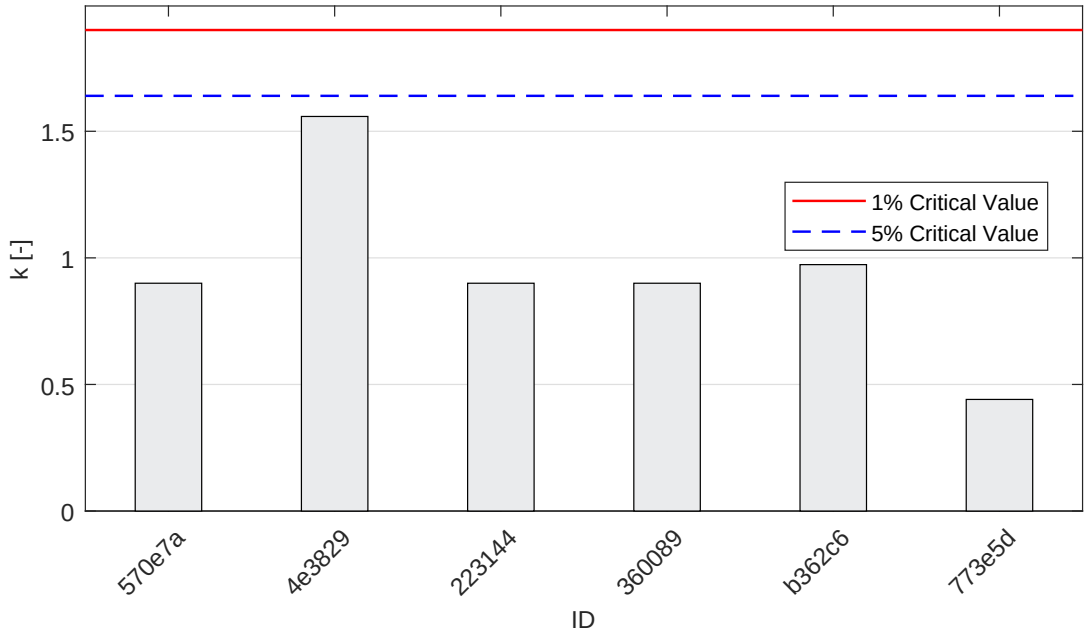

Figure 37: Intralaboratory Consistency Statistic k: 1% critical value - red color; 5% critical value - blue color

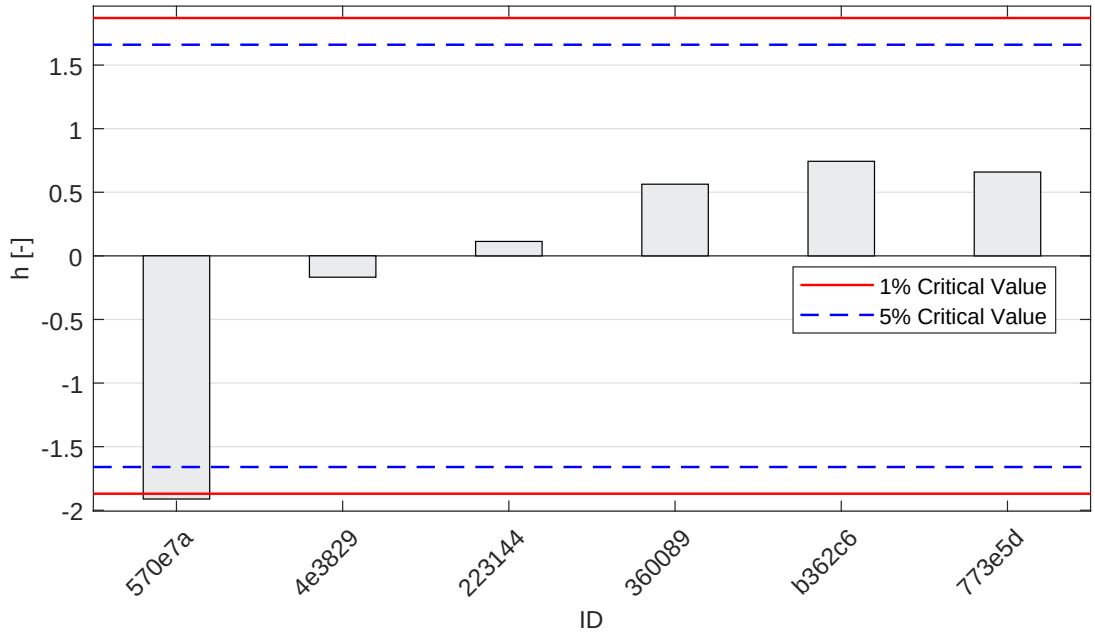

Figure 38: Interlaboratory Consistency Statistic h: 1% critical value - red color; 5% critical value - blue color

9.4 Calculation of Performance Statistics

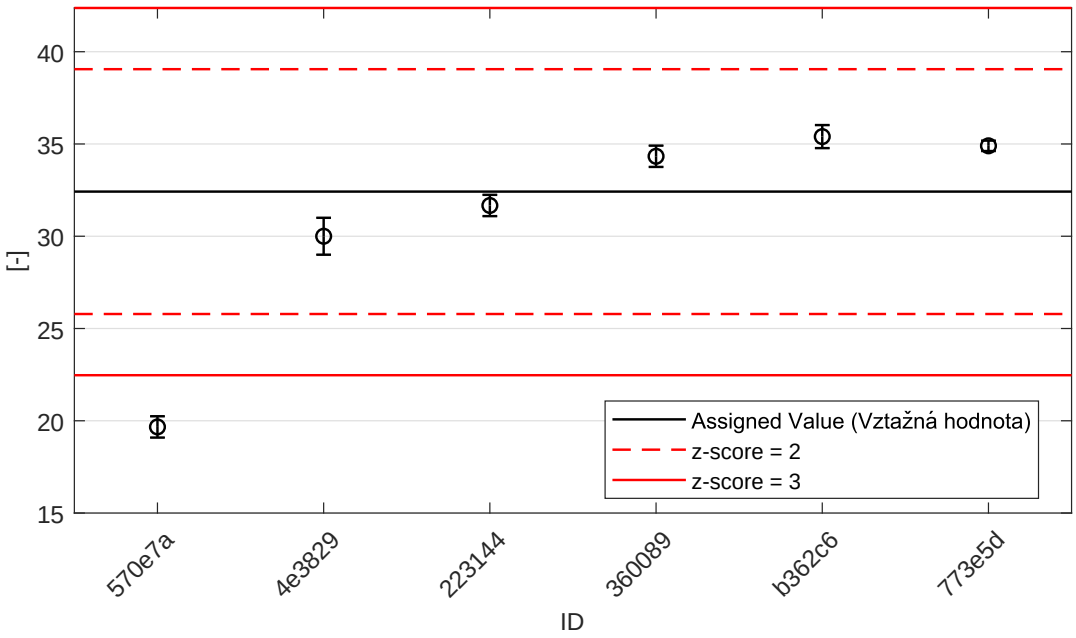

Figure 39: Average values and sample standard deviations

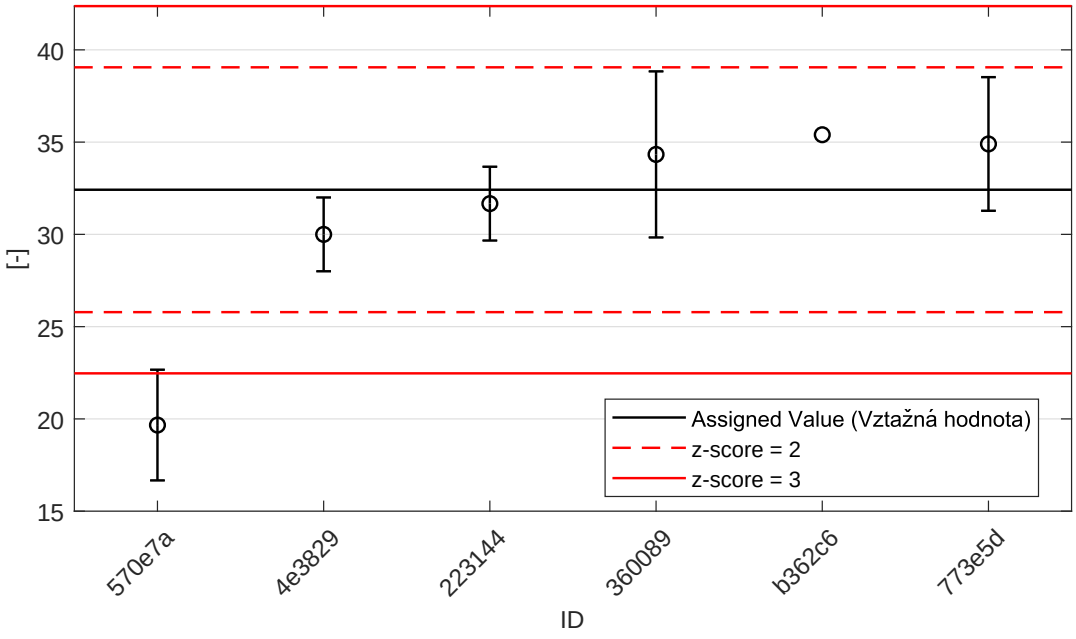

Figure 40: Average values and extended uncertainties of measurement

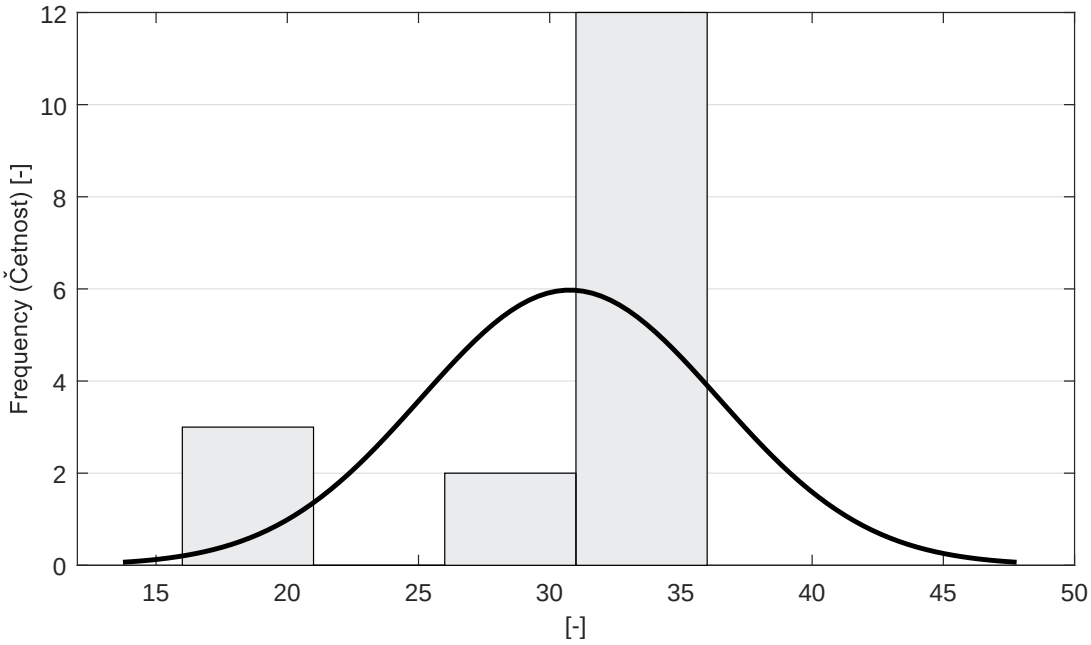

Figure 41: Histogram of all test results

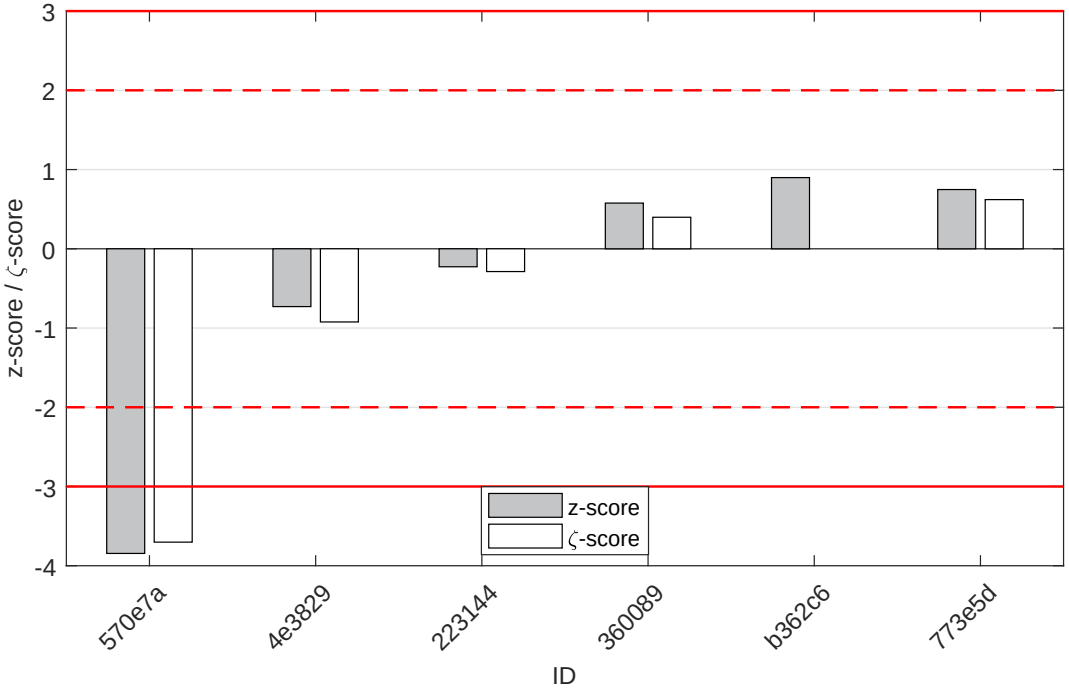

Figure 42: z-score and ζ-score

Table 12: z-score and ζ-score

ID	z-score [-]	ζ-score [-]
570e7a	-3.84	-3.70
4e3829	-0.73	-0.92
223144	-0.23	-0.29
360089	0.58	0.40
b362c6	0.90	-
773e5d	0.75	0.62

10 Appendix – EN 1542, ČSN 736242, Appendix B – Measurement of bond strength by pull-off

10.1 Test results

Table 13: Test results - ordered by average value. Outliers are marked by star. u_X - extended uncertainty of measurement; $\bar{x}$ - average value; s_0 - sample standard deviation; V_X - variation coefficient

ID of participant	Test results [N/mm^2]					u_X [N/mm^2]	$\bar{x}$ [N/mm^2]	s_0 [N/mm^2]	V_X [%]
570e7a	0.60	0.57	0.45	0.74	0.59	0.10	0.59	0.10	17.52
3c45a1	0.67	0.75	0.68	0.74	0.65	0.10	0.70	0.04	6.36
4e3829	0.92	0.25	0.64	0.99	0.89	0.11	0.74	0.30	41.07
cbf6fb	0.90	1.00	0.90	1.50	1.60	3.00	1.18	0.34	28.99
773e5d	1.39	1.24	1.32	1.00	2.05	0.21	1.40	0.39	28.00
2c694b	1.43	1.48	1.38	1.53	1.48	0.10	1.46	0.06	3.90

10.2 The Numerical Procedure for Determining Outliers

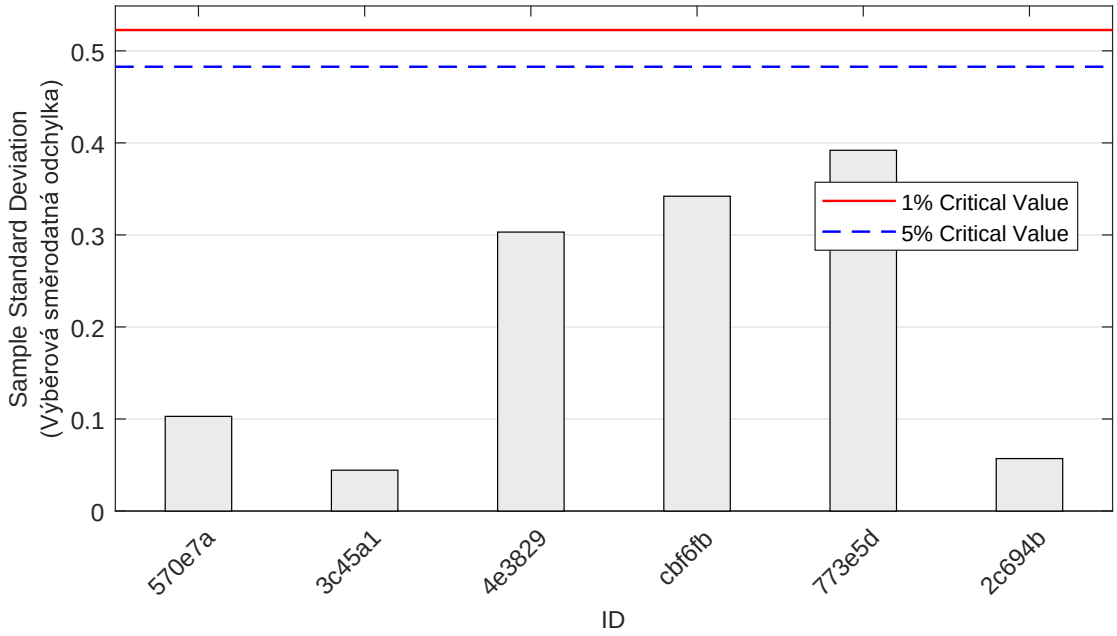

Figure 43: **Cochran's test** - sample standard deviations: 1% critical value - red color; 5% critical value - blue color

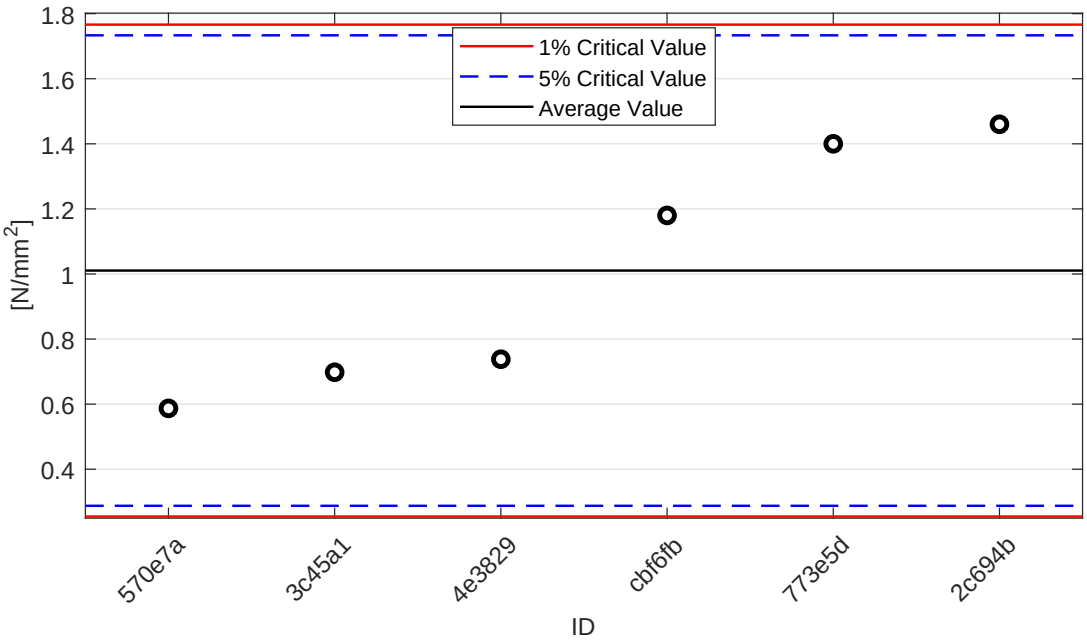

Figure 44: **Grubbs' test** - average values: 1% critical value - red color; 5% critical value - blue color

10.3 Mandel's Statistics

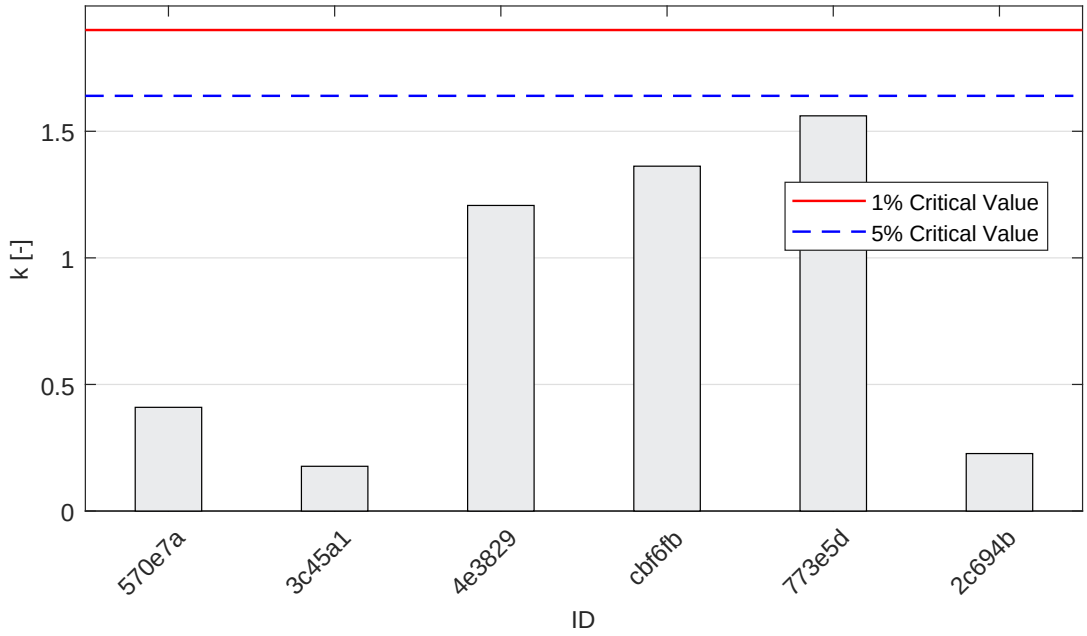

Figure 45: Intralaboratory Consistency Statistic k: 1% critical value - red color; 5% critical value - blue color

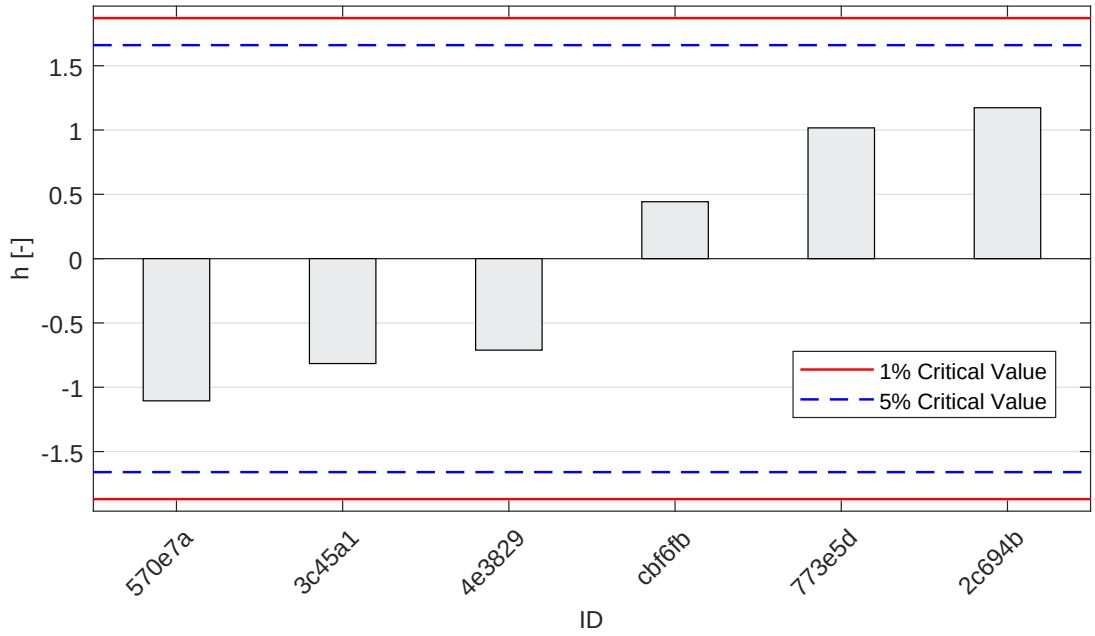

Figure 46: Interlaboratory Consistency Statistic h: 1% critical value - red color; 5% critical value - blue color

10.4 Calculation of Performance Statistics

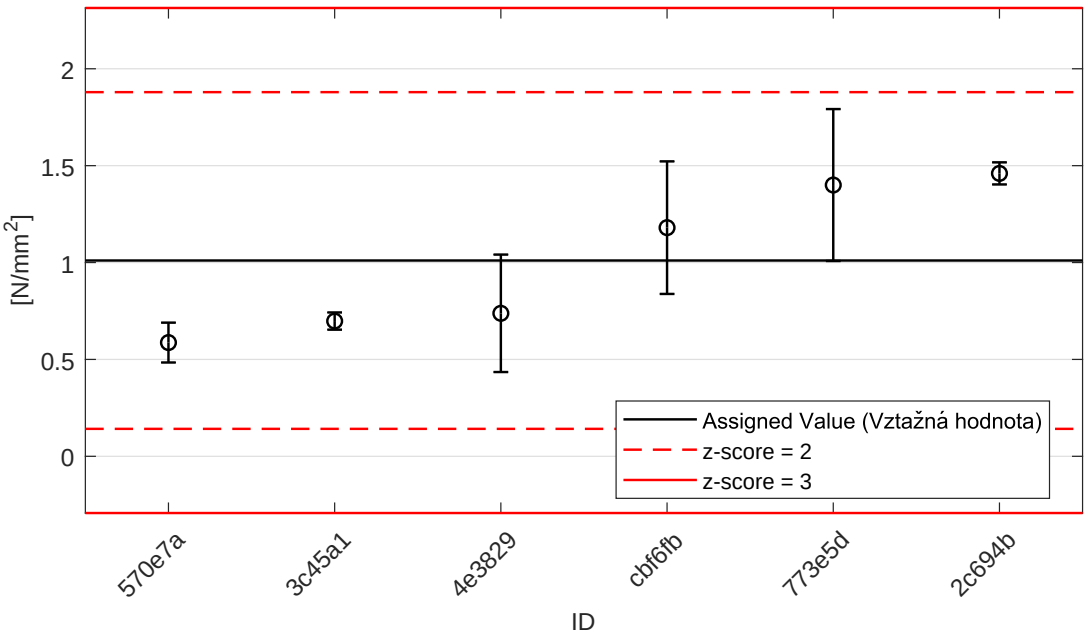

Figure 47: Average values and sample standard deviations

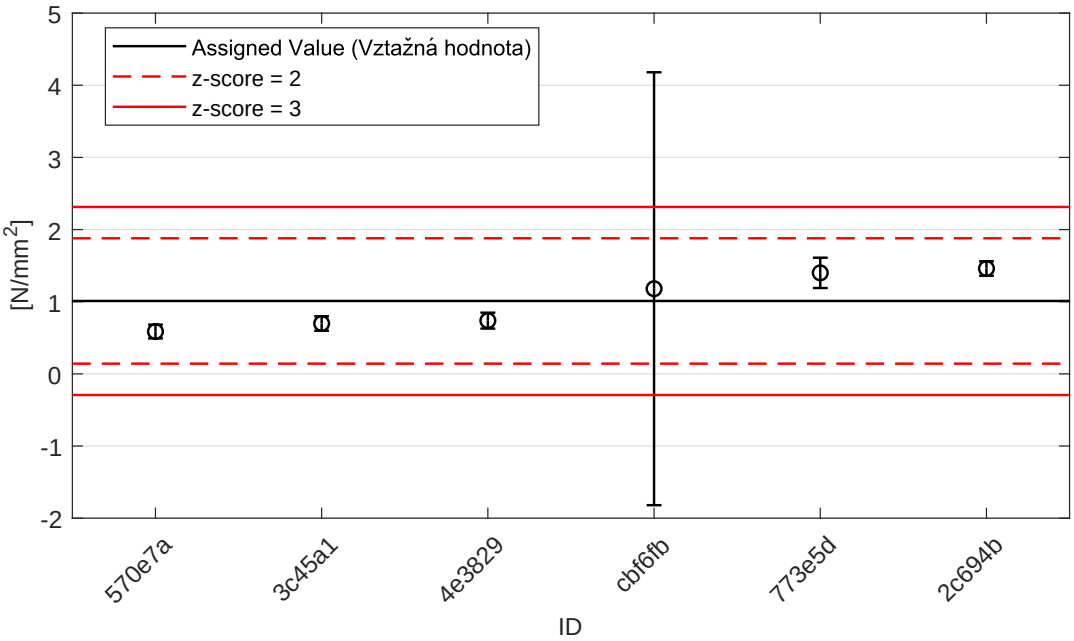

Figure 48: Average values and extended uncertainties of measurement

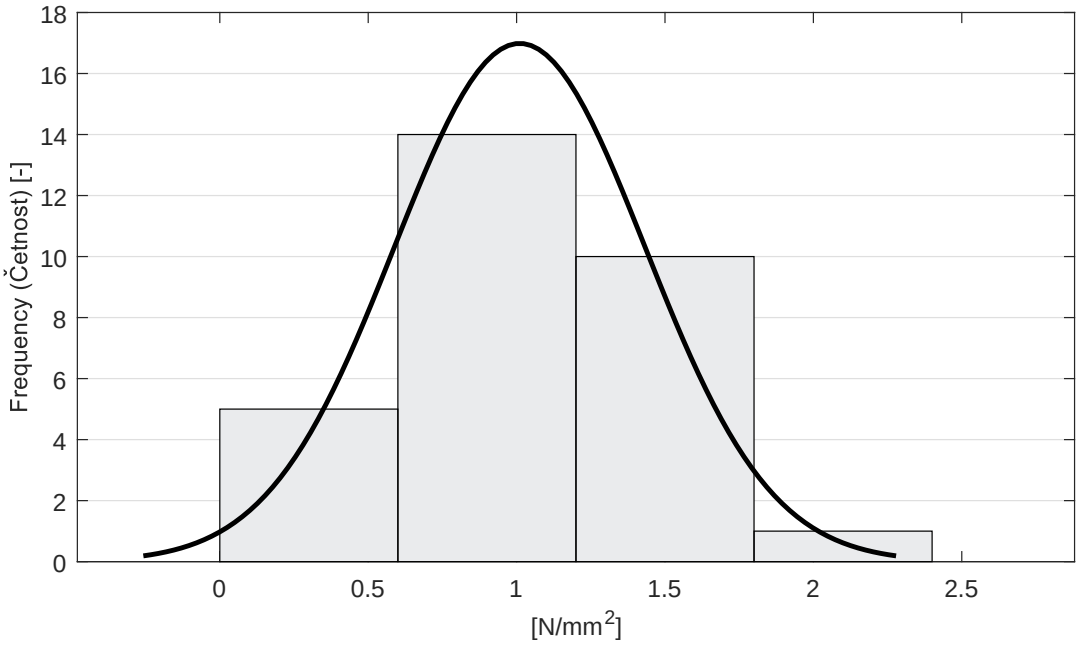

Figure 49: Histogram of all test results

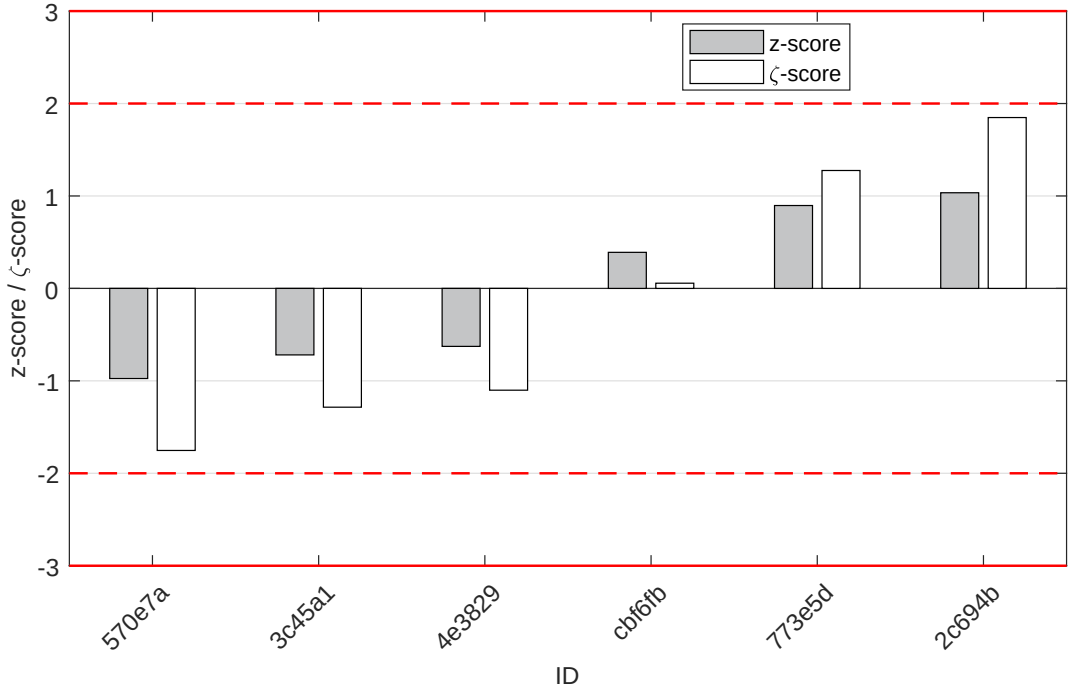

Figure 50: z-score and ζ-score

Table 14: z-score and ζ-score

ID	z-score [-]	ζ-score [-]
570e7a	-0.97	-1.75
3c45a1	-0.72	-1.28
4e3829	-0.63	-1.10
cbf6fb	0.39	0.06
773e5d	0.90	1.28
2c694b	1.03	1.85