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CONCRETE INTERLOCKING PAVING BLOCKS COMPRESSION STRENGTH DETERMINATION USING NON-DESTRUCTIVE METHODS

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ABSTRACT

In this paper, the non-destructive testing methods are analyzed in view of their usability in evaluation of the interlocking paving blocks' compressive strength. Ultrasonic pulse method and impact method (Schmidt impact hammers) were chosen for testing. Testing methodology and way of the results processing considering requests of the national and European standards are described there. In addition, calibration correlations for compression strength and parameter of non-destructive testing method like propagation velocity of ultrasonic pulses or hardness tester rebound are mentioned in this paper.

***Keywords**:* Concrete interlocking paving blocks, Non-destructive testing methods, Ultrasonic pulse method, Schmidt impact hammer, Propagation velocity of ultrasonic pulses, Compression strength

1. Introduction

Production inspection plays an important role in production of building materials. Inspection requirements as to concrete interlocking paving blocks increased because of Quality Management System implementation to EN ISO 9001.

This paper describes evaluation of non-destructive testing method utilization for compression strength determination of vibropressed interlocking paving blocks. Compression strength along with resistance to water, frost and de-icing chemicals are basic physical/mechanical characteristics as to this kind of product.

In line with ČSN 73 6131-1 provisions, compression strength of these products is to be determined at the age of 28 days however, at this time the paving blocks are sold in principle. That is why there is necessary to determine strength earlier than the above age. Compression strength can be determined in two ways: destructively – product testing in testing machines, or using non-destructive testing methods.

Most interlocking block manufacturers do not dispose of non-destructive testing equipment. On this account, we offer using non-destructive testing methods for working tests and inspection of concrete interlocking paving blocks. After evaluation of most widespread non-destructive testing equipment in building industry practice, two testing instrumentation have been chosen i.e. scleroscopes (Schmidt impact hammer type N and L made by Swiss PROCEQ Co.), and

dynamic procedure i.e. ultrasonic pulse method. Their usage is subject to elaboration of testing/evaluation procedure including appropriate calibration correlations.
Within the scope of experimentation, concrete rectangular interlocking paving blocks sized 200 × 100 × 60 mm have been tested.

2. Evaluation of Compression Strength Obtained by Non-Destructive Schmidt Impact Hammer

Three ways of test result evaluation are described and analyzed, in particular according to 731373, ČSN EN 12504-2, and procedure as specified by the manufacturer of the Schmidt impact hammer type L.

2.1 Test result evaluation according to ČSN 73 1373

Using all valid measurements (5 at the least) on one test spot, arithmetic mean is calculated rounding it to 1 scale division (R). Particular valid measurement values must not differ from this arithmetic mean for more than ± 20%. All values out of these limits are rejected; remaining valid measurements (again 5 at the least) shall serve for arithmetic mean calculation once more. Concrete compression strength is determined based on rebound corresponding to one test spot using common calibration relation whereas the hammer deviation from normal line is taken into account.

2.2 Test result evaluation according to ČSN EN 12504-2

Mean value results from all readings taking into account, if appropriate, hammer deviation from normal line in line with manufacturer's instruction; this value is to be provided as integer. In case more than 20 % of all readings differ from mean value for more than 6 scale division, the whole reading set has to be put aside.

2.3 Test result evaluation as recommended by the hammer manufacturer

Required number of readings is performed, followed by rebound arithmetic mean calculation. In consequence, all values differing from rebound mean for more than 5 values have to be put aside. Using remaining values, rebound arithmetic mean for the given test spot is calculated once again.

2.4 Assessment of compression strength evaluation using Schmidt impact hammer

Assessing of the above mentioned procedures implies as follows:

- Particular evaluations feature considerable different admissible deviations on the same spot whether rebounds or compression strength.
- As to the Schmidt impact hammer type L, evaluation according to ČSN 73 1373 allows minimum mean deviations; on the other hand, evaluation according to ČSN EN 12504-2 leads to maximum deviations.
- Particular evaluation procedures differ markedly as to number of tolerated invalid readings. Evaluating in line with hammer manufacturer, number of invalid readings is zero because these readings are replaced immediately by new valid ones; ČSN EN 12054-2 tolerates 20 % of invalid readings, whereas ČSN 73 1371 does not specify their maximum number so percentage of invalid readings covering the whole set can reach theoretically up to 100 %.
- To evaluate non-destructive test results within the scope of the dissertation in question, we used admissible deviation limits (maximum and minimum) from mean rebound value amounting to 13 % i.e. lower limit = 87 % and upper limit = 113 %, taking into account mean rebound value on the testing spot. These deviations correspond to 20 % deviation

from mean compression strength which can be consider as acceptable dispersion of compression strength value on the test spot.

See the Fig. 1 below for graphic illustration of particular concrete compression strength value deviation from mean value on the test spot using Schmidt impact hammer type L along with calibration correlations, as indicated in ČSN 73 1373 and by manufacturer (PROCEQ Co.) respectively.

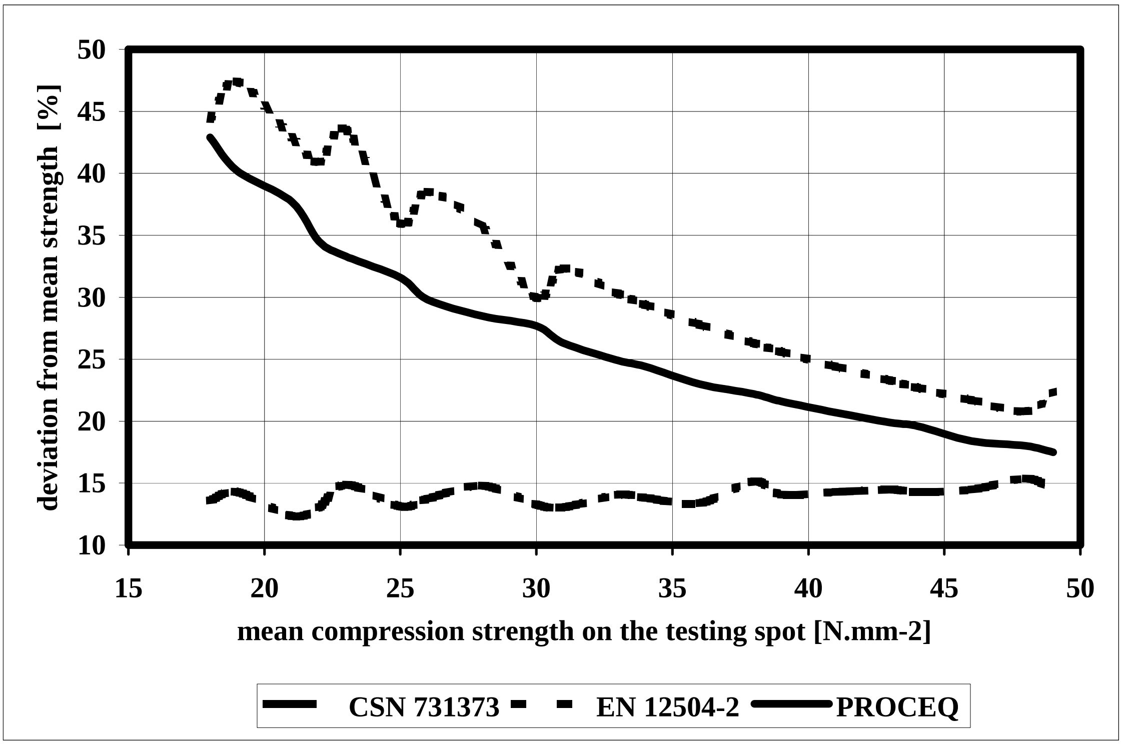

Fig. 1: Compression strength deviation from mean value on the test spot

3. Testing Procedures

3.1 Testing by impact hammers

- *Testing equipment* - Schmidt impact hammer type N/L. Testing stand providing fixed gripping by pressure steel plates guided by vertical guide bars. Grip force: 14 to 15 N.m by means of torque wrench. See the Fig. 2 for test samples gripping.
- *Test sample* – the paving block surface under testing is to be grinded down for smooth face with no outthrust, unevenness and/or failure; also, there is necessary to remove dirt or other heterogeneous particles.
- *Testing* – minimum distance between individual testing spots and/or paving block edge: 25 mm. Bottom horizontal surface is being tested (paving blocks are manufactured in two layers as a rule i.e. top concrete wear layer quality differs from the concrete core of its own). Minimum readings: 8.
- *Testing results* – test ends in a set of rebound values. A set of particular rebound R_{zi} values serves to calculation of mean rebound R_z value and maximum/minimum limits deviating ± 13 % from mean value. R_z values out of these limits are rejected. Remaining valid measurements shall serve for mean calculation once more, being assigned with corresponding compressive strength value of f_{ce} of unconfirmed accuracy using appropriate calibration correlation. In case less than 6 valid values remains (after rejecting extreme R_{zi} values, the product under testing is to be suspended and replaced by a new ones.

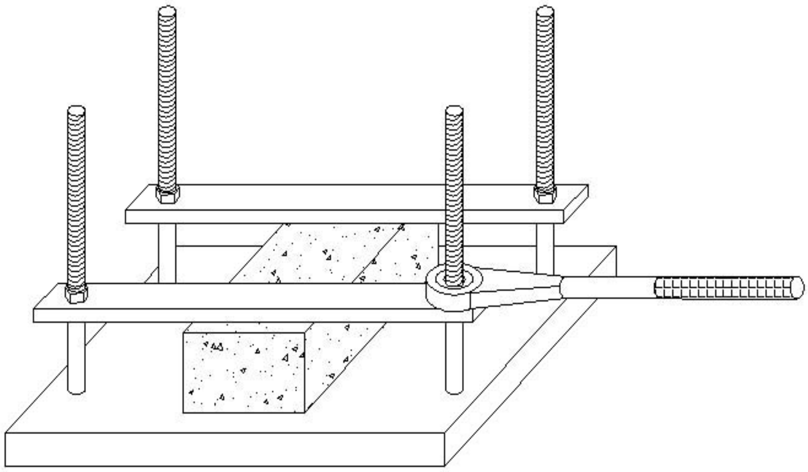

Fig. 2: Test sample gripping during non-destructive tests

3.2 Ultrasonic testing

- *Measuring equipment* – ultrasonic apparatuses featuring 0.1 μs accuracy. Exciter service frequency: 80 to 100 kHz. A calibration element has to be at hand.
- *Test sample* – see the above mentioned impact hammer specification for sample's surface. In case the surface does not meet these requirements, it is necessary to perform grinding for instance.
- *Measuring* – use opposite sounding for measurement of ultrasonic pulse pass time. Also, use plasticine for good acoustic passage. Repeat measuring twice on each test spot. In case measuring data do not vary for more than 5 %, the measuring is considered as satisfactory. Should the data variance exceeds 5 % there is necessary to perform another measuring using all data not exceeding this 5 % limit. If in default, such test spot is to be excluded.
- *Measuring results* – measurement data equates to ultrasonic pulse pass time; using this time plus length of measuring base serve for ultrasonic pulse propagation velocity calculation (in 1 $m.s^{-1}$ or 0,001 $km.s^{-1}$ respectively).

3.3 Compression strength destructive testing

- Paving blocks are tested for compression strength in a press using pressure steel plates thick 30 mm at the least.
- These plates are sized in line with block thickness, observing ČSN 73 6131-1. For instance – blocks 60 thick shall use 60 × 120 mm pressure steel plates.
- Block pressure surface planing: grinding of both surfaces i.e. wear layer and bottom surface.
- Compression strength is calculated using formula (1) as follows:

$$R_b = \frac{F}{A_c} \quad [N.mm^{-2}] \tag{1}$$

where:

R_b – compression strength,
F – destruction force in N,
A_c – pressure surface in mm^2.

4. Test Results and Calibration Correlations

4.1 Test results

This paper describes testing of 103 rectangular paving blocks sized 200 × 100 × 60 mm, made in two manufacturing plants. These blocks were tested at age of 3, 7, 14, 21, and 28 days. Based on both destructive and non-destructive test results, calibration correlations have been elaborated using method of least squares to determine compression strength following non-destructive test parameter (see impact hammer rebound, ultrasonic pulse propagation velocity).
See Figures 3 and 4 for test results including calibration correlations (Schmidt impact hammers) and Figure 5 (ultrasonic method) respectively.

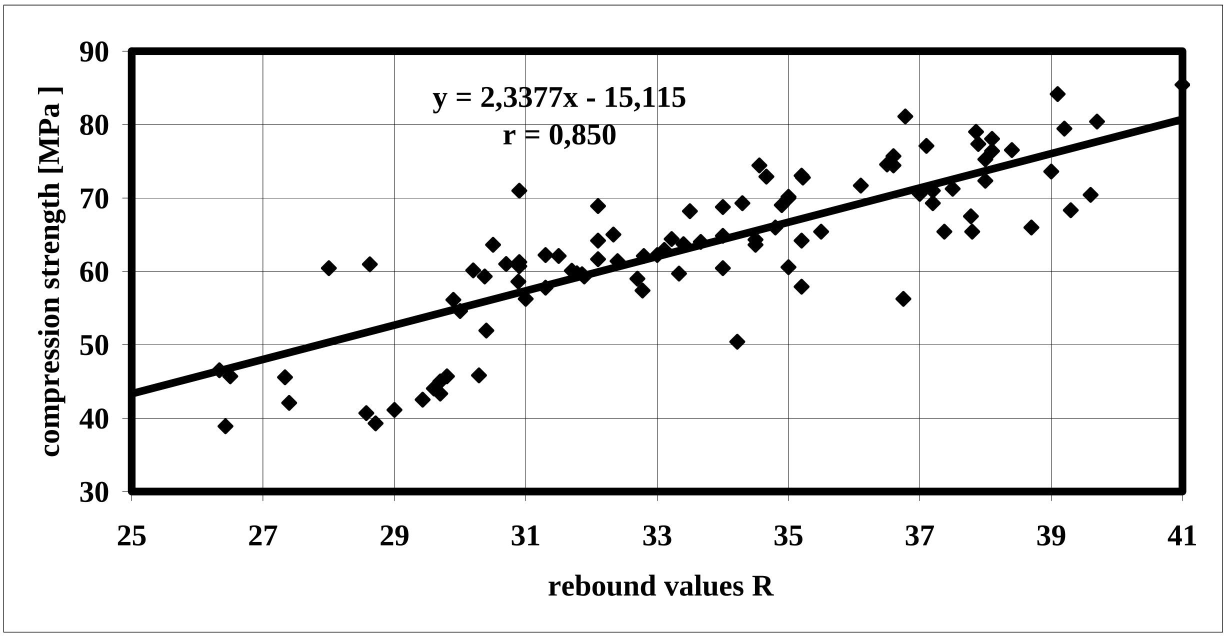

Fig. 3: Paving block compression strength test results using Schmidt impact hammer type L

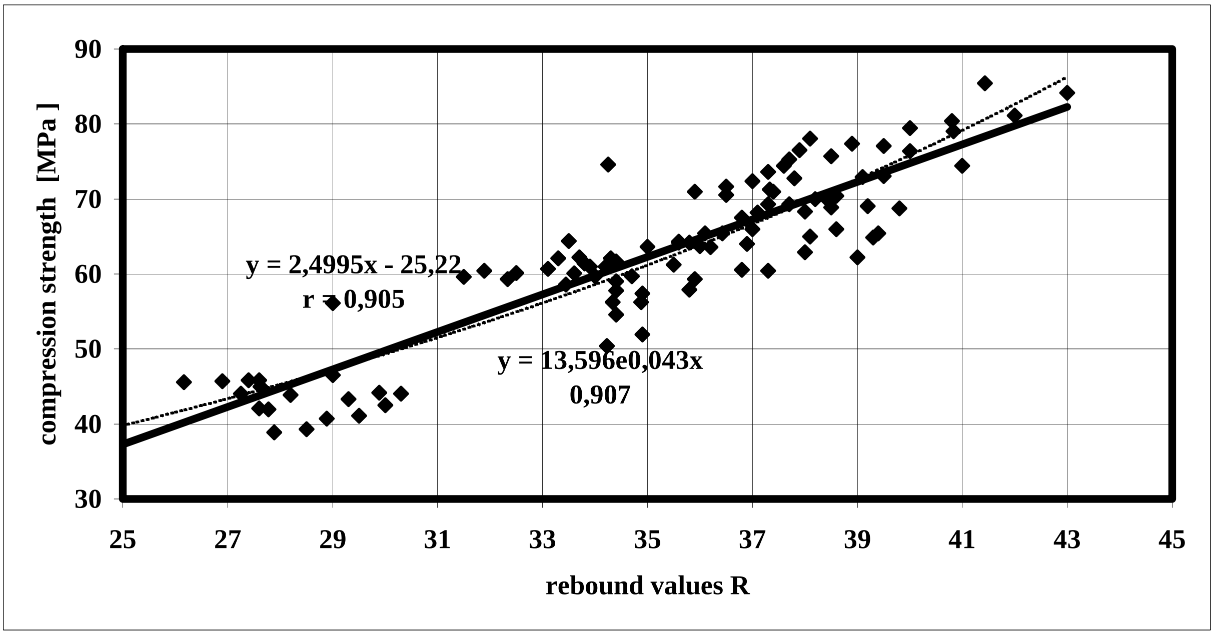

Fig. 4: Paving block compression strength test results using Schmidt impact hammer type N

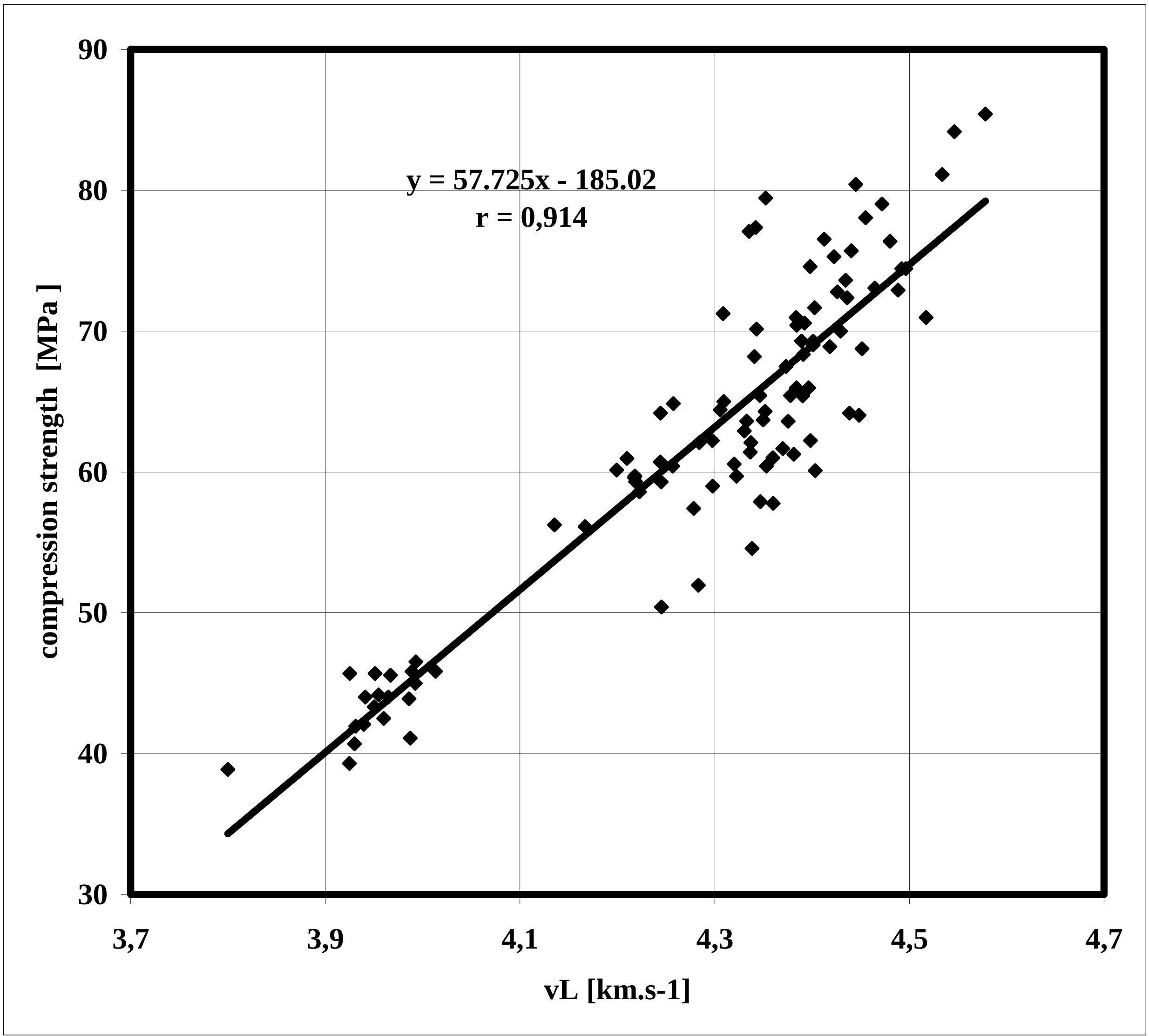

Fig. 5: Paving block compression strength test results using ultrasonic pulse method

4.2 Calibration correlation

For calibration correlation – as expressed by straight line dependence – are correlation closeness and, subsequently, its efficiency in practice evaluated in terms of **r** correlation coefficient value. This one defines correlation closeness between compression strength and non-destructive testing parameter. See [1] for correlation coefficient relevance as follows:

$r \leq 0.3$	-	Low degree of correlation closeness – not very important, in particular for small files
$0.3 \geq r < 0.5$	-	Moderate degree of correlation closeness
$0.5 \geq r < 0.7$	-	Significant correlation closeness
$0.7 \geq r < 0.9$	-	High degree of correlation closeness
$r \geq 0.9$	-	High cohesion between variables

In point of practical utilization, calibration correlation corresponding to correlation coefficient **r ≥ 0.85** is acceptable.

Below are described calibration correlations as elaborated for particular methods:

- Compression strength as calculated from rebound values of the Schmidt impact hammer type L (2):

$$f_{c,ZD,L} = 2{,}338.R_L - 15{,}12 \qquad r = 0.850 \qquad R_L \in \{26\ ;\ 41\} \tag{2}$$

- Compression strength as calculated from rebound values of the Schmidt impact hammer type N (3):

$$f_{c,ZD,L} = 2{,}5.R_L - 25{,}2 \qquad r = 0.905 \qquad R_N \in \{26 ; 43\} \qquad (3)$$

- Compression strength as calculated from ultrasonic pulse propagation values (4):

$$f_{c,ZD,L} = 57{,}73.v_L - 185 \qquad r = 0.914 \qquad v_L \in \{3.8 ; 4.7\} \, [km.s^{-1}] \qquad (4)$$

5. Conclusions

Based on experimental testing results, calibration correlations have been elaborated to determine paving block compression strength using non-destructive testing parameter (ultrasonic pulse propagation velocity or Schmidt impact hammer rebound respectively); these correlations show high cohesion between variables – see correlation coefficient r = 0.914 or 0.905 respectively. As to the Schmidt impact hammer type L, its calibration correlation equals to 0.85; this figure shows high cohesion of correlation nevertheless, such value is bound to practical usability.
Scleroscopic impact hammer testing methods are based on hardness of concrete cement binder. In case of paving blocks, the maximum nominal aggregate gradation is lower than the same in structural concrete (up to 8 mm as a rule); however, space between coarse aggregates is smaller creating more compact structure. That is why – using Schmidt impact hammer – these aggregates are affected to a certain extent, even if the test spots are chosen as carefully as possible.
Schmidt impact hammer type L rebound values at one test spot shows greater diffusion than the same in case of hammer type N, which is explainable through better response of the hammer type L to macrostructure of concrete under testing.
Determining paving block compression strength using non-destructive testing, it appears that both methods i.e. ultrasonic pulse method and Schmidt impact hammer type N are acceptable. As stated above, the Schmidt impact hammer type L is inadvisable.
However, to ensure reproducibility of impact hammer test results there is necessary to fix the sample piece tightly in the testing stand to prevent it from undesirable displacement falsificating measured variable; also grip force is to be defined accurately.

Acknowledgments
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6. References

[1] Janko J.: Statistical Tables, NČSAV, Prague, 1958.
[2] ČSN 73 1371 Method of Ultrasonic Pulse Testing of Concrete.
[3] ČSN 73 1372 Testing of Concrete by Resonance Method.
[4] ČSN 73 1373 Testing of Concrete by Hardness Testing Methods.
[5] ČSN EN 12504-2 Testing of Concrete in Structures – Part 2: Non-Destructive Testing - Determination of Rebound Number.