IV Conferencia Panamericana de END
Buenos Aires – Octubre 2007

AAENDE
Asociación Argentina de Ensayos No Destructivos y Estructurales

Non-destructive Testing of Solid Brick Compression Strength in Structures

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Abstract

Solid burnt brick sized 290 × 140 × 65 mm or 303 × 145 × 70 mm respectively, represents one of most widespread brick building material, both structural and non-bearing ones, in Czech historical buildings. During their rebuilding and reconstruction, we frequently ask for brickwork material strength. Most exact method is to take test samples just from the construction and put them to trial nevertheless; such method is inapplicable in principle due to damage of the construction under testing. Other potentiality consists in collection of test samples just from brickwork and preparation of small test specimens. However; currently there is no sufficient number of data for elaboration of correct rates for conversion coefficients as to compression/tensile bending strength for small test specimens and whole brick failure strength. Brick strength can be detected also by means of non-destructive testing method such as ultrasonic pulse method. Practically, it appears that non-destructive testing and ultrasonic pulse method are optimal. This paper evaluates efficiency of these methods for brick strength evaluation; It also describes – for selected methods – testing methodology and test result evaluation along with calibration correlations to determine strength based on non-destructive testing parameter. The set of 300 values for each of parameter under monitoring is adequate to specify appropriate calibration correlation. Defined correlation coefficients for given calibration are high enough (more than 0.9) so presented correlations are usable in practice.

1. Introduction

In the Czech Republic, historical buildings as well as construction built up to fifties of last century are characterized mostly by solid burnt brick sized 290 (303) × 140 (145) × 65 (70) mm in both structural parts and brick nogging.

Namely over the last 15 years – as a result of industry restructuring, variation in utilization, or in an effort to extent flooring of existing buildings for purpose of housing or administration – the brick construction are restored or revamped.

In these renovations there is necessary to find out brickwork capacity i.e. strength of built-in bricks along with joint mortar. This paper treats with compression strength testing concerning built-in solid bricks.

There are several ways to determine compression strength of solid bricks as follows:

- Professional assessment as to brick strength mark from experience of products made at the same time for other constructions however, there is necessary to take account of sizable risk of undervaluation or overvaluation as to compression strength.
- Destructive tests of samples taken out of construction – such procedure leads to construction impairment due to taking of whole bricks; on the other hand – when testing small samples (brick cutout or core dia. 50 mm) – the problem consists in absence of sufficiently exact rates for conversion of compression strength as detected on small samples taken out of brickwork to compression strength of the whole product.
- Non-destructive testing; these methods need calibration correlation between non-destructive testing parameter and compression strength.
- Practically speaking, use of hardness testing methods and ultrasonic pulse method seems to be optimal. This paper discusses efficiency of these methods to find out brick strength; at the same time, we describe methodics and test result evaluation along with calibration correlation to determine strength on the basis of non-destructive testing parameter.

In civil engineering, the non-destructive methods are used mostly for concrete testing; testing procedures are codified by technical standards. Some methods are also accompanied by calibration correlations for compression strength calculation on the basis of non-destructive testing parameter; in particular, they are as follows:

- hardness testing methods such as drope-hardness test, thrust hardness test (Waitzmann hammer), point chisel test : CSN 73 1373(6), EN 12504-2(7);
- ultrasonic pulse method : CSN 73 1371(4), EN 12504-4(8);
- resonance method : CSN 73 1372(5).

As to solid bricks, no non-destructive testing procedures are indicated in these standards as well as calibration correlations between non-destructive testing parameter and compression strength.

This paper describes testing methodics and calibration correlations along with efficiency of thrust hardness test and ultrasonic pulse method to find out compression strength of built-in solid bricks.

Examined were – within the scope of experimentation – solid burnt bricks of classical size i.e. 290 × 140 × 65 mm or, in some case, also 303 × 145 ×70 mm (made between 1910 and 1930, thereinafter called “old bricks”). So called “new bricks” are made between 1993 and 2002 in various Czech and Moravian brickworks. Compression strength of the old bricks varies from 11 to 45 MPa; compression strength of the new ones varies from 9 to 40 MPa. As a whole, 303 samples were tested ("new": 203 products; "old": 100 products).

2. Thrust hardness test: Waitzmann hammer (see Figure 1)

This method is based on measurement of a dimple as created in material under examination by thrust of a tool of defined size. Functionally, the Waitzmann hammer is identical to the Poldi hammer used for measurement of steel hardness however, the pressure force is not constant but variable depending on impulse of beater or hammer. Detected are dimple diameters on a foil laid on tested material, as compared to diameters on the hammer reference bar. At testing, the hammer exerts pressure force so that dimple diameter on the reference bar is approximately 2 mm. For each pair of dimples, calculated is a *B* ratio using the formula 1. Using calibration correlation, corresponding compression strength is assigned from such *B* ratio. Advantage of the Waitzmann hammer – as compared with other impact hammers – consists in the fact that its thrust is automatically eliminated.

$$B = \frac{d_1}{d_2}.\sqrt{G} \qquad (1)$$

Where:

d_1 – dimple diameter on the reference bar [mm]

d_2 – dimple diameter on the foil [mm]

G – ratio between actual steel hardness of the reference bar and nominal steel hardness (700 MPa)

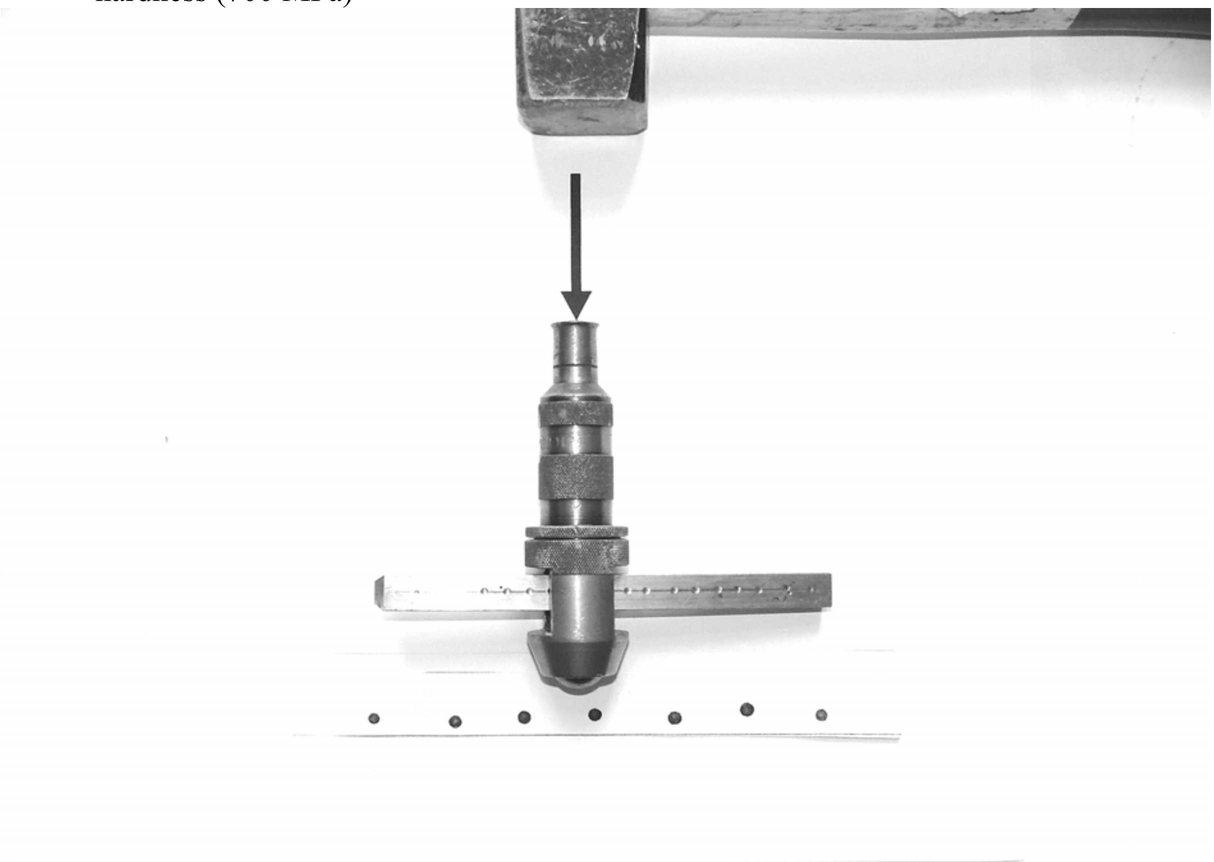

Figure 1. Waitzmann hammer

2.1. Methodics of Testing and Test Result Evaluation:

a) Test sample preparation and non-destructive testing

Surface under testing is to be smoothed down without any jutting, irregularity or failure.

Minimum distance between particular testing spots: 25 mm.

Testing of its own is performed on vertical surfaces i.e. surfaces normal to cutting or pressing surface.

Testing spot minimum distance from sample edge: 25 mm.

Number of tests on one particular sample: minimum 16 (for preparation of calibration correlation) or 7 (in situ testing) respectively.

Brick surface is covered by the test foil and the Waitzmann hammer is applied; with that the steel beater strikes the die. In case of indistinct or anomalous dimple, additional testing is necessary to carry out.

Test result consists in a set of dimples on product under testing.

b) Evaluation of non-destructive testing

Read dimple diameter by a magnifying lens in two directions normal each other (foil accuracy: 0.1 mm; reference bar accuracy: 0.05 mm).

For each dimple: calculate mean value of two readings.

Using the formula 1, calculate B ratio of each pair of dimples on the test sample.

Taking into account particular B ratios on the product, calculate B_z mean bounce value on the product.

For B_i set of values on the product, calculate upper/lower limits equal to 13% from mean value i.e. B_i values are between 0.87 and 1.13 of the B_z mean bounce value on the product.

Exclude B_i values outside of these limits. Using remaining values, calculate mean value once again.

According to relevant calibration correlation, assign corresponding f_{CP} compression strength to detected B_z mean value on test surface. In the case less than 12 (calibration correlation) or 5 (in situ testing) significant values remain after exclusion of outlying B_{zi} values, such product is to be leaved aside and replaced by a new one.

c) Compression strength being tested destructively

The CSN EN 772-1 [9] has been used to detect compression strength.

Brick surface under testing is to be smoothed down.

Formula 2 serves for compression strength calculation as follows:

$$f = \frac{F}{A_c} \quad \text{[MPa]} \qquad (2)$$

Where:

f – compression strength [MPa]

F – ultimate rupture force [N]

A_c – surface under testing [mm^2]

2.2. Test Results

See Fig. 2 to 4 for graphic representation including relation between ratio and compression strength. These results are prepared in two versions: separately for new/old bricks and en bloc for the whole set of test samples.

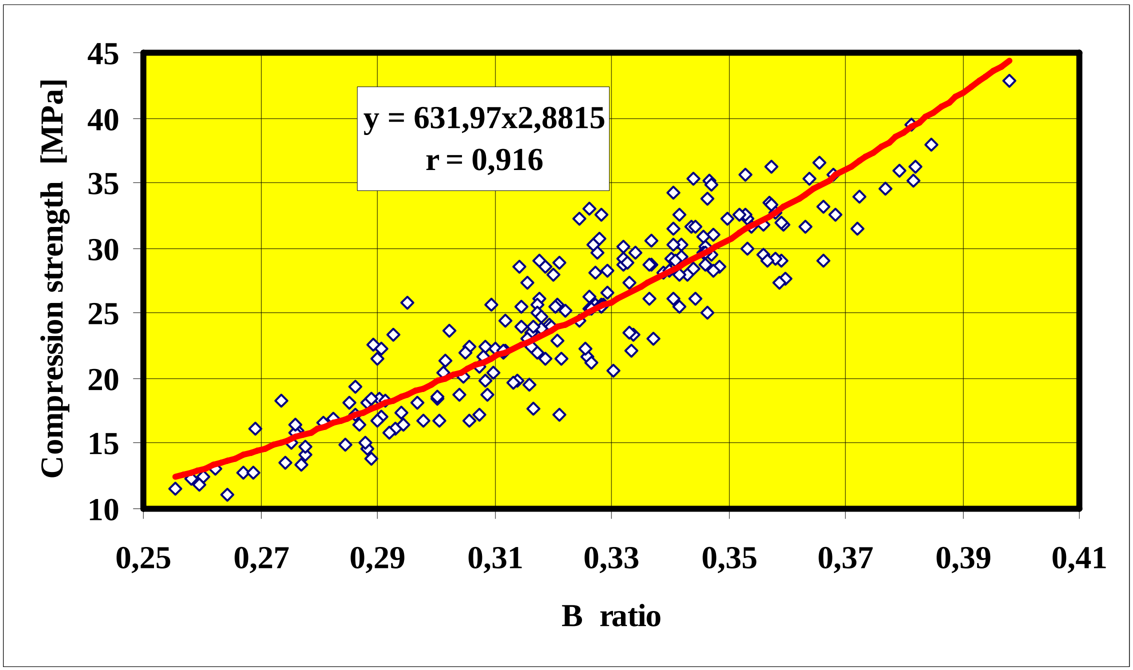

Figure 2. Test Results for "new" solid bricks: relation between *B* ratio and compression strength

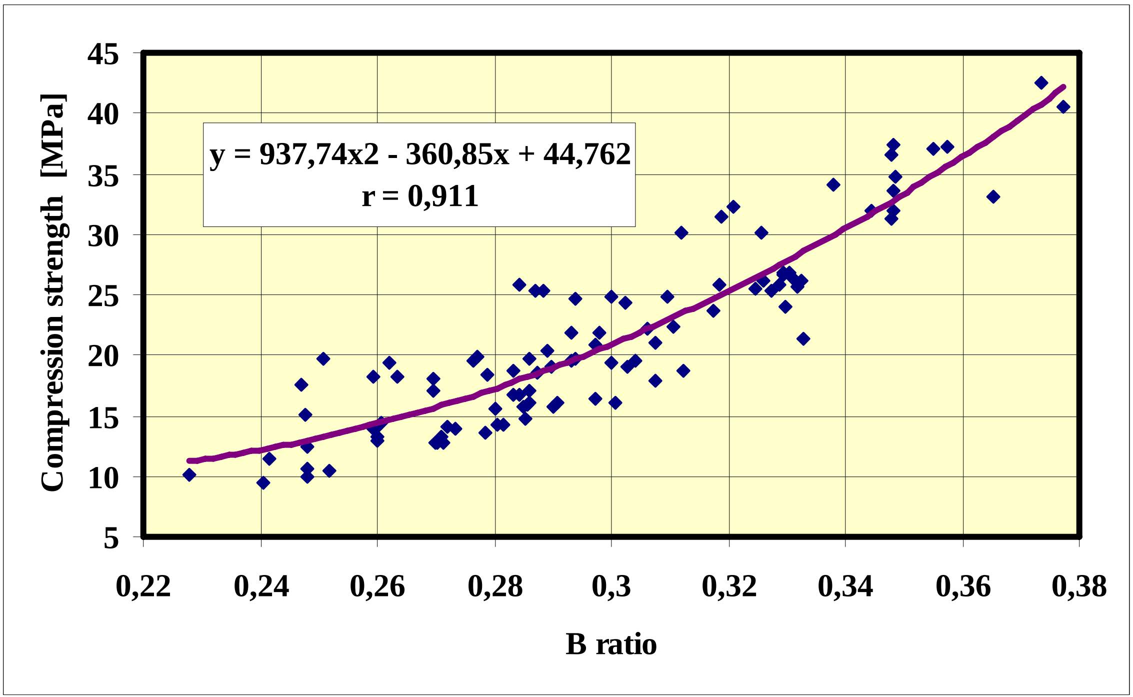

Figure 3. Test Results for "old" solid bricks: relation between *B* ratio and compression strength

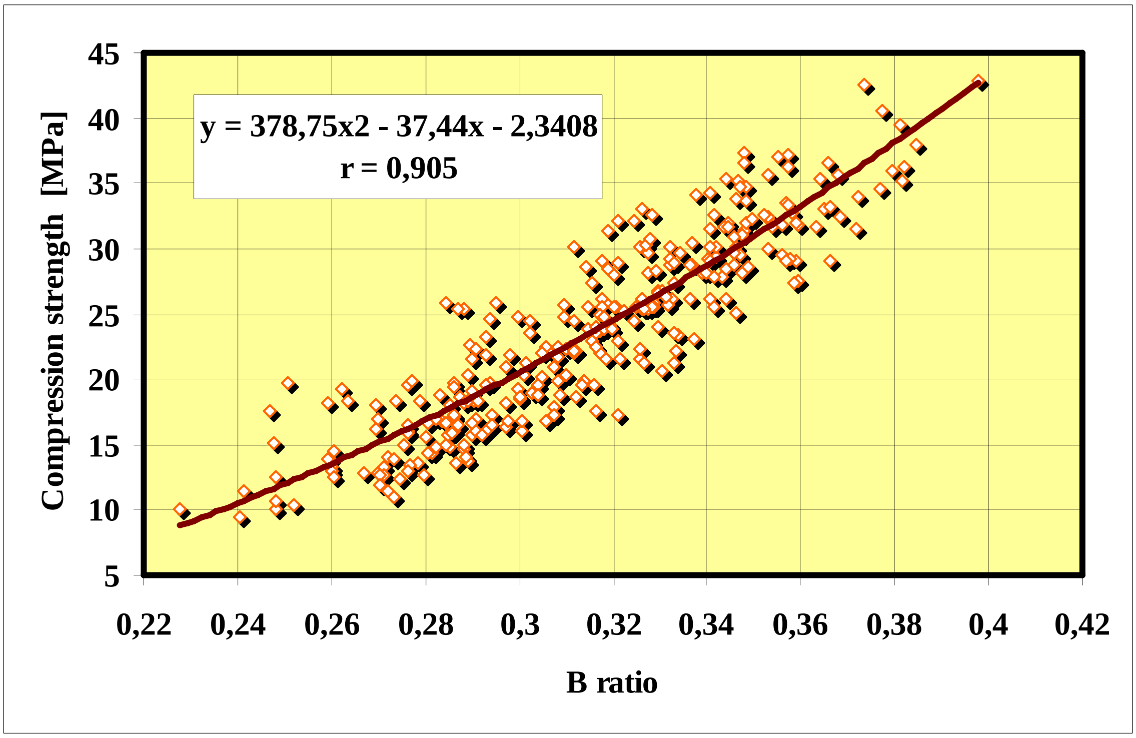

Figure 4. Test Results for solid bricks: – set of 303 test samples (both “old” and “new”)

3. Ultrasonic pulse method

Both test results are described here: solid bricks of the set under hardness testing as well as solid bricks made in Liptovský Mikuláš brickworks (1937 to 1938) featuring compression strength between 20 and 45 MPa. Ultrasonic probes (natural frequency: 82 and 100 kHz) were situated in two versions: against each other – so called Direct Transmission, or one of them round the corner – so called Semi-direct Transmission, see Fig. 5 and 6. Before testing, surfaces were smoothed. Each bricks has been ten times tested (antipodal sounding) or eight times tested (round the corner sounding).

Figure 5. Direct Transmission

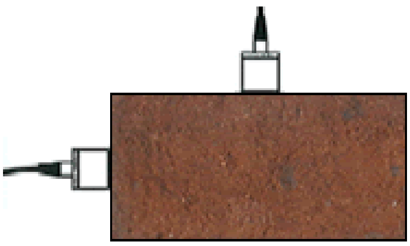

Figure 6. Semi-direct Transmission

Consistency of correlation between ultrasonic pulse velocity and compression strength for particular sets and sounding methods is as follows:

Set	*Testing Method*	*Correlation Coefficient*
“Old” solid bricks	Direct Transmission	0.284
“Old” solid bricks	Semi-direct Transmission	0.266
“New” solid bricks	Direct Transmission	0.520
“New” solid bricks	Semi-direct Transmission	0.541
Liptovský Mikuláš solid bricks	Direct Transmission	**0.898**

As an illustration, the next Fig. 7 indicates graphically test results on the solid bricks made in the Liptovský Mikuláš brickworks.

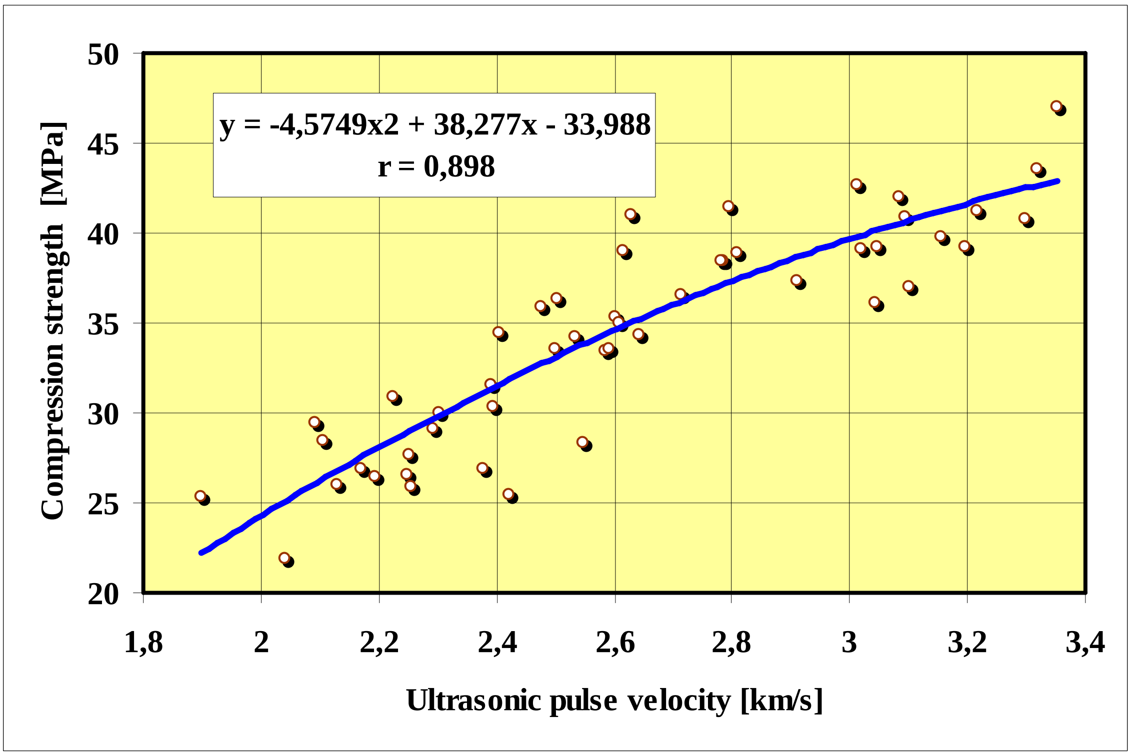

Figure 7. Test results (Liptovsky Mikulas solid bricks) – correlation between ultrasonic pulse velocity and compression strength

4. Calibration correlation

Calibration correlations for brick compression strength determination as tested by Waitzmann hammer and ultrasonic pulse method are indicated below.

4.1. Waitzmann hammer

Solid bricks: 1910 to 1930 (“old”); number of test samples: 100

$$f_{CP-W} = 937{,}7B^2 - 360{,}9B + 44{,}8 \quad (3)$$

$r = 0.0{,}911 \quad B \quad 0.2200;\ 0.3800$

Solid bricks:1993 to 2002 (“new”); number of test samples: 203

$$f_{CP-W} = 631{,}97B^{2{,}8815} \quad (4)$$

$r = 0.916 \quad B \quad 0.2600;\ 0.4000$

Solid bricks: “old” + “new”; number of test samples: 303

$$f_{CP-W} = 378{,}8{,}7B^2 - 37{,}4B + 2{,}3 \text{ ....(5)}$$

$r = 0.905$ B 0.2200; 0.4000

Where :
$f_{CP\text{-}W}$ – compression strength solid brick [MPa]
B - ratio from formula (1) [-]

4.2. Ultrasonic pulse method

Solid bricks: 1937 to 1938 (Liptovský Mikuláš brickworks), number of test samples: 60

$$f_{CP-UPM} = 138{,}27{,}7V - 4{,}57V^2 - 34 \text{ ....(6)}$$

$r = 0.891$ 1.9; 3.4 [km/s]

Where :
$f_{CP\text{-}UPM}$ – compression strength solid brick [MPa]
V – ultrasonic pulse velocity [km/s]

5. Conclusion

5.1. Thrust Hardness test: Waitzmann Hammer

Correlation between *B* ratio and compression strength has been tested using bricks made by different technology (“old”: pressing; “new”: drawing). Pressed bricks feature less body defects (cracks in particular); on the other hand, they include larger grains of various inclusions e.g. grogs. As to the body cracks – brickware standards do not take them for harmful unless they do not decrease their strength. Body cracks do not impact on compression strength significantly.
Prepared calibration relations for determination of compression strength based on *B* ratio show high level of correlation since correlation coefficient lies between 0.898 and 0.912 (in practice, correlation coefficient r   0.85 is considered as usable). In view of impact to the *B* ratio, the manufacturing technology does not affect it.
Useful efficiency of this method for determination of compression strength covering built-in solid bricks has been proved.

5.2. Ultrasonic Pulse Method

Efficiency of the ultrasonic pulse method for determination of solid brick compression strength is disputable although helpful in some cases. When testing set of “old & new” bricks, no close calibration correlations have been found to enable their practical use – see Article 3.
Two sounding methods have been used i.e. direct and semi-direct (so called “round the corner” in case of built-in products). When analyzing impact of sounding method to ultrasonic pulse velocity detected, we have detected that there is some difference; such difference is bigger in solid bricks made by drawing technology. The reason consists in greater volume of heterogeneous microstructure defects.

The ultrasonic pulse method is significantly influenced by body defects nevertheless, there is not necessary to proscribe this method as such. As shown in Fig. 7 for solid bricks made in Liptovsky Mikulas brickworks, this method is usable also for testing of solid bricks however for particular manufacturing plant only, in particular for pressed bricks featuring minimum body defects.

Acknowledgements

The work was supported by MSM 0021630511 plan: Progressive Building Materials with Utilization of Secondary Raw Materials and their Impact on Structures Durability.

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