Natural stone test methods — Determination of sound speed propagation

The European Standard EN 14579:2004 has the status of a British Standard

ICS 73.020; 91.100.15

National foreword

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The UK participation in its preparation was entrusted to Technical Committee B/545, Natural stone, which has the responsibility to:

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English version

Natural stone test methods - Determination of sound speed propagation

Méthodes d'essai pour pierres naturelles - Détermination de la vitesse de propagation du son

Prüfverfahren für Naturstein - Bestimmung der Geschwindigkeit der Schallausbreitung

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Contents

Foreword

This document (EN 14579:2004) has been prepared by Technical Committee CEN/TC 246 “Natural stones”, the secretariat of which is held by UNI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2005, and conflicting national standards shall be withdrawn at the latest by April 2005.

This standard is one of the series for tests on natural stone.

Test methods for natural stone consist of the following parts:

EN 1925, *Natural stone test methods – Determination of water absorption coefficient by capillarity*

EN 1926, *Natural stone test methods – Determination of compressive strength*

EN 1936, *Natural stone test methods – Determination of real density and apparent density, and of total and open porosity*

EN 12370, *Natural stone test methods – Determination of resistance to salt crystallisation*

EN 12372, *Natural stone test methods – Determination of flexural strength under concentrated load*

EN 12407, *Natural stone test methods – Petrographic examination*

EN 13161, *Natural stone test methods – Determination of flexural strength under constant moment*

EN 13364, *Natural stone test methods - Determination of the breaking load at dowel hole*

EN 13373, *Natural stone test methods – Determination of geometric characteristics on units*

EN 13755, *Natural stone test methods – Determination of water absorption at atmospheric pressure*

EN 13919, *Natural stone test methods – Determination of resistance to ageing by* SO_2 *action in the presence of humidity*

EN 14066, *Natural stone test methods – Determination of resistance to ageing by thermal shock*

EN 14147, *Natural stone test methods – Determination of resistance to ageing by salt mist*

EN 14205, *Natural stone test methods - Determination of Knoop hardness*

EN 14231, *Natural stone test methods – Determination of the slip resistance by means of the pendulum tester*

EN 14157:2004, *Natural stone test methods – Determination of abrasion resistance*

EN 14158:2004, *Natural stone test methods – Determination of rupture energy*

EN 14579:2004, *Natural stone test methods – Determination of sound speed propagation*

prEN 14580:2002, *Natural stone test methods – Determination of the static elastic modulus*

prEN 14581:2002, *Natural stone test methods – Determination of linear thermal expansion coefficient*

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1 Scope

This document specifies a method for the determination of the velocity of propagation of pulses of ultrasonic longitudinal waves in natural stone, both in laboratory and in situ.

2 Principle

A pulse of longitudinal vibrations is produced by an electro-acoustical transducer held in contact with one surface of the stone under test. After traversing a known path length in the stone, the pulse of vibrations is converted into an electrical signal by a second transducer and electronic timing circuits enable the transit time of the pulse to be measured.

3 Symbols and abbreviations

V pulse velocity, in km/s

L path length, in mm

T time taken by the pulse to transverse the length, in μs

4 Apparatus

4.1 General

4.1.1 The apparatus consists essentially of an electrical pulse generator, a pair of transducers, an amplifier and an electronic timing device for measuring the time interval elapsing between the onset of a pulse generated at the transmitting transducer and the onset of its arrival at the receiving transducer.

4.1.2 Two forms of electronic timing apparatus are available:

a) an oscilloscope on which the first front of the pulse is displayed in relation to a suitable time scale;

b) an interval timer with a direct reading digital display.

NOTE An oscilloscope provides the facility for examining the wave form, which can be advantageous in complex situations.

4.2 Performance requirements

The apparatus shall comply with the following performance requirements:

- to measure transit times in the calibration bar to an accuracy of ± 0,1 μs;

- to ensure a sharp pulse onset, that is the electronic excitation pulse applied to the transmitting transducer shall have a rise time of not greater than one-quarter of its natural period;

- the pulse repetition frequency shall be low enough to ensure that the onset of the received signal is free from interference by reverberations.

4.3 Transducers

The natural frequency of the transducers shall be within the range 20 to 150 kHz.

NOTE Frequencies as low as 10 kHz and as high as 200 kHz may sometimes be used. High frequency pulses have a well defined onset, but, as they pass through the natural stone, they become attenuated more rapidly than pulses of lower frequency. It is therefore preferable to use high frequency transducers (82 kHz to 200 kHz) for short path lengths (down to 50 mm) and low frequency transducers (10 kHz to 40 kHz) for long path lengths (up to a maximum of 15 m). Transducers with a frequency of 40 kHz to 82 kHz are found to be useful for most applications.

4.4 Apparatus for the determination of the arrival time of the pulse

The apparatus shall be capable of determining the time of arrival of the first front of the pulse, even though this may be of small amplitude compared with that of the first half wave of the pulse.

4.5 Other apparatus

A weighing instrument with an accuracy of 0,01 % of the mass to be weighed.

A ventilated oven capable of maintaining a temperature of (70 ± 5) °C.

5 Preparation of the specimens

5.1 Sampling

The sampling is not the responsibility of the test laboratory except where specially requested.

At least 6 specimens shall be selected from a homogeneous batch (see also 5.2.3)

5.2 Test specimens

5.2.1 General

As a standard reference the surface finish of the faces of the specimens shall be sawn or honed.

5.2.2 Dimensions

5.2.3 The test specimens shall be prisms of 300 mm x 75 mm x 50 mm with a tolerance of ± 2mm. Planes of anisotropy

If the stone shows planes of anisotropy (e.g. bedding, foliation) the specimens shall be prepared with the long axis either parallel or perpendicular to these planes.

5.2.4 Drying the specimens

The specimens shall be dried at a temperature of (70 ± 5) °C to constant mass. This is assumed to have been attained when the difference between two weighings at an interval of (24 ± 2) h is not greater than 0,1 % of the first of these two masses.

6 Test procedure

6.1 General

The apparatus shall be used within the operating conditions stated by the manufacturer.

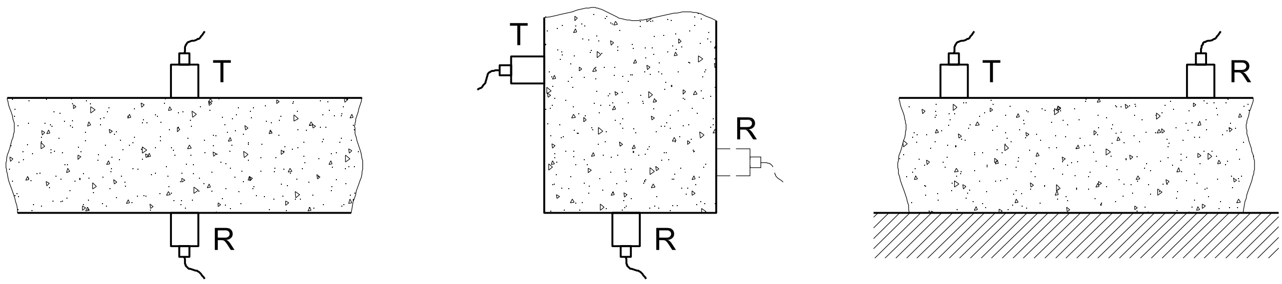
6.2 Determination of Pulse Velocity

6.2.1 Factors influencing pulse velocity measurements

In order to provide a measurement of pulse velocity which is reproducible, it is necessary to take into account various factors which can influence the measurements. These are set out in informative Annex B.

6.2.2 Transducer arrangement

Although the direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer, it is possible to detect pulses which have travelled through the natural stone in some other direction. It is therefore possible to make measurements of pulse velocity by placing the two transducers either on opposite face (direct transmission), or on adjacent faces (semi-direct transmission), or on the same face (indirect or surface transmission). (see Figure 1).



a) b) c)

T = transmitter

R = receiver

a) direct transmission

b) semi-direct transmission

c) indirect or surface transmission

Figure 1 — Different transducer arrangements for the determination of pulse velocity

NOTE 1 It may be necessary to place the transducers on opposite faces but not directly opposite each other. Such arrangement shall be regarded as a semi-direct transmission. (see Figure 1.b).

NOTE 2 The indirect transmission arrangement is the least sensitive and should only be used, for in situ measurements when only a single face of the natural stone is accessible, or when it is more important to determine the strength of the layer near the surface than that of the body of the stone itself.

NOTE 3 The semi-direct transmission arrangement has a sensitivity intermediate between the other two arrangements and should only be used when the direct arrangement cannot be used.

6.2.3 Path length measurement

For direct transmission, the path length is the distance between the transducers measured with an accuracy of ± 1 %.

For semi-direct transmission, it is generally found to be sufficiently accurate to take the path length as the distance measured from centre to centre of the transducers faces. The accuracy of the measurement of the path length is dependent upon the size of the transducers compared with the centre to centre distance and it shall be estimated.

With indirect transmission, the path length is not measured, but a series of measurements is made with the transducers at different distances apart.

6.2.4 Coupling the transducer onto the stone

There shall be adequate acoustical coupling between the stone and the face of each transducer. For sufficiently smooth surface finishes a good acoustical contact is ensured by the use of a coupling medium such as petroleum jelly, grease, soft soap and kaolin/glycerol paste and by pressing the transducer against the stone surface.

Repeated readings of the transit time shall be made until a minimum value is obtained, so as to allow the layer of couplant to become thinly spread.

When the surface finish is very rough and uneven, the surface area shall be smoothed and levelled by grinding, or by the use of a quick-setting epoxy resin.

NOTE Special transducers are available for use on very rough surfaces

6.2.5 Measurement of the transit time

Using the electronic device the time interval indicated shall be recorded.

7 Expression of the results

For direct and semi-direct transmissions the pulse velocity shall be calculated from the formula:

$$V = \frac{L}{T}$$

where

V is the pulse velocity, in km/s

L is the path length, in mm

T is the time taken by the pulse to transverse the length, in µs

For indirect transmission, the velocity shall be calculated in accordance with normative Annex A.

The pulse velocity shall be expressed to the nearest 0,01 km/s.

NOTE Recommendations on the procedures for correlating test results to compressive strength are given in EN 12504-4.

8 Test report

The test report shall contain the following information:

a) unique identification number of the report;

b) number, title and date of issue of this document;

c) name and address of the test laboratory and address where the test was carried out if different from the test laboratory;

d) name and address of the client;

e) it is the responsibility of the client to supply the following information:

- petrographic name of the stone;
- commercial name of the stone;
- country and region of extraction;
- name of the supplier

- direction of any existing plane of anisotropy (if relevant to the test) to be clearly indicated on the sample or on each specimen by means of two parallel lines;

- name of the person or organization which carried out the sampling;
- surface finish of the specimens (if relevant to the test);

f) date of delivery of the sample or of the specimens;

g) date when the specimens were prepared (if relevant) and the date of testing;

h) number of specimens in the sample;

i) dimensions of the specimens;

j) type and make of apparatus used, including:

- dimensions of contact area of the transducers;
- natural pulse frequency of the transducers;
- any special characteristics;

k) transducer arrangements and transmission method (sketch, if appropriate);

l) surface finish and preparation of the stone at test points (if relevant);

m) coupling medium used (if relevant);

n) orientation of the direction of propagation of the pulse with respect to the position of the anisotropy planes;

o) measured values of path length, (for direct and semi-direct transmission), including, the method of measurement;

p) measured values of transit times;

q) calculated values of pulse velocity along each path.

r) a statement on measurement uncertainty (where appropriate);

s) all deviations from the standard and their justification;

t) remarks.

The test report shall contain the signature(s) and role(s) of the responsible(s) for the testing and the date of issue of the report. It shall also state that the report shall not be partially reproduced without the written consent of the test laboratory.

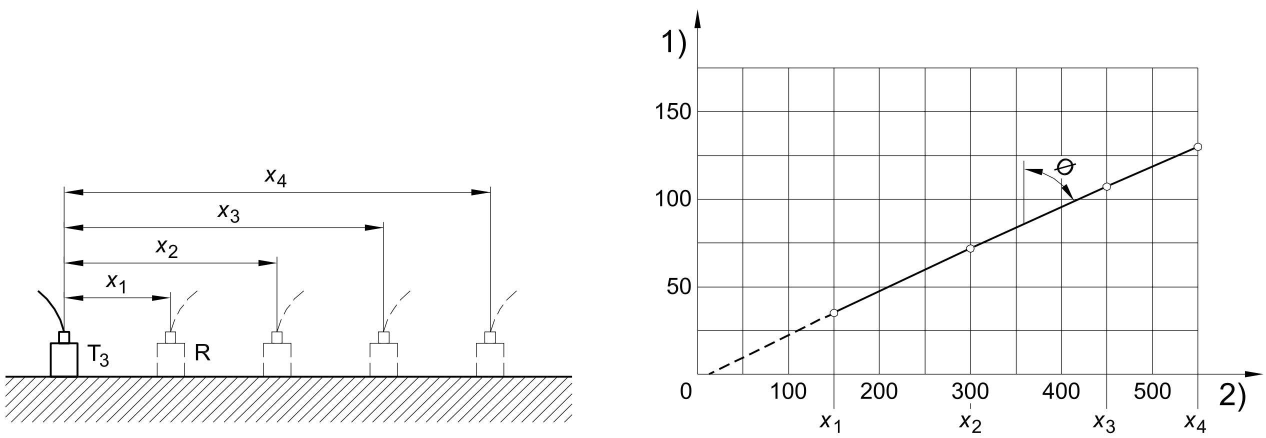
Annex A
(normative)

Determination of pulse velocity in the case of indirect transmission

With indirect transmission there is some uncertainty regarding the exact length of the transmission path, because of the significant size of the areas of contact between the transducers and the stone. It is therefore preferable to make a series of measurements with the transducers at different distances apart to eliminate this uncertainty.

To do this, the transmitting transducer shall be placed in contact with the stone surface at a fixed point x and the receiving transducer shall be placed at previously foreseen distances x_1, x_2 – x_n along a chosen line on the surface. The transmission times recorded should be plotted as points on a graph showing their relation to the distance separating the transducers. An example of such a plot is shown in Figure A 1.

The slope of the best straight line drawn through the points shall be measured and recorded as the mean pulse velocity along the chosen line on the stone surface. Where the points measured and recorded in this way indicate a discontinuity, it is likely that a surface crack or surface layer of inferior quality is present and a velocity measured in such an instance is unreliable.



Key

1) times

2) distances separating the transducers

Figure A.1 — Pulse velocity determination by indirect (surface) transmission

Annex B
(informative)

Factors influencing the measurement of the velocity of sound

B.1 General Points

To obtain some measure of the velocity that is reproducible and which is essentially a function of the properties of the stone submitted to testing, it is necessary to take into consideration the different factors that exert an influence on the velocity. This is also essential to establish the correlations, which exist with the different physical characteristics of the stone.

B.2 Water Content

The water content exerts an influence on the velocity. This can be up to 50 % of the value determined on the dry specimen.

This effect is certainly of importance in the production of the final correlation to give some estimate of the identity or the physical characteristics (strength, porosity etc).

The differences in the velocity between cubic or cylindrical test specimens submitted to a normal drying process and some intricate pieces of building elements can be important.
The great majority of these variations are attributable to the different conditions of humidity, that is to say to the presence of water inside the pores.

It is necessary to take this effect into consideration in a rigorous way, with the aid of specific calibration curves.

B.3 Path Length

The path length on which the measurement of the velocity of sound is carried out should be sufficiently long so that it is not influenced by the heterogeneity of the stone.

The path lengths should at least be those given in Table B1 for three velocities of propagation of sound and four frequencies of resonance of the transducer. For different values of velocities or frequencies, values of minimum path length can be extrapolated.

The Table B.1 is valid for a maximum path length of 15 m.

The velocity is not generally affected by the variations in the path length, even though the electronic timing devices are likely to give some indications that the speed can slightly decrease if the length of the path increases.

This peculiarity is due to the fact that the high frequency components which form the impulse are diminished in greater proportion than the lower frequency components, and that the shape of the first impulse will become rounder as the path length increases.

The apparent reduction in velocity is normally slight and is within the accuracy of the timer given in 4.2.

Nevertheless particular care shall be taken on the transmissions carried out on important path lengths.

B.4 Shape and sizes of the test specimens

B.4.1 The velocity of short vibratory impulses is independent of the size and shape of the test specimens which they traverse, only if the smallest lateral dimension is not less than defined minimum value. Below this value, the velocity can be considerably reduced. The amount of this reduction depends primarily on the relationship between the wave length of the impulse to the smallest lateral dimension of the test specimen, but it is insignificant if that relation is less than one. The relationships that exist between the velocity across the stone, the frequency of the transducer and the smallest admissible lateral dimension of the test specimen are given in Table B.1.

B.4.2 In the case where the minimum lateral dimension is less than the wave length or in the case of utilisation of the apparatus for indirect transmission, the mode of transmission changes, and this will entail modifications of the measured velocity. This phenomenon shows its importance in the case of comparisons between stone units of very different dimensions.

Table B.1— Influence of specimen dimensions on impulses transmission

Frequency of the transducer	Sound speed propagation (longitudinal) across the stone (in km/s)		
	3,50	4,00	4,50
	Smallest admissible lateral dimensions of the test specimen		
KHz	mm	mm	mm
24	146	167	188
54	65	74	83
82	43	49	55
150	23	27	30

B.5 Fissures and voids

B.5.1 When an ultrasonic impulse crossing a stone meets an air-stone interface, the quantity of energy transmitted across this junction is negligible. In this way all cracks filled with air or all voids positioned exactly between the two transducers, will be an obstacle to the ultrasonic beam if the projection of the length of the void is greater than the size of the transducers and the length of the wave used. When this phenomenon is produced, the first impulse received by the receiving transducer will undergo a diffraction at the edge of the anomaly and this gives a longer path time compared to a transmission taking place in stone with no fissure or void.

B.5.2 In the case of a cracked stone where the broken sides are kept firmly in contact by compression, the ultrasonic energy can cross the crack without being interrupted. It is possible, for example, that this phenomenon is produced in the cases of vertical load bearing columns showing some cracks. In the case of a cracked stone in which the cracks are filled with a liquid capable to transmit the ultrasonic energy, for example in maritime constructions, the crack will not be revealed when using a timer with a direct reading digital display. In this case, reliable results can be obtained using a measure of attenuation.

Bibliography

[1] EN 12504-4, *Testing concrete - Determination of ultrasonic pulse velocity*[1]

[1] EN 12504-4:2004 was registered as prEN 13296 at enquiry stage

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