BRITISH STANDARD

BS EN 12504-4:2004

Testing concrete —

Part 4: Determination of ultrasonic pulse velocity

The European Standard EN 12504-4:2004 has the status of a British Standard

ICS 91.100.30

British Standards

National foreword

This British Standard is the official English language version of EN 12504-4:2004. It supersedes BS 1881-203:1986 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee B/517, Concrete, to Subcommittee B/517/1, Concrete production and testing, which has the responsibility to:

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Essais pour béton dans les structures - Partie 4: Determination de la vitesse de propagation du son

Prüfung von Beton - Teil 4: Bestimmung der Ultraschallgeschwindigkeit

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Contents

page

Foreword

This document (EN 12504-4:2004) has been prepared by Technical Committee CEN/TC 104 “Concrete and related products”, the secretariat of which is held by DIN.

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of an identical text or by endorsement, at the latest by February 2005, and conflicting national standards shall be withdrawn at the latest by February 2005.

A draft standard was submitted in 1998 to CEN enquiry as prEN 13296. It was one of a series of individually numbered test methods for fresh or hardened concrete. For convenience it has now been decided to combine these separate draft standards into three new standards with separate Parts for each method, as follows:

— Testing fresh concrete (EN 12350)

— Testing hardened concrete (EN 12390)

— Testing concrete in structures (EN 12504)

This series, EN 12504, includes the following Parts where the brackets give the numbers under which particular test methods were submitted to CEN enquiry:

EN 12504, *Testing concrete in structures*

Part 1: Cored specimens — Testing, examining and testing in compression (former prEN 12504:1996)

Part 2: Non-destructive testing — Determination of rebound number (former prEN 12398:1996)

Part 3: Determination of pull-out force (former prEN 12399:1996)

Part 4: Determination of ultrasonic pulse velocity (former prEN 12396:1998)

This European Standard is based on ISO/DIS 8047 "*Concrete hardened — Determination of ultrasonic pulse velocity*". It is recognised that the ultrasonic pulse velocity determined using this standard is a convention in as much that the path length over which the pulse travels may not strictly be known.

The measurement of pulse velocity can be used for the determination of the uniformity of concrete, the presence of cracks or voids, changes in properties with time and in the determination of dynamic physical properties. These subjects were considered to be outside the scope of this standard, but some information is given in Annex B and more information can be found in the technical literature. The measurement may also be used to estimate the strength of in-situ concrete elements or specimens. However, it is not intended as an alternative to the direct measurement of the compressive strength of concrete.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

1 Scope

This document specifies a method for the determination of the velocity of propagation of pulses of ultrasonic longitudinal waves in hardened concrete, which is used for a number of applications.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 206-1:2000, *Concrete — Part 1: Specification, performance, production and conformity.*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 206-1:2000 and the following apply.

3.1
transit time
time taken for an ultrasonic pulse to travel from the transmitting transducer to the receiving transducer, passing through the interposed concrete

3.2
onset
leading edge of the pulse detected by the measuring apparatus

3.3
rise time
time for the leading edge of the first pulse to rise from 10 % to 90 % of its maximum amplitude

4 Principle

A pulse of longitudinal vibrations is produced by an electro-acoustical transducer held in contact with one surface of the concrete under test. After traversing a known path length in the concrete, 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.

5 Apparatus

5.1 General

The apparatus consists 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. A calibration bar is provided to provide a datum for the velocity measurement.

Two forms of the 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 monitoring the wave form of the pulse, which can be advantageous in complex testing situations or in automatic system measurements.

5.2 Performance requirements

The apparatus shall conform to the following performance requirements:

– It shall be capable of measuring transit times in the calibration bar to a limit deviation of ± 0,1 μs and an accuracy of 2 %.

– The electronic excitation pulse applied to the transmitting transducer shall have a rise time of not greater than one-quarter of its natural period. This is to ensure a sharp pulse onset.

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

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

5.3 Transducers

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

NOTE Frequencies as low as 10 kHz and as high as 200 kHz can sometimes be used. High frequency pulses have a well defined onset, but, as they pass through the concrete, they become attenuated more rapidly than pulses of lower frequency. It is therefore preferable to use high frequency transducers (60 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 60 kHz are found to be useful for most applications.

5.4 Apparatus for determination of arrival time of the pulse

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

6 Procedures

6.1 Determination of Pulse Velocity

6.1.1 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 Annex B.

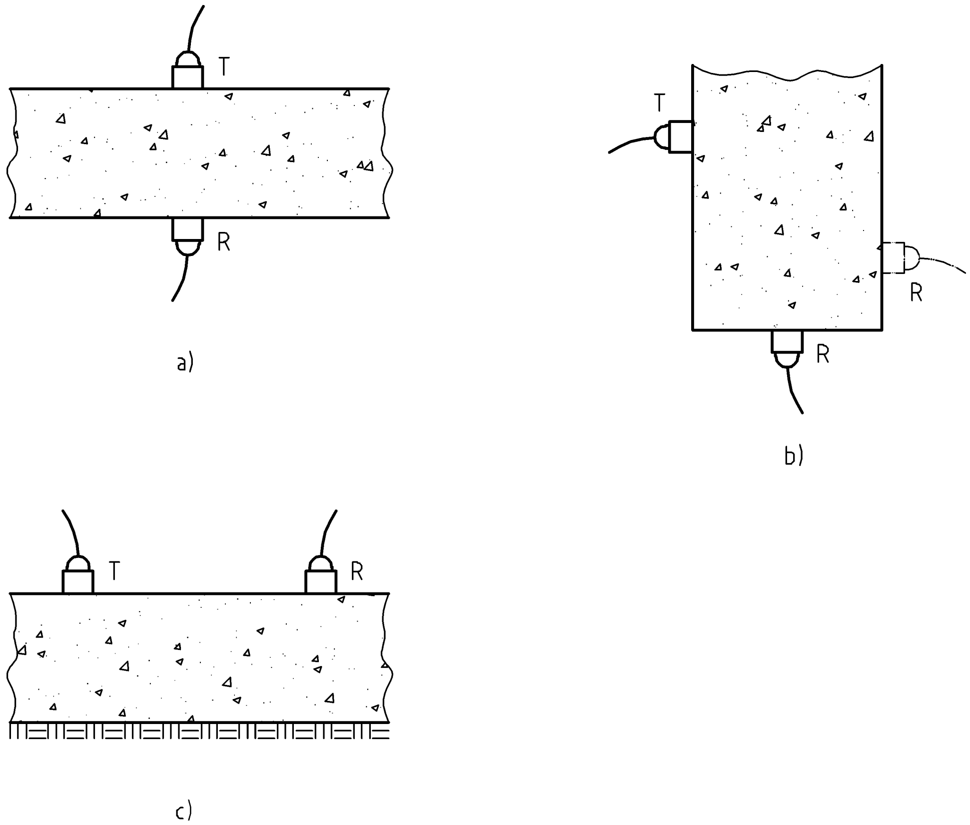
6.1.2 Transducer arrangement

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 concrete in some other direction. It is therefore possible to make measurements of pulse velocity by placing the two transducers on opposite faces (direct transmission), or on adjacent faces (semi-direct transmission), or the same face (indirect or surface transmission) (see Figure 1) of a concrete structure or specimen.

NOTE 1 Where it is 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 be used, when only one face of the concrete is accessible, or when the quality of the surface concrete relative to the overall quality is of interest.

NOTE 3 The semi-direct transmission arrangement is used when the direct arrangement cannot be used, for example at the corners of structures.



Key

R is the receiver transducer
T is the transmitter transducer

Figure 1 — Transducer positioning

6.1.3 Path length measurement

For direct transmission, the path length is the shortest distance between the transducers. The accuracy of measurement of the path length shall be recorded to 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 transducer faces. The accuracy of path length is dependent upon the size of the transducer compared with the centre to centre distance.

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

6.1.4 Coupling the transducer onto the concrete

There shall be adequate acoustical coupling between the concrete and the face of each transducer. For many concrete surfaces, the finish is sufficiently smooth to ensure good acoustical contact 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 concrete surface.

Repeated readings of the transit time should be made until a minimum value is obtained, indicating that the thickness of the couplant has been reduced to a minimum.

When the concrete surface is very rough and uneven, the area of the surface should 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.

6.1.5 Measurement of transit time

Using the electronic device the time interval indicated shall be determined in accordance with the manufacturer's instruction (see 5.2).

7 Expression of result

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

$$V = \frac{L}{T} \quad 1$$

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 the velocity by indirect transmission, see Annex A.

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

8 Test report

The test report shall include the following:

– identification of the concrete structure or specimens tested;

– location of performance of the test;

– date of the test;

– description of the concrete including mix proportions (if known);

– age of concrete, at time of test (if known);

– temperature of the concrete, at time of test (when appropriate, see B 3);

– type and make of apparatus used, including:

  a) dimensions of contact area transducers;

  b) natural pulse frequency of transducers;

  c) any special characteristics;

– transducer arrangements and transmission method (sketch, when appropriate);

– details of reinforcing steel or ducts in the vicinity of the test areas (if known);

– surface conditions and preparation at test points;

- measured values of path length, (for direct and semi-direct transmission) including:
  - a) method of measurement;
  - b) accuracy of measurement;
- calculated values of pulse velocity along each path;
- a declaration by the person technically responsible for the test, that it was carried out in accordance with this document;
- any deviation from the methods set out in the document.

9 Precision

There are no precision data available for this test.

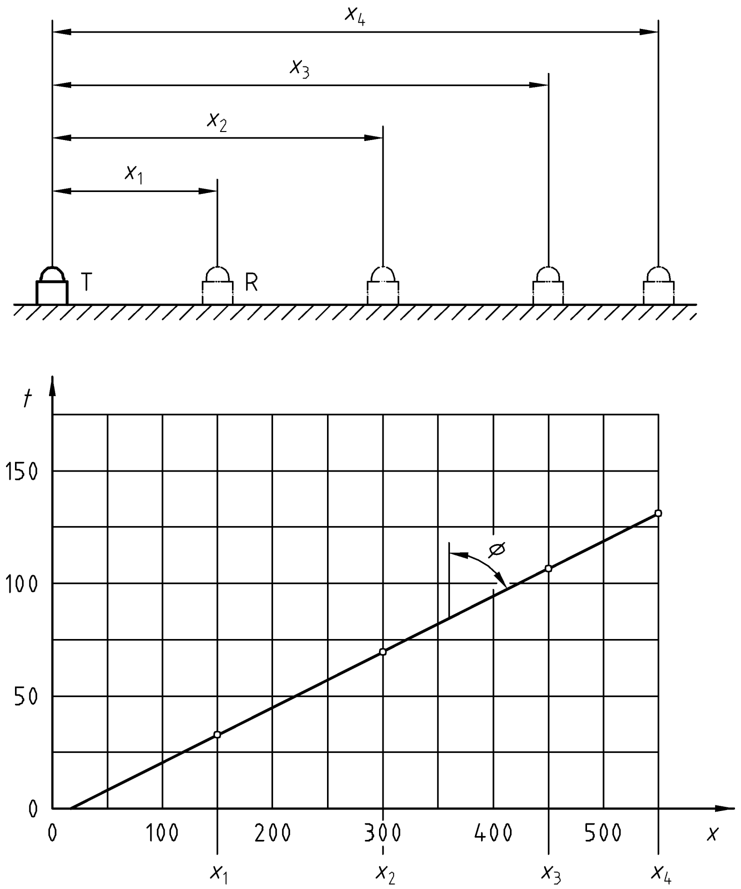
Annex A
(informative)

Determination of pulse velocity — indirect transmission

A.1 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 concrete. It is therefore preferable to make a series of measurements with the transducers at different distances apart to eliminate this uncertainty.

A.2 To do this, the transmitting transducer shall be placed in contact with the concrete surface at a fixed point x and the receiving transducer shall be placed at fixed increments 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.

A.3 The slope of the best straight line drawn through the points (tan ∅) shall be measured and recorded as the mean pulse velocity along the chosen line on the concrete 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 (see B.7) and a velocity measured in such an instance in unreliable.



Key

R is the receiver transducer
T is the transmitter transducer

Figure A.1 — Example of the determination of pulse velocity by indirect (surface) transmission

Annex B
(informative)

Factors influencing pulse velocity measurements

B.1 General

In order to provide a measurement of pulse velocity which is reproducible and which depends essentially on the properties of the concrete under test, it is necessary to consider the various factors which can influence pulse velocity and its correlation with various physical properties of the concrete.

B.2 Moisture content

The moisture content has two effects on the pulse velocity, one chemical, the other physical. These effects are important in the production of correlations for the estimation of concrete strength. Between a properly cured standard cubical or cylindrical specimen and a structural element made from the same concrete, there can be a significant pulse velocity difference. Much of the difference is accounted for by the effect of different curing conditions on the hydration of the cement, while some of the difference is due to the presence of free water in the voids. It is important that these effects are carefully considered when estimating strength (see Annex C).

B.3 Temperature of the concrete

Variations of the concrete temperature between 10 °C and 30 °C have been found to cause no significant change without the occurrence of corresponding changes in strength or elastic properties. Corrections to pulse velocity measurements should be made only for temperatures outside this range using guidance in the relevant literature.

B.4 Path length

The path length over which the pulse velocity is measured should be long enough not to be significantly influenced by the heterogeneous nature of the concrete. It is recommended that, except for the conditions stated in B.5, the minimum path length should be 100 mm for concrete in which the nominal maximum size of aggregate is 20 mm or less and 150 mm for concrete in which the nominal maximum size of aggregate is between 20 mm and 40 mm. The pulse velocity is not generally influenced by changes in path length, although the electronic timing apparatus can indicate a tendency for velocity to reduce slightly with increasing path length. This is because the higher frequency components of the pulse are attenuated more than that lower frequency components and the shape of the onset of the pulse becomes more rounded with increased distance travelled. Thus, the apparent reduction of pulse velocity arises from the difficulty of defining exactly the onset of the pulse and this depends on the particular method used for its definition. This apparent reduction in velocity is usually small and well within the tolerance of time measurement accuracy given in 5.2, but particular care needs to be taken when transmitting over long path lengths.

B.5 Shape and size of specimen

The velocity of short pulses of vibrations is independent of the size and shape of specimen in which they travel, unless its least lateral dimension is less than a minimum value. Below this value, the pulse velocity may be reduced appreciably. The extent of this reduction depends mainly on the ratio of the wave length of the pulse vibrations to the least lateral dimension of the specimen but is insignificant if the ratio is less than unity. Table B.1 gives the relationship between the pulse velocity in the concrete, the transducer frequency and gives recommendations for the minimum permissible lateral dimension of the specimen.

If the minimum lateral dimension is less than the wavelength or if the indirect transmission arrangement is used, the mode of propagation changes and, therefore, the measured velocity will be different. This is particularly important in cases where concrete elements of significantly different sizes are being compared.

Table B.1 — Effect of specimen dimensions on pulse transmission

Transducer frequency kHz	**Pulse velocity in concrete** (km/s)		
	v_c = 3,50	V_c = 4,00	v_c = 4,50
	Minimum recommended lateral specimen dimension (mm)		
24	146	167	188
54	65	74	83
82	43	49	55
150	23	27	30

B.6 Effect of reinforcing bars

When possible, measurements in close proximity to steel reinforcing bars, parallel to the direction of pulse propagation should be avoided.

B.7 Cracks and voids

When an ultrasonic pulse travelling through concrete meets a concrete-air interface, there is negligible transmission of energy across this interface. Thus, any air-filled crack or void lying immediately between two transducers will obstruct the direct ultrasonic beam when the projected length of the void is greater than the width of the transducers and the wavelength of sound used. When this happens, the first pulse to arrive at the receiving transducer will have been diffracted around the periphery of the defect and the transit time will be longer than in similar concrete with no defect.

Depending on the distance separating the transducers it is possible to make use of this effect for locating flaws, voids or other defects greater than about 100 mm in diameter or depth. Relatively small defects have little or no effect on transmission times, but equally are probably of minor engineering importance. Plotting contours of equal velocity often gives significant information regarding the quality of a concrete unit. Examination of the signal attenuation may also provide helpful information.

In cracked members, where the broken faces of the members are held tightly together in close contact by compression forces, the pulse energy may pass unimpeded across the crack. As an example, this can occur in cracked vertical bearing piles. If the crack is filled with liquid which transmits the ultrasonic energy, e.g. in marine structures or if the crack is partially filled with solid particles, the crack is undetectable using digital reading equipment. Measurements of attenuation can give valuable information in these cases.

A survey of measurements at grid points on the concrete structure enables a large cavity to be investigated by measuring the transit times of pulses passing between the transducers when they are placed so that the cavity lies in the direct path between them. The size of such cavities may be estimated by assuming that the pulses pass along the shortest path smallest transit times between the transducers and around the cavity. Estimates are valid only when the concrete around the cavity is uniformly dense and the pulse velocity can be measured in that concrete.

Annex C
(informative)

Correlation of pulse velocity and strength

C.1 General

The important physical properties of materials that influence pulse velocity are the elastic modulus and the density. In concrete these properties are related to the type of aggregate, their proportion and physical properties and the physical properties of the cement paste, which relate, mainly, to the original water/cement ratio and the maturity of the concrete. On the other hand, the strength of concrete is more related to water/cement ratio than to aggregate type and proportions of aggregate and paste. Thus correlations between the pulse velocity and strength of concrete are physically indirect and have to be established for the specific concrete mix. For an unknown concrete, the estimation of strength, on the basis of pulse velocity alone, is not reliable.

C.2 Correlation using moulded specimens

The method used for varying the strength of the specimens influences the correlation. It is therefore essential that only one method of strength variation is used for a particular correlation and that it be appropriate to the application required. The correlation of pulse velocity with strength is less reliable as the strength of concrete increases. A correlation obtained by varying the age of the concrete is appropriate when monitoring strength development but for quality control purposes a correlation obtained by varying the water/cement ratio is preferable.

The appropriate test specimens should be made and cured in accordance with EN 12390-1 and EN 12390-2. At least three specimens should be cast from each batch. The pulse velocity should be measured between moulded faces for cubes or axially for cylinders or cores. In the case of beams, it is preferable to measure the pulse velocity along their length to obtain greater accuracy. For each specimen there should be at least three measurements spaced between its top and bottom. The variation between the measured transit times on single test specimens should be within ± 1 % of the mean value of these three measurements, otherwise the specimen should be rejected as abnormal. The test specimens should then be tested for strength according to EN 12390-3.

The mean pulse velocity and mean strength obtained from each set of three nominally identical test specimens provide the data to construct a correlation curve. A correlation curve produced in this way relates only to test specimens produced, cured and tested in a similar way; different correlation curves will be obtained for the same concretes if air curing is substituted for water curing.

C.3 Correlation by tests on cores

When making a correlation from tests on cores taken from a structure it will not be possible to vary the strength of the concrete deliberately. Pulse velocity tests should, therefore, be used to locate areas of different quality and cores taken from these areas will give a range of strengths. The pulse velocity through the concrete at proposed core locations should be used for preparing the correlation. Pulse velocities taken from cores after cutting and soaking will generally be higher than those taken prior to coring and should not be used for direct correlation.

The cores should be cut and tested for strength according to EN 12504-1 and a correlation curve plotted.

For a given moisture state, the shape of the correlation line is sensibly the same for any given concrete. Therefore using the curve obtained by testing reference specimens with a similar moisture state can extend the limited range obtained from core samples.

C.4 Correlation with the strength of precast units

When precast components are required to conform to strength requirements, conformity may be established by measuring the pulse velocity and using a safe relationship between pulse velocity and strength.

The pulse velocity should be measured at the critical parts of the precast elements, i.e. those parts that are likely to fail first under conditions of use.

Bibliography

EN 12390-1, *Testing hardened concrete — Part 1: Shape, dimensions and other requirements for test specimens and moulds*

EN 12390-2, *Testing hardened concrete — Part 2: Making and curing specimens for strength tests*

EN 12390-1, *Testing hardened concrete - Part 3: Compressive strength of test specimens*

EN 12504-1, *Testing concrete in structures — Part 1: Cored specimens - Testing, examining and testing in compression*

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