Natural stone test methods — Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency)

The European Standard EN 14146:2004 has the status of a British Standard

ICS 73.020; 91.100.15

National foreword

This British Standard is the official English language version of EN 14146:2004.

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

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

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English version

Natural stone test methods - Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency)

Méthodes d'essai pour pierres naturelles - Détermination du module d'élasticité dynamique (par la mesure de la fréquence de résonance fondamentale)

Prüfverfahren für Naturstein - Bestimmung des dynamischen - Elastizitätsmoduls (durch Messung der Resonanzfrequenz der Grundschwingung)

This European Standard was approved by CEN on 16 January 2004.

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Foreword

This document (EN 14146:2004) 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of an identical text or by endorsement, at the latest by October 2004, and conflicting national standards shall be withdrawn at the latest by October 2004.

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

Test methods for natural stone consist of the following:

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 12371, *Natural stone test methods - Determination of frost resistance*

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 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*

prEN 14157, *Natural stone test methods – Determination of the abrasion resistance*

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

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

prEN 14579, *Natural stone test methods – Determination of sound speed propagation*

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

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

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1 Scope

This European Standard defines methods to determine the fundamental resonance frequency of natural stone and the calculation of the dynamic modulus of elasticity.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative reference are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

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

3 Principle

The present standard defines methods to determine the fundamental resonance frequency and to calculate the dynamic modulus of elasticity.

There are two methods for measuring fundamental resonance, depending on which method is used to vibrate the specimen under analysis. One method is based on continuous excitation, the other is based on instantaneous excitation. Both methods consist of making a specimen of stone vibrate using either longitudinal, flexural or torsional vibrations, and then determining the corresponding fundamental resonance frequency.

4 Symbols

b	width of a prismatic specimen in millimetres
d	diameter of a cylindrical specimen in millimetres
h	height of prismatic specimen in millimetres
ℓ	length of specimen in millimetres
F_L	longitudinal fundamental resonance frequency in Hertz
F_F	flexural fundamental resonance frequency in Hertz
F_T	torsional fundamental resonance frequency in Hertz
F_1 and F_2	frequency for amplitudes equal to Ö2/2 of the maximum amplitude
	apparent density of the specimen in kg m^{-3}
i	radius of giration of the section of the specimen $i = \sqrt{\frac{I}{A}}$ in mm
A	surface area of the cross section of the specimen
I	moment of inertia of the specimen

$I = \frac{bh^3}{12}$ for prismatic specimens with a rectangular base

$I = \frac{b^4}{12}$ for prismatic specimens with a square base

$I = \frac{d^4}{64}$ for cylindrical specimens

Poisson coefficient

T correction coefficient for calculating Ed_L

C correction coefficient for calculating Ed_F

R correction coefficient for calculating Ed_T

Ed_L longitudinal dynamic modulus of elasticity in MPa, determined from the longitudinal fundamental resonance frequency

Ed_F flexural dynamic modulus of elasticity in MPa, determined from the flexural fundamental resonance frequency

Ed_T torsional dynamic modulus of elasticity in MPa, determined from the torsional fundamental resonance frequency

s standard deviation

5 Apparatus

5.1 Continuous excitation mode

The apparatus comprises:

5.1.1 a variable frequency generator, with a frequency range of min. 20kHz,

5.1.2 an emitting transducer and a receiving transducer that must be brought into contact with the specimen. It is recommended to generate slight adhesion to the test specimen using a bonding product (rubber, putty, etc.). The natural resonance frequency of the transducer must be at least twice the presumed fundamental resonance frequency of the specimen.

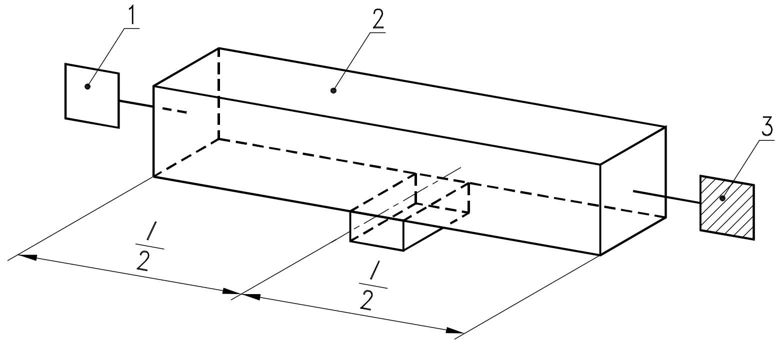
5.1.3 a device that is used to record or indicate the beginning of specimen resonance,

5.1.4 a system that measures or calculates the specimen’s fundamental resonance frequency with an accuracy better than or equal to 0,5%,

5.1.5 a work surface isolated from external vibrations, with the possibility to make measurements

5.1.6 specimen stands made of rigid metal whose length is at least equal to the width b

NOTE These supports are either rectangular or square section prisms whose width is less than 5% of the length ℓ of the specimens for longitudinal and torsional vibration (see Figures 1a and 2a) or small triangular section prisms for flexural vibration (see Figure 3a). In the case of cylindrical specimens, the supports should be notched. The positions of the supports are indicated in Figures 1, 2 and 3.



Key
1 Emitter
2 Specimen
3 Receiver

Figure 1a - Position of the transducers for longitudinal vibration

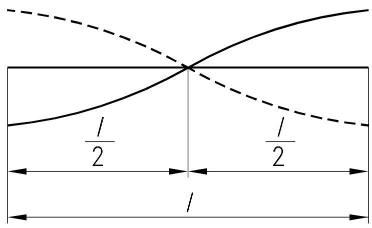


Figure 1b - Fundamental mode for longitudinal vibration

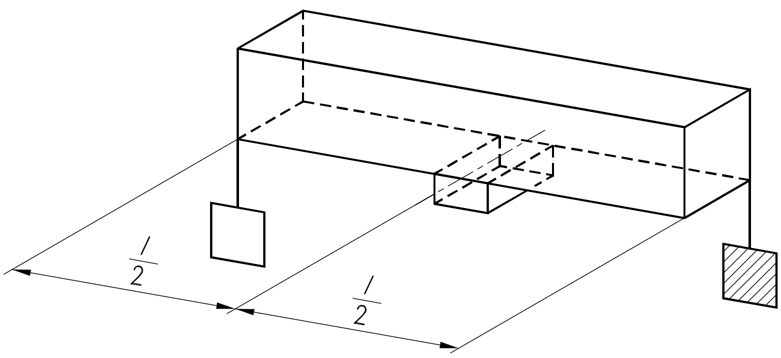


Figure 2a - Position of the transducers for torsional vibration

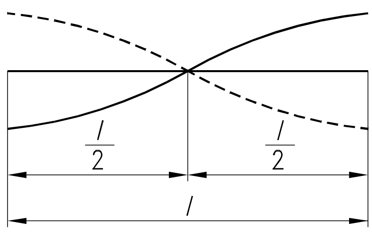


Figure 2b - Fundamental mode for torsional vibration

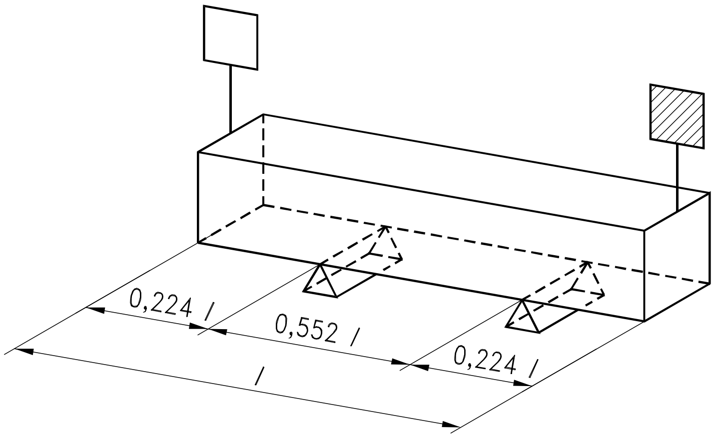


Figure 3a - Position of the transducers for flexural vibration

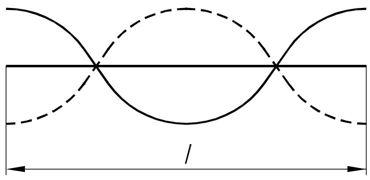


Figure 3b - Fundamental mode for flexural vibration with the nodes at 0,224 *l* from the ends

5.2 Instantaneous excitation mode

The apparatus comprises:

a) a mechanical pulse generator, which can be a hammer or an electric pulse generator;

b) a receiving transducer in the form of a vibration sensor pin. The resonance frequency of the transducer must be at least twice the presumed fundamental resonance frequency of the specimen;

c) a device that is used to record or indicate the beginning of the specimen resonance;

d) a system that measures or calculates the specimen’s fundamental resonance frequency with an accuracy better than 0,5%;

e) a work surface isolated from external vibrations, with the possibility to make measurements;

f) specimen stands made of rigid metal whose length is at least equal to the width *b*;

The position and shape of the test specimen supports are as described in 5.1.

5.3 Testing the repeatability of the apparatus

This verification must be carried out before and after each series of tests. The measurement of repeatability is tested at (20 3)°C with a square based calibration prism made of duraluminium. If the difference between the certified and the actual longitudinal fundamental resonance frequency of the prism is greater than 0,5% or the difference between the measurement before and after a test is greater than 0,1% then the test shall be declared invalid.

5.4 Additional apparatus for the two excitation modes

5.4.1 A balance with an accuracy of 0,01% of the mass to be determined.

5.4.2 A linear measuring device with an accuracy of 0,1 mm.

5.4.3 A rectangular parallelepiped with a square base, dimensions (40 1) mm x (160 1) mm, made of duraluminium.

NOTE Duraluminium is an alloy made of aluminium and copper.

6 Preparation of the specimens

6.1 Sampling

The sampling is not the responsibility of the testing laboratory except when it is especially requested.

At least six specimens from an homogeneous batch shall be tested.

6.2 Specimens

The test specimens shall be prismatic or cylindrical in shape. The length of cylindrical, square or rectangular based prisms shall be at least twice the largest dimension of the base.

6.3 Tolerances

The tolerances of the dimensions ℓ, b, d, h shall be 1 mm.

6.4 Planes of anisotropy

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

6.5 Conditioning the specimens

The measurements can be carried out with any water content and so the specimens require no conditioning before testing. However, the condition (that is wet or dry) and the temperature shall be reported exactly.

7 Procedure

7.1 Preliminary operations

If the specimens are wet they shall be wiped with a damp cloth before testing.

Measure the geometric dimensions, ℓ, b, h or d of each specimen to the nearest 0,1 mm in accordance with EN 13373.

Place the transducers as shown in Figures 1, 2 and 3.

Evaluate the corresponding fundamental resonance frequency using the chosen vibration mode F_L, F_T or F_F.

7.2 Excitation mode

7.2.1 Continuous excitation mode

Measure the excitation frequency using a frequency meter until the test specimen begins to resonate.

Record the beginning of the specimen resonance, which is obtained when the receiver records maximum energy.

On the frequency meter read the fundamental resonance frequency F_L, F_T or F_F. corresponding to the chosen vibration mode.

NOTE Is not always easy to accurately determine the moment at which resonance starts when testing a specimen with a relatively flat response curve (see Figure 4). In this case, scan the frequencies on either side of the fundamental resonance frequency and take frequency values, F, called F_1 and F_2 for amplitudes equal to Ö2/2 of the maximum amplitude. The fundamental resonance frequency is then equal to:

$$F_L \text{ or } F_F \text{ or } F_T \quad \frac{F_1 + F_2}{2}$$

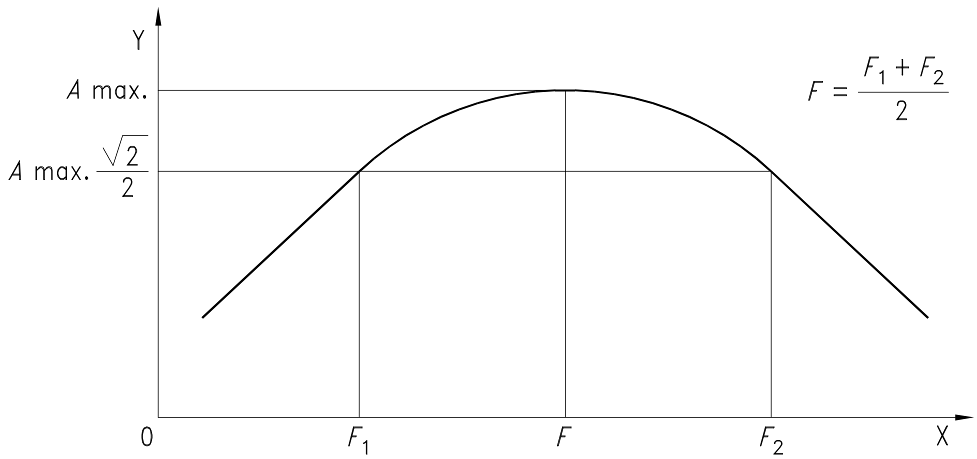


Figure 4 - Relationship between amplitude and frequency for a flat response curve

7.2.2 Instantaneous excitation mode

The specimen is vibrated repeatedly until three consecutive values are found at 60 Hz of the fundamental resonance frequency.

8 Calculation of the dynamic modulus of elasticity

8.1 General

This section gives the main formulae for calculating the dynamic modulus of elasticity and the application of these formulae in the case of prismatic specimens of length 4b or cylinders of length 4d or 3d, called “preferred specimens”.

8.2 Calculations of the longitudinal dynamic modulus of elasticity by means of the longitudinal resonance frequency.

8.2.1 Any specimens

The longitudinal dynamic modulus of elasticity, calculated from the fundamental resonance frequency in longitudinal vibration F_L is given by the formula:

$$Ed_{L} = 4 \quad 10^{\ 6} \quad \ell^{2} \quad F_{L}^{2} \qquad T \tag{1}$$

in which *T* is a correction factor which depends on *i* and and which is given by the formula:

$$T = 1 + \frac{\ ^{2} \quad ^{2} \quad i^{2}}{\ell^{2}}$$

8.2.2 Preferred specimens

In the case of the preferred specimens and if ℓ is expressed in metres, the value of *T* can be considered as 1. If *l* is expressed in metres, in kg/m^3 and F_L in Hz, the formula (1) for the longitudinal dynamic modulus of elasticity is simplified and becomes:

$$Ed_{L} = 4 \quad 10^{\ 6} \quad \ell^{2} \quad F_{L}^{2} \qquad \text{(in MPa)}$$

8.3 Calculation of the flexural dynamic modulus of elasticity by means of the flexural resonance frequency.

8.3.1 Any specimens

The flexural dynamic modulus of elasticity calculated from the fundamental resonance frequency in flexural vibration F_F, is given by the formula:

$$Ed_{F} = 4x10^{\ 6} \frac{\ ^{2}\ell^{4}}{\left(4{,}73^{4}\right) i^{2}} F_{F}^{\ 2} \qquad C \ \text{(in MPa)} \tag{2}$$

in which:

C is correction factor which depends on *i* and on .

$$C = \frac{1}{2} + \frac{(4{,}73)^{2}}{2} \quad \frac{i^{2}}{\ell^{2}} \quad 1 + \frac{6}{5} \quad 2(1+ \quad) + \sqrt{\frac{1}{4} + \frac{(4{,}73)^{2}}{2} \quad \frac{i^{2}}{\ell^{2}} \quad 1 + \frac{6}{5} \quad 2(1+ \quad) + \frac{(4{,}73)^{4}}{4} \quad \frac{i^{4}}{\ell^{4}} \quad 1 \quad \frac{6}{5} \quad 2(1+ \quad)^{\ 2}}$$

Some values of *C* are given in Table 1 for any specimens.

8.3.2 Preferred specimens

In the case of preferred specimens, if ℓ is expressed in metres, the formula (2) for the longitudinal dynamic modulus of elasticity is simplified and becomes:

for prismatic specimens with a square base:

$$Ed_{F} = 15{,}136 \quad 10^{\ 6} \quad \ell^{2} \quad F_{F}^{2} \qquad C \ \text{(in MPa)}$$

C = 1,409 to 1,451 for varying from 0,14 to 0,30 (see Table 2);

for cylindrical specimens with $\ell = 3 \times d$:

$$Ed_{\mathrm{F}} = 11{,}358 \quad 10^{\ 6} \quad \ell^2 \quad F_{\mathrm{F}} \qquad C \text{ (in MPa)}$$

C = 1,537 to 1,593 for   varying for 0,14 to 0,30 (see Table 2);

for cylindrical specimens with $\ell = 4 \times d$:

$$Ed_{\mathrm{F}} = 20{,}190 \quad 10^{\ 6} \quad \ell^2 \quad F_{\mathrm{F}} \qquad C \text{ (in MPa)}$$

C = 1,311 to 1,342 for   varying for 0,14 to 0,30 (see Table 2);

Table 1 — Value of *C* for any specimens

i/ ℓ	Poisson Coefficient								
	0,140	0,160	0,180	0,200	0,220	0,240	0,260	0,280	0,300
0,03	1,074	1,075	1,076	1,077	1,078	1,079	1,080	1,081	1,082
0,04	1,131	1,132	1,134	1,136	1,137	1,139	1,141	1,142	1,144
0,05	1,202	1,204	1,207	1,210	1,212	1,215	1,217	1,220	1,222
0,06	1,287	1,291	1,294	1,298	1,302	1,305	1,309	1,313	1,316
0,07	1,386	1,391	1,396	1,401	1,406	1,411	1,415	1,420	1,425
0,08	1,497	1,504	1,510	1,517	1,528	1,529	1,536	1,542	1,549
0,09	1,622	1,630	1,638	1,646	1,654	1,662	1,670	1,678	1,686
0,10	1,758	1,768	1,778	1,787	1,797	1,807	1,817	1,827	1,837

Table 2 — Value of *C* for preferred specimens

	Poisson Coefficient								
	0,140	0,160	0,180	0,200	0,220	0,240	0,260	0,280	0,300
Cylindrical specimens (ℓ /*d* = 4) (*i*/ ℓ = 0,0625)	1,311	1,315	1,318	1,322	1,326	1,330	1,334	1,338	1,342
Cylindrical specimens (ℓ /*d* = 3) (*i*/ ℓ = 0,0833)	1,537	1,544	1,551	1,558	1,565	1,572	1,579	1,586	1,593
Prismatic Specimens (ℓ /*b* = 4) (*i*/ ℓ = 0,0722)	1,409	1,414	1,419	1,425	1,430	1,435	1,440	1,446	1,450

8.4 Torsional dynamic modulus of elasticity by means of the torsional resonance frequency

8.4.1 Any specimens

The torsional dynamic modulus of elasticity, calculated from the fundamental resonance frequency in torsion F_T, is given by the formula :

$$Ed_T = 4 \quad 10^{\;6} \quad \ell^2 \quad F_F^2 \qquad R \tag{3}$$

In which R is a correction factor.

In the case of prismatic specimens, the value R is:

$$R = \frac{\frac{h}{b} + \frac{b}{h}}{4\frac{b}{h} \quad 2{,}52\left(\frac{b}{h}\right)^2 + 0{,}21\left(\frac{b}{h}\right)^6}$$

In case of cylindrical specimens, the value R equals to 1.

8.4.2 Preferred Specimens

In the case of preferred specimens, the values of R are:

1 for cylindrical specimens

1,183 for prismatic specimens with a square base

9 Test report

The test report shall contain the following information:

a) unique identification number of this report;

b) number, title and date of issue of this European Standard;

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

d) name and the address of the client;

e) it is the responsibility of the client to give 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 each specimen by two parallel lines;

-name of the person or organisation which carried out the sampling;

-surface finish of the specimen (if relevant to the test);

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

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

h) number of specimens in the sample;

i) dimensions of the specimens;

j) orientation of the long axis of the specimens with respect to the anisotropy planes;

k) state of the specimens (e.g. wet or dry) and the temperature at the time of testing;

l) resonance mode or modes;

m) individual fundamental resonance frequency in Hertz for each specimen;

n) apparent density in kg/m^3 for each specimen;

o) dynamic modulus of elasticity in MPa;,

p) mean dynamic modulus of elasticity in MPa to the nearest 10 MPa;

q) standard deviation in MPa to the nearest 10 MPa and the coefficient of variation;

r) all deviations from the standard and their justification.

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