The fundamental resonance frequency measurement: critical evaluation of test method on natural stone

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Synopsis

Fundamental Resonance Frequency method (FRF) is foreseen by European Standard for the evaluation of the durability and state of conservation of natural stones. For these reason it is important to understand if this technique, widely applied in the determination of mechanical property of industrial materials as concrete and ceramics, can provide reliable results in the applications on natural stone. In this work, European Standard EN 14146:2004 (natural stone test method) has been analysed, starting from the comparison with American ASTM C215:2014 (concrete specimens test method). Four different stones have been tested with FRF method in order to obtain values of dynamic modulus of elasticity, following respectively EN and ASTM instructions. The same samples have been additionally tested with Ultrasonic Pulse Velocity (UPV) measurement, in direct mode, by means European Standard EN14579:2004. Results obtained with FRF method following both ASTM and EN Standards are comparable for all the rock samples and these values do not differ significantly from dynamic modulus of elasticity from UPV measurement. Both ASTM and EN standard can be applied testing natural stones but with accurate consideration about rock fabric, sample dimensions, position of supports and location of the impulse. Indication suggested for artificial material as concrete can be therefore used in natural stone samples with approximate homogeneous composition and structure.

Keywords

Dynamic modulus of elasticity, standardized test method, ultrasonic pulse velocity.

Introduction

The value of dynamic modulus of elasticity, used to express mechanical properties of rock materials, may be obtained by means of two non-destructive tests: Ultrasonic Pulse Velocity (UPV) and Fundamental Resonance Frequency measurements (FRF). The first technique measures P and S ultrasonic wave velocity transmitted in a stone specimen, while the second one measures the mechanical resonance frequency.

UPV test is one of the most common methods used to assess the state of conservation of a stone element measuring elastic modulus; it gives accurate results, well correlated to mechanical properties of stones tested even with flexural strength measurements. Different kind of rocks has been tested with this method and lots of data are available in literature (Luodes et al. 2017, Bellopede et al. 2016, Rasolofosaon et al. 2000). The European test method for determination of UPV in natural stones, both in laboratory and in situ, is the European Standard EN 14579:2004.

The determination of dynamic modulus of elasticity with the FRF method in natural stones is foreseen by the European Standard EN 14146:2004. Moreover this technique is required by the EN 14066:2013 to evaluate the damage caused on natural stones to the thermal shock cycles. The determination of resistance to thermal shock cycles is required for CE marking of natural stone products as slabs for cladding (EN 1469:2013), modular tiles (EN 12057:2004) and slabs for floor and stairs (EN 12058:2004).

Considering therefore the requirement of European Standards for the evaluation of the durability and state of conservation of natural stones, it is important to understand if this technique, widely applied in the determination of mechanical property of industrial materials as concrete and ceramics (considered as homogeneous, elastic isotropic materials) can really provide reliable results in the applications on natural stones. For this reason, the European Standard for the determination of dynamic modulus of elasticity by measuring the fundamental resonance frequency in natural stones (EN14146:2004) has been analysed, starting from the comparison with ASTM C215:2014.

The European and International Standards on the Fundamental Resonance Frequency measurements

The FRF method measures the modulus of elasticity exciting a specimen by means of a mechanical impulse and analysing the transient natural vibration during the subsequent free relaxation. Complex vibratory phenomena are generated on depending on the nature of the material (Chantre et al, 1978). Specimens can be excited into longitudinal, flexural (indicated as "transverse mode" by ASTM Standards) and torsional modes in order to obtain, respectively, the modulus of elasticity (E) in either flexural and longitudinal mode and the modulus of rigidity (G) in the torsional one. The method is limited to specimens with regular geometries (rectangular parallelepiped, cylinder and discs) with no discontinuities (large cracks) for with analytical equations are available. Concerning the standardized test methods, while EN 14146 refers to natural stones, ASTM C215 covers the determination of dynamic elastic properties for concrete specimens.

Apparatus and test specimens

The equipment used for FRF measurement, suggested in both EN 14146 and ASTM C215 instructions, is made by an impulser, a receiver (pick up transducer) to convert the mechanical vibration into an electrical signal, an electronic system and a support system. According to the standardized methods, test specimens shall be prismatic or cylindrical in shape. Both EN 14146:2004 and ASTM C215:2014 foresee that the length of cylindrical square or rectangular based prisms shall be at least twice the largest dimension of the base.

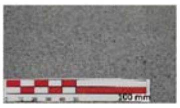
Supports and Location of the impulse/transmitter

Both EN14146 and ASTM C215 foresee to work on an isolated surface using specimen stands. EN suggest the use of rigid rectangular or square section prismatic metal stands (in longitudinal and torsional mode), whose width is less than 5% of the length of the specimen, or triangular section prisms (in flexural mode). Standards suggests that the specimen supports shall be located in correspondence of the specimen nodal points for different modes of vibrations. The difference between the two standards is the location of the impulser/transmitter that should be positioned at the extremity of the specimen (opposite to the receiver) according to EN, at the center of the specimen according to ASTM.

Materials and methods

Specimens with dimensions 400x100x100mm (rectangular parallelepiped) have been tested: Trachite (TRA), Red Balmoral Granite (RO), Basalt (BA), Gneiss Lodrino (LO) (Tab. 1).

Table 1. Description of rock specimens: origin, textural and mineralogical characteristics.

Rock specimen	Acronym	Textural and mineralogical description	Macroscopic aspect
Trachite	TRA	Fine grained volcanic rock from Banari (Sardinia) with a porphyritic structure; it is mainly composed of alkali feldspar (sanidine, orthoclase), subordinate plagioclase, biotite, amphibole and pyroxene.	
Red Balmoral Granite	RO	Non-foliated, equigranular, medium-grained red granite from Finland. This intrusive rock is mainly composed of alkali feldspar, quartz, plagioclase, biotite and muscovite.	
Basalt	BA	Fine grained volcanic rock from Sardinia with a porphyritic structure, mainly composed of plagioclase, pyroxene (augite), olivine and subordinate hornblende, biotite and opaque minerals (hematite and magnetite).	
Gneiss Lodrino	LO	Foliated metamorphic rock from Swisse characterized by alternating layers composed of different mineral. Main composing minerals are feldspar (albite, alkali feldspar), quartz, biotite, muscovite, and subordinated amphibole	

FRF measurements were performed with a Resonance Frequency meter 58-E0035/C (Fig. 1) equipped with a display of harmonic frequencies in order to better evaluate the results. To excite the response, a light and elastic tap was executed following Standard suggestion. To detect the resulting vibration and converting it into electrical signals, a hand-held piezoelectric detector was used in contact with the test sample. In ASTM instructions more detailed information regarding the position of nodal points are given. Concerning the FRF in transversal mode, as the execution according EN didn't give reliable results, impacts in the center according ASTM have been executed; however the E_{transv} has been calculated with the EN equation. The Ultrasonic Pulse Velocity (UPV) have been measured in direct mode by means PUNDIT device in order to verify the reliability of FRF results.

Fig. 1 Resonance Frequency meter 58-E0035/C.

Results

Table 2 resumes data obtained by means of both FRF measurements according EN 14146 and ASTM C215 (converted in GPa), and UPV measurements, with their value of uncertainty ($e = std/E_{mean}*100$) calculated as ratio between standard deviation (std) and mean value (E_{mean}) in percentage. FRF data obtained were used to calculate values of elastic modulus of elasticity (E) and modulus of rigidity (G) using different equations following EN and ASTM instructions. UPV values of E were obtained according with Santamarina J.C. (2001) equation.

Table 2. Comparison FRF results according EN 14146:2004, ASTM C215:2014 and UPV.

	E (UPV)		E transv (FRF)			E long (FRF)			G tors (FRF)		
	E (GPa)	(e) %	EN (GPa)	ASTM (GPa)	(e) %	EN (GPa)	ASTM (GPa)	(e) %	EN (GPa)	ASTM (GPa)	(e) %
TRA	33.9	0.35	32.7	32.6	0.57	30.9	30.9	0.56	12.3	12.3	0.73
RO	30.7	0.93	30.3	29.7	1.21	27.0	27.0	0.61	13.6	13.6	0.12
BA	54.2	0.33	48.5	48.1	1.11	45.8	45.8	0.55	18.3	18.3	0.63
LO	40.3	0.00	37.4	37.3	0.84	36.7	36.7	0.53	13.0	13.0	0.57

Discussion and conclusions

The E_{long} and G, obtained with ASTM and EN Standards equations, are the same for all the rock tested. Instead, E_{transv} calculated according EN is different from E_{transv} calculated according ASTM because of different factor corrections suggested by the two standards. The results of dynamic modulus obtained by means UPV are in all cases higher than those obtained by FRF measurement.

In conclusions, considering the results obtained, both ASTM and EN standards can be applied on natural stones taking into account sample dimensions, position of support and location of the impulse and rock fabric (presence of anisotropy, large cracks or voids). So, indication suggested for concrete, can be used in natural stone samples with approximate homogeneous composition and structure and in absence of fractures.

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