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THE MECHANICAL RESISTANCE OF SATURATED STONES

Paola Marini[1], Rossana Bellopede[1]
[1] *Land, Environment and Geo-Engineering Department -Politecnico di Torino, Corso Duca degli Abruzzi 24 – 10129 Torino, Italy, paola.marini@polito.it, rossana.bellopede@polito.it*

Abstract

This paper aims at investigating the effect of the presence of water on the mechanical resistance of stones. The presence of water, connected to the intrinsic properties of the stone (mineralogical composition, fabric, texture, etc.) and to the conditions of use (anchoring systems, climatic parameters, etc), is the main cause of stone decay. However, the presence of water alone inside stone could cause a decrease in mechanical resistance .

The obtained data could in fact be useful to correct the safety coefficient and should be taken into account in the planning of structural stonework.

Moreover, useful suggestions can be drawn for the in situ monitoring, taking into account that non destructive tests, together with conventional mechanical methods, are influenced by the presence of water in stones and should be corrected.

Three kinds of stones, which have historically been used for structural purposes, have been studied: Pietra di Luserna (gneiss, Piedmont, Italy), Pietra Verde Argento (gneiss, Piedmont, Italy) and Pietra di Courtil (mica-schist, Aosta Valley, Italy).

The flexural strength, rupture energy, open porosity and ultrasonic pulse velocity (UPV) have been determined on specimens in dried and saturated conditions at different accelerated ageing steps.

As far as the UPV test is concerned, its results are well correlated with the flexural strength values but, without other parameters, it cannot give information on whether the specimen is filled with water, therefore suitable procedures to correct the UPV value obtained in situ are suggested.

Destructive methods, and in particular the flexural strength method, instead, give lower resistance values for saturated specimens than dried ones, thus confirming the weakness of the stone due to the water inside.

Keywords: water influence, mechanical resistance, saturation

1. Introduction

In the last few years there have been many cases of fault in stone modillions or stone balcony slabs (fig. 1, 2 and 3). These faults have mainly occurred in historical buildings and the involved stones that have been used for centuries, normally with very good performances and resistant to decay.

Figure 1: The remains of a balcony in Pietra di Courtil.

The research has been started in order to explain how the anomalous breaking has occurred.

A database has been set up pertaining to 62 cases of stone balconies in Piedmont (Perino 2008).This database reports the kind of stone and its conditions, the dimensional characteristics and the structural of the balcony.

Figure 2: The broken balcony slab of figure 1.

The study has been organized in two directions: non destructive and destructive tests performed on three historical stones that are extensively used for balconies and modillions in Northern Italy. It has been decided to test stone specimens in both wet and dry conditions because it is known in the scientific stone community that water has a bad influence on materials in use (Luodes et al. 2006, Chen et al. 2004, Winkler 1994).

Figure 3: Details of a balcony were the beam leans in correspondence to a fracture.

Almost all the ageing methods used on natural stones involve water, which together with other factor induces weathering: thermal shock (EN 14066), freeze and thaw (EN 12371), salt crystallization (EN12370), resistance to humidity and SO_2 (EN 13919) resistance thermal and moisture cycling (work item of the TC 246). Moreover it is important to consider the loss in mechanical resistance due to the wet condition of the stone.

Winkler (1994) on the basis of previous work by Colback and Wiid (1965) and by Michalopoulos and Triafilidis (1976), proposed a correlation between flexural resistance in wet and in dry condition, that is useful for a quick evaluation of the quality of a stone. This method has been used by some authors (e.g. Wasserman, 2002) to assess the quality of stones.

Some catalogues or publications present the mechanical properties of stones in wet and dry conditions (Yu et al. 2001; Smith 1999) but European Standards only foresee tests in dry conditions, while ASTM foresees tests in wet conditions if necessary.

On the basis of the results of the research, the dimensioning of balconies which have fractures and faults has been verified. It has been observed that, in most cases, if the data relative to the mechanical resistance, obtained from tests on saturated samples, had been inserted into the project, rupture of the balcony would have been avoided as it would have been dimensioned correctly

The goal of the research is to offer useful indications for the monitoring of buildings by means of non destructive tests, taking into account that test such as UPV (Ultrasonic Pulse Velocity) are influenced to a great extent by the presence of water, and to underline the risks of only considering the mechanical strength in dry conditions, when the design involves natural stones.

2. Materials and method

Three kinds of stones, which have been employed historically with structural functions, have been studied.

Pietra di Luserna: gneiss. This stone outcrop over an area of about 50 km^2 between Val Pellice and Val Po (Piedmont, Italy). Some of its characteristics, such as its easy splitting and the high resistance and durability, have favoured its utilization for both inside use (floorings, windowsills) and for outdoors (balconies, modillions, staircases, coverings, fireplaces and coverages) over the centuries. In the 19th century The greatest architectural work was the Mole Antonelliana in Turin, where Luserna stone was employed by Alessandro Antonelli (1798-1888) to cover the great dome and the steeple above.

Pietra di Courtil: micascist. This comes from the Hône quarry (Aosta Valley, Italy). The stone has probably been used since the Middle Ages, but its systematic exploitation started at the beginning of 19h century. It has been used both indoors and outdoors (mainly to cover roofs) because of its rustic aspect and its quality and hardness characteristics.

Pietra Verde Argento: gneiss. This is exploited in the Settimo Vittone quarries (Piedmont, Italy). This green coloured stone, characterized by silver mica, has been used both indoors and outdoors for centuries,.

The following tests have been executed on the stone specimens, in both wet and dry conditions: flexural strength (according to EN 12372: 2006), open porosity (according to EN 1936: 2006), UPV in indirect method (according to EN 14579: 2004). These techniques have been used in order to detect the decay of natural stones (Bellopede et al. 2005a and b, Kaharaman 2007, Marini et al. 2009) and their results are well correlated.

In order to reproduce the real exposure conditions of natural stones in buildings , the stones have been subjected to artificial ageing by means of freezing-thawing cycles according to

EN 12371: 2001 standard. A total of 60 cycles have been performed. The same specimens have been tested at t_0, at intermediate steps and at t_{60} in the non destructive tests (open porosity and UPV). The flexural strength test has been performed on two different sets of specimens, one in natural conditions and the other subjected to 60 freezing and thawing cycles.

3. Results

The freezing and thawing cycles did not produce an appreciable decay in the three stones.

The results of the open porosity test are shown in table 1as the mean value of 6 specimens. As the variation in p_o from t_0 to t_{60} is very limited, the results are reported with a precision of 0,01%, and a very slight decay can be appreciated for the Pietra di Courtil as can be seen from the 6% increase in p_o.

Table 1. Determination of open porosity at different decay steps

Cycles	Pietra di Courtil $p_o(\%)$	Pietra Verde Argento $p_o(\%)$	Pietra di Luserna $p_o(\%)$
T_0	0,70	0,64	0,83
T_{30}	0,71	0,64	n.d.
T_{60}	0,74	0,64	0,84

The results of UPV for each freeze-thaw step are reported in the graph of figure. 4.

The graph show no variation for the dry conditions, while the specimens tested with UPV in wet conditions have a higher standard deviation and a different trend, probably due to the increase in porosity (even though very limited) and as a consequence of the presence of a higher amount of water.

In spite of the open porosity results, the UPV measurements do not reveal the limited real weathering state to which the stone has been subjected.

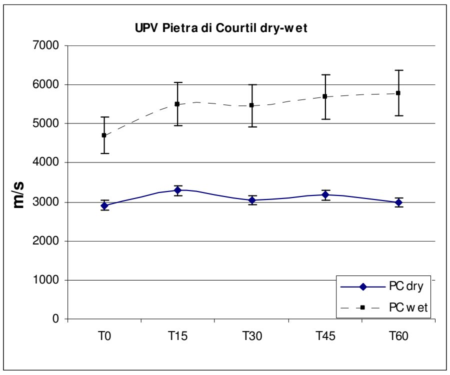

Figure 4: UPV (indirect method) on Pietra di Courtil in wet and dry conditions for each ageing step.

As far as the destructive tests are concerned, the flexural resistance test performed on the dry specimens subjected to the ageing cycles compared with the one executed on dry specimens in a natural state only varies from to 2% to 4,8 %. It should be considered that the comparison is made between two different sets of specimens and the variability of the stone should be taken in account.

The comparison between the results of flexural strength on specimens in dry conditions compared to wet conditions, shows a decrease in the values from 5% to 24%. The flexural strength values for the three kinds of stones, in dry conditions and in wet conditions, both at t_0 and t_{60} are reported in figure 5.

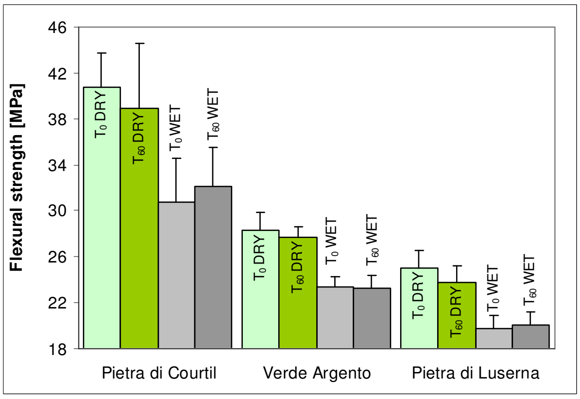

Figure 5: Flexural strength results in dry and wet conditions at T_0 and T_{60} ageing steps.

4. Discussion and conclusion

4.1 UPV and open porosity

UPV tests are not able to show slight differences induced by decay because of the high uncertainty in the results. This kind of measurement is conditioned by the water content, which can cause even higher ultrasonic velocity values than those obtained in dry conditions, and sometimes even higher than 50% (Figure 6). (Rotonda and Ribacchi 1995, Weiss et al. 2002).

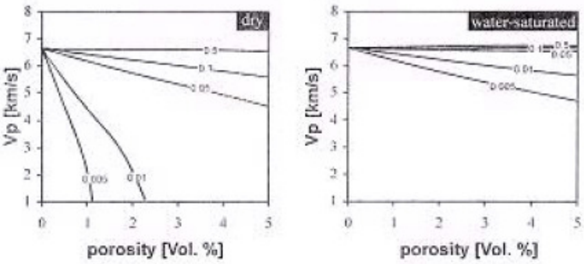

Figure 6: Porosity versus UPV in dry and wet conditions in function of pores dimensions (from Weiss et al. 2002)

Some indication can be found in literature on how to correct the UPV results on wet specimens: using either a reference stone (with controlled temperature and moisture - Bellopede et al. 2005), or by means mathematical models (Vasconcelos et al. 2008, Kaharaman 2007).

4.2 Flexural strength and open porosity

From the results obtained from the flexural strength tests in dry and wet conditions, stones, even when very durable, show the effects of water inside, which considerably lowers their resistance. The flexural strength on wet specimen of all the stone tested is much lower than the values obtained on dry specimens, for the corresponding ageing steps (Table 2). This effect has been faced in different ways (Winkler, 1994; West 1994), only considering it for porous stones. However, taking into account that it happens for stones with low porosity, it should be further explained.

The decrease in flexural strength from T_0 to $T_{60}$of specimens in dry conditions, correlated to the increase of porosity, does not occur in wet condition (Table 3).

Table 2: Flexural strength variations from dry to wet condition at T_0 and T_{60}

	Flexural strength variation from dry to wet condition [%]		
Cicli	Pietra di Courtil	Pietra Verde Argento	Pietra di Luserna
T_0	-24	-17	-21
T_{60}	-17	-16	-15

Table 3: Flexural strength and open porosity variations from T_0 to T_{60}

Tests	Pietra di Courtil		Pietra V. Arg.		Pietra di Luserna	
	ΔT_0-T_{60} dry [%]	ΔT_0-T_{60} wet [%]	ΔT_0-T_{60} dry [%]	ΔT_0-T_{60} wet [%]	ΔT_0-T_{60} dry [%]	ΔT_0-T_{60} wet [%]
Fl.Str.	-4,6	+4	-2,1	-0,9	-5	+2
Op.por	+6		+1		+1,3	

5. Conclusions

The three kinds of stones during both non destructive and destructive tests show a good resistance to weathering.

Of the three stones that have been analysed, the micascist Pietra di Courtil is the one that is most influenced by freeze-thaw cycles, and it suffers more than the others two gneiss from the presence of water probably because it has a higher percentage of mica. This can be see from the flexural strength and open porosity results, while the UPV test cannot detect the very limited change in the structure of the stone.

The flexural strength values obtained from specimens tested in wet conditions are surely useful to dimension buildings where such stones will be employed, as they allow the project resistance to be calculated. By recalculating the dimensions of the balcony of figure 1 and 2, it has been possible to demonstrate the previously mentioned assumption. By using the results obtained from the flexural strength in wet condition in the calculation, it has been observed that the modillions should have been positioned at a closer distance in order to prevent the slab from being subjected to high flexural load.

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