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COMPRESSIVE STRENGTH OF TUFF BRICKS IN DIFFERENT TEST CONDITIONS. FINAL RESULTS

Giorgio Frunzio[1] Camilla D'Onofrio[1] and Michela Monaco[2]

ABSTRACT

This paper is the final part of an experimental research program aimed at collecting information about the most used masonry stone in the Neapolitan area, the yellow tuff. The influence of shape, dimentions, moisture, friction between testing machine platen and specimens on the compressive strength is investigated. The results of the analysis is presented both graphically and numerically.

INTRODUCTION

Yellow tuff has been an important building material for hundreds of years, in the Neapolitan area, thus a large part of architectural heritage of the region consists of this natural stone masonry building. In spite of the great interest in restoration of ancient building, there is a great lack of data about the mechanical characteristics together with the lack of standardized testing methodology, so the few available data are not always useful. Hence, the accuracy and consistency with which the mechanical properties are determined is significant, so reliable testing procedures are required together with experimental data.

This paper deals with the results of a large number of tests, performed on cylindrical, prismatic and cubic specimens in different moisture and restraint conditions. In order to collect information about yellow tuff mechanical properties, which vary from quarry to quarry, the results of a large number of compressive tests performed on tuff specimens taken from two different quarries are presented.

[1]Researcher, Dipartimento di Scienza delle Costruzioni, Università degli Studi "Federico II", Napoli, Italia.
[2]PHD, Dipartimento di Scienza delle Costruzioni, Università degli Studi "Federico II", Napoli, Italia.

MATERIALS AND PROCEDURE

Materials

Yellow tuff is a pyroclastic soft rock originated from the volcanic activity of Phlaegrean Fields, formed by an ashy matrix in which pumices and lithic fragments (volcanic glass particles, crystal and lava fragments) are chaotically arranged. Lithic consistence is due to a diagenetic process.

Specimens were prepared with stone units acquired from two different quarries in the Neapolitan area. Tuff units A-type, coming from "Cava Quarto" exhibited almost homogeneous texture, with inclusions of little dimensions (up to 15 mm pumice fragments and sandy size lithic ones). Tuff units B-type, coming from "Cava Camaldoli", presented grains irregularly shaped, and their size might range from few mm to several cm.

Tests setup

The two types of tuff investigated [Frunzio et al., 1992; 1994] present material properties with cylindrical symmetry. Strength along the symmetry axis, the vertical one in situ (quarry), corresponding to the direction of the longest side of stone units, is the lowest one.

The influence of two different parameters has been investigated:

a) *Interface conditions*: specimens were tested wheter without interface with machine platen or with an interface assembly consisting of two layers of teflon (2 mm) to reduce the end lateral restraint, since a complete elimination of interface friction was not expected.

b) *Moisture conditions*: tests were performed both on dried and saturated to constant mass specimens. Saturated ones were obtained putting them directly in water from room conditions. A previous drying process to constant mass, according to [Rilem, 1990], before the immersion in water, could have caused damage to the wholeness of the specimen [Frunzio et al., 1992], because the particular structure of pumices inclusions.

c) *Shape*: tests were performed on cubic, prismatic and cylindrical specimens.

d) *Dimensions*: cubic specimens with side of 4, 5, 7, 10 cm, prismatic 7x7x14 cm and cylindrical 7x14 ones were tested.

The testing machine consisted of an universal testing machine C_1 class with a servo-controlled hydraulic actuator with 200 kN force rating. The loading rate was 5 N/mm^2 sec.

Specimens surfaces were ground until a representative surface was obtained [Rilem, 1990].

Four test conditions were realized:

1) Specimens, dried to constant mass, tested without interface medium.
2) Specimens, dried to constant mass, tested with interface medium.
3) Specimens, saturated to constant mass, tested without interface medium.
4) Specimens, saturated to constant mass, tested with interface medium.

RESULTS

Tests results are reported in following figures and tables.

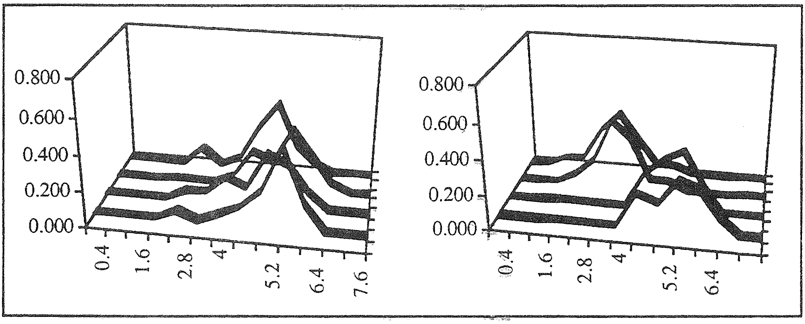

Fig.1 Distribution of the compressive strength in the four test conditions for A-Type (left) and B-Type (right) cylindrical specimens

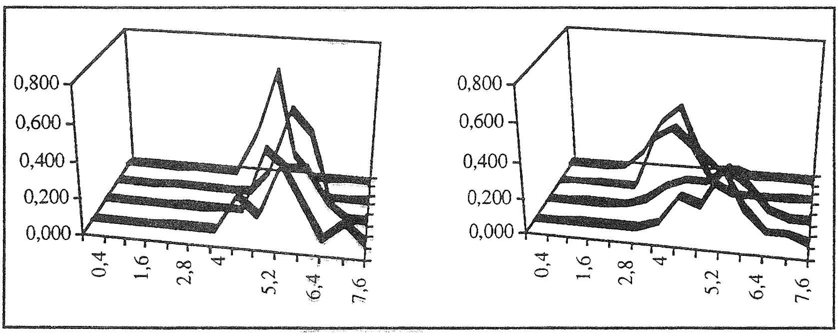

Fig.2 Distribution of the compressive strength in the four test conditions for A-Type (left) and B-Type (right) prismatic specimens

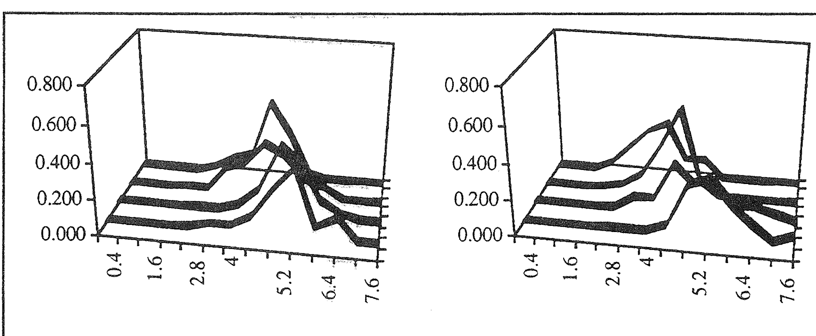

Fig. 3 Distribution of the compressive strength in the four test conditions for A-Type (left) and B-Type (right) 70 mm cubic specimens

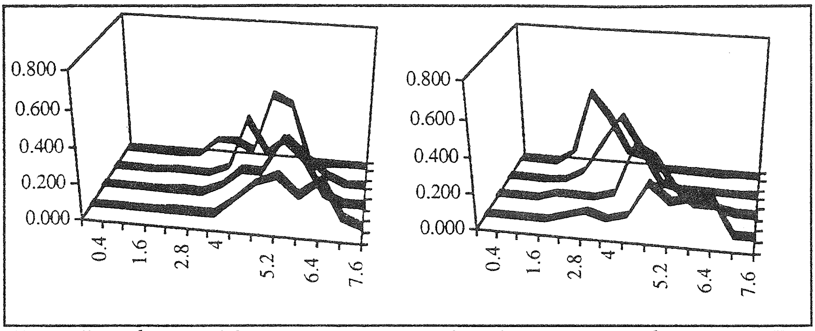

Fig. 4 Distribution of the compressive strength in the four test conditions for A-Type (left) and B-Type (right) 100mm cubic specimens

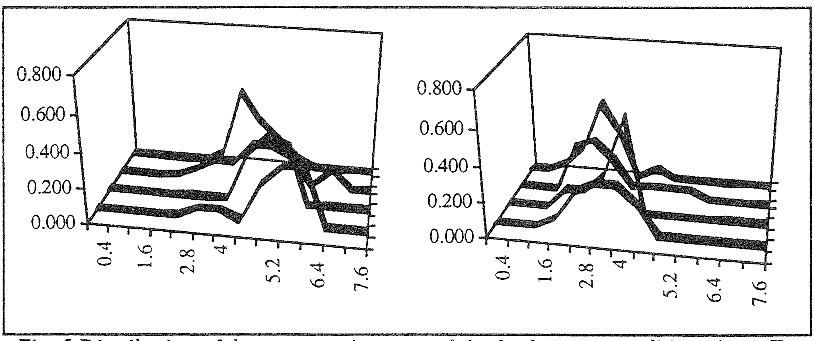

Fig. 5 Distribution of the compressive strength in the four test conditions for A-Type (left) and B-Type (right) 50mm cubic specimens

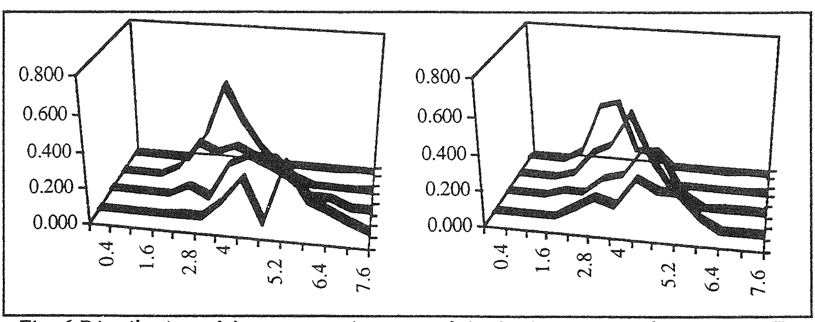

Fig. 6 Distribution of the compressive strength in the four test conditions for A-Type (left) and B-Type (right) 40mm cibic specimens

CONCLUSIONS

From the analysis of the test results it can be concluded that:

- Compressive strength is strongly related to grain size and to homogeneity of texture, so in general to the inner structure of the material, and to the dimensions of the specimens, which must be related to that of the inclusions.

- There is a sensible difference wet and dry testing conditions: the compressive strength dispersion is significant, in both A and B cases, for dry specimens, though the distribution presents a higher mean value. Wet conditions ensure more statistically congruent results. The reduced compressive strength in this last case is probably due to microcrscks formed during the immersion in water, as it has been previously noted [Frunzio et al., 1992]

- As expected, in general the presence of the teflon layers reduces the compressive strength, but there is not significant influence on its frequency distribution, since the little variation of the standard deviation does not allow big differences to be seen in the two conditions. 70mm cubes, cylinders and prisms seem to represent suitable specimens shapes in both cases presented: the minimum dimension in this three cases is compatible with the inclusions dimensions. The compressive strength in the 40mm and 50mm cubes seem to be influenced by the local texture.

- The standard deviation ranges from 7,7%to 27,2%, so a suitable reference value for the compressive strength can be obtained only by means of a large number of tests, as an appropriate statistical distribution must be developed.

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	A TUFF							
	CYLINDERS							
	D-NT		D-T		W-NT		W-T	
	ρ	σ	ρ	σ	ρ	σ	ρ	σ
N. of Sp	20	20	20	20	20	20	20	20
Mean value	1,14	5,17	1,11	4,70	1,48	5,25	1,48	4,61
St Deviation	0,05	0,88	0,04	0,90	0,03	0,74	0,02	0,91
St. D %	4,2%	16,9%	3,7%	19,1%	2,1%	14,0%	1,6%	19,8%
Max. value	1,31	6,27	1,17	6,07	1,55	6,68	1,52	6,02
Min. value	1,06	2,45	1,02	2,75	1,41	3,82	1,43	2,24
Kurtosis	10,03	6,47	2,55	2,52	3,30	2,45	2,75	4,77
Skewness	2,10	-1,55	-0,32	-0,52	-0,24	-0,21	-0,34	-1,18
Mode		5,61		3,67		5,35		4,38
Char val. 5%		3,78		3,19		4,21		2,53
	PRISMS							
N. of Sp	10	10	11	11	8	8	8	8
Mean value	1,08	5,48	1,10	5,54	1,45	5,62	1,43	4,85
St Deviation	0,03	0,90	0,03	0,58	0,01	0,46	0,03	0,37
St. D %	2,9%	16,3%	2,6%	10,5%	1,0%	8,3%	1,8%	7,7%
Max. value	1,12	7,41	1,15	6,69	1,48	6,37	1,46	5,41
Min. value	1,03	4,12	1,06	4,84	1,43	4,93	1,38	4,20
Kurtosis	1,60	3,96	1,96	2,43	5,73	1,73	2,62	2,50
Skewness	-0,02	0,53	0,46	0,67	1,40	0,18	-0,63	-0,44
Mode						5,33		
Char val. 5%		4,21		4,89		5,02		4,27
	70 mm CUBES							
N. of Sp	31	31	30	30	30	30	31	31
Mean value	1,07	5,26	1,08	5,15	1,44	4,39	1,45	4,26
St Deviation	0,04	0,84	0,03	0,67	0,07	0,79	0,06	0,62
St. D %	3,4%	16,0%	2,6%	13,1%	4,6%	18,0%	4,3%	14,6%
Max. value	1,18	6,97	1,16	6,77	1,60	6,05	1,58	5,25
Min. value	1,01	2,84	1,02	3,84	1,34	3,08	1,36	2,60
Kurtosis	3,62	4,14	3,47	2,97	2,81	2,60	2,27	3,59
Skewness	0,70	-0,40	0,11	0,39	0,88	0,16	0,74	-0,77
Mode		5,29		4,97		5,21		4,40
Char val. 5%		4,03		4,16		3,12		3,10

Fig. 7 Statistical parameters evaluated for the distribution of the density ρ $[g/cm^2]$ and the compressive strength σ $[N/mm^2]$.

	A TUFF							
	D-NT		D-T		W-NT		W-T	
	ρ	σ	ρ	σ	ρ	σ	ρ	σ
	100 mm CUBES							
N. of Sp	20	20	20	20	20	20	20	20
Mean value	1,10	5,75	1,09	5,33	1,43	5,05	1,43	4,78
St Deviation	0,02	0,81	0,03	0,77	0,03	0,83	0,04	0,75
St. D %	1,9%	14,0%	2,9%	14,4%	1,9%	16,4%	3,1%	15,8%
Max. value	1,14	7,20	1,15	6,97	1,49	6,71	1,54	5,79
Min. value	1,06	4,34	1,02	3,78	1,37	3,45	1,37	3,30
Kurtosis	2,94	2,01	2,72	2,91	3,63	2,24	2,69	2,75
Skewness	0,17	-0,03	0,02	-0,11	-0,32	0,13	0,46	-0,85
Mode		6,69		5,67		4,51		4,96
Char val. 5%		4,41		4,08		4,08		3,37
	50 mm CUBES							
N. of Sp	18	18	18	18	18	18	18	18
Mean value	1,09	5,33	1,09	4,94	1,47	4,57	1,42	4,08
St Deviation	0,03	0,76	0,03	0,43	0,07	1,15	0,08	0,60
St. D %	2,6%	14,2%	2,5%	8,7%	4,8%	25,1%	5,5%	14,8%
Max. value	1,14	6,28	1,13	5,42	1,57	6,83	1,58	5,42
Min. value	1,05	3,37	1,04	4,08	1,37	2,67	1,34	3,06
Kurtosis	1,52	4,18	1,76	2,18	1,42	2,68	2,21	2,99
Skewness	0,06	-1,18	-0,03	-0,77	-0,13	0,30	0,91	0,67
Mode				5,38		4,79		3,61
Char val. 5%		3,84		4,15		2,87		3,39
	40 mm CUBES							
N. of Sp	20	20	19	19	19	19	19	19
Mean value	1,11	5,25	1,07	4,64	1,53	3,63	1,57	3,29
St Deviation	0,04	0,97	0,06	0,96	0,06	0,99	0,05	0,57
St. D %	3,7%	18,5%	5,9%	20,7%	3,9%	27,2%	3,0%	17,4%
Max. value	1,17	7,11	1,16	6,99	1,59	5,27	1,63	4,35
Min. value	1,05	3,68	0,88	2,58	1,34	2,08	1,47	2,33
Kurtosis	1,67	2,01	6,47	4,10	6,98	1,64	2,28	2,02
Skewness	0,38	-0,01	-1,18	0,46	-1,80	0,02	-0,68	0,16
Mode		4,05		4,91		2,45		3,92
Char val. 5%		3,85		3,73		2,42		2,44

Fig. 8 Statistical parameters evaluated for the distribution of the density ρ [g/cm²] and the compressive strength σ [N/mm²].

	B TUFF							
	CYLINDERS							
	D-NT		D-T		W-NT		W-T	
	ρ	σ	ρ	σ	ρ	σ	ρ	σ
N. of Sp	20	20	20	20	20	20	20	20
Mean value	1,20	5,42	1,22	5,11	1,64	3,27	1,63	3,09
St Deviation	0,03	0,79	0,03	0,57	0,02	0,63	0,02	0,76
St. D %	2,5%	14,6%	2,3%	11,1%	1,4%	19,2%	1,4%	24,6%
Max. value	1,25	6,78	1,31	5,91	1,66	4,72	1,66	4,89
Min. value	1,14	4,03	1,18	4,08	1,58	1,89	1,56	1,58
Kurtosis	2,67	2,13	7,02	1,98	3,38	3,59	4,93	3,43
Skewness	-0,47	-0,19	1,61	-0,31	-0,85	0,05	-0,93	0,38
Mode		6,22		5,81		3,67		3,98
Char val. 5%		4,12		4,18		2,37		1,97
	PRISMS							
N. of Sp	25	25	23	23	30	30	30	30
Mean value	1,05	5,28	1,02	4,99	1,47	3,76	1,46	3,53
St Deviation	0,05	0,87	0,04	0,92	0,07	0,51	0,08	0,65
St. D %	5,2%	16,6%	3,7%	18,4%	5,0%	13,5%	5,7%	18,4%
Max. value	1,17	7,27	1,15	6,41	1,60	4,76	1,61	5,41
Min. value	0,97	3,64	0,97	3,26	1,34	2,84	1,35	2,24
Kurtosis	3,70	2,81	9,30	2,02	2,07	2,25	1,85	4,28
Skewness	1,24	0,09	1,93	-0,17	0,44	0,12	0,60	0,63
Mode		5,47				3,24		3,52
Char val. 5%		4,01		3,49		3,00		2,56
	70 mm CUBES							
N. of Sp	21	21	28	28	32	32	19	19
Mean value	1,03	5,62	1,08	4,94	1,43	4,00	1,50	3,45
St Deviation	0,03	0,84	0,09	1,03	0,03	0,47	0,08	0,75
St. D %	3,1%	15,0%	7,9%	20,8%	2,0%	11,9%	5,6%	21,7%
Max. value	1,10	7,99	1,25	7,15	1,47	4,93	1,66	4,88
Min. value	0,97	4,20	0,93	3,02	1,36	2,74	1,38	2,12
Kurtosis	3,02	4,54	2,16	2,42	2,47	3,48	1,90	2,54
Skewness	0,31	1,02	0,65	0,19	-0,53	-0,64	0,49	0,07
Mode		4,72		4,00		4,00		
Char val. 5%		4,72		3,40		3,15		2,27

Fig. 9 Statistical parameters evaluated for the distribution of the density ρ [g/cm²] and the compressive strength σ [N/mm²].

	B TUFF							
	D-NT		D-T		W-NT		W-T	
	ρ	σ	ρ	σ	ρ	σ	ρ	σ
	100 mm CUBES							
N. of Sp	31	31	31	31	29	29	29	29
Mean value	1,03	5,35	1,03	4,56	1,48	3,62	1,49	2,91
St Deviation	0,03	1,10	0,04	0,91	0,05	0,52	0,08	0,64
St. D %	3,3%	20,5%	3,4%	19,9%	3,7%	14,3%	5,7%	22,2%
Max. value	1,11	6,92	1,10	6,57	1,60	4,71	1,65	4,46
Min. value	0,97	2,70	0,94	2,16	1,41	2,33	1,36	1,81
Kurtosis	2,69	3,07	3,27	4,10	2,50	3,30	1,87	3,32
Skewness	0,52	-0,78	-0,41	-0,50	0,76	-0,22	0,41	0,76
Mode		5,20		4,46		3,68		2,31
Char val. 5%		3,16		2,84		2,81		2,21
	50 mm CUBES							
N. of Sp	18	18	18	18	19	19	18	18
Mean value	1,11	3,30	1,11	3,29	1,56	2,89	1,56	2,62
St Deviation	0,06	0,59	0,05	0,55	0,04	1,01	0,06	0,70
St. D %	5,1%	18,0%	4,6%	16,7%	2,3%	35,1%	3,6%	26,7%
Max. value	1,19	4,24	1,17	3,92	1,60	5,57	1,62	4,43
Min. value	0,95	1,88	0,98	2,08	1,50	1,65	1,44	1,22
Kurtosis	5,48	2,98	5,03	2,90	1,95	4,20	2,69	4,51
Skewness	-1,40	-0,46	-1,45	-0,97	-0,68	1,32	-1,00	0,51
Mode		2,75		3,69		2,28		3,34
Char val. 5%		2,55		2,18		1,93		1,62
	40 mm CUBES							
N. of Sp	31	31	31	31	31	31	31	31
Mean value	0,98	4,43	0,97	4,17	1,39	3,41	1,39	3,00
St Deviation	0,04	0,99	0,04	0,84	0,05	0,63	0,06	0,63
St. D %	4,2%	22,3%	4,1%	20,2%	3,4%	18,3%	4,2%	21,2%
Max. value	1,06	5,95	1,03	5,52	1,56	4,60	1,50	4,54
Min. value	0,91	2,21	0,89	1,90	1,33	1,96	1,28	1,84
Kurtosis	2,05	2,49	1,93	3,46	7,64	2,67	2,59	3,32
Skewness	0,00	-0,49	-0,07	-0,94	1,89	-0,49	0,21	0,61
Mode		4,29		4,66		3,49		3,13
Char val. 5%		2,73		2,67		2,33		2,08

Fig. 10 Statistical parameters evaluated for the distribution of the density ρ [g/cm^2] and the compressive strength σ [N/mm^2].

(B)

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THIN STAINLESS STEEL FLAT-JACKS: CALIBRATION AND TRIALS FOR MEASUREMENT OF IN-SITU STRESS and ELASTICITY of MASONRY

by R.C.de Vekey

SUMMARY

The flat jack is a flat flexible envelope which is filled with hydraulic fluid and can be pressurised using a pump and used to generate small movements in structures and apply substantial forces. Suitable arrangements allow the measurement of compressive stress in members and the local stress strain behaviour with minimal, easily reparable damage of the masonry. The BRE version is described and some calibration work and application trials are discussed. The work indicates that for most purposes provided the 'jack effective area' has been measured for each individual size and the hole size is allowed for, all the calibration data for a range of wall sections and materials fits a common curve and can be used interchangeably.

INTRODUCTION

There are numerous situations where it is advantageous, or even essential, to know the state of stress existing in a structure. One way of measuring such stresses is to use a flat-jack. Such jacks have often been used to determine the stresses in rock formations, and are made from steel sheet, welded and filled with hydraulic fluid.

The use of a flat-jack as a method of assessing the in-situ vertical stresses in masonry walls has been suggested by a number of researchers, including Rossi 1982, Sacchi Landriani and Talierco 1986, and Noland et al 1990. Recently a RILEM international

Head of Masonry Structures Section, Building Research Establishment, Watford, UK, WD2 7JR.