NAM

Material Characterisation Version 1.3 Report

EUCENTRE – P&P – TU Delft – TU Eindhoven

Datum January 2016

Editors Jan van Elk & Dirk Doornhof

General Introduction

As part for the studies into the risk associated with induced seismicity in Groningen, a large experimental testing campaign was performed to investigate the mechanical properties of building materials used in the existing masonry buildings. The experimental campaign, which included in-situ and laboratory testing, was motivated by the lack of available information on the masonry typology that is found in the Groningen area.

The main aim of this document is to present the results of both in-situ and laboratory testing, compare these results and draw some correlations between the different mechanical parameters. A preliminary masonry abacus is proposed. The latter is aimed to provide a list of the main masonry typologies that can be found in the Groningen area and it will serve as a tool for the practitioners who will have to assess the capacity of existing masonry buildings in the area. In the abacus each typology is characterized by an extensive photographic documentation, which will allow an easy and quick identification, and a range of variation of all the necessary mechanical properties.

The properties of the building materials measured in this material characterisation program have been used in the modelling of masonry buildings. An example of this is the building modelling performed before and after the shake table test of a Terraced House in Pavia at the EUcentre facilties. This study has been documented in the report "EUCentre Shaketable Test of Terraced House Modelling Predictions and Analysis Cross Validation".
Based on the modelling of a building, an estimate is made of the response of the building when exposed to an earthquake. The chance of severe damage (Damage State 5) is captured in the fragility curve for the building. The report "Development of v2 Partial Collapse Fragility and Consequence Functions for the Groningen Field" describes the development of the fragility curves for the building typologies.

Both reports can both be downloaded from:
www.namplatform.nl/feiten-en-cijfers/onderzoeksrapporten

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<tr><td>Author(s)</td><td>EUCENTRE – P&P – TU Delft – TU Eindhoven</td><td>Editors</td><td colspan="3">Jan van Elk
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<tr><td>Directly linked research</td><td colspan="5">(1) Report: “EUCentre Shaketable Test of Terraced House Modelling Predictions and Analysis Cross Validation” by ARUP, EUCENTRE, TUDelft.
(2) Report: “Development of v2 Partial Collapse Fragility and Consequence Functions for the Groningen Field” by Helen Crowley, Rui Pinho, Barbara Polidoro and Peter Stafford.</td></tr>
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MATERIAL CHARACTERIZATION

Version 1.3 Report

OCTOBER 28, 2015

EUCENTRE – P&P – TU DELFT – TU EINDHOVEN

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1 Introduction

In the framework of the *Groningen Earthquakes – Structural Upgrading* project a large experimental testing campaign was performed to investigate the mechanical properties of existing masonry building. The experimental campaign, which included in-situ and laboratory testing, was motivated by the lack of available information on the masonry typology that can be found in the Groningen area.

The main aim of this document is to present the results of both in-situ and laboratory testing, compare these results and draw some correlations between the different mechanical parameters. Finally a preliminary masonry abacus will be proposed. The latter is aimed to provide a list of the main masonry typologies that can be found in the Groningen area and it will serve as a tool for the practitioners who will have to assess the capacity of existing masonry buildings in the area. In the abacus each typology will be characterized by an extensive photographic documentation, which will allow an easy and quick identification, and a range of variation of all the necessary mechanical properties.

2 Nomenclature

Symbol	**Material property**
$f_{m,h}$	Compressive strength of masonry in the direction parallel to the bed joints
$f_{m,v}$	Compressive strength of masonry in the direction perpendicular to the bed joints
$f_{mu,c}$	Compressive strength of masonry unit
$f_{bu,c}$	Normalised compressive strength of masonry unit
$f_{mu,t}$	Tensile strength of masonry unit derived by a three-point bending test
f_{x2}	Masonry bending strength with the moment vector orthogonal to the bed joints and in the plane of the wall (out-of-plane bending, crack plane perpendicular to bed joints)
f_{x3}	Masonry bending strength with the moment vector orthogonal to plane of the wall (in-plane bending)
$E_{m,v}$	Young's vertical modulus of masonry
$E_{m,v(LIN)}$	Young's vertical modulus of masonry from laboratory Vertical Compression Test evaluated as the slope of the most linear part of the stress-strain curve
$E_{m,v(30\text{-}70)}$	Young's vertical modulus of masonry from laboratory Vertical Compression Test evaluated as the secant modulus in the range between 30% and 70% of the compressive strength
$E_{m,v(IS)}$	Young's vertical modulus of masonry from in-situ Double Flat Jack Test
$E_{m1,h}$	Young's modulus of masonry subject to a compressive loading parallel to the bed joints, evaluated at a stress equal to $0.3f_m$
$E_{m2,h}$	Young's modulus of masonry subject to a compressive loading parallel to the bed joints, evaluated at a stress equal to $0.7f_m$
$E_{chord,h}$	Chord modulus of masonry subject to a compressive loading parallel to the bed joints, evaluated between $0.3f_m$ and $0.7f_m$
$E_{mu,c}$	Chord modulus of masonry unit calculated from compression test, evaluated between $0.3f_m$ and $0.7f_m$
$E_{mu,t(h)}$	Chord modulus of masonry unit calculated from bending test from horizontal LVDT, evaluated between $0.3f_m$ and $0.7f_m$
$E_{mu,t(v)}$	Chord modulus of masonry unit calculated from bending test from vertical LVDT, evaluated between $0.3f_m$ and $0.7f_m$
$E_{m,fx2(h)}$	Chord modulus of masonry calculated from out-of-plane bending test from horizontal LVDTs, evaluated between $0.3f_m$ and $0.7f_m$
$E_{m,fx2(v)}$	Chord modulus of masonry calculated from out-of-plane bending test from vertical LVDTs, evaluated between $0.3f_m$ and $0.7f_m$
$E_{m,fx3(h)}$	Chord modulus of masonry calculated from in-plane bending test from horizontal LVDTs, evaluated between $0.3f_m$ and $0.7f_m$
$E_{m,fx3(v)}$	Chord modulus of masonry calculated from in-plane bending test from vertical LVDTs, evaluated between $0.3f_m$ and $0.7f_m$

$f_{b,bj}$	Bond strength of masonry
$G_{f\text{-}c,h}$	Fracture energy in compression test (loading parallel to bed joints)
μ	Masonry friction coefficient
σ_v	Vertical compressive stress in the masonry
τ_0	Masonry cohesion
$\tau_{0,(LAB)}$	Masonry cohesion from laboratory Shear Triplet Test
$\tau_{0,(IS)}$	Masonry cohesion from in-situ Shove Test

3 Masonry Categories and Testing Objects

The preliminary information available at the beginning of the project, before the experimental campaign was performed, lead to the identification of different masonry typologies present in the Groningen area. The typologies were subdivided in terms of material type in: calcium silicate units and clay units. Additionally, since the stock of building in the area comprises structure built in a pretty wide range of years, it was also necessary to identify sub typologies according to the year of construction. The decision was taken considering that the evolution of the construction processes highly influenced the mechanical properties of the masonry units. Therefore, the final subdivision included five main masonry typologies was:

- Clay brick masonry < 1945
- Clay brick masonry > 1945
- Calcium silicate masonry < 1985
- Calcium silicate masonry > 1985

Besides this masonry materials during the experimental campaign it also happened to find further materials like concrete units, aerated autoclaved units and calcium silicate plate units. The results on this material will be eventually listed but it will not take into consideration for the formulation of additional typologies, this report will therefore focus its attention only on the four main masonry typologies previously listed.

In this report it will be underlined and shown that a further subdivision of the above mentioned typologies could be necessary. The main reason for this is because the quality of the masonry material does not uniquely depends on the quality of the masonry units but also on the quality of the mortar and of the layout of the material. Therefore, it is possible that for two houses build in the same period and with the same material we can find a “good quality” and “bad quality” masonry where the difference of the two primarily lays on the quality of the mortar and how the masonry was assembled.

Concerning the testing object, 13 different buildings were investigated. The latter are all located in the Groningen are, built in different ages and with different masonry materials. In Table 1 the building are shortly presented. For each building the following information are given: building code, address, picture of the front of the building, category of building and masonry typology. It must be underlined that in certain cases, especially for big public buildings like school, it was possible to find different material typologies in the same building. In each building several non-destructive and slightly destructive tests were performed in-situ and additionally, when possible, samples were collected and then sent to the laboratories to be tested. In the table the term “CS” is used to indicate Calcium Silicate units. In the case of the JOH-H building the category CS > 1985* is used to indicated that the masonry is not composed by brick units but by big calcium silicate plate units.

Table 1. Resume of the building subjected to in-situ testing.

CODE	**ADDRESS**	**PICTURE**
BEA-H	Beatrixstraat 1-19, Leens	
	TYPOLOGY	
	Terraced House	
	CATEGORY	
	CS < 1985	
CODE	**ADDRESS**	**PICTURE**
WIL-H	Wilhelminalaan 47, Baflo	
	TYPOLOGY	
	Terraced House	
	CATEGORY	
	CS < 1985 / Clay > 1945	
CODE	**ADDRESS**	**PICTURE**
WIR-H	Wirdumersweg 57-73, Loppersum	
	TYPOLOGY	
	Villa	
	CATEGORY	
	Clay < 1945	

CODE	ADDRESS	PICTURE
LAG-H	Lagelandsterweg 6, Lageland	
	TYPOLOGY	
	Detached House	
	CATEGORY	
	CS < 1985	
CODE	**ADDRESS**	**PICTURE**
JUL-H	Koningin Julianalaan 52, Delfzijl	
	TYPOLOGY	
	Semi-Detached House	
	CATEGORY	
	Concrete	
CODE	**ADDRESS**	**PICTURE**
KWE-H	Kwelder 1, Loppersum	
	TYPOLOGY	
	Detached House	
	CATEGORY	
	CS > 1985 / Clay > 1945	

CODE	**ADDRESS**	**PICTURE**
BEA-S	Beatrix School, Loppersum	
	TYPOLOGY	
	School	
	CATEGORY	
	Clay > 1945	
CODE	**ADDRESS**	**PICTURE**
ROE-S	Roemte School, Loppersum	
	TYPOLOGY	
	School	
	CATEGORY	
	CS > 1985/Clay < 1945/Clay > 1945	
CODE	**ADDRESS**	**PICTURE**
MID-H	Middelstumerweg 2 Kantens	
	TYPOLOGY	
	Villa	
	CATEGORY	
	Clay < 1945	

CODE	**ADDRESS**	**PICTURE**
JOH-H	Johan Dijkstrastraat 22, Ten Boer	
	TYPOLOGY	
	Semi-Detached House	
	CATEGORY	
	CS > 1985*	
CODE	**ADDRESS**	**PICTURE**
HOO-H	Hoofdstraat 49, Uithuizermeeden	
	TYPOLOGY	
	Detached House	
	CATEGORY	
	Clay > 1945	
CODE	**ADDRESS**	**PICTURE**
SCH-H	Scholeksterpad 4 Ten Boer	
	TYPOLOGY	
	Terraced House	
	CATEGORY	
	CS < 1985	

CODE	ADDRESS	PICTURE
MOL-H	Molenweg 32, Loppersum	
	TYPOLOGY	
	Detached House	
	CATEGORY	
	Clay < 1945	

4 Experimental Testing Campaign

The experimental testing campaign comprised both in-situ and laboratory testing; in-situ testing were performed by the company P&P while laboratory testing were performed by the laboratories of TU Delft and TU Eindhoven.

4.1 In-Situ Testing

The experimental tests performed in-situ can be divided into two categories:

- Non-destructive tests:
    - Rebound Hammer Test
    - Penetrometric Test on Mortar
    - Ultrasonic Test
- Slightly destructive tests:
    - Single Flat Jack Test
    - Double Flat Jack Test
    - Shove Test

Each test performed was aimed to investigate a different mechanical parameter of the masonry material, in the following paragraphs each test will be quickly presented. More detailed information concerning the in-situ tests can be found in the testing protocols.

4.1.1 Rebound Hammer Test

The purpose of the test is to provide indications on the quality of the brick measuring the hardness of the material as well as the uniformity of the quality in different locations of the structure. The results from the test can be correlated to the compressive strength of the bricks.

The instrument used to perform the test is the Schmidt Rebound Hammer N type (impact energy = 2.207 Nm) (Figure 1).

Figure 1. Rebound Hammer Test: identification of the 4 zones (left) and performance of the test (right).

4.1.2 Penetrometric Test on Mortar

The purpose of the test is the definition of the quality of the mortar joints as well as the investigation of the homogeneity of the mortar quality in different locations of the structure.

The test is based on the idea of measuring the number of strokes necessary to penetrate for a certain distance a probe into the mortar (Figure 2).

The results of the test can be correlated to the compressive strength of the mortar.

Figure 2. Penetrometric Test on Mortar.

4.1.3 Ultrasonic Test

The test is aimed to obtain indications on the quality of the masonry material, to identify possible flaws, cracks and voids into the masonry and investigate the homogeneity of the masonry material in different parts of the structure.

The test measures the time of travel of ultrasonic way between a transmitter and a receiver placed in different locations. Knowing the distance of the source and arrival of the ultrasonic signal it is possible to evaluate the speed of propagation which can be also related to mechanical properties like, for example, the vertical and horizontal elastic modulus.

The measurement can be (Figure 3):

- Direct if the transmitter and the receiver are aligned one opposite to the other, with the sample in between;
- Indirect if the transmitter and receiver are positioned on the same plane (*e.g.* same wall side).

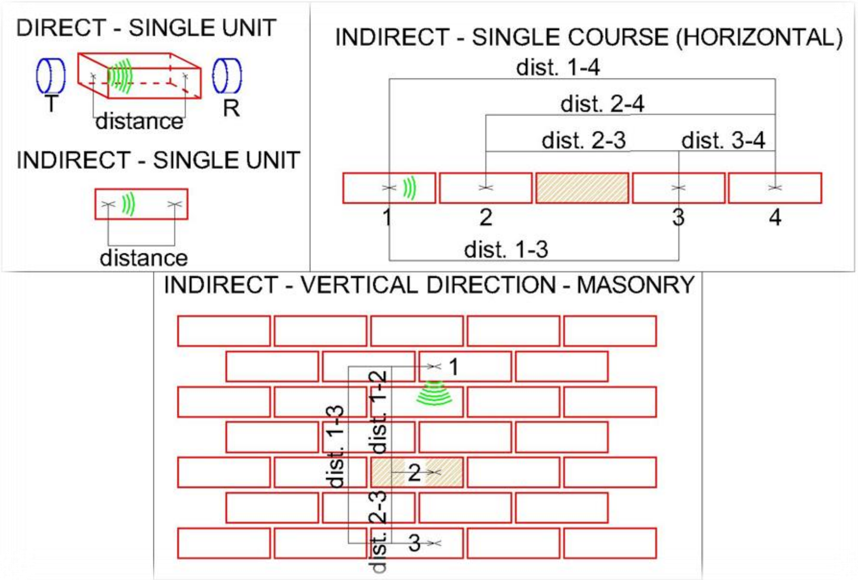


Figure 3. Ultrasonic Test: direct and indirect single unit configuration (top left) indirect horizontal configuration (top right) and indirect vertical configuration (bottom).

Figure 4. Ultrasonic Test: indirect horizontal configuration (left) and indirect vertical configuration (right).

4.1.4 Single Flat Jack Test

The purpose of the test is to evaluate, in-situ, the average compressive stress σ_v in unreinforced solid-unit masonry.

The test is based on the idea of cutting a slot in a masonry bed joint (Figure 5). Four couples of points across the slot are selected before the cutting and their distance is measured (Figure 6). Consequently to the cut of the slot the compressive stress acting on the slot will cause a reduction of thickness of the slot, i.e. reduction of the distance of the couples of points. At this point a flat jack is inserted in the slot and oil is pumped in to increase the pressure, when the original thickness of the slot is restored it means that the pressure in the flat jack equalized the compressive stress in the wall.

Figure 5. Single Flat Jack Test: cutting of the slot in the masonry wall.

Figure 6. Single Flat Jack Test: measurement of the point distance (left) and performance of the test (right).

4.1.5 Double Flat Jack Test

The aim of the test is to measure the deformability of a portion of the masonry wall, from the test results the vertical elastic modulus E_m of the masonry material can be obtained.

The test procedure is to cut two slots in two parallel bed joints in the masonry wall, the two slots must be cut at a certain distance (Figure 7). Two flat jacks are then inserted in the two slots and the masonry portion between the two is instrumented with LVDTs measuring the vertical distance between couples of points. The pressure is increased in the flat jacks and the deformation of the masonry is controlled real time, in this way it is possible to build a pressure/deformation (i.e. stress/strain) curve.

The test is performed in two different configurations: the “standard configuration” (Figure 7 left) and in the “Shove Test configuration” (Figure 7 right). The latter of the two is necessary for the interpretation of the Shove Test

Figure 7. Double Flat Jack Test: "standard configuration" (left) and "Shove Test configuration" (right).

4.1.6 Shove Test

The test allows the definition of the bed joint shear strength parameters for the Coulomb strength criterion, i.e. cohesion τ_0 and friction coefficient μ.

The test is usually performed after the Single and Double Flat Jack test. The flat jacks used for the latter are kept into place, a masonry unit is selected as reference and the two units on the side are removed (Figure 8). At this point a horizontal jack is inserted on one side of the brick and a horizontal LVDT is installed to record horizontal displacements of the reference unit. By controlling the vertical compression stress using the flat jack and the horizontal force it is possible to obtain several couple of points vertical compressive stress/shear stress. Plotting this point in a graph and performing a linear regression it is possible to obtain the value of cohesion and friction coefficient of the masonry material.

Figure 8. Shove Test: setup.

4.2 Laboratory testing

Several material samples were extracted from the in—situ tested buildings, the samples were delivered to the TU Delft and TU Eindhoven laboratories were different type of tests were performed.

The division of the tests among the two laboratories is the following:

- TU Delft:
    - Compression Test on Masonry Unit
    - Flexural Test on Masonry Unit
    - Horizontal Compression Test on Masonry Sample
    - Bending Test on Masonry Sample
    - Bond Wrench Test
- TU Eindhoven:
    - Vertical Compression Test on Masonry Sample
    - Shear Triplet Test

More detailed information concerning the test procedures, testing apparatus and test results can be found in the testing report produced by the two laboratories.

4.2.1 Compressive Test on Masonry Unit

The test is performed to measure the compressive strength, $f_{mu,c}$, the normalised compressive strength, $f_{bu,c}$, and also the elastic modulus, $E_{mu,c}$, of masonry units.

Figure 9. Compression Test on Masonry Unit.

4.2.2 Flexural Test on Masonry Unit

The test, named also three point bending test, allows the calculation of the tensile strength of the masonry unit, $f_{mu,t}$, as well as vertical and horizontal elastic modulus, $E_{mu,h}$ and $E_{mu,v}$.

Figure 10. Flexural Test on Masonry Unit.

4.2.3 Horizontal Compression Test on Masonry Samples

In this test the masonry samples is tested with the mortar bed joints parallel to the direction of application of the force (Figure 11). The test allows the calculation of different mechanical parameters like: the compressive strength of masonry for horizontal configuration $f_{m,h}$, the secant Young's modulus in the horizontal direction evaluated at 30% of the ultimate strength $E_{m1,h}$ and at 70% of the ultimate strength $E_{m2,h}$, the horizontal Young's modulus evaluated in the stage between the 30% and 70% of the ultimate strength $E_{chord,h}$ and finally the fracture energy G_{c-f}.

Figure 11. Horizontal Compression Test on Masonry Samples.

4.2.4 Bending Test on Masonry Samples

The bending test was performed in two different configuration:

- Four-point-bending test where the masonry sample is loaded out-of-plane with the load applied orthogonally to the bed joints (Figure 12 left)
- Four-point-bending test where the masonry sample is loaded in-plane (Figure 12 right)

From the out-of-plane test it can be obtained the flexural strength, f_{x2}, and the Young's modulus in the vertical and horizontal direction $E_{m,fx2(v)}$ and $E_{m,fx2(h)}$. The in plane test provides the following quantities: flexural strength f_{x2} and Young's modulus in the vertical and horizontal direction $E_{m,fx3(v)}$ and $E_{m,fx3(h)}$.

Figure 12. Bending Test on Masonry Samples: out-of-plane test (left) and in-plane test (right).

4.2.5 Bond Wrench Test

The test is performed to investigate the bond wrench strength of the bed joints, $f_{b,bj}$.

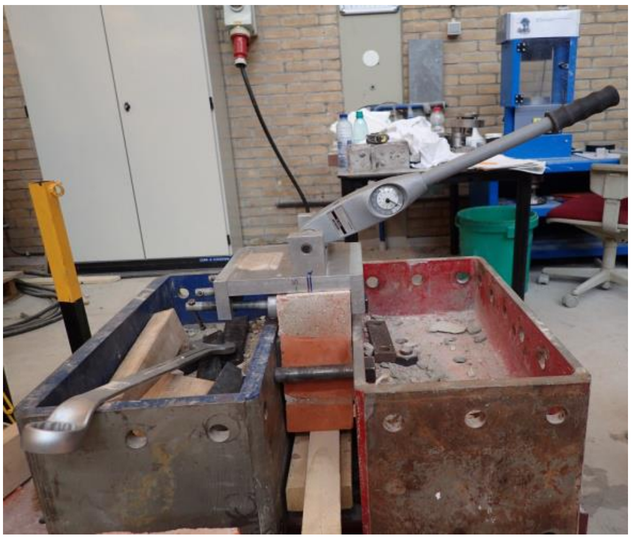


Figure 13. Bond Wrench Test.

4.2.6 Vertical Compression Test on Masonry Samples

The test is performed to calculate the vertical elastic modulus of the masonry material $E_{m,v}$ as well as the compressive strength $f_{m,v}$. The mechanical parameters obtained from the test can be directly compared to the ones obtained from the Double Flat Jack Test performed in.situ.

Figure 14. Vertical Compression Test on Masonry Samples.

4.2.7 Shear Triplet Test

The tests allows the calculation of the bed join shear strength parameters for the Coulomb criterion, i.e. cohesion τ_0 and friction coefficient μ. The results of this test can be directly compared with the results of the Shove Test performed in-situ.

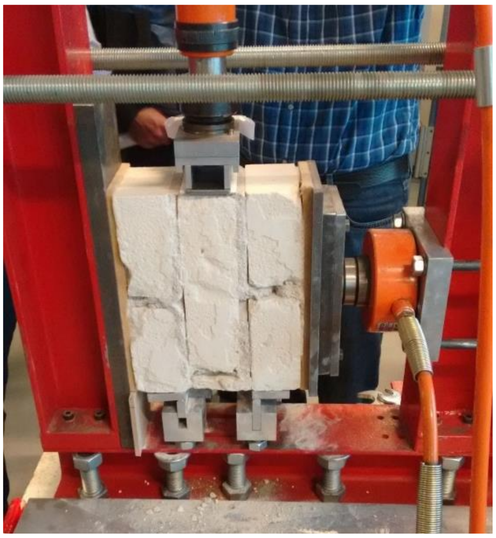


Figure 15. Shear Triplet Test.

5 Test Results

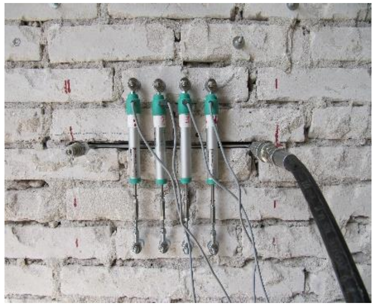
5.1 In-Situ Test

In this section the results of the test performed in-situ are reported in a table format. For each building all the necessary information will be provided. At the top of the table the code of the building is given. For every building a certain number of location was picked, the first column “Test” indicates the location number, in can be seen that the location number is progressive moving from one building to the other in such a way to have a unique identification for each single test that was performed. The second column “Blocks” indicate which type of masonry material was the one in the test location. The third column “σ_v” indicate the compressive stress in the wall obtained as a result of the Single Flat Jack Test and the following column “$E_{m,v(IS)}$” indicates the vertical elastic modulus obtained from the Double Flat Jack Test. The two following columns report the results of the Shove Test, i.e. the friction coefficient “μ” and the cohesion “τ_0”. Then an image of the test location is reported in order to better identify the masonry material. The column “Rebound Hammer” reports the average number of rebound hammer hits recorded in the area of the test, the reported value is the average value among all the test performed in the area. “Vert Vel” and “Hor Vel” reports the vertical and horizontal velocity recorded with the Ultrasonic Test, in both the cases the value reported is the one relative to the longest configuration, i.e. configuration 1-3 for the vertical test and 1-4 for the horizontal test (Figure 3). Finally the last two columns report the results from the Ultrasonic Test on the single brick in the Direct and Indirect configuration respectively. Finally, for each building a secondary table is provided with the results of the Penetrometric Test on Mortar. For this test the number of strokes necessary to penetrate each centimetre is indicated. The symbol “//” indicates that more than 25 strokes were necessary to penetrate the mortar, in that case the test was stopped for the current location. The symbol “/” indicates that the penetration of the current centimetre of mortar was reached with the previous centimetre.

BEA-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
1	CS < 1985	0.15	-	0.53	0.03		31.35	1033	1317	2790	2272
2	CS < 1985	0.3	2783	0.46	0.14		30.9	1662	1671	2660	3014
3	CS < 1985	0.3	5245	0.50	0.09		34.25	1638	1437	2800	2982

4	CS < 1985	0.28	1381	0.39	0.00		31.9	717	1346	2660	2143

BEA-H	**1**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	5	11	11	12	11
	Test 2	8	10	11	11	11
	2	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	8	11	12	12	10
	Test 2	14	18	20	22	//
	Test 3	7	10	12	13	13
	Test 4	7	10	11	11	13
	3	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	9	15	17	//	
	Test 2	11	15	18	20	//
	4	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	4	5	5	5	7
	Test 2	2	3	4	3	5
	Test 3	3	4	5	5	5

WIL-H-1											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
5	CS < 1985	0.225	2049	0.73	0.06		35.675	1481	1598	2878	2717
6	CS < 1985	0.23	3721	0.78	0.23		33.875	1371	1772	2697	3225
7	CS < 1985	0.13	950	0.94	0.09		36.85	780	1318	2778	2130

8	CS < 1985	0.07	1769	0.69	0.29		37.25	916	1479	2840	2777

	5	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	12	2	//		
	Test 2	//				
	Test 3	//				
	Test 4	12	//			
	6	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	10	7	17	23	//
	Test 2	13	20	24	//	
	Test 3	7	17	//		
	Test 4	10	8	7	18	26
WIL-H-1	prova 5	13	16	21	28	//
	7	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	8	3	2	3	//
	Test 2	8	6	16	30	//
	Test 3	10	22	//		
	Test 4	15	24	31	//	
	8	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				
	Test 4	//				

WIL-H-2												
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
9	Clay < 1945	1.30	12446	-	0.00		50.475	2505	1523	2150	2813

	9	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
WIL-H-2	Test 1	24	17	//		
	Test 2	6	2	/	3	2
	Test 3	9	//			
	Test 4	14	2	1	4	22
	Test 5	5	//			

WIR-H											
TEST	**BLOCKS**	σ_v [MPa]	$E_{m,v(IS)}$ [MPa]	μ [-]	τ_0 [MPa]	**IMAGE**	**Rebound Hammer** [-]	**Vert Vel** [m/s]	**Hor Vel** [m/s]	**Hor Vel Brick Ind** [m/s]	**Hor Vel Brick Ind** [m/s]
10	Clay < 1945	0.13	411	0.44	0.14		29.95	1363	1180	-	2982
11	Clay < 1945	0.3	3008	0.32	0.01		53.175	1175	1282	-	2259
12	Clay < 1945	0.35	20684	-	1.24		53.7	2427	2517	-	2118

13	Clay < 1945	0.13	6760	-	0.37		47.8	1991	1921	-	2754

	10	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	1	1	2	1	2
	Test 2	/	/	1	1	3
	Test 3	/	/	/	/	1
	Test 4	1	/	1	/	1
	Test 5	/	/	/	/	/
	11	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	5	2	2	3	4
	Test 2	15	2	//		
	Test 3	9	4	4	3	4
WIR-H	Test 4	5	3	4	4	3
	12	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	7	1	7	15	//
	Test 3	2	5	7	4	1
	Test 4	10	17	//		
	13	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	11	/	/	1	2
	Test 2	//				
	Test 3	//				
	Test 4	10	10	//		

LAG-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
14	CS < 1985	0.08	4390	0.45	0.00		33.625	1325	1425	2518	2659
15	CS < 1985	0.11	4834	0.45	0.00		32.85	560	2017	2432	2307
16	CS < 1985	0.23	12529	0.89	0.23		36.625	2298	1914	2641	3042

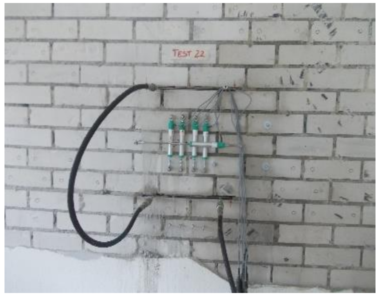
17	CS < 1985	0.29	26900	0.65	0.18		36.75	2270	2723	2578	2808

	14	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	18	//			
	Test 2	//				
	Test 3	//				
	15	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
LAG-H	Test 3	//				
	16	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	17	//			
	Test 3	//				
	17	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	12	21	//		
	Test 2	17	//			
	Test 3	16	22	//		

JUL-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
18	Concrete	0.17	7222	-	-		26.425	1483	1673	2678	1874
19	Concrete	0.25	9462	-	0.26		26.525	1440	1382	1560	1807
20	Concrete	0.19	8247	-	-		26.325	1517	1329	2631	1763

JUL-H	**18**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	3	12	21	//	
	Test 2	1	4	5	//	
	Test 3	9	//			
	Test 4	5	15	//		
	19	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	20	//			
	Test 2	4	//			
	Test 3	//				
	Test 4	//				
	20	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				

KWE-H-1

TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
22	CS > 1985	0.26	3961	0.67	0.02		26.65	2080	1615	-	1913

23	CS > 1985	0.06	6721	0.83	0.00		21.775	813	1504	-	2765

KWE-H-1	**22**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	23	19	//		
	Test 2	19	21	20	25	//
	Test 3	25	//			
	Test 4	18	20	24	//	
	23	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	14	13	14	10	2
	Test 2	22	21	25	26	//
	Test 3	14	12	17	23	18
	Test 4	16	19	10	6	3

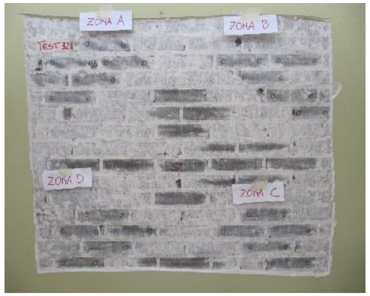
KWE-H-2											
TEST	**BLOCKS**	**σ_v**	**$E_{m,v(IS)}$**	**μ**	**τ_0**	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
24	Clay > 1945	0.45	9698	0.88	0.00		34.675	1693	1837	-	2830
25	Clay > 1945	0.15	3469	0.96	0.11		30.95	1480	1570	-	2928

KWE-H-2	**24**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	9	//			
	Test 2	10	23	//		
	Test 3	7	16	//		
	Test 4	6	25	//		
	25	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	9	19	//		
	Test 2	8	8	6	9	9
	Test 3	13	24	//		
	Test 4	23	24	//		

BEA-S-1											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
26	Clay > 1945	0.38	12545	0.39	0.09		51.925	2261	1735	3280	2527
27	Clay > 1945	0.23	8294	-	0.22		52.575	1520	1556	3340	2140
28	Clay > 1945	0.13	5664	-	0.14		48.375	1528	1617	3580	3892

29	Clay > 1945	0.3	11052	0.65	0.11		52.125	1924	1598	3580	2346

BEA-S-1	**26**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	14	//			
	Test 3	//				
	Test 4	//				
	27	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	20	//			
	Test 2	//				
	Test 3	//				
	Test 4	14	19	//		
	28	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	21	22	24	25	//
	Test 2	25	//			
	Test 3	14	15	17	18	17
	Test 4	25	//			
	29	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	25	//			
	Test 3	//				
	Test 4	//				

BEA-S-2											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
30	Clay > 1945	0.14	4319	-	-		40.525	1121	1180	1510	1620
31	Clay > 1945	0.23	21661	-	-		50.125	2657	1477	1350	1959
32	Clay > 1945	0.07	8844	0.55	0.11		47	1598	1806	2460	2622

33	Clay > 1945	0.092	6622	0.68	0.38		47.45	1716	1278	2120	2527

BEA-S-2	**26**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	7	//			
	Test 2	//				
	Test 3	//				
	Test 4	25	//			
	27	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	5	//			
	Test 2	//				
	Test 3	//				
	Test 4	//				
	28	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	10	4	5	8	17
	Test 2	13	//			
	Test 3	19	25	//		
	Test 4	//				
	29	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				
	Test 4	//				

ROE-S-1											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
38	Clay < 1945	0.28	26662	0.36	0.17		59.1	2290	1583	-	2671
39	Clay < 1945	0.375	26514	-	-		57.55	1675	1633	-	2953
40	Clay < 1945	0.17	29108	-	-		50.675	2929	1760	1662	3427

45	Clay < 1945	0.18	8443	-	-		56.1	1187	1282	2748	3042
46	Clay < 1945	0.41	6220	-	-		51.775	2366	942	2450	2329

ROE-S-1	**38**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	10	6	3	2	4
	Test 2	17	//			
	Test 3	11	8	9	11	13
	Test 4	13	14	//		
	39	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				
	40	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	17	//			
	Test 2	//				
	Test 3	17	7	17	//	
	Test 4	6	7	6	9	9
	45	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	11	17	//		
	Test 2	12	//			
	Test 3	11	13	16	//	
	Test 4	8	13	20	20	//
	46	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	15	10	21	23	24
	Test 2	13	16	18	//	
	Test 3	17	20	22	//	
	Test 4	6	9	//		

ROE-S-2											
TEST	**BLOCKS**	**σ_v** [MPa]	**$E_{m,v(IS)}$** [MPa]	**μ** [-]	**τ_0** [MPa]	**IMAGE**	**Rebound Hammer** [-]	**Vert Vel** [m/s]	**Hor Vel** [m/s]	**Hor Vel Brick Dir** [m/s]	**Hor Vel Brick Ind** [m/s]
41	Clay > 1945	0.238	14188	0.40	0.15		49.025	2392	1359	2513	3467
42	Clay > 1945	0.09	4459	0.28	0.13		50.025	1286	1377	1974	2710
43	Clay > 1945	0.124	18972	0.41	0.00		56.75	2610	2149	3595	4120

44	Clay > 1945	0.12	14844	0.52	0.17		55.775	1735	1954	3386	3643

ROE-S-2	**41**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	7	15	25	//	
	Test 2	7	//			
	Test 3	15	//			
	Test 4	16	//			
	42	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	4	1	1	10	//
	Test 2	4	2	//		
	Test 3	8	//			
	Test 4	7	//			
	43	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	22	//			
	Test 2	11	//			
	Test 3	9	//			
	Test 4	1	3	//		
	44	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	10	//			
	Test 2	17	//			
	Test 3	3	5	6	//	
	Test 4	10	22	//		

ROE-S-3											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
34	Clay > 1945	0.225	5161	0.81	0.09		46.275	1887	1781	2320	2209
35	Clay > 1945	0.23	5076	0.98	0.10		44.075	1466	1756	2361	3217

ROE-S-3	**34**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				
	Test 4	//				
	35	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	8	//			
	Test 3	8	16	//		
	Test 4	4		11	17	12

ROE-S-4											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
36	CS > 1985	0.05	3947	0.69	0.09		29.875	1405	1142	2488	2888

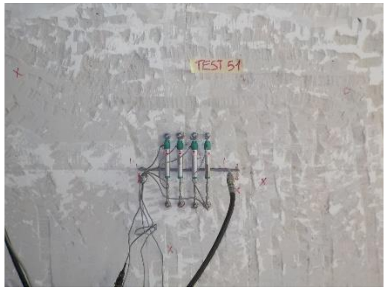
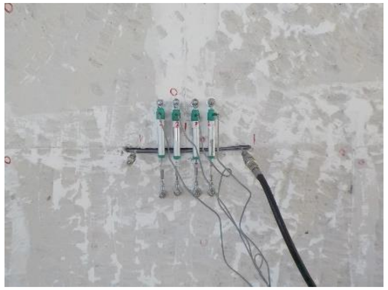
37	CS > 1985	0.04	4692	0.49	0.00		35.4	1015	1566	2617	3385

ROE-S-4	**36**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				
	Test 4	//				
	37	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	23	24	//		
	Test 4	24	21	//		

MID-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
47	Clay < 1945	0.32	8642	0.31	0.00		56.675	2410	1771	3280	2621
48	Clay < 1945	0.35	6549	-	0.06		49.175	1532	1220	2100	1782
49	Clay < 1945	0.7	11665	-	0.00		54.75	756	1485	3100	2882

50	Clay < 1945	0.33	29862	-	-		58.925	2577	1932	3800	2522

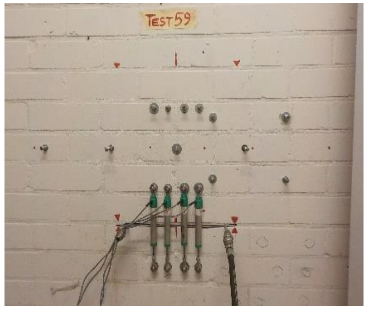
MID-H	**47**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	8	7	9	11	13
	Test 2	12	9	11	14	10
	Test 3	7	9	9	12	10
	Test 4					
	48	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	20	//			
	Test 2	/	/	2	7	2
	Test 3	/	/	/	2	7
	Test 4	3	3	5	5	6
	49	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	19	//			
	Test 2	14	10	11	11	//
	Test 3	22	//			
	Test 4	/	/	1	3	2
	Test 5	/	/	3	8	7
	Test 6	10	18	18	8	8
	50	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				
	Test 4	//				

JOH-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
51	CS > 1985*	0.56	-	-	-		-	2161	2021	-	2024
52	CS > 1985*	0.5	-	-	-		-	1936	1973	-	1997

HOO-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
53	Clay > 1945	0.43	10308	0.45	0.03		36.275	1602	1618	2461	2748
54	Clay > 1945	0.65	13660	1.08	0.02		34.95	1469	1242	2430	2208
55	Clay > 1945	0.13	4573	0.58	0.03		32.925	1106	1562	2548	2459

	53	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	19	5	4	3	//
	Test 3	24	18	//		
	Test 4	//				
	54	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	22	//			
HOO-H	Test 2	25	//			
	Test 3	13	20	13	23	//
	Test 4	15	20	//		
	55	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	16	//			
	Test 2	14	3	5	4	6
	Test 3	17	12	//		
	Test 4	//				

SCH-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
56	CS < 1985	0.17	5753	-	-		33.375	1488	1735	2687	2339
57	CS < 1985	0.23	7188	0.88	0.91		30.875	1587	1769	2578	2259
58	CS < 1985	0.22	6840	0.71	0.31		30.875	1284	1773	2741	2768

59	CS < 1985	0.16	7785	0.76	0.21		37.3	1782	1819	2517	2279
60	CS < 1985	0.39	7465	0.78	0.27		36.225	1990	1812	2741	2880

SCH-H	**56**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	15	//			
	Test 2	2	1	4	2	4
	Test 3	8	//			
	Test 4	4	//			
	56	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	16	//			
	Test 2	7	//			
	Test 3	13	14	//		
	Test 4	18	//			
	58	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	13	//			
	Test 2	15	//			
	Test 3	//				
	Test 4	//				
	59	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	/	2	//		
	Test 2	16	//			
	Test 3	8	17	//		
	Test 4	8	//			
	60	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	//				
	Test 2	//				
	Test 3	//				

MOL-H											
TEST	**BLOCKS**	σ_v	$E_{m,v(IS)}$	μ	τ_0	**IMAGE**	**Rebound Hammer**	**Vert Vel**	**Hor Vel**	**Hor Vel Brick Dir**	**Hor Vel Brick Ind**
		[MPa]	**[MPa]**	**[-]**	**[MPa]**		**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
61	Clay < 1945	0.12	691	0.21	0.15		47	665	997	2518	-
62	Clay < 1945	0.29	2087	0.22	0.00		45.075	643	795	1261	2203
63	Clay < 1945	0.18	3833	-	-		50.125	1572	1109	1465	2130

64	Clay < 1945	0.36	2178	0.22	0.09		45.275	1077	797	2488	2078

	61	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	4	//			
	Test 2	/	/	/	1	4
	Test 3	2	8	//		
	Test 4	/	1	1	8	8
	Test 5	/	1	3	4	2
	62	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	6	8	9	10	6
	Test 2	6	6	8	7	4
	Test 3	7	8	13	12	9
MOL-H	**63**	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	/	2	3	2	4
	Test 2	/	/	1	17	15
	Test 3	3	9	12	11	9
	Test 4	/	1	//		
	Test 5	2	/	1	1	8
	64	n. Strokes 1st cm	n. Strokes 2nd cm	n. Strokes 3rd cm	n. Strokes 4th cm	n. Strokes 5th cm
	Test 1	3	4	6	7	8
	Test 2	3	/	1	3	4
	Test 3	1	4	6	8	6
	Test 4	4	5	8	9	11

Some comment must be added for certain buildings to complement the information provided in the previous tables.

Building WIL-H. The table for this structure has been subdivided in two sub-tables because tests have been performed on different masonry materials. WIL-H-1 identifies the tests performed on calcium silicate walls, internal leaf of the structure. The second code WIL-H-2 identifies the test performed on and external wall of the structure that was built using clay units.

Building WIR-H. 4 different test locations were identified, it must be underlined that, despite being all clay units, the Test 10 was performed on an internal wall while Test from 11 to 13 were performed on external walls. This information is important because, as it can easily be observed from the pictures, the two type of clay units are significantly different, additionally the external walls were characterized by a pretty regular layout and properly filled mortar joints, the same thing is not true for the internal wall.

Building JUL-H. It is possible to observe that for this building from the Shove Test only the cohesion value for Test 19 is available. This because generally in the test locations the shove test was performed but due to the poor quality of the masonry units the test had to be prematurely stopped because the contrast unit was cracking before observing the sliding failure of the central unit. The shove test is used to define the shear strength for considering a Coulomb failure criterion which defines the sliding failure of the masonry, if the rapture is observed in the masonry unit the test becomes meaningless.

Building KWE-H. This structure was characterized by the presence of different masonry typologies, a part of the house was built using calcium silicate units and another using clay units. For this reason the table for this structure has been subdivided in two sub-tables. KWE-H-1 identifies the tests performed on calcium silicate walls while the code KWE-H-2 identifies the test performed on clay units.

Building BEA-S. The results of the test performed in this building were divided into two different tables BEA-S-1 and BEA-S-2. Despite the fact that all the masonry walls of the building belong to the category of material Clay > 1945 it was observed that the building was composed by two parts built with different type of units. BEA-S-1, as can be seen from the table, was built with not well shaped units, with an intense red colour, and the masonry layout was not perfect. The masonry found in BEA-S-2 was composed by dark well shaped masonry units, the units were hollow core and laid with a regular layout. In BEA-S-1 for Test 27 and 28 only the values of cohesion were reported and not the values of friction coefficient because they were considered not reliable. The same observation is valid both for cohesion and friction coefficient for Test 30 and 31 for BEA-S-2

Building ROE-S. This building is a school that, over the years, has experienced several expansions and renovation, for this reason in the building several masonry typologies were found. The table ROE-S-1 is relative to the oldest part of the structure which was built using clay units belonging to the category Clay > 1945. Both part ROE-S-2 and ROE-S-3 are characterized by the presence of clay units of the category Clay > 1945, the two were divided to differentiate the different units. In ROE-S-2 older clay units were used while in ROE-S-3 fairly new clay units were used with a really good layout and good quality mortar joints. It can be observed that for many of the shove test performed in the oldest part, ROE-S-1, the test results are not report since the test were not considered reliable mainly due to the rapture of the contrast unit.

Building MID-H. Shove test results for Test 50 are not available because despite the high level of horizontal force no movement of the reference masonry unit was observed, for this reason also the value of the elastic modulus is not considered completely reliable.

Building JOH-H. The category of masonry for this building was defined CS > 1985*. The masonry units found in this structure were not observed anywhere else, they were big calcium silicate “plates”; the size of the plates were: length 1.5 m, height 70 cm and thickness 10 cm. In this building not all the test have been performed, also because the masonry typology was clearly not so interesting in the optic of the performed study. Among the slightly destructive testing only the Single Flat Jack Test was performed to investigate the compressive stress in the walls. Among the non-destructive tests only the Ultrasonic Test was performed.

Building SCH-H. Shove Test results for Test 56 are not available because the test was stopped prematurely due to the rapture of the contrast unit.

Building MOL-H. Shove Test results for Test 63 are not available because the test was stopped prematurely due to the rapture of the contrast unit.

5.1.1 In-Situ Results Resume

In this section the results of the in-situ test, which were presented in the previous pages, are gathered together in order to draw some general conclusions.

The first main step is to pass from a “building organisation” of the results to a “masonry typology organisation”. Therefore the results are collected in different tables where each one of them represents one of the five main material typologies that were identified at the beginning of the project.

5.1.1.1 Calcium Silicate < 1985

The results for the category Calcium Silicate < 1985 are reported in Table 2. There are 4 buildings were this type of material was found: BEA-H, WIL-H-1, LAG-H and SCH-H. It must be underlined that two values of elastic moduli (Test 16 and Test 17) for building LAG-H were removed from the table because not considered reliable since significantly higher respect all the other values. At the bottom of the table for each mechanical parameter, apart the compressive stress in the wall, the average value, the standard deviation and the coefficient of variation are indicated. It is possible to observe a certain scatter in the results especially when referring to the elastic modulus and the cohesion. This is also confirmed by Figure 16 and Figure 18 where the distribution of the vertical elastic modulus and of the cohesion are presented in a bar graph. Looking at the picture of the masonry material in the different test locations it was evident that the quality of the masonry was not uniform. In the building BEA-H and WIL-H it was observed that the calcium silicate units were not well shaped and the masonry joints were poorly filled, moreover the mortar quality did not seem so go (Figure 19). Contrarily, for LAG-H and SCH-H it was observed a better quality of the masonry material, the calcium silicate units were properly shaped, the mortar joints were fully filled with good quality mortar and the masonry layout was good (Figure 20). The observations on the quality of the mortar joints were also supported by the results of the Penetrometric Test where it is visible that the quality for the LAG-H and SCH-H building was significantly higher than for the other two structures.

The above mentioned observations suggested that for the Calcium Silicate < 1985 typology it is necessary the definition of two sub typologies (Table 3):

- Calcium Silicate < 1985 Good Quality
- Calcium Silicate < 1985 Poor Quality

With "Poor Quality" and "Good Quality" it is mainly referred, as previously mentioned, to the quality of the mortar, the filling of the joints and the layout. A visual description of the two masonry sub typology is proposed in Figure 19 and Figure 20

Referring to Table 3 we can see that generally there is a decrease of the dispersion of the results, this supports the idea that a subdivision of the main material typology in two sub typologies is beneficial and necessary.

Table 2. Results for the Calcium Silicate < 1985 masonry typology.

	σ_v	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
	[MPa]	**[MPa]**	**[-]**	**[MPa]**	**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
BEA-H	0.15	-	0.53	0.03	31.35	1033	1317	2790	2272
	0.3	2783	0.46	0.14	30.90	1662	1671	2660	3014
	0.3	5245	0.50	0.09	34.25	1638	1437	2800	2982
	0.28	1381	0.39	0.00	31.90	717	1346	2660	2143
WIL-H-1	0.225	2049	0.73	0.06	35.68	1481	1598	2878	2717
	0.23	3721	0.78	0.23	33.88	1371	1772	2697	3225
	0.13	950	0.94	0.09	36.85	780	1318	2778	2130
	0.07	1769	0.69	0.29	37.25	916	1479	2840	2777
LAG-H	0.08	4390	0.45	0.00	33.63	1325	1425	2518	2659
	0.11	4834	0.45	0.00	32.85	560	2017	2432	2307
	0.23	-	0.89	0.23	36.63	2298	1914	2641	3042
	0.29	-	0.65	0.18	36.75	2270	2723	2578	2808
SCH-H	0.17	5753	-	-	33.38	1488	1735	2687	2339
	0.23	7188	0.88	0.91	30.88	1587	1769	2578	2259
	0.22	6840	0.71	0.31	30.88	1284	1773	2741	2768
	0.16	7785	0.76	0.21	37.30	1782	1819	2517	2279
	0.39	7465	0.78	0.27	36.23	1990	1812	2741	2880

	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
	[MPa]	**[-]**	**[MPa]**	**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
AVG	4439	0.66	0.19	34.15	1422	1701	2679	2624
STD	2383	0.18	0.22	2.42	510	341	124	354
COV	0.54	0.27	1.16	0.07	0.36	0.20	0.05	0.13

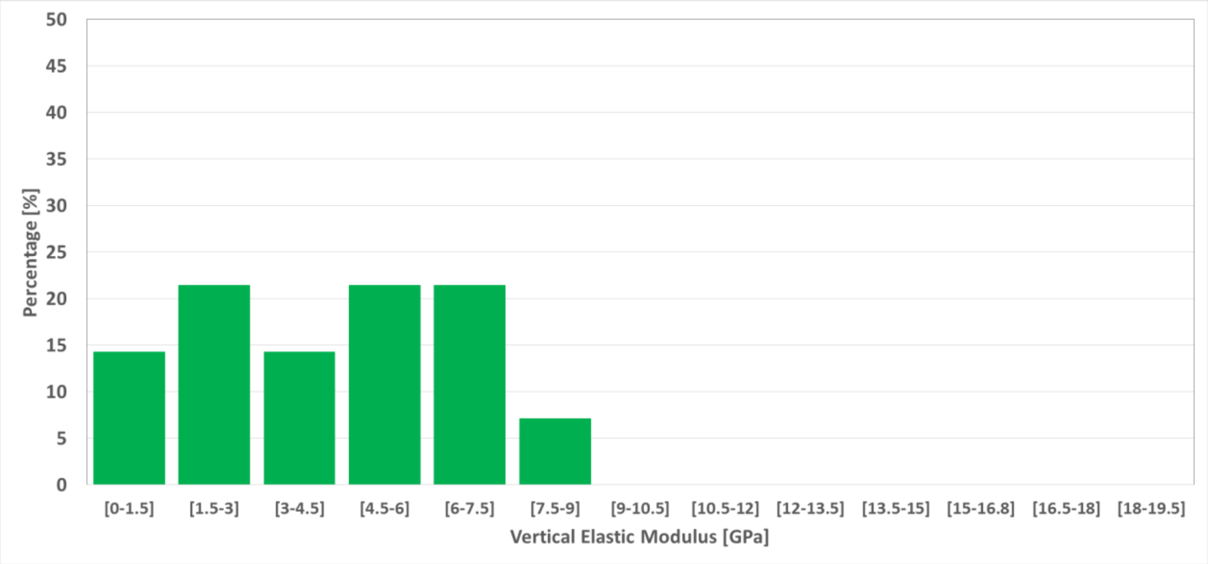


Figure 16. Vertical elastic modulus distribution for Calcium Silicate < 1985 masonry typology.

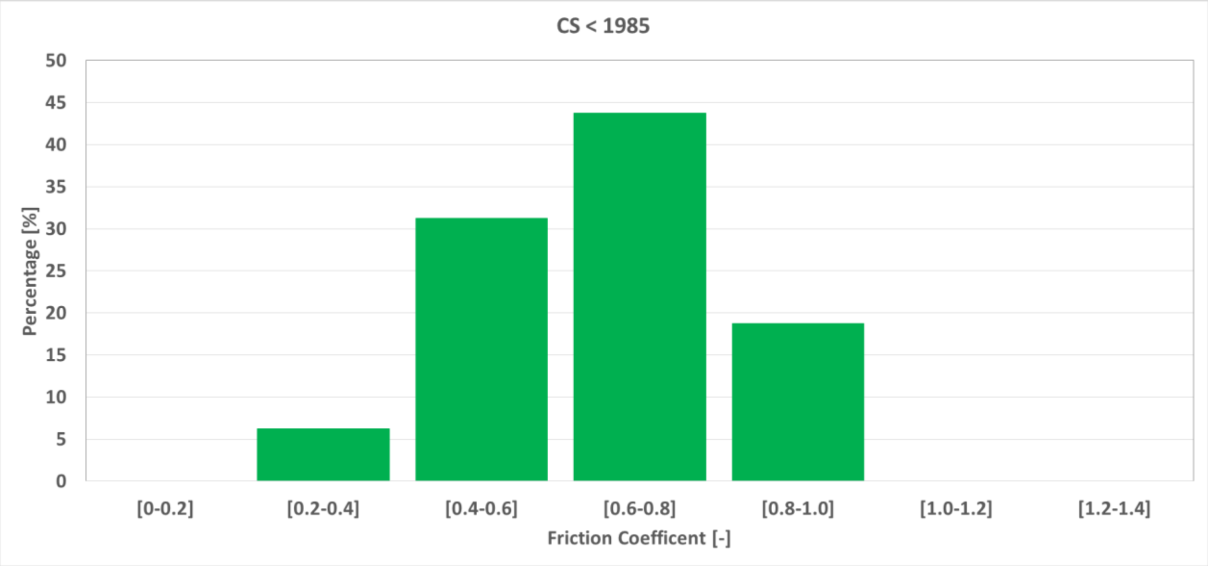


Figure 17. Friction coefficient distribution for Calcium Silicate < 1985 masonry typology.

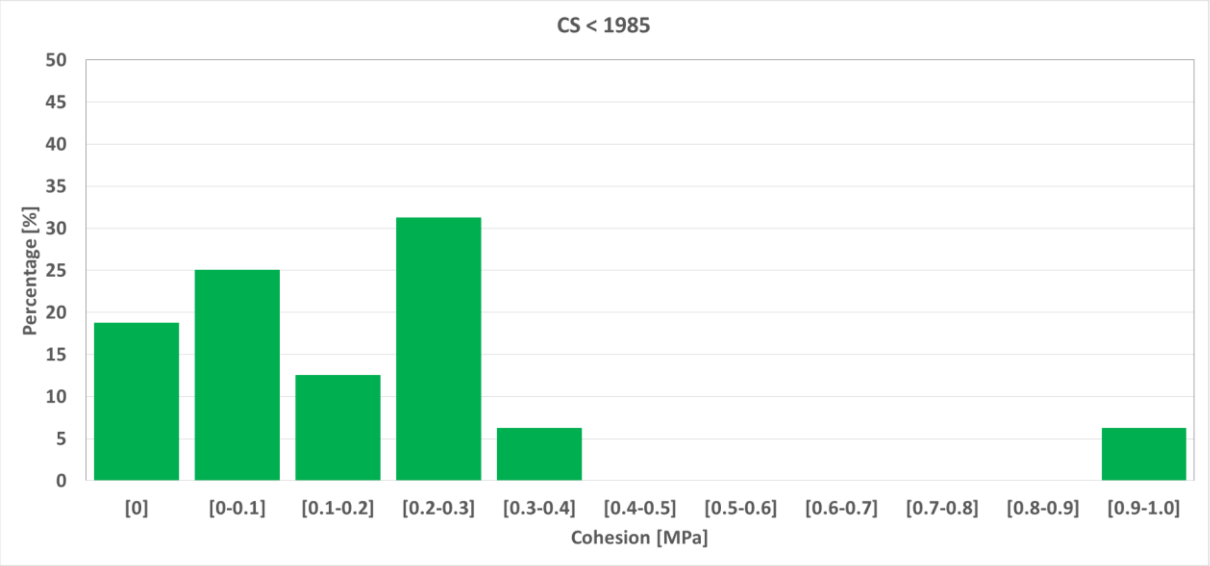


Figure 18. Cohesion distribution for Calcium Silicate < 1985 masonry typology.

Table 3. Definition of sub-categories for Calcium Silicate < 1985 typology.

CS < 1985									
		$E_{m,v(IS)}$	μ	τ_0	**R.H.**	**Vel V**	**Vel H**	**V Dir**	**V Ind**
		[MPa]	**[-]**	**[MPa]**	**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
Poor quality (Test:1-2-3-4-5-6-7-8-9)									
Poor Quality	**AVG**	2557	0.63	0.12	34.01	1200	1492	2763	2658
	STD	1499	0.19	0.10	2.47	384	172	82	425
	COV	0.59	0.30	0.85	0.07	0.32	0.12	0.03	0.16
Good quality (Test:14-15-56-57-58-59-60)									
Good Quality	**AVG**	6322	0.70	0.26	34.28	1431	1764	2602	2499
	STD	1338	0.7	0.28	2.52	457	176	122	262
	COV	0.21	0.25	1.08	0.07	0.32	0.10	0.05	0.10

Figure 19. Example of Poor Quality masonry for the Calcium Silicate < 1985 typology.

Figure 20. Example of Good Quality masonry for the Calcium Silicate < 1985 typology.

5.1.1.2 Calcium Silicate > 1985

Table 4 reports the results for the typology Calcium Silicate > 1985, this material typology was found only in the buildings KWE-H-1 and ROE-S-4 and therefore only 4 tests on this type of material are available. In this case there is a small variation of the mechanical parameters, apart for the cohesion (Figure 23) that in general always showed a pretty large scatter for all the material typologies. From the visual analysis of the pictures for the four test locations it can be concluded that in all the cases the masonry material was in good conditions (well shaped units, good joint filling and masonry layout). It can be therefore concluded that for this material typology a further subdivision it is not necessary, this is also supported by the very limited scatter of the results.

Table 4. Results for the Calcium Silicate > 1985 masonry typology.

	σ_v	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
	[MPa]	[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
KWE-H-1	0.26	3961	0.67	0.02	26.65	2080	1615	-	1913
	0.06	6721	0.83	0.00	21.78	813	1504	-	2765
ROE-S-4	0.05	3947	0.69	0.09	29.88	1405	1142	2488	2888
	0.04	4692	0.49	0.00	35.40	1015	1566	2617	3385

	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
	[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
AVG	4830	0.67	0.03	28.43	1328	1457	2553	2738
STD	1308	0.14	0.04	5.72	558	215	91	612
COV	0.27	0.21	1.62	0.20	0.42	0.15	0.04	0.22

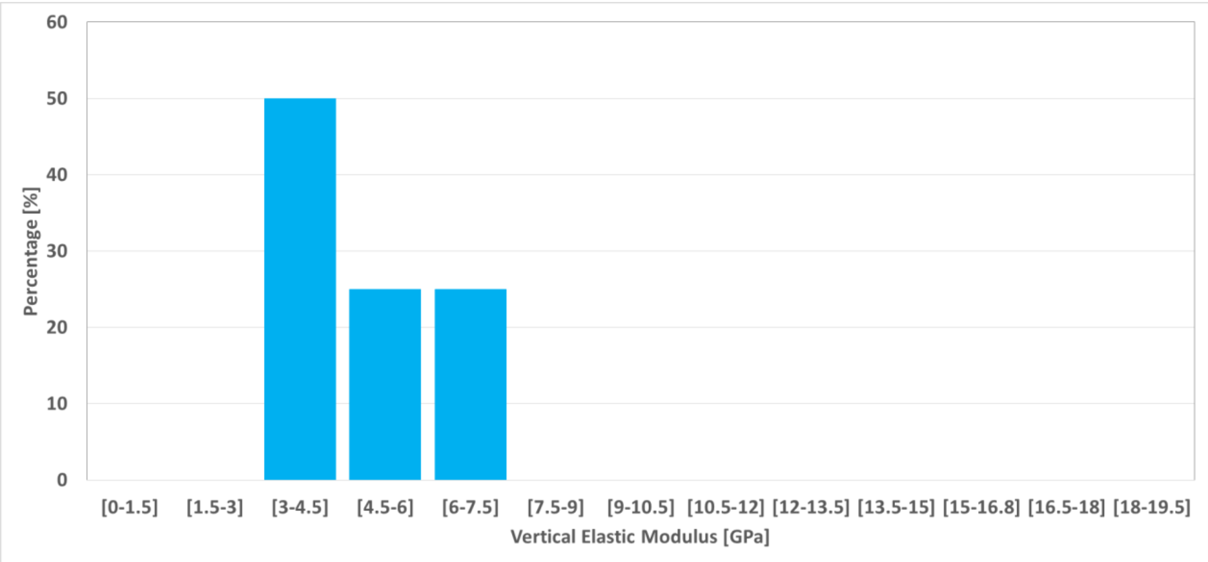


Figure 21. Vertical elastic modulus distribution for Calcium Silicate > 1985 masonry typology.

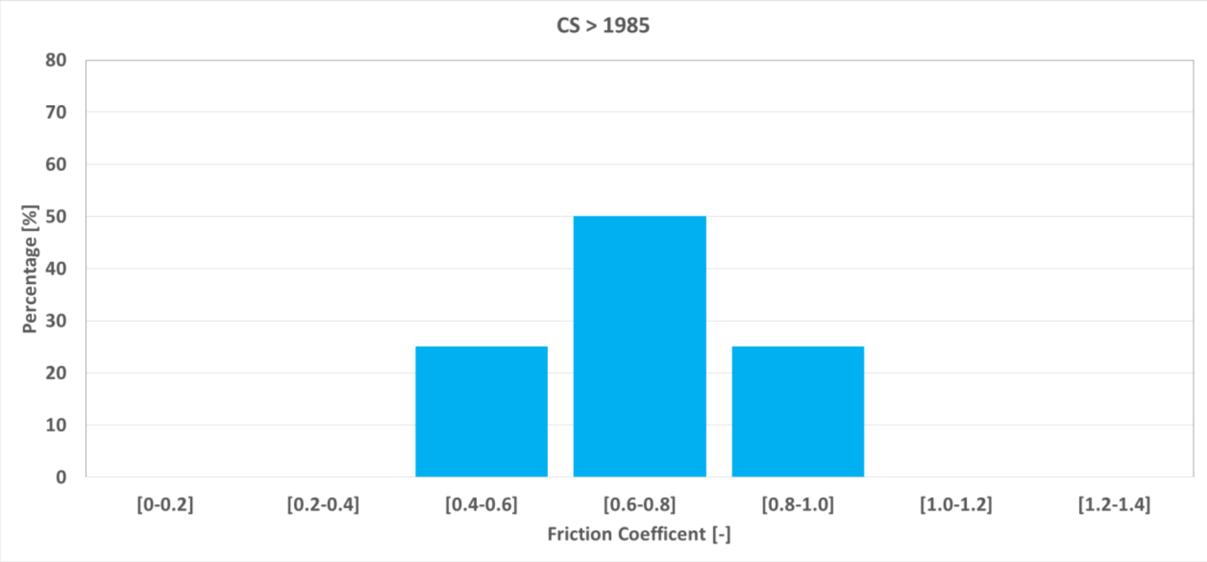


Figure 22. Friction coefficient distribution for Calcium Silicate > 1985 masonry typology.

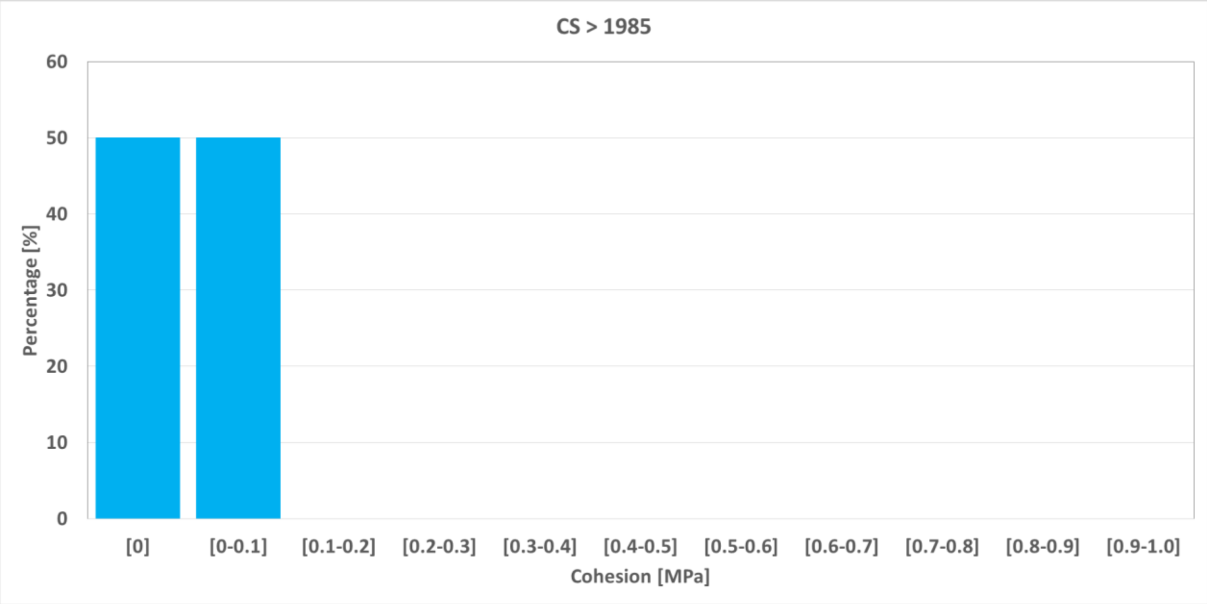


Figure 23. Cohesion distribution for Calcium Silicate > 1985 masonry typology.

5.1.1.3 Clay < 1945

The results for the Clay < 1945 masonry typology are reported in Table 5. For the building WIR-H, Test 10 was performed on an internal wall while the following three tests (from 11 to 13) were performed on external wall. Therefore, for the evaluation of average values of the mechanical parameters only the first of the four test was considered. Additionally, for building MID-H the value of elastic modulus of Test 50 was not considered reliable being significantly higher than all the rest of the tests in the same building. The same consideration is valid for test 38, 39 and 49 for building ROE-S-1.

For this masonry typology there is a pretty large scatter in the results. This can be explained by the difference in layout of the masonry and quality of the joints from building to building; ROE-S-1 and MID-H have the same characteristic presenting a pretty "Good Quality" masonry differently from MOL-H and WIR-H (Test 10). It is therefore considered suitable also in this case the definition of two sub typologies defined according to the quality of the mortar joints and of the masonry layout. The subdivision of the two new typologies is presented in Table 6, the two sub typologies are named "Poor Quality" and "Good Quality", for each sub typology the Test number are indicated. Also in this case it is beneficial the subdivision since it leads to a decrease in the scatter of the results especially of observing the values related to the elastic modulus. A visual differentiation of the two typologies is reported in Figure 27 and Figure 28.

Table 5. Results for the Clay < 1945 masonry typology.

	σ_v	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
	[MPa]	[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
WIR-H	0.13	411	0.44	0.14	29.95	1363	1180	-	2982
ROE-S-1	0.28	-	0.36	0.17	59.10	2290	1583	-	2671
	0.38	-	-	-	57.55	1675	1633	-	2953
	0.17	-	-	-	50.68	2929	1760	1662	3427
	0.18	8443	-	-	56.10	1187	1282	2748	3042
	0.41	6220	-	-	51.78	2366	942	2450	2329
MID-H	0.32	8642	0.31	0.00	56.68	2410	1771	3280	2621
	0.35	6549	-	0.06	49.18	1532	1220	2100	1782
	0.7	11665	-	0.00	54.75	756	1485	3100	2882
	0.33	-	-	-	58.93	2577	1932	3800	2522
MOL-H	0.12	691	0.21	0.15	47.00	665	997	2518	-
	0.29	2087	0.22	0.00	45.08	643	795	1261	2203
	0.18	3833	-	-	50.13	1572	1109	1465	2130
	0.36	2178	0.22	0.09	45.28	1077	797	2488	2078

	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	Vel H B	V Ind
	[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
AVG	5072	0.29	0.08	50.87	1646	1320	2443	2586
STD	3812	0.09	0.07	7.72	756	376	785	468
COV	0.75	0.32	0.96	0.15	0.46	0.28	0.32	0.18

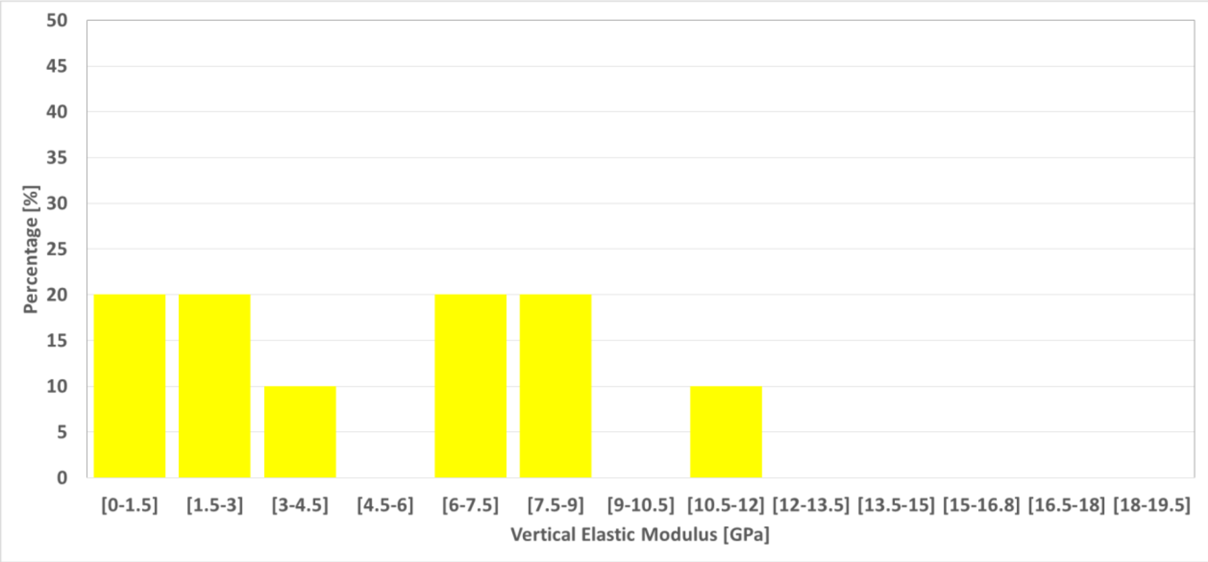


Figure 24. Vertical elastic modulus distribution for Clay < 1945 masonry typology.

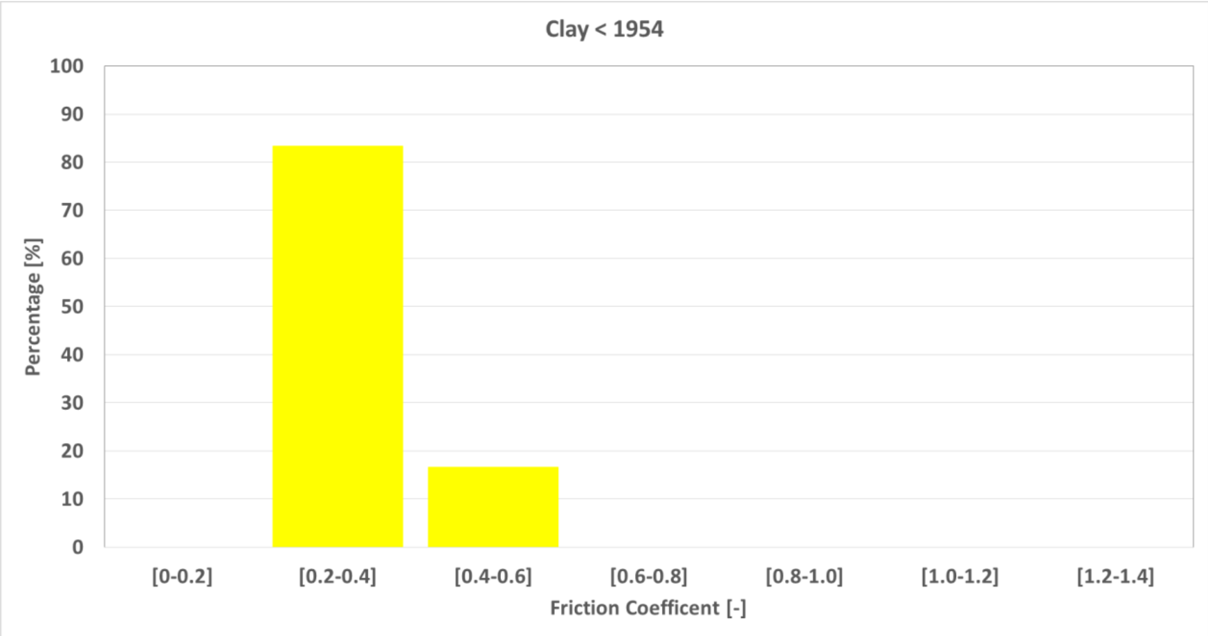


Figure 25. Friction coefficient distribution for Clay < 1945 masonry typology.

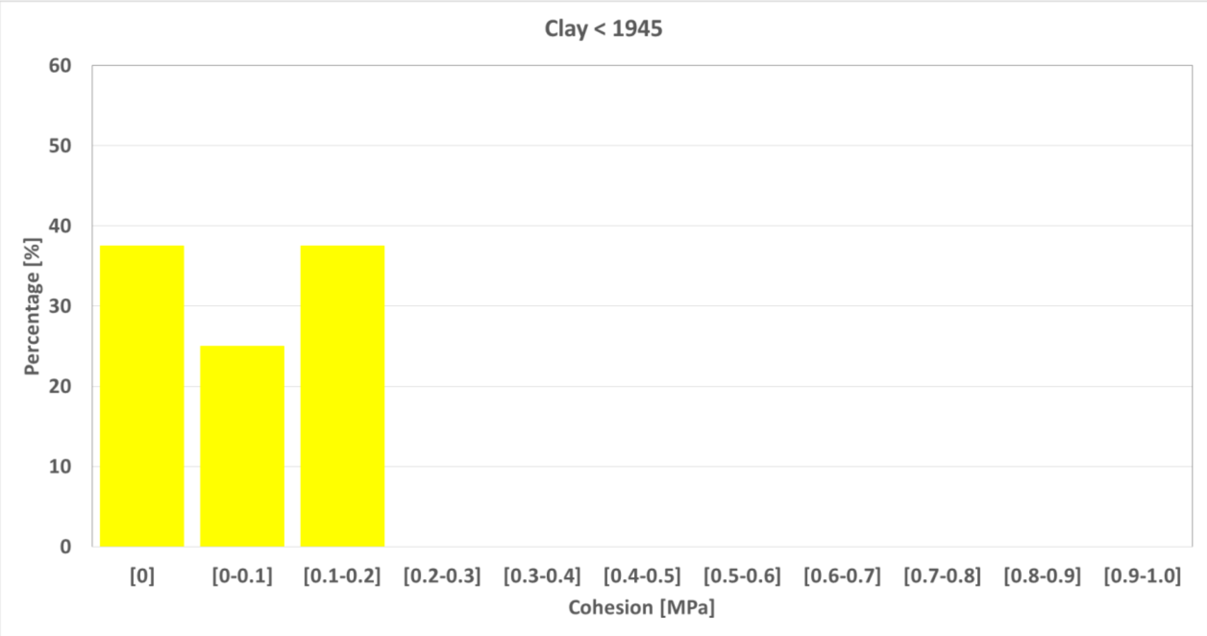


Figure 26. Cohesion distribution for Clay < 1945 masonry typology.

Figure 27. Example of Poor Quality masonry for the Clay < 1945 typology.

Figure 28. Example of Good Quality masonry for the Clay < 1945 typology.

Table 6. Definition of sub-categories Clay < 1945 typology.

Clay < 1945									
		$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
		[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
Poor quality (10-61-62-63-64)									
Poor Quality	AVG	1840	0.27	0.10	43.49	1064	976	1933	2348
	STD	1370	0.11	0.07	7.83	414	177	664	426
	COV	0.74	0.41	0.73	0.18	0.39	0.18	0.34	0.18
Good quality (38-39-40-45-46-47-48-49)									
Good Quality	AVG	8304	0.34	0.06	54.97	1969	1512	2734	2692
	STD	2171	0.03	0.08	3.64	716	314	730	469
	COV	0.26	0.09	1.43	0.07	0.36	0.21	0.27	0.17

5.1.1.4 Clay > 1945

The results for the typology Clay > 1945 are reported in Table 7. From a visual analyses of the test locations of the current typology it can be recognised a large heterogeneity of the type of bricks and layout. Despite this, the scatter in the results is less accentuated respect to other masonry typologies, apart for the cohesion. It must be underlined that for the building BEA-S-2 Test 30 the value of elastic modulus has not been reported since it was significantly different respect the other three test in the same building and therefore not considered reliable. Additionally the building WIL-H-2 has not been included in the table since it was the only case of test performed on an external wall and therefore it was not considered consistent including it to the group.

Table 7. Results for the Clay > 1945 masonry typology.

	σ_v	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
	[MPa]	[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
KWE-H-2	0.45	9698	0.88	0.00	34.68	1693	1837	-	2830
	0.15	3469	0.96	0.11	30.95	1480	1570	-	2928
BEA-S-1	0.38	12545	0.39	0.09	51.93	2261	1735	3280	2527
	0.23	8294	-	0.22	52.58	1520	1556	3340	2140
	0.13	5664	-	0.14	48.38	1528	1617	3580	3892
	0.30	11052	0.65	0.11	52.13	1924	1598	3580	2346
BEA-S-2	0.14	4319	-	-	40.53	1121	1180	1510	1620
	0.23	-	-	-	50.13	2657	1477	1350	1959
	0.07	8844	0.55	0.11	47.00	1598	1806	2460	2622
	0.09	6622	0.68	0.38	47.45	1716	1278	2120	2527
ROE-S-2	0.24	14188	0.40	0.15	49.03	2392	1359	2513	3467
	0.09	4459	0.28	0.13	50.03	1286	1377	1974	2710
	0.12	18972	0.41	0.00	56.75	2610	2149	3595	4120
	0.12	14844	0.52	0.17	55.78	1735	1954	3386	3643
ROE-S-3	0.23	5161	0.81	0.09	46.28	1887	1781	2320	2209
	0.23	5076	0.98	0.10	44.08	1466	1756	2361	3217
HOO-H	0.43	10308	0.45	0.03	36.28	1602	1618	2461	2748
	0.65	13660	1.08	0.02	34.95	1469	1242	2430	2208
	0.13	4573	0.58	0.03	32.93	1106	1562	2548	2459

	$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
	[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
AVG	8986	0.64	0.11	45.36	1740	1603	2636	2746
STD	4427	0.25	0.09	7.85	473	245	700	648
COV	0.49	0.39	0.85	0.17	0.27	0.15	0.27	0.24

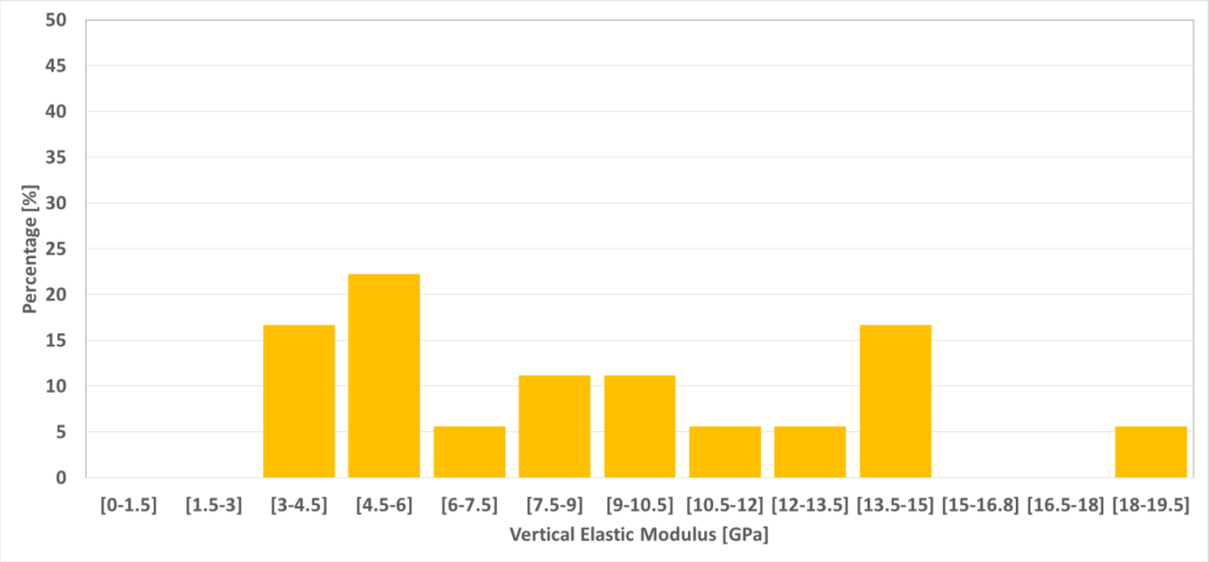


Figure 29. Elastic modulus distribution for Clay > 1945 masonry typology.

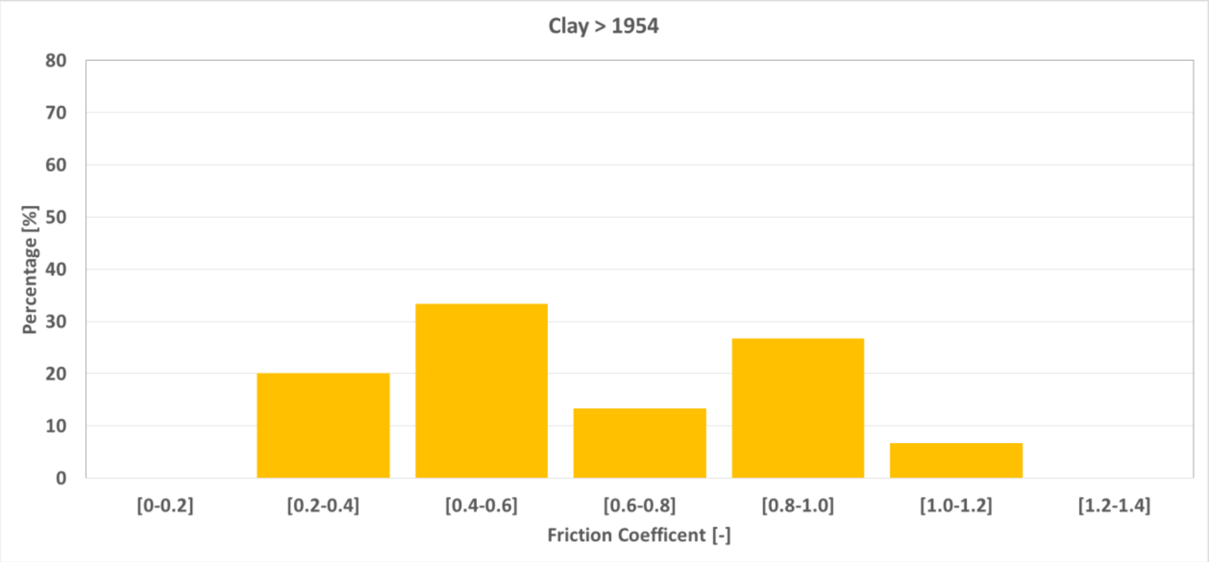


Figure 30. Friction coefficient distribution for Clay > 1945 masonry typology.

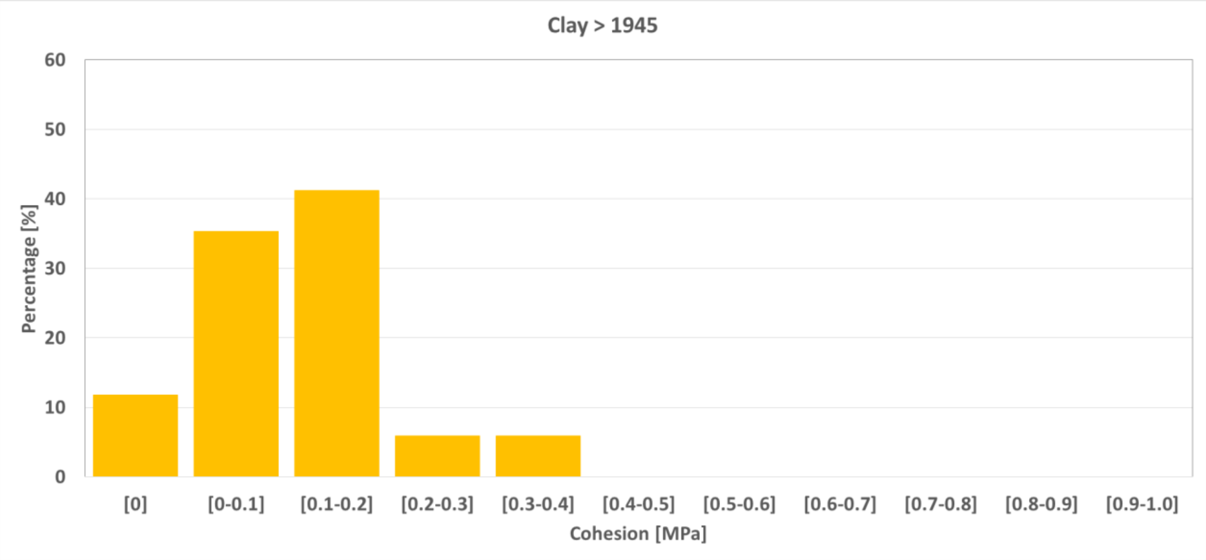


Figure 31. Cohesion distribution results for Clay > 1945 masonry typology.

Despite the limited variability of this masonry typology it is possible to identify some sub typologies that are here presented. It was observed that in several buildings belonging to this group the test location showed "newer" masonry units with a really good layout and perfectly filled joints we refer in particular to: KWE-H-2, ROE-S-3 and HOO-H. The test performed in these three structures have been grouped in a sub typology called "Newer Units" (Table 8, Figure 32). In the remaining structures it is visible that the masonry walls where build in an older period. The latter can be divided according to the layout and the masonry units in three sub typologies. The first sub typology is called "Older Poor Quality" (Figure 33) and it groups the location where a poor quality masonry was found, this group includes test location found in the building: BEA-S-1 and location 42 of the structure ROE-S-2. The second group is the one including all the Test of the structure BEA-S-2 where particular masonry units were found. The latter are characterized by a well-defined shape and a dark colour, from the extraction of masonry sample from the wall it was possible to see that these units are hollow core and not solid. This sub-typology was labelled with the name "Older Dark Good Quality" (Figure 34). The fourth and final sub typology was called "Older Good Quality" (Figure 35) and includes the locations 41, 43 and 44 of the structure ROE-S-2. As expected the subdivision of the main material typology Clay > 1945 in four sub typologies leads to a reduction of the scatter in the results for each single typology.

Table 8. Definition of sub-categories Clay > 1945 typology.

Clay > 1945									
		$E_{m,v(IS)}$	μ	τ_0	R.H.	Vel V	Vel H	V Dir	V Ind
		[MPa]	[-]	[MPa]	[-]	[m/s]	[m/s]	[m/s]	[m/s]
Newer Units (24-25-34-35-53-54-55)									
Newer Units	AVG	7421	0.82	0.05	37.16	1529	1624	2424	2657
	STD	3803	0.23	0.04	5.76	241	200	89	380
	COV	0.51	0.28	0.83	0.16	0.16	0.12	0.04	0.14
Older Poor Quality (26-27-28-29-42)									
Older Poor Quality	AVG	8403	0.44	0.14	51.01	1704	1577	3151	2723
	STD	3437	0.19	0.05	1.76	387	130	672	687
	COV	0.41	0.44	0.36	0.03	0.23	0.08	0.21	0.25
Older Dark Good Quality (30-32-33)									
Older Dark Good Quality	AVG	6595	0.61	0.24	44.99	1478	1421	2030	2256
	STD	2262	0.10	0.19	3.87	315	337	481	553
	COV	0.34	0.16	0.80	0.09	0.21	0.24	0.24	0.25
Older Good Quality (41-43-44)									
Older Good Quality	AVG	16001	0.44	0.11	53.85	2246	1821	3165	3743
	STD	2594	0.07	0.09	4.21	455	412	574	338
	COV	0.16	0.15	0.87	0.08	0.20	0.23	0.18	0.09

Figure 32. Example of Newer Units masonry for the Clay > 1945 typology.

Figure 33. Example of Older Poor Quality masonry for the Clay > 1945 typology.

Figure 34. Example of Older Dark Good Quality masonry for the Clay > 1945 typology.

Figure 35. Example of Older Good Quality masonry for the Clay > 1945 typology.

5.1.1.5 Concrete

Finally the results of the last masonry typology Concrete are reported in Table 9. For this typology we have only one structure, JUL-H, therefore this is a really limited level of dispersion of the results.

Table 9. Results for the Concrete masonry typology.

	σ_v	**$E_{m,v(IS)}$**	**μ**	**τ_0**	**R.H.**	**Vel V**	**Vel H**	**V Dir**	**V Ind**
	[MPa]	**[MPa]**	**[-]**	**[MPa]**	**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
JUL-H	0.17	7222	-	-	26.425	1483	1673	2678	1874
	0.25	9462	-	0.26	26.525	1440	1382	1560	1807
	0.19	8247	-	-	26.325	1517	1329	2631	1763
		$E_{m,v(IS)}$	**μ**	**τ_0**	**R.H.**	**Vel V**	**Vel H**	**V Dir**	**V Ind**
		[MPa]	**[-]**	**[MPa]**	**[-]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
	AVG	8310	-	0.26	26.425	1480	1461	2290	1815
	STD	1121	-	-	0	39	185	632	56
	COV	0.13	-	-	0.00	0.03	0.13	0.28	0.03

5.1.2 Results Correlations

This section is intended to provide correlations between the different mechanical parameters collected in the in-situ experimental campaign.

5.1.2.1 Correlation between Double Flat Jack Test and Ultrasonic Test

The Double Flat Jack Test provides a direct measure of the vertical deformability, i.e. vertical elastic modulus, of the masonry material. At the same time also the Ultrasonic Test in the vertical configuration gives us an indirect measure of the same mechanical parameter. Therefore, it was thought to investigate the correlation of the Elastic Modulus against the Vertical Velocity, Figure 36 and Figure 37. In Figure 36 the results are divided by material typology, despite a certain dispersion of the results it is possible to identify a certain trend. In Figure 37 all the results are plotted together and trend lines are added; two different format have been used a linear trend line (in red) and a logarithmic trend line (in green).

Such a correlation could be really helpful in the case one did not have the means to perform an invasive testing as the Double Flat Jack Test. By simply performing an Ultrasonic Test, which is faster and cheaper, one has the possibility of obtaining a measure of the Elastic Modulus. However, at this stage of the project due to the limited number of samples and the dispersion in the results it is observable how the correlation is characterised by a really low value of coefficient of determination. Such a low values indicates a weak correlation therefore at this stage the correlation cannot be used to directly evaluate the elastic modulus starting from the results of the Ultrasonic Test. The correlation could be instead be of use to check if the results obtained from the two test are reliable and fall into a certain range.

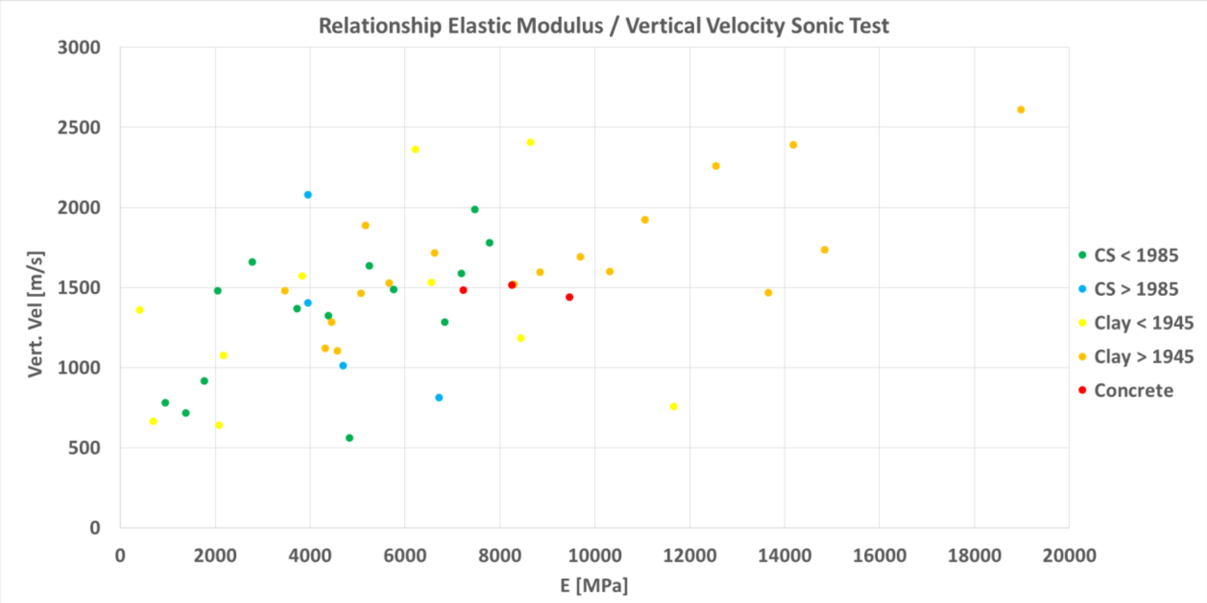


Figure 36. Correlation between Vertical Elastic Modulus and Vertical Velocity.

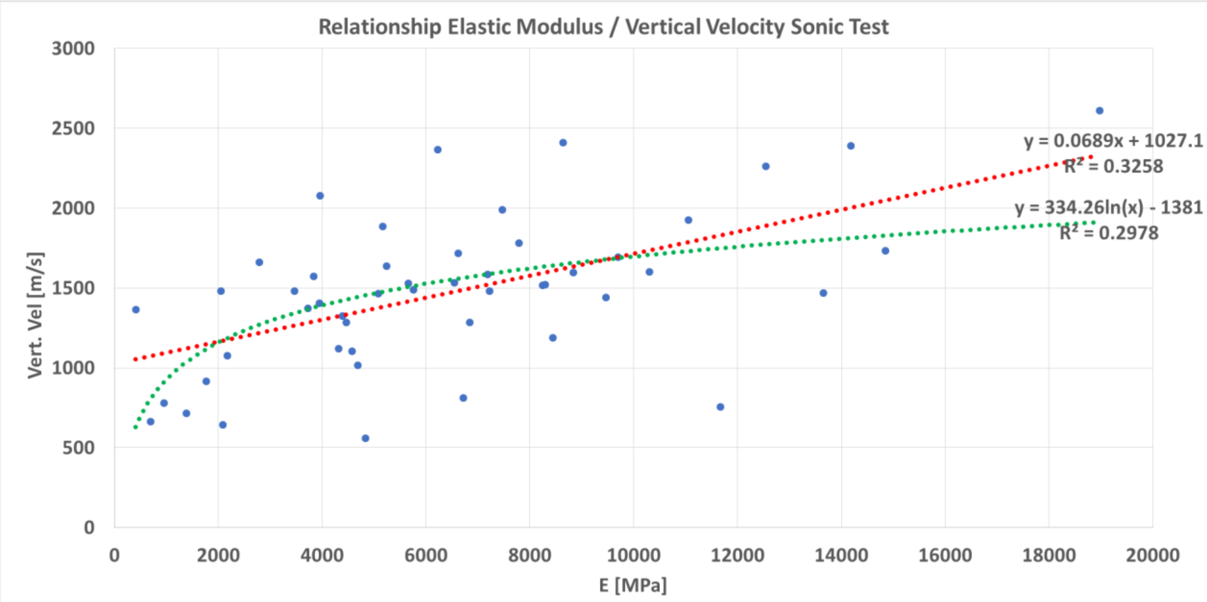


Figure 37. Correlation between Vertical Elastic Modulus and Vertical Velocity.

5.1.2.2 Correlation between Rebound Hammer Test and Ultrasonic Test

A second point investigated is the possibility of correlating the results obtained from the Rebound Hammer Test and the Ultrasonic Test on a single brick. Both the test should provide information concerning the strength and the deformability of the masonry units so it was thought to verify if a correlation stands between the results of the two. Figure 38 presents the correlation between the results of the Rebound Hammer Test and the one of the Ultrasonic Test on a single brick in the direct configuration, the comparison with the results of the Ultrasonic

Test on a single brick for the indirect configuration are instead presented in Figure 39. Analysing the two figure it is possible to state there are no strong correlation between the two tests.

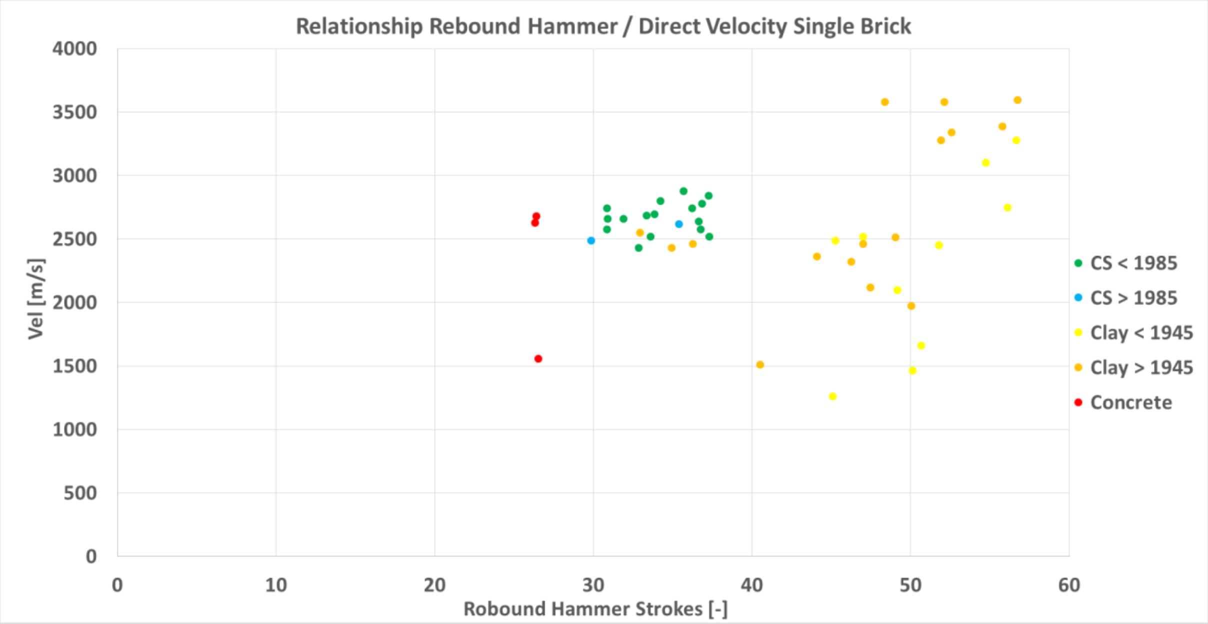


Figure 38. Correlation of results from Rebound Hammer Test and Ultrasonic Test direct configuration a single brick.

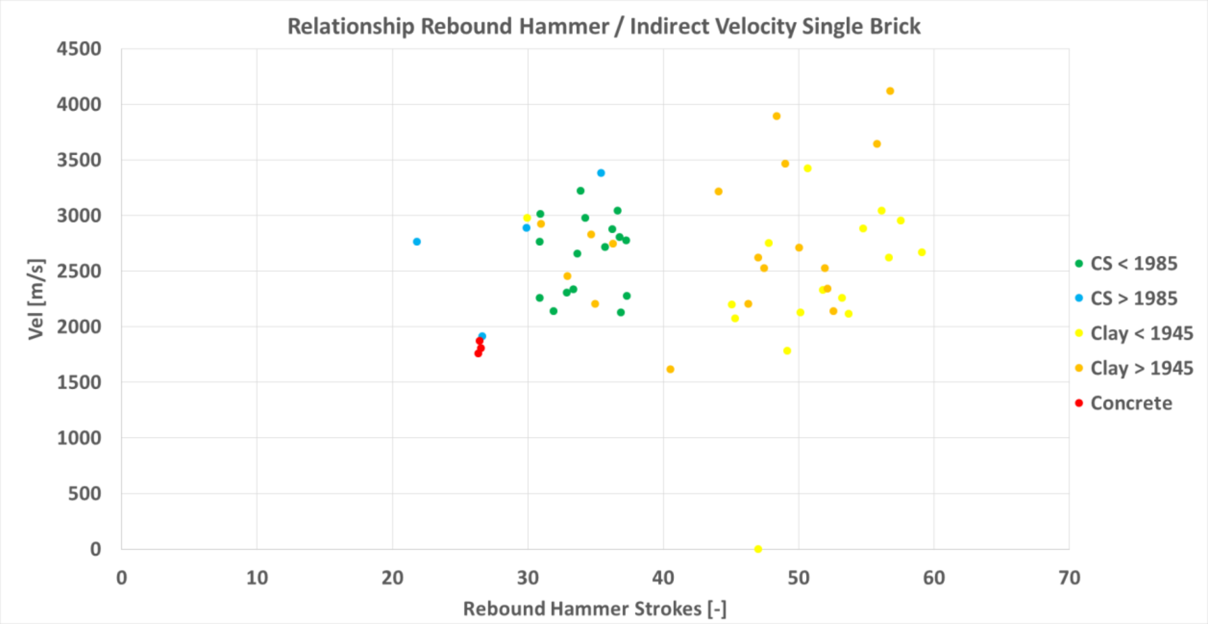


Figure 39. Correlation of results from Rebound Hammer Test and Ultrasonic Test indirect configuration a single brick.

5.1.2.3 Correlation between Penetrometric Test on Mortar and Flat Jack Results

In paragraph 5.1.1.1 it was said that the subdivision of the Clay < 1985 in sub-categories was also supported by the results of the Penetrometric Test on Mortar, it was therefore thought of trying to draw a correlation between the results of the latter and the results of the Double Flat Jack Test in terms of Elastic Modulus. The results of the Penetrometric Test on Mortar are not of easy interpretation especially because no correlations are provided to directly relate the test to a mechanical parameters like the compressive strength of the mortar. The test, as it was performed, provides the number of strokes necessary to a metallic probe to penetrate of 5 cm into the mortar. For each centimeter the number of strokes necessary to penetrate it are recorded, if more than 25 strokes are necessary the test is performed and the symbol "//" is used, if no strokes are necessary to penetrate the centimeter the symbol "/" is used. To obtain a single value of strokes it was thought of summing up the strokes for each centimeter, the "/" was considered equal to 0 while "//" was considered 25 strokes if obtained at the 5th centimeter, 50 strokes at the 4th centimeter, 75 strokes at the 3rd centimeter, 100 strokes at the 2nd centime and 125 strokes at the 1st centimeter. The obtained results are plotted against the Elastic Modulus as shown in Figure 40. In general it is observable there is no strong correlation between the results of the Penetrometric Test and the Elastic Modulus, moreover a significant dispersion of the results it is observable. The feeling is that the results of the Penetrometric Test can, in certain cases, support the visual information concerning the mortar joints but they cannot be directly used for subdividing the results into "good" and "bad" quality, i.e. for the definition of subcategories. This definition must be performed taking into account all the available information (pictures, results of slightly destructive and non destructive test) and cannot be performed based only on a single test.

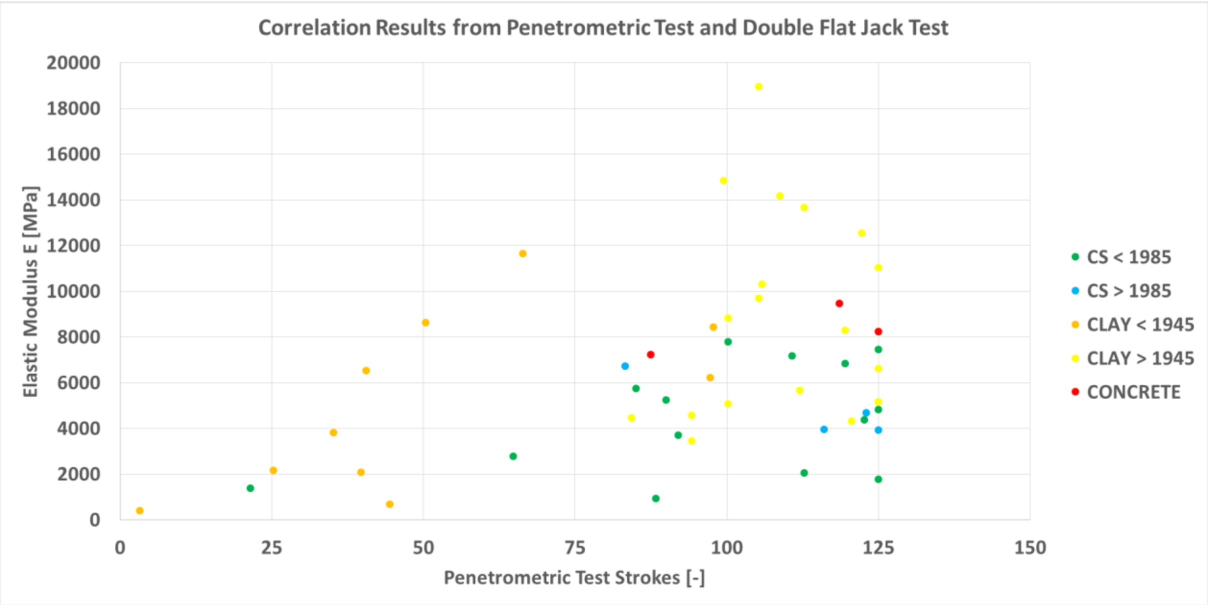


Figure 40. Correlation between the results from the Penetrometric Test on Mortar and the results from the Double Flat Jack Test.

5.2 Laboratory Test Results

This sections reports the results of the experimental testing performed on the laboratory of TU Delft and TU Eindhoven. It must be underlined that not for all tests samples coming from all the buildings were available, in fact sometimes due to the small size of the building a limited number of samples was possible to be obtained and in certain cases due to the bad quality of the mortar joints samples reached the laboratory already damaged or it was not possible to extract them. Detailed information concerning the test apparatus, the test procedure, the samples tested and the results can be found in the final test reports produced by the laboratories.

5.2.1 Compression Test on Masonry Units

The results of the Compression Test on Masonry Units are presented in Table 10, Table 11 and Table 12 for Calcium Silicate < 1985, Clay > 1945 and Clay > 1945 typologies respectively. The mechanical parameter obtained from the test are: the compressive strength $f_{mu,c}$, the normalised compressive strength $f_{bu,c}$ and the elastic modulus $E_{mu,c}$.

Table 10. Result of Compression Test on Calcium Silicate < 1985 units.

Calcium Silicate < 1985				
Sample name	$f_{mu.c}$ [MPa]	$E_{mu.c}$ [GPa]	***Shape factor***	$f_{bu.c}$ [MPa]
WIL-H-1	8.81	0.74	0.75	6.59
	11.36	0.64	0.76	8.64
	7.33	0.38	0.77	5.64
	20.85	0.80	0.78	16.24
BEA-H	31.37	5.14	0.75	23.37
	22.45	2.80	0.75	16.72
	24.16	3.10	0.75	18.00
	20.35	2.05	0.75	15.16
	21.68	3.07	0.75	16.15
	20.49	3.03	0.76	15.26
LAG-H	13.83	3.76	0.87	12.03
	17.47	2.24	0.86	15.07
	18.88	2.31	0.87	16.44
	20.32	3.72	0.87	17.68
	22.25	4.69	0.88	19.49
	20.76	5.24	0.88	18.18
SCH-H	18.19	3.04	0.87	15.86
	17.19	4.49	0.87	14.90
	15.49	1.64	0.87	13.51
	22.33	3.27	0.87	19.36
	19.21	3.29	0.87	16.66
	19.85	3.36	0.87	17.21
AVG	**18.28**	**2.67**	**0.81**	**14.86**
STDV	**5.24**	**1.41**	**0.06**	**4.13**
COV	**0.29**	**0.53**	**0.07**	**0.28**

Table 11. Result of Compression Test on Clay < 1945 units.

Clay < 1945				
Sample name	$f_{mu.c}$ [MPa]	$E_{mu.c}$ [GPa]	***Shape factor***	$f_{bu.c}$ [MPa]
WIR-H	27.46	1.13	0.76	20.81
	33.61	3.19	0.77	25.88
	35.64	5.57	0.75	26.77
	35.42	4.02	0.76	26.37
	21.28	1.88	0.76	16.24
	55.21	-	0.75	41.19
ROE-S-1.1	24.05	0.46	0.77	18.45
	19.97	0.32	0.79	15.72
	24.13	0.43	0.78	18.72
	23.64	0.32	0.76	18.04
	21.16	0.24	0.82	17.31
	19.58	0.48	0.83	16.23
MOL-H	31.18	1.19	0.75	23.35
	27.90	0.97	0.74	20.62
	23.40	0.86	0.75	17.64
	32.71	0.95	0.76	24.70
	29.79	-	0.75	22.34
AVG	**28.62**	**1.51**	**0.77**	**21.78**
STDV	**8.71**	**1.58**	**0.02**	**6.24**
COV	**0.30**	**1.04**	**0.03**	**0.29**

Table 12. Result of Compression Test on Clay > 1945 units.

Clay > 1945				
Sample name	$f_{mu.c}$ [MPa]	$E_{mu.c}$ [GPa]	***Shape factor***	$f_{bu.c}$ [MPa]
BEA-S-1	48.10	3.12	0.75	36.17
	18.99	0.69	0.76	14.49
	24.46	1.06	0.76	18.71
	30.21	1.44	0.78	23.47
	24.80	0.64	0.75	18.60
	39.71	1.80	0.76	30.02
ROE-S-3	30.68	1.67	0.74	22.70
	36.34	0.91	0.74	27.00
	33.69	0.88	0.74	24.93
	34.04	0.60	0.75	25.60
	29.05	0.88	0.74	21.64
	29.07	0.76	0.75	21.71
KWE-H-2	19.59	0.24	0.75	14.59
	19.32	0.14	0.75	14.41
	23.70	0.18	0.75	17.80
	24.25	-	0.75	17.85
	18.67	0.34	0.77	14.30
	17.77	0.29	0.75	13.24
HOO-H	9.41	0.44	0.82	7.75
	10.46	0.56	0.82	8.56
	12.90	1.52	0.82	10.64
	10.05	0.52	0.82	8.25
	11.04	0.83	0.85	9.36
	21.99	0.95	0.82	18.10
AVG	**24.10**	**0.86**	**0.77**	**18.33**
STDV	**10.06**	**0.67**	**0.03**	**7.31**
COV	**0.42**	**0.78**	**0.04**	**0.40**

5.2.2 Flexural Test on Masonry Units

The results of the Flexural Test on masonry units are reported in the following tables, the mechanical parameters obtained from the test are: tensile strength $f_{mu,t}$, elastic modulus in the horizontal direction $E_{mu,t(h)}$ and the elastic modulus in the vertical direction $E_{mu,t(v)}$. Results for the Calcium Silicate < 1985 are reported in Table 13, Table 14 reports the results for the Clay < 1945 masonry typology. The results for the Clay > 1945 are reported in three separated tables due to differences in the different types of units. The results for the solid units are reported in

Table 15, Table 16 lists the results of the samples from the building BEA-S-2 where perforated (hollow-core) units were found and Table 17 reports the results on the clay units from the building HOO-H where frogged units were found. Finally the results from the concrete units found in the building JUL-H are listed in Table 18.

Table 13. Result of Flexural Test on Calcium Silicate < 1985 units.

Calcium Silicate < 1985							
Sample name		**$f_{mu.t}$ [MPa]**		**$E_{mu.t(h)}$ [GPa]**		**$E_{mu.t(v)}$ [GPa]**	
			AVG		**AVG**		**AVG**
WIL-H-1	D1	2.7	4.2	11.7	18.1	-	8.8
	D2	2.58		12.5		2.6	
	D3	1.95		15.5		3.9	
	D4	2.17		1.5		-	
	D5	7.97		12.8		15.2	
	D6	4.47		31		8.4	
	D7	4.98		26.7		17.7	
	D8	3.44		16		11.3	
	D9	8.36		35.7		-	
	D10	7.37		-		-	
	D11	1.16		-		2.2	
	D12	3.11		17.3		-	
BEA-H	D1	6.07	4.1	35	23.4	-	10.3
	D2	4.02		18.8		-	
	D3	2.14		21.6		2.4	
	D4	3.25		18.4		1.1	
	D5	3.18		28.3		11.2	
	D6	4.32		0.6		0.8	
	D7	3.32		27.7		23.9	
	D8	3.04		27.5		-	
	D9	3.55		27.2		-	
	D10	6.25		-		24.6	
	D11	2.84		17.5		8	
	D12	6.66		34.3		-	
LAG-H	D1	5.43	4.5	30.3	27.2	14.2	10.2
	D2	3.41		25.9		8.4	
	D3	4.66		26.2		8.5	
	D4	5.25		27.5		10.1	
	D5	4.02		18.9		9.4	
	D6	3.88		23.3		9.2	
	D7	4.28		24.5		8.7	
	D8	4.69		30.4		12.6	
	D9	4.5		32.1		10.1	
	D10	5.31		33.4		12.1	
	D11	4.2		30.9		7.5	
	D12	4.55		22.8		11.5	
SCH-H	D1	5.55	5.01	29.2	27.7	15.1	13.1
	D2	4.55		29.6		-	
	D3	5.59		28.4		-	
	D4	4.99		24.9		-	
	D5	3.78		23.7		9.5	
	D6	5.57		30.1		14.8	
AVG		**4.44**		**23.8**		**10.7**	
STDV		**1.58**		**8.6**		**5.7**	
COV		**0.36**		**0.36**		**0.53**	

Table 14. Result of Flexural Test on Clay < 1945 units.

Clay < 1945						
Sample name	$f_{mu.t}$ **[MPa]**		$E_{mu.t(h)}$ **[GPa]**		$E_{mu.t(v)}$ **[GPa]**	
		AVG		**AVG**		**AVG**
MID-H	10.85	10.42	55.9	45.03	20.3	14.88
	8.18		44.9		-	
	8.23		35.3		13.3	
	8.86		36.9		20.4	
	17.35		45.4		6.0	
	9.05		51.8		14.4	
WIR-H	7.63	4.73	25.7	28.22	-	9.89
	6.22		22.6		12.4	
	2.71		-		9.1	
	6.04		35.4		-	
	3.74		30.3		9.2	
	3.57		-		5.9	
	6.36		-		13.4	
	3.24		29.2		9.7	
	1.77		14.9		7.4	
	3.41		21.4		7.0	
	9.38		64.1		20.0	
	2.68		10.4		4.8	
ROE-S-1.1	1.54	4.51	4.7	19.85	1.6	7.63
	6.22		28.3		1.6	
	1.02		1.7		1.1	
	6.33		27.8		11.3	
	9.79		43.9		25.8	
	2.17		12.7		4.4	
ROE-S-1.2	12.21	9.73	64.5	42.38	26.6	24.72
	8.39		37.0		29.2	
	7.58		25.7		20.9	
	2.87		21.1		10.5	
	13.79		60.5		31.9	
	13.51		45.5		29.2	
MOL-H	3.42	2.78	15.0	11.57	10.7	8.69
	1.69		11.3		3.9	
	6.60		23.8		15.2	
	2.76		7.3		-	
	0.71		0.9		0.5	
	1.49		11.1		13.15	
AVG	**6.43**		**29.41**		**12.76**	
STDV	**4.11**		**18.03**		**8.91**	
COV	**0.64**		**0.61**		**0.70**	

Table 15. Result of Flexural Test on Clay > 1945 units.

Clay > 1945							
Sample name		$f_{mu.t}$ **[MPa]**		$E_{mu.t(h)}$ **[GPa]**		$E_{mu.t(v)}$ **[GPa]**	
			AVG		**AVG**		**AVG**
BEA-S-1	D1	3.17	4.06	20.3	18.58	12.3	9.96
	D2	4.98		25.0		11.7	
	D3	4.70		21.8		13.1	
	D4	4.76		14.6		9.5	
	D5	2.67		11.2		3.2	
KWE-H-2	D1	4.11	5.22	15.3	17.80	10.6	7.18
	D2	4.50		19.3		3.6	
	D3	5.80		20.9		7.5	
	D4	4.98		20.6		-	
	D5	6.19		-		10.9	
	D6	5.71		12.9		3.3	
ROE-S-2	D1	1.98	2.80	3.3	11.07	1.3	4.65
	D2	2.41		9.3		1.6	
	D3	2.63		12.4		4.8	
	D4	4.46		22.3		9.3	
	D5	3.58		13.5		5.9	
	D6	1.75		5.6		5.0	
ROE-S-3	D1	8.74	6.46	24.7	20.34	13.4	11.86
	D2	8.79		19.8		11.2	
	D3	5.31		25.1		11.1	
	D4	3.27		9.9		8.8	
	D5	6.17		22.2		14.8	
WIL-H-2	D1	7.68	4.94	30.5	25.37	-	8.17
	D2	2.71		15.3		3.8	
	D3	4.96		35.4		10.9	
	D4	6.60		25.2		-	
	D5	2.60		22.4		-	
	D6	5.09		23.4		9.8	
AVG		**4.69**		**18.63**		**8.36**	
STDV		**1.90**		**7.42**		**4.04**	
COV		**0.40**		**0.40**		**0.48**	

Table 16. Result of Flexural Test on Clay > 1945 perforated units.

Perforated -clay-brick > 1945							
Sample name		$f_{mu.t}$ **[MPa]**		$E_{mu.t(h)}$ **[GPa]**		$E_{mu.t(v)}$ **[GPa]**	
			AVG		**AVG**		**AVG**
BEA-S-2	D1	4.2	3.38	13.5	12.75	11.7	8.23
	D2	3.4		12.6		9.9	
	D3	3.0		11.6		5.6	
	D4	3.2		13.0		8.7	
	D5	3.0		12.5		3.6	
	D6	3.5		13.3		9.9	
AVG		**3.38**		**12.75**		**8.23**	
STDV		**0.45**		**0.68**		**3.04**	
COV		**0.13**		**0.05**		**0.37**	

Table 17. Result of Flexural Test on Clay > 1945 frogged units.

Frogged-clay brick > 1945							
Sample name		$f_{mu.t}$ **[MPa]**		$E_{mu.t(h)}$ **[GPa]**		$E_{mu.t(v)}$ **[GPa]**	
			AVG		**AVG**		**AVG**
HOO-H	D1	2.8	3.18	18.4	14.58	12.4	8.20
	D2	4.3		15.6		7,7	
	D3	1.3		10,2		6.8	
	D4	3.3		7.6		8.1	
	D5	2.5		15.4		6.5	
	D6	4.9		20.3		7.7	
AVG		**3.18**		**14.58**		**8.20**	
STDV		**1.29**		**4.84**		**2.14**	
COV		**0.41**		**0.33**		**0.26**	

Table 18. Result of Flexural Test on Concrete units.

Perforated -concrete block								
Sample name		**Year of Cons**	$f_{mu.t}$ **[MPa]**		$E_{mu.t(h)}$ **[GPa]**		$E_{mu.t(v)}$ **[GPa]**	
				AVG			**AVG**	
JUL-H	D1	1957	1.7	1.25	14.5	12.6	10.6	7.3
	D2		1.5		15.3		-	
	D3		2.4		17.9		10.4	
	D4		0.4		10.2		9.2	
	D5		1.2		-		5.4	
	D6		0.4		5.2		1.0	
Weighted average			**1.27**		**12.6**		**7.3**	
Standard deviation			**0.78**		**5.0**		**4.1**	
Coefficient of variation			**0.61**		**0.40**		**0.56**	

5.2.3 Horizontal Compression Test on Masonry Samples

This test allowed to evaluate the compressive strength $f_{m,h}$ of the masonry samples as well as the secant Young's modulus evaluated at 30% of the ultimate strength $E_{m,h}$, the chord modulus evaluated between the 30% and 70% $E_{m,chord}$ of the ultimate strength and finally the fracture energy G_{c-f}. The results for the Calcium Silicate < 1985 masonry typology are reported in Table 19,Table 20 reports the results for the WIR-H structure which was the only one where specimen were taken ffor the Clay < 1945 masonry typology. Samples for the Clay > 1945 masonry typology for this test were extracted only from the WIL-H-2 building and the results are reported in Table 21. Finally Table 22 reports the results of the test on aerated autoclaved concrete (AAC) units found in the HOO-H building.

Table 19. Result of Horizontal Compression Test on Calcium Silicate < 1985 masonry samples.

Sample name		**Test type**	$f_{m,h}$	**AVG**	$E_{m1,h}$	$E_{m2,h}$	$E_{chord,h}$	**AVG**	$G_{f-c,h}$	**AVG**
			[MPa]		**[MPa]**	**[MPa]**	**[MPa]**		**[N/mm]**	
BEA-H	C4	monotonic	4.93	4.24	7620	3633	4788	5375	37.52	36.45
	C5		3.55		4647	5317	5961		17.51	
LAG-H	C4	monotonic	7.52	7.53	4174	2995	2474	3386	53.11	57.13
	C5		6.68		5640	3188	2405		38.80	
	C6		8.39		6682	5803	5280		69.32	
WIL-H-1	C4	monotonic	6.75	7.01	5615	5034	4671	4450	40.76	69.14
	C5		8.00		8453	6925	6103		38.36	
	C6		6.27		2985	2736	2576		49.26	
AVG			**6.26**		**5772**	**4456**	**4404**		**41.35**	
STDV			**1.61**		**1814**	**1529**	**1569**		**14.92**	
COV			**0.26**		**0.31**	**0.34**	**0.36**		**0.36**	

Table 20. Result of Horizontal Compression Test on Clay < 1945 masonry samples.

Sample name		**Test type**	$f_{m.h}$	**AVG**	$E_{m1,h}$	$E_{m2,h}$	$E_{chord.h}$	**AVG**	$G_{f-c.h}$	**AVG**
			[MPa]		**[MPa]**	**[MPa]**	**[MPa]**		**[N/mm]**	
WIR-H	C1	monotonic	11.73	10.86	13556	11695	10602	8933	91.39	83.09
	C2		9.99		11341	8587	7264		74.78	
AVG			**10.86**		**12449**	**10141**	**8933**		**83.09**	
STDV			**1.23**		**1566**	**2198**	**2360**		**11.75**	
COV			**0.11**		**0.13**	**0.22**	**0.26**		**0.14**	

Table 21. Result of Horizontal Compression Test on Clay > 1945 masonry samples.

Sample name		Test type	$f_{m.h}$	AVG	$E_{m1,h}$	$E_{m2,h}$	$E_{chord.h}$	AVG	$G_{f\text{-}c.h}$	AVG
			[MPa]		[MPa]	[MPa]	[MPa]		[N/mm]	
WIL-H-2	F1	monotonic	7.41	11.00	6697	5791	5183	5470	43.67	47.59
	F2		8.97		6383	5340	4756		29.22	
	F4		10.58		7486	6095	5349		43.76	
	C4	cyclic	14.23		7979	6291	5428		56.68	
	C5		12.57		8731	7175	6327		70.96	
	C6		12.22		9062	7017	5778		41.26	
AVG			**11.00**		**7723**	**6285**	**5470**		**47.59**	
STDV			**2.51**		**1075**	**707**	**536**		**14.40**	
COV			**0.23**		**0.14**	**0.11**	**0.10**		**0.30**	

Table 22. Result of Horizontal Compression Test on aerated autoclaved concrete units (AAC).

Sample name		Test type	$f_{m,h}$	$E_{m1,h}$	$E_{m2,h}$	$E_{chord,h}$	$G_{f\text{-}c,h}$
			[MPa]	[MPa]	[MPa]	[MPa]	[N/mm]
HOO-H1	C1	cyclic	1.17	640	602	577	5.70
	C2		2.41	1154	1136	1121	12.39
	C3		2.96	1698	1167	946	10.09
AVG			**2.18**	**1164**	**968**	**881**	**9.39**
STDV			**0.92**	**529**	**318**	**278**	**3.40**
COV			**0.42**	**0.45**	**0.33**	**0.32**	**0.36**

5.2.4 Bending Test on Masonry Samples

Two types of bending test were performed: out-of-plane bending and in-plane bending.

The results of the out-of-plane bending test are presented in Table 23 and Table 24 for Clay < 1945 and Clay > 1945 masonry typology respectively. Table 25 reports the result of the test on the samples from BEA-S which were composed by perforated clay units (Clay > 1945). Finally Table 26 reports the result on samples composed by AAC units from HOO-H building and on units composed by concrete units from JUL-H building. For this type of test no samples were available for calcium silicate masonry. The mechanical parameters obtained from the test are: the flexural strength f_{x2}, the elastic modulus evaluated between the 30% and the 70% of the maximum strength both in the vertical and horizontal direction ($E_{m,fx2(v)}$ and $E_{m,fx2(h)}$).

Table 23. Results of out-of-plane Bending Test on Clay < 1945 masonry samples.

Solid-clay-brick masonry < 1945							
Sample name		f_{x2} [MPa]	AVG	$E_{m,fx2(v)}$ [GPa]	AVG	$Em_{,fx2(h)}$ [GPa]	AVG
WIR-H	B2	1.28	0.83	4	3.8	10.6	13.4
	B4	0,67		3.3		9.7	
	B5	0.55		4		19.8	
AVG		**0.83**		**3.8**		**13.4**	
STDV		**0.39**		**0.40**		**5.59**	
COV		**0.47**		**0.11**		**0.42**	

Table 24. Results of out-of-plane Bending Test on Clay > 1945 masonry samples.

Solid-clay-brick masonry > 1945							
Sample name		f_{x2} [MPa]	AVG	$E_{m,fx2(v)}$ [GPa]	AVG	$Em_{,fx2(h)}$ [GPa]	AVG
WIL-H-2	B1	1.16	1.21	-	7.6	5.6	7.1
	B3	1.03		6.0		5.6	
	B5	1.43		9.1		10.1	
BEA-S-1	B1	1.38	1.09	6.0	5.4	5.4	4.5
	B3	0.84		5.8		4.5	
	B4	1.06		4.4		3.7	
ROE-S-2	B2	0.76	1.26	3.1	7.4	3.5	6.4
	B5	1.58		9.9		9.7	
	B6	1.45		9.2		6.0	
ROE-S-3	B4	0.59	1.14	4.6	4.9	3.4	4.5
	B6	1.68		5.1		5.5	
KWE-H-2	B1	1.38	1.38	4.7	4.7	2.8	2.8
AVG		**1.22**		**5.98**		**5.06**	
STDV		**0.34**		**2.24**		**2.32**	
COV		**0.28**		**0.37**		**0.46**	

Table 25. Results of out-of-plane Bending Test on Clay > 1945 perforated masonry samples.

Perforated-clay-brick masonry > 1945							
Sample name		f_{x2}	**AVG**	$E_{m,fx2(v)}$	**AVG**	$Em_{,fx2(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
BEA-S-2	B4	0.83	0.87	1.9	2.6	2.0	3.1
	B5	0.81		2.6		3.8	
	B6	0.96		3.4		3.4	
AVG		**0.87**		**2.63**		**3.07**	
STDV		**0.08**		**0.75**		**0.95**	
COV		**0.10**		**0.29**		**0.31**	

Table 26. Results of out-of-plane Bending Test for AAC and concrete masonry samples.

Sample name		f_{x2}	**AVG**	$E_{m,fx2(v)}$	**AVG**	$E_{m,fx2(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
HOO-H1 - Aerated Concrete	B4	0.44	0.47	1.7	1.7	2.3	2.1
	B5	0.50		1.7		1.9	
JOH-H1- CS elements	B3	1.2	1.29	5.7	5.6	7	6.4
	B4	1.38		5.4		5.7	

The results of the in-plane bending test are reported in Table 27 for Calcium Silicate < 1985 masonry units, while the results for Clay < 1945 and Clay > 1945 units are reported in Table 28 and Table 29 respectively. The results on masonry samples composed by perforated units from BEA-S-2 structure are listed in Table 30 while the results on the samples composed by frogged units found in HOO-H structure are reported in Table 31. Finally Table 32 reports the results on: concrete units samples from JUL-H structure, AAC units samples from HOO-H structure and on calcium silicate “plate” elements from JOH-H structure. The results from the test are the flexural strength f_{x3}, the elastic moduli evaluated between 30% and 70% of the maximum strength in the vertical and horizontal direction ($E_{m,fx3(v)}$ and $E_{m,fx3(h)}$).

Table 27. Results of in-plane Bending Test on Calcium Silicate < 1985 masonry samples.

Calcium silicate masonry < 1985							
Sample name		f_{x3}	**AVG**	$E_{m,fx3(v)}$	**AVG**	$E_{m,fx3(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
BEA-H	B3	0.13	0.24	2.4	2.25	1.1	2.5
	B6	0.35		2.1		3.9	
LAG-H	B1	0.46	0.61	1.9	3.35	1	5.6
	B6	0.76		4.8		10.1	
SCH-H1	B3	0.41	0.24	3.2	1.87	2.8	1.7
	B4	0.17		2		-	
	B5	0.13		0.4		0.6	
AVG		**0.36**		**2.5**		**3.3**	
STDV		**0.23**		**1.3**		**3.6**	
COV		**0.63**		**0.5**		**1.1**	

Table 28. Results of in-plane Bending Test on Clay < 1945 masonry samples.

Solid-clay masonry < 1945							
Sample name		f_{x3}	**AVG**	$E_{m,fx3(v)}$	**AVG**	$E_{m,fx3(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
WIR-H	B1	1.12	0.75	9.0	7.1	12.2	8.0
	B3	0.83		10.4		8.7	
	B6	0.29		2.0		3.2	
ROE-S1.1	B1	0.68	0.51	3.0	4.0	1.5	4.1
	B2	0.41		5.2		7.1	
	B3	0.44		3.7		3.7	
ROE-S1.2	B1	0.85	0.57	6.2	3.9	5.7	3.1
	B2	0.38		2.0		1.3	
	B3	0.49		3.5		2.4	
AVG		**0.61**		**5.00**		**5.09**	
STDV		**0.28**		**3.01**		**3.67**	
COV		**0.45**		**0.60**		**0.72**	

Table 29. Results of in-plane Bending Test on Clay > 1945 masonry samples.

Solid-clay masonry > 1945							
Sample name		f_{x3}	**AVG**	$E_{m,fx3(v)}$	**AVG**	$E_{m,fx3(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
WIL-H-2	B2	0.35	0.71	0.9	3.4	1.8	3.5
	B4	0.38		0.6		0.8	
	B6	1.4		8.6		7.9	
KWE-H-2	B2	0.74	0.82	5.9	5.9	4.7	3.4
	B3	0.77		7.1		3.6	
	B4	0.95		4.8		2.0	
BEA-S-1	B2	0.83	1.06	7.1	9.5	3.7	6.0
	B5	1.36		13.2		11.6	
	B6	0.99		8.3		2.6	
ROE-S-2	B1	0.57	0.71	1.0	2.6	0.8	2.8
	B3	0.67		2.7		4.2	
	B4	0.88		4.1		3.3	
ROE-S-3	B1	0.57	0.48	4.1	3.1	8.1	4.6
	B3	0.39		2.1		1.0	
	B5	Problem with recording of force					
AVG		**0.76**		**4.91**		**4.04**	
STDV		**0.33**		**3.60**		**3.18**	
COV		**0.44**		**0.73**		**0.79**	

Table 30. Results of in-plane Bending Test on Clay < 1945 perforated masonry samples.

Perforated-clay masonry > 1945							
Sample name		f_{x3}	**AVG**	$E_{m,fx3(v)}$	**AVG**	$E_{m,fx3(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
BEA-S-2	B1	1.05	0.81	4.0	3.0	4.5	2.9
	B2	0.56		1.9		1.2	
	B3	Pump Dysfunction					
AVG		**0.81**		**3.0**		**2.9**	
STDV		**0.35**		**1.48**		**2.33**	
COV		**0.44**		**0.49**		**0.82**	

Table 31. Results of in-plane Bending Test on Clay < 1945 frogged masonry samples.

Frogged-clay masonry > 1945							
Sample name		f_{x3}	**AVG**	$E_{m,fx3(v)}$	**AVG**	$E_{m,fx3(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
HOO-H	B1	Failure immediately after load application					
	B4	0.17	0.14	1.9	1.6	2.9	1.75
	B6	0.11		1.2		0.6	
AVG		**0.14**		**1.55**		**1.75**	
STDV		**0.04**		**0.49**		**1.63**	
COV		**0.30**		**0.32**		**0.93**	

Table 32. Results of in-plane Bending Test on concrete/AAC/Calcium Silicate Plates.

Sample name		f_{x3}	**AVG**	$E_{m,fx3(v)}$	**AVG**	$E_{m,fx3(h)}$	**AVG**
		[MPa]		**[GPa]**		**[GPa]**	
JUL-H1 Concrete blocks	B1	0.28	0.31	1.5	1.73	0.6	1.43
	B2	0.33		1.8		1.5	
	B3	0.33		1.9		2.2	
HOO-H1 Aerated Concrete	B1	0.50	0.58	1.5	1.30	1.8	1.73
	B2	0.69		1.5		1.8	
	B3	0.55		0.9		1.6	
JOH-H1 CS elements	B1	1.44	0.87	5.4	4.23	6.5	9.30
	B2	0.71		4.5		7.4	
	B5	0.47		2.8		14.0	

5.2.5 Bond Wrench Test

For each sample the bond wrench strength $f_{b,bj}$ is reported as well as the type of failure. The possible types of failure are listed in Figure 41. The results for the Calcium Silicate < 1985 masonry typology are reported in Table 33. The results from Clay < 1945 and Clay > 1945 are reported in Table 34 and Table 35 respectively. Finally Table 36 includes the results on different samples which are not belonging to the four main masonry typologies like: concrete units, perforated and frogged clay units, AAC units and calcium silicate “plate” elements.

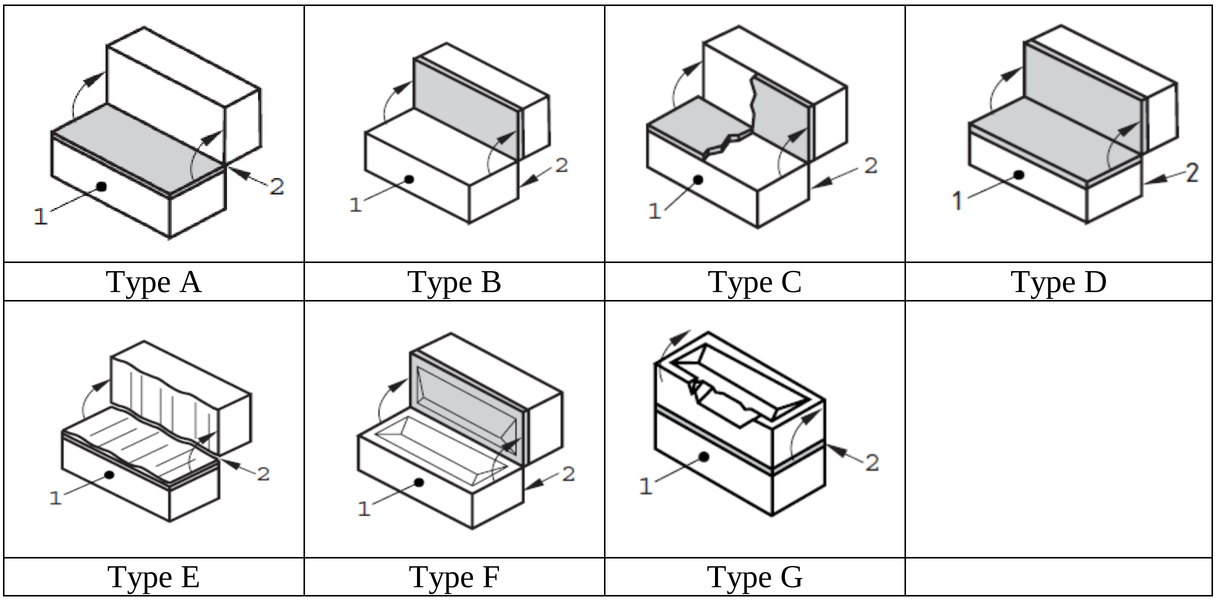


Figure 41. Bond Wrench Test type of failure.

Table 33. Result of Bond Wrench Test on Calcium Silicate < 1985 masonry samples.

Object	**Sample**	$f_{b,bj}$ **[MPa]**	**Failure Mode**	**AVG**	**STDV**	**COV**
LAG-H	1	0.18	Type A	0.18	0.06	0.33
	2	0.08	Type A			
	3	0.22	Type A			
	4	0.20	Type A			
	5	0.23	Type A			
	No other suitable samples were available.					
SCH-H	No suitable samples were available.					
WIL-H-1	No suitable samples were available.					
BEA-H	No suitable samples were available.					

Table 34. Result of Bond Wrench Test on Clay < 1945 masonry samples.

Object	Sample	$f_{b,bj}$ [MPa]	Failure Mode	AVG	STDV	COV
WIR-H	1	0.71	Type D	0.60	0.15	0.25
	2	0.42	Type D			
	3	0.70	Type D			
	4	0.41	Type D			
	5	0.71	Type D			
	6	0.62	Type D			
ROE-S-1.1	1	0.34	Type A	0.25	0.11	0.44
	2	0.24	Type A			
	3	0.21	Type B			
	4	0.39	Type D			
	5	0.22	Type A			
	6	0.08	Type A			
ROE-S-1.2	1	0.33	Type C	0.15	0.11	0.74
	2	0.09	Type B			
	3	0.03	Type B			
	4	0.08	Type C			
	5	0.21	Type A			
	6	0.14	Type A			
Solid Clay Brick Masonry				**0.33**	**0.23**	**0.69**

Table 35. Result of Bond Wrench Test on Clay > 1945 masonry samples.

Object	Sample	$f_{b,bj}$ [MPa]	Failure Mode	AVG	STDV	COV
WIL-H-2	1	0.65	Type D	0.63	0.17	0.28
	2	0.47	Type D			
	3	0.95	Type D			
	4	0.63	Type D			
	5	0,48	Type D			
	6	0,61	Type D			
BEA-S-1	1	0.19	Type A	0.23	0.05	0.19
	2	0.20	Type B			
	3	0.29	Type A			
	4	0.29	Type B			
	5	0.22	Type A			
	6	0.21	Type A			
ROE-S-2	1	0.24	Type C	0.54	0.21	0.40
	2	0.40	Type C			
	3	0.41	Type A			
	4	0.69	Type B			
	5	0.76	Type C			
	6	0.72	Type C			
ROE-S-3	1	0.64	Type A	0.42	0.24	0.58
	2	0.52	Type A			
	3	0.47	Type A			
	4	0.12	Type A			
	5	0.12	Type A			
	6	0.65	Type A			
KWE-H-2	1	0.33	Type A	0.31	0.09	0.29
	2	0.47	Type B			
	3	0.24	Type A			
	4	0.25	Type A			
	5	0.35	Type A			
	6	0.24	Type A			
Solid Clay Brick Masonry				**0.43**	**0.22**	**0.51**

Table 36. Result of Bond Wrench Test on different types of units not falling in the four main masonry typologies.

Object	Sample	$f_{b,bj}$ [MPa]	Failure Mode	AVG	STDV	COV
JUL-H Concrete block	1	0.47	Type C	0.23	0.13	0.56
	2	0.19	Type C			
	3	0.26	Type C			
	4	0.14	Type C			
	5	0.13	Type C			
	6	0.18	Type C			
BEA-S-2 Perforated clay brick	1	0.16	Type B	0.15	0.03	0.20
	2	0.12	Type A			
	3	0.16	Type A			
	4	0.20	Type B			
	5	0.13	Type A			
	6	-	Crushing			
HOO-H Frogged clay brick	1	-	No bond	0.08	0.02	0.28
	2	0.06	Type A			
	3	0.09	Type A			
	No other suitable samples were available for testing, due to the poor condition of the original specimens.					
HOO-H Aerated concrete block	Crushing of blocks where clamped for small values of M.					
JOH-H1 CS element	Crushing of elements where clamped for M=250 Nm.					

5.2.6 Vertical Compression Test on Masonry Samples

In this section the results from the Vertical Compression test on masonry samples are presented. For each sample the value of compressive strength $f_{m,v}$ and vertical elastic modulus $E_{m,v}$ are reported. The results for the different typologies are reported from Table 37 to Table 44.

The original results provided by TU Eindhoven were interpreted by EUCENTRE and therefore there are some differences between the values here listed and the ones indicated in the TU Eindhoven test report. The original results were provided from two different evaluations: Young’s modulus evaluated starting from deformations measured from LVDT in the testing machine and Young’s modulus evaluated from deformations from LVDT installed over the specimen. The second methodology is considered being more reliable and therefore values obtained in that way are here considered. Since several of the tested specimen where plastered on one side it was observed that some of the LVDT were providing unreliable measures. Additionally in some batch of samples there was a sample which was characterised by a Young's modulus largely different from the one of the samples from the same structure, in that case it was considered that for different reason complications arose during the test such that the results from the single sample was not reliable. In that case the sample was removed from the results.

Additionally to the original interpretation performed by TU Eindhoven a second interpretation of the data performed by TU Delft is proposed. TU Eindhoven evaluate the elastic modulus ($E_{m,v(30\text{-}70)}$) as the secant modulus between the 30% and 70 % of the maximum compressive strength of the specimen. TU Delft evaluated the elastic modulus ($E_{m,v(LIN)}$) as the slope of the most linear part of the stress-strain curve. Additionally to the elastic modulus and the compressive strength TU Delft also evaluated the fracture energy, $G_{f\text{-}c,v}$. This second interpretation is beneficial due to the fact that in-situ the Double Flat Jack Test does not allow to reach high levels of vertical stress in the wall. Therefore, the elastic modulus evaluated in-situ is representative of a lower range of stresses (about 10%-30% of the compressive strength of the masonry). The elastic modulus evaluated according the TU Delft interpretation can be more compatible to what measured in-situ and therefore more representative in the comparison of the results of in-situ and laboratory tests.

In the case of Clay < 1945 masonry typology (Table 39 and Table 40) the samples relative to the building WIR-H have been reported in the table but not used to evaluate the average values for the entire typology. The reason is because the samples were collected from the external walls, to be therefore consistent with what has been done for in-situ testing the external walls are not considered significant. In the same way for the Clay > 1945 (Table 41 and Table 42) the samples relative to the building WIL-H-2 have been reported in the table but not used for the definition of average values of the masonry typology.

Table 37. Results of Vertical Compression test on Calcium Silicate > 1985 masonry samples.

Building	$f_{m,v}$ [MPa]	$E_{m,v(30-70)}$ [MPa]	AVG $f_{m,v}$ [MPa]	AVG $E_{m,v(30-70)}$ [MPa]
BEA-H	6.02	1659	5.72	1666
	5.42	1674		
WIL-H-1	9.97	5548	9.55	5702
	9.12	5856		
LAG-H	13.45	8906	14.15	7836
	15.78	7085		
	13.22	7517		
SCH-H	13.69	8730	13.63	8468
	12.97	8702		
	13.27	8401		
	14.60	8426		
	13.63	8084		

	$f_{m,v}$ [MPa]	$E_{m,v(30-70)}$ [MPa]
AVG	10.76	5918
STDV	3.94	3072
COV	0.37	0.52

Table 38. Results of Vertical Compression test on Calcium Silicate > 1985 masonry samples according to TU Delft interpretation.

Building	$f_{m,v}$		$E_{m,v(LIN)}$		$G_{f-c,v}$	
	[MPa]	AVG	[MPa]	AVG	[N/mm]	AVG
BEA-H	6.02	5.72	5491	3984	11.60	12.38
	5.42		2476		13.15	
WIL-H-1	9.97	9.55	5882	6276	17.17	16.11
	9.12		6669		15.05	
LAG-H	13.45	14.15	9909	9156	17.11	17.54
	15.78		9163		19.62	
	13.22		8395		15.88	
SCH-H	13.69	13.63	11481	9293	12.80	15.26
	12.97		9875		11.87	
	13.27		8268		20.82	
	14.60		8348		16.37	
	13.63		8491		14.44	
AVG		10.76		7177		15.32
STDV		3.94		2543		2.18
COV		0.37		0.35		0.14

Table 39. Results of Vertical Compression Test on Clay < 1945 masonry samples.

Building	$f_{m,v}$ [MPa]	$E_{m,v(30-70)}$ [MPa]	AVG $f_{m,v}$ [MPa]	AVG $E_{m,v(30-70)}$ [MPa]
WIR-H	14.54	11396	14.74	11882
	14.94	12369		
MID-H	12.02	1742	12.02	1477
	13.17	1420		
	10.85	1269		
	15.84	4388	13.40	4577
	10.95	4766		
ROE-S-1	11.77	6878	11.27	8222
	9.25	8004		
	12.80	9784		
MOL-H	4.35	2140	3.93	2032
	4.35	2464		
	3.09	1310		
	3.85	1275	3.92	1038
	4.79	1074		
	3.11	765		

	$f_{m,v}$ [MPa]	$E_{m,v(30-70)}$ [MPa]
AVG	8.91	3469
STDV	4.61	2990
COV	0.52	0.86

Table 40. Results of Vertical Compression Test on Clay < 1945 masonry samples according to TU Delft interpretation.

Building	$f_{m,v}$		$E_{m,v(LIN)}$		$G_{f\text{-}c,v}$	
	[MPa]	**AVG**	**[MPa]**	**AVG**	**[N/mm]**	**AVG**
WIR-H	14.54	14.74	12872	16394	-	28.49
	14.94		19916		28.49	
MID-H1	12.02	12.01	5471	4613	62.13	62.58
	13.17		4436		65.63	
	10.85		3933		59.97	
	15.84	13.40	10274	6807	92.65	81.92
	10.95		3339		71.18	
ROE-S-1	11.77	11.27	9560	10054	36.13	40.61
	9.25		10548		38.37	
	12.80		-		47.33	
MOL-H	4.51	3.98	3843	3568	13.19	11.64
	4.35		4048		11.21	
	3.09		2813		10.53	
	3.85	3.92	2445	1690	19.00	21.06
	4.79		1355		20.28	
	3.11		1269		23.90	
AVG		8.92		5346		43.56
STDV		4.60		3216		29.01
COV		0.52		0.60		0.67

Table 41. Results of Vertical Compression Test on Clay > 1945 masonry samples.

Building	$f_{m,v}$ [MPa]	$E_{m,v(30-70)}$ [MPa]	AVG $f_{m,v}$ [MPa]	AVG $E_{m,v(30-70)}$ [MPa]
BEA-S-1	13.99	7098	14.06	6518
	16.54	8098		
	16.50	7279		
	11.97	3565		
	11.27	6552		
KWE-H	11.48	6312	10.56	4980
	11.18	6206		
	10.17	4456		
	9.39	2948		
WIL-H-2	22.96	12608	20.51	11032
	20.15	9229		
	18.43	11259		
ROE-S-3	9.38	5161	9.10	3081
	9.77	2272		
	8.29	2454		
	8.96	2436		
	28.60	10370	28.00	9397
	27.41	8425		
BEA-S-2	19.44	7464	20.74	7888
	20.93	9256		
	18.86	7783		
	21.41	7980		
	22.18	6939		
	18.17	6771		
	26.26	10778		
	18.66	6136		
ROE-S-2	12.91	9016	15.44	9797
	18.12	12105		
	12.27	10049		
	16.09	7792		
	17.78	10021		
HOO-H	8.40	2628	7.95	2826
	8.07	2474		
	7.35	2236		
	8.05	3216		
	7.89	3577		

	$f_{m,v}$ [MPa]	$E_{m,v(30-70)}$ [MPa]
AVG	15.12	6355
STDV	7.16	2844
COV	0.47	0.45

Table 42. Results of Vertical Compression Test on Clay > 1945 masonry samples according to TU Delft interpretation.

Building	$f_{m,v}$		$E_{m,v(LIN)}$		$G_{f\text{-}c,v}$	
	[MPa]	AVG	[MPa]	AVG	[N/mm]	AVG
WIL-H-2	22.96	20.51	14696	12348	23.46	22.82
	20.15		9666		24.88	
	18.43		12681		20.11	
BEA-S-1	13.99	14.06	8804	6779	24.01	24.02
	16.54		6301		23.24	
	16.50		8662		28.78	
	11.97		2213		23.44	
	11.27		7916		20.61	
ROE-S-2	12.91	15.44	15248	13262	24.25	23.73
	18.12		15366		23.45	
	12.27		7876		18.02	
	16.09		12218		26.89	
	17.78		15604		26.05	
ROE-S-3	9.38	9.15	7151	4332	31.53	31.37
	9.77		3876		31.73	
	8.29		3716		32.67	
	8.96		2584		29.53	
	28.60	28.00	9851	8418	-	39.69
	27.41		6986		39.69	
KWE-H	11.48	10.56	7287	5930	17.93	19.69
	11.18		5631		19.62	
	10.17		6980		16.99	
	9.39		3821		24.21	
BEA-S-2	19.44	20.74	10918	8688	27.81	29.82
	20.93		9998		23.91	
	18.86		8098		26.88	
	21.41		8121		30.43	
	22.18		6883		35.39	
	18.17		6718		24.69	
	26.26		11327		42.48	
	18.66		7444		26.99	
HOO-H	8.40	7.95	2575	2575	13.85	14.97
	8.07		1199		19.45	
	7.35		1806		14.87	
	8.05		3423		12.94	
	7.89		3871		13.75	
AVG		15.13		7141		26.18
STDV		7.15		3460		8.18
COV		0.47		0.48		0.31

Table 43. Result for Vertical Compression Test on Concrete masonry samples.

Building	$f_{m,v}$ [MPa]	$E_{m,v(30-70)}$ [MPa]	AVG $f_{m,v}$ [MPa]	AVG $E_{m,v(30-70)}$ [MPa]
JUL-H	6.12	4726	5.57	4286
	4.60	3659		
	5.99	4473		
	$f_{m,v}$ [MPa]	**$E_{m,v}$ [MPa]**		
AVG	5.57	4286		
STDV	0.84	557		
COV	0.15	0.13		

Table 44. Result for Vertical Compression Test on Concrete masonry samples according to TU Delft interpretation.

Building	$f_{m,v}$		$E_{m,v(LIN)}$		$G_{f\text{-}c,v}$	
	[MPa]	AVG	[MPa]	AVG	[N/mm]	AVG
JUL-H	6.12	5.57	5674	5229	9.28	8.13
	4.60		4688		4.67	
	5.99		5326		10.43	
AVG		5.57		5229		8.13
STDV		0.84		500		3.05
COV		0.15		0.10		0.38

5.2.7 Shear Triplet Test

In this section the results from the Shear Triplet Test on masonry samples are presented. In this case the results for the single sample are not provided but the values from the values of cohesion τ_0 and friction coefficient μ obtained from linear regression are provided.

Similarly to what has been done for the Vertical Compression Test, presented in the previous paragraph, the results for the buildings WIR-H-1 (Clay < 1945,

Table 46) and WIL-H-2 (Clay > 1945, Table 47) have been reported in the respective tables but not used to evaluate average values since the samples referred to external walls which are not considered significant in this campaign. It must also be underlined that the values relative to the building SCH-H are considered not reliable (e.g. (I) $\mu<0$) and therefore not taken into account in the evaluation.

It should also be noticed that in some cases the tested samples were just a fraction of the specimens cut on site. This because the quality of the masonry was too poor, in that cases some specimens broke right after the removal from the wall. The fact that the lab tested only the survived masonry wallets could modify the statistical sample increasing the apparent average of cohesion. The symbol * identifies the building where more than 30% of the specimens were broken during the sampling.

The results of the Shear Triplet Test, as for the Vertical Compression Test, were also object of a second interpretation performed by TU Delft. In this case no difference were found respect the first interpretation performed by TU Eindhoven which was therefore confirmed reliable.

Table 45. Results of the Triplet Shear Test on Calcium Silicate < 1985 masonry.

	ULTIMATE		RESIDUAL	
	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]
BEA-H	0.18	0.74	0.07	0.66
LAG-H	0.03	1.10	0.02	0.72
SCH-H	0.53*	0.53	0.78	-0.39 (I)
WIL-H-1	0.22*	0.85	0.10	0.57
	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]
AVG	0.14	0.90	0.06	0.65
STDV	0.10	0.18	0.04	0.08
COV	0.71	0.20	0.67	0.12

Table 46. Results of the Shear Triplet Test on Clay < 1945 masonry.

	ULTIMATE		RESIDUAL	
	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]
MID-H.1	0.30	0.50	0.10	0.51
MID-H.2	0.34	0.80	0.05	0.82
MOL-H.1	0.25	0.62	0.00	0.69
MOL-H.2	0.17	0.56	0.06	0.54
ROE-S-1.1	0.38	0.69	0.09	0.65
ROE-S-1.2	0.26	1.23	0.05	0.73
WIR-H	0.43*	1.19	-0.04	1.00
	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]
AVG	0.28	0.73	0.06	0.66
STDV	0.07	0.27	0.03	0.12
COV	0.26	0.36	0.61	0.18

Table 47. Results of the Shear Triplet Test on Clay > 1945 masonry.

	ULTIMATE		RESIDUAL	
	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]
BEA-S-1	0.46*	0.81	0.08	0.77
BEA-S-2	0.84	0.45	0.06	0.72
HOO-H	0.15	0.69	0.07	0.70
KWE-H-2	0.60	0.67	0.04	0.79
ROE-S-2	0.46	0.94	0.04	0.69
ROE-S-3	0.21	0.90	0.12	0.66
WIL-H-2	0.52*	1.12	0.06	0.70
	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]
AVG	0.45	0.74	0.07	0.72
STDV	0.26	0.18	0.03	0.05
COV	0.57	0.24	0.43	0.07

Table 48. Results of the Shear Triplet Test on Concrete masonry.

	ULTIMATE		RESIDUAL	
	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]
JUL-H	0.39	0.94	0.17	0.71

Additional consideration are necessary when analysing the results of the Shear Triplet Test presented above. It is observable that in general the friction coefficient evaluated at the ultimate load is higher than the residual coefficient. From past test it was noticed that this two values are in general very similar.

From the test lab report, it was notice that the test setup did not allow to keep the horizontal compression force in the sample perfectly constant. This could generate some unreliable interpretation of the actual compressive force in the exact moment of maximum shear force considering also the low sampling rate of acquisition (1 Hz). Up to now, the residual friction coefficient is considered more reliable since it is less influenced by the sampling rate. Therefore it is here assumed that the values of mechanical parameter for the different masonry typologies are: the cohesion obtained at ultimate condition and the residual friction coefficient.

More interpretations on this data will necessary in the next future in order to have a better estimate of these parameters.

5.3 Comparison between in-situ and laboratory results

This section is aimed to compare those mechanical parameters that have been calculated both by in-situ and laboratory testing.

It must be underlined that average values of the mechanical parameter have been evaluated in different ways for laboratory and in-situ results. In terms of laboratory results the average value has been calculated as the weighted average which accounts the fact that for different buildings a different number of samples was available. In terms of in-situ results the average values of the mechanical parameters have been calculated as the straight average of all the available values. It was decided to treat these results differently from the laboratory one because in-situ sometimes the number of performed test was too low to consider them representative of a particular sub-category. In any case, the difference between this two interpretations is always lower than 7% in the final average. As soon as more results will be available another data treatment could be considered more appropriate than the one used in this document.

5.3.1 Comparison Double Flat Jack Test and Vertical Compression Test

The first parameter that can be compared is the vertical elastic modulus $E_{m,v(IS)}$ that has been calculated by the Double Flat Jack in-situ and the two values of elastic modulus obtained from the Vertical Compression Test on Masonry samples ($E_{m,v(30\text{-}70)}$ and $E_{m,v(LIN)}$).

The comparison for the Calcium Silicate < 1985 masonry is presented in Table 49, it is observable that from in-situ testing we obtain a lower value of elastic modulus respect to laboratory testing and there is anyway a significant difference from building to building. We can additionally observed, as expected, that the elastic modulus evaluated in the 30%-70% strength range tend to be lower than the one evaluated as the slope of the most linear part of the stress-strain range. This is due to the fact that in general the most linear part of the relationship occurs at a lower range of strength where the masonry tend to be stiffer. This observation is confirmed by the fact that for all the different masonry typologies $E_{m,v(30\text{-}70)}$ is lower than $E_{m,v(LIN)}$.

In Table 50 it can be seen that no samples were tested in laboratory for Calcium Silicate > 1985 since some of them reached the laboratory already damaged or it was not possible to extract them.

Table 51 reports the results for Clay < 1945 are compared, in this case we can observe that there is a pretty good match between the in-situ results and the laboratory results according to the Delft interpretation. Again, the elastic modulus evaluated in the 30%-70% ranges tend to underestimate what obtained in-situ.

The results for the Clay > 1945 masonry typology (Table 52) follow the same observations drawn for the previous typology, even if in this case the difference between in-situ and laboratory is a bit more accentuated.

Finally, for the Concrete specimen the results from the laboratory are significantly lower respect the values from in-situ (Table 53).

Table 49. Comparison of vertical elastic modulus from in-situ e laboratory tests for Calcium Silicate < 1985 masonry.

	LAB. TUe		LAB. TUd		IN-SITU
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
BEA-H	5.72	1666	5.72	3984	3136
WIL-H-1	9.55	5702	9.55	6276	2122
LAG-H	14.15	7836	14.15	9156	4612
SCH-H	13.63	8468	13.63	9293	7006
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
AVG	10.76	5918	10.76	7177	4439
STDV	3.94	3072	3.94	2543	2383
COV	0.37	0.52	0.37	0.35	0.54

Table 50. Comparison of vertical elastic modulus from in-situ e laboratory tests for Calcium Silicate > 1985 masonry.

	LAB. TUe		LAB. TUd		IN-SITU
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[MPa]	[MPa]	[MPa]	[MPa]	[Mpa]
KWE-H	-	-	-	-	5341
ROE-S-4	-	-	-	-	4320
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[Mpa]	[Mpa]	[MPa]	[MPa]	[Mpa]
AVG	-	-	-	-	4830
STDV	-	-	-	-	1308
COV	-	-	-	-	0.27

Table 51. Comparison of vertical elastic modulus from in-situ e laboratory tests for Calcium Clay < 1945 masonry.

	LAB. TUe		LAB. TUd		IN-SITU
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
WIR-H	14.74	11882	14.74	16394	411
MID-H	12.01	1477	12.01	4613	8952
	13.40	4577	13.40	6807	
ROE-S-1	11.27	8222	11.27	10054	7332
MOL-H	3.93	2032	3.98	3568	2197
	3.92	1038	3.92	1690	
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
AVG	8.91	3469	8.92	5346	5072
STDV	4.61	2990	4.60	3216	3812
COV	0.52	0.86	0.52	0.60	0.75

Table 52. Comparison of vertical elastic modulus from in-situ e laboratory tests for Calcium Clay > 1945 masonry.

	LAB. TUe		LAB. TUd		IN-SITU
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
BEA-S-1	14.06	6518	14.06	6779	9389
KWE-H-2	10.56	4980	10.56	5930	6583
WIL-H-2	20.51	11032	20.51	12348	12446
ROE-S-3	9.10	3081	9.15	4332	5119
	28.00	9397	28.00	8418	
BEA-S-2	20.74	7888	20.74	8688	6595
ROE-S-2	15.44	9797	15.44	13262	13116
HOO-H	7.95	2826	7.95	2575	9514
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
	[Mpa]	[Mpa]	[MPa]	[MPa]	[Mpa]
AVG	15.12	6355	15.13	7141	8986
STDV	7.16	2844	7.15	3460	4427
COV	0.47	0.45	0.47	0.48	0.49

Table 53. Comparison of vertical elastic modulus from in-situ e laboratory tests for Concrete masonry.

	LAB. TUe		LAB. TUd		IN-SITU
	$f_{m,v}$	$E_{m,v(30\text{-}70)}$	$f_{m,v}$	$E_{m,v(LIN)}$	$E_{m,v(IS)}$
JUL-H	**[MPa]**	**[MPa]**	**[MPa]**	**[MPa]**	**[Mpa]**
AVG	5.57	4286	5.57	5229	8310
STDV	0.84	557	0.84	500	1121
COV	0.15	0.13	0.15	0.10	0.13

5.3.2 Comparison Shove-Test and Triplet Shear Test

The second comparison concerns the shear mechanical parameters, i.e. cohesion and friction coefficient, obtained from the Shove Test in-situ and from the Shear Triplet Test on masonry samples in laboratory. The comparison for the Calcium Silicate < 1985 masonry is reported in Table 54. It is observable that in from in-situ testing a lower value of friction coefficient is obtained while in terms of cohesion there results from in-situ and laboratory are pretty similar. For Calcium Silicate > 1985 no samples were tested in laboratory because they reached the lab already damaged or they were not delivered because they broke during the extraction process. This testify that the quality of the mortar was pretty bad, which is confirmed by the value of cohesion measured in-situ (Table 55). In Table 56 we can see the comparison of the results for the Clay < 1945 masonry typology. In this case there is a significant difference in term of friction coefficient, anyway the value obtained in-situ seems fairly low while the value obtained in laboratory is in line with the value obtained for the other types of masonry. In term of cohesion the value obtained in laboratory is higher with respect of the one in-situ, in this case it must be underlined that in-situ there are several test where the cohesion is 0 while in laboratory the pre-damaged sample were not tested therefore it is implied to have a higher value of cohesion. In Table 57 the results for the Clay > 1945 masonry are reported. For this typology the friction coefficient obtained in-situ and in laboratory are similar, even if in-situ slightly lower results were obtained. Concerning the cohesion in laboratory significantly higher are obtained, in this case it must be observed that in-situ for many test locations the results from Shove Test were not obtained due to the fact that the rapture of the masonry was in the brick and no in the joint. This confirms that there is a good cohesion and therefore the value obtained in laboratory should be considered more reliable. Finally for Concrete masonry (Table 58), a comparison is not possible since the Shove Test performed in-situ never provided reliable results.

Table 54. Comparison of shear mechanical parameters from in-situ and laboratory tests for Calcium Silicate < 1985 masonry.

	CS < 1985					
	LABORATORY				IN-SITU	
	ULTIMATE		RESIDUAL			
	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]
BEA-H	0.18	0.74	0.07	0.66	0.06	0.47
LAG-H	0.03	1.10	0.02	0.72	0.10	0.61
SCH-H	0.53*	0.53	0.79	-0.39	0.42	0.78
WIL-H-1	0.22*	0.85	0.10	0.57	0.17	0.79
	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]
AVG	0.14	0.90	0.06	0.65	0.19	0.66
STDV	0.10	0.18	0.04	0.08	0.22	0.18
COV	0.71	0.20	0.67	0.12	1.16	0.27

Table 55. Comparison of shear mechanical parameters from in-situ and laboratory tests for Calcium Silicate > 1985 masonry.

	CS > 1985					
	LABORATORY				IN-SITU	
	ULTIMATE		RESIDUAL			
	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]
KWE-H	-	-	-	-	0.01	0.75
ROE-S-4	-	-	-	-	0.05	0.59
	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]	τ_0 [MPa]	μ [-]
AVG	-	-	-	-	0.03	0.67
STDV	-	-	-	-	0.04	0.14
COV	-	-	-	-	1.62	0.21

Table 56. Comparison of shear mechanical parameters from in-situ and laboratory tests for Clay < 1945 masonry.

	Clay < 1945					
	ULTIMATE		**RESIDUAL**		IN-SITU	
	τ_0	μ	τ_0	μ	τ_0	μ
	[MPa]	**[-]**	**[MPa]**	**[-]**	**[MPa]**	**[-]**
MID-H.1	0.30	0.50	0.10	0.51	0.02	0.31
MID-H.2	0.34	0.80	0.05	0.82		
MOL-H.1	0.25	0.62	0.00	0.69	0.08	0.22
MOL-H.2	0.17	0.56	0.06	0.54		
ROE-S-1.1	0.38	0.69	0.09	0.65	0.17	0.36
ROE-S-1.2	0.26	1.23	0.05	0.73		
WIR-H-1	0.43*	1.19	-0.04	1.00	0.14	0.44
	τ_0	μ	τ_0	μ	τ_0	μ
	[MPa]	**[-]**	**[MPa]**	**[-]**	**[MPa]**	**[-]**
AVG	0.28	0.73	0.06	0.66	0.08	0.29
STDV	0.07	0.27	0.03	0.12	0.07	0.09
COV	0.26	0.36	0.61	0.18	0.96	0.32

Table 57. Comparison of shear mechanical parameters from in-situ and laboratory tests for Clay > 1945 masonry.

	Clay > 1945					
	ULTIMATE		**RESIDUAL**		**IN-SITU**	
	τ_0	μ	τ_0	μ	τ_0	μ
	[MPa]	**[-]**	**[MPa]**	**[-]**	**[MPa]**	**[-]**
BEA-S-1	0.46*	0.81	0.08	0.77	0.14	0.52
BEA-S-2	0.84	0.45	0.06	0.72	0.24	0.61
HOO-H	0.15	0.69	0.07	0.70	0.03	0.70
KWE-H-2	0.60	0.67	0.04	0.79	0.05	0.92
ROE-S-2	0.46	0.94	0.04	0.69	0.11	0.40
ROE-S-3	0.21	0.90	0.12	0.66	0.09	0.89
WIL-H-2	0.52*	1.12	0.06	0.70	0.00	-
	τ_0	μ	τ_0	μ	τ_0	μ
	[MPa]	**[-]**	**[MPa]**	**[-]**	**[MPa]**	**[-]**
AVG	0.45	0.74	0.07	0.72	0.11	0.64
STDV	0.26	0.18	0.03	0.05	0.09	0.25
COV	0.57	0.24	0.43	0.07	0.85	0.39

Table 58. Comparison of shear mechanical parameters from in-situ and laboratory tests for Concrete masonry.

	CONCRETE					
	ULTIMATE		RESIDUAL		IN-SITU	
	τ_0	μ	τ_0	μ	τ_0	μ
	[MPa]	[-]	[MPa]	[-]	[MPa]	[-]
JUL-H	0.39	0.94	0.17	0.71	-	0.26

5.4 Correlation between in-situ and laboratory results

The aim of this section is to investigate possible correlations existing between mechanical parameters investigated in-situ and parameters obtained from laboratory testing.

5.4.1 Correlation between Rebound Hammer Test and Compression Test on Masonry Units

A first idea is trying to correlate the results from Rebound Hammer Test and Compression Test on masonry units since both should provide information concerning the strength and deformability of masonry units. The correlation is shown in Figure 42 where we can see there is a certain correlation even if the latter is not so strong.

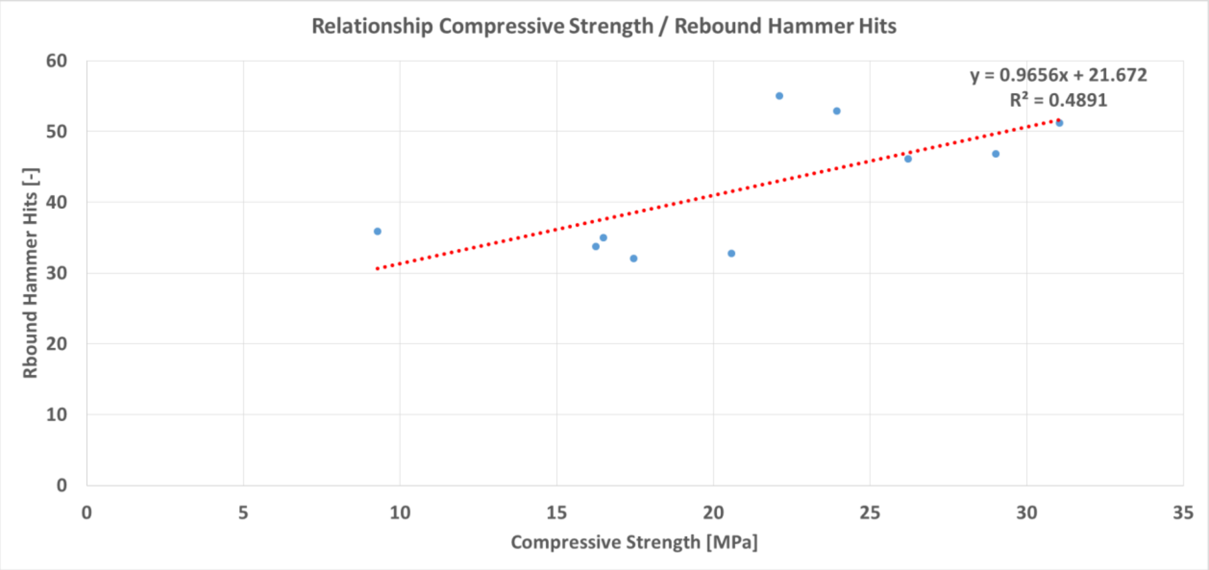


Figure 42. Correlation between the results from Compression Test on masonry units and the results of Rebound Hammer Test.

5.4.2 Correlation between Ultrasonic Test and Compression Test on Masonry Units

It was additionally thought to try investigating the possibility of correlating the results from the Compression Test on masonry units with the results of the Ultrasonic Test performed on single units both in the direct and indirect configuration. The attempt is shown in Figure 43 and Figure 44 respectively where we can see that in both cases despite a certain variation in the compressive strength of the units the velocity obtained from the Ultrasonic Test remains fairly constant.

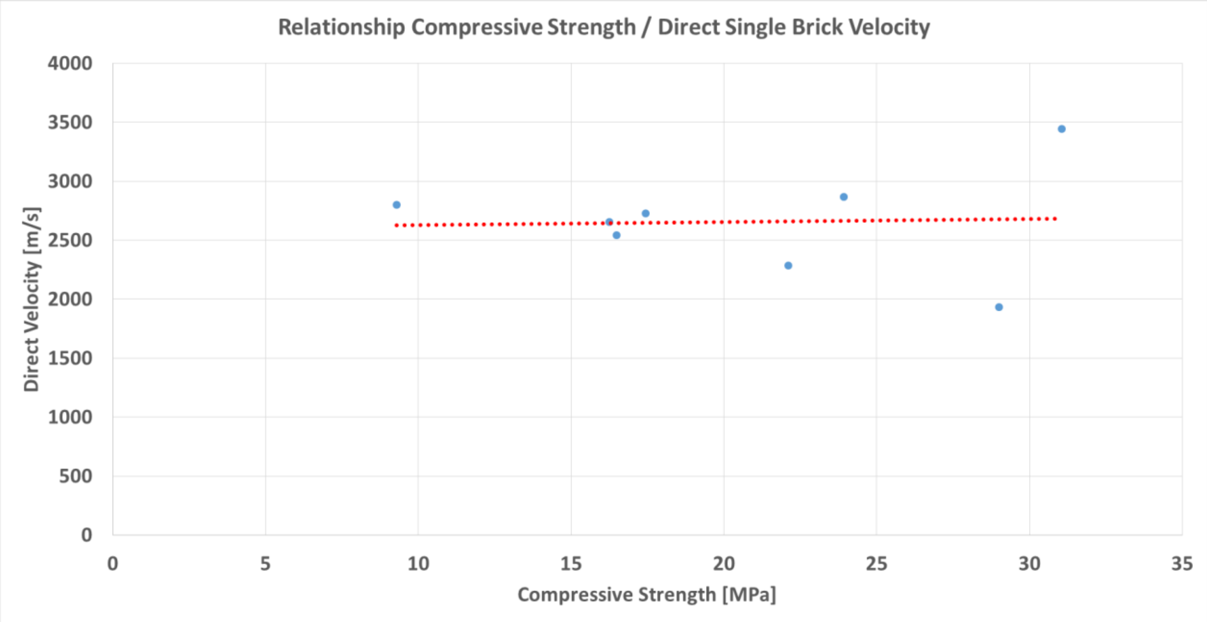


Figure 43. Correlation between the results from Compression Test on masonry units and the results of Ultrasonic Test on a single brick direct configuration.

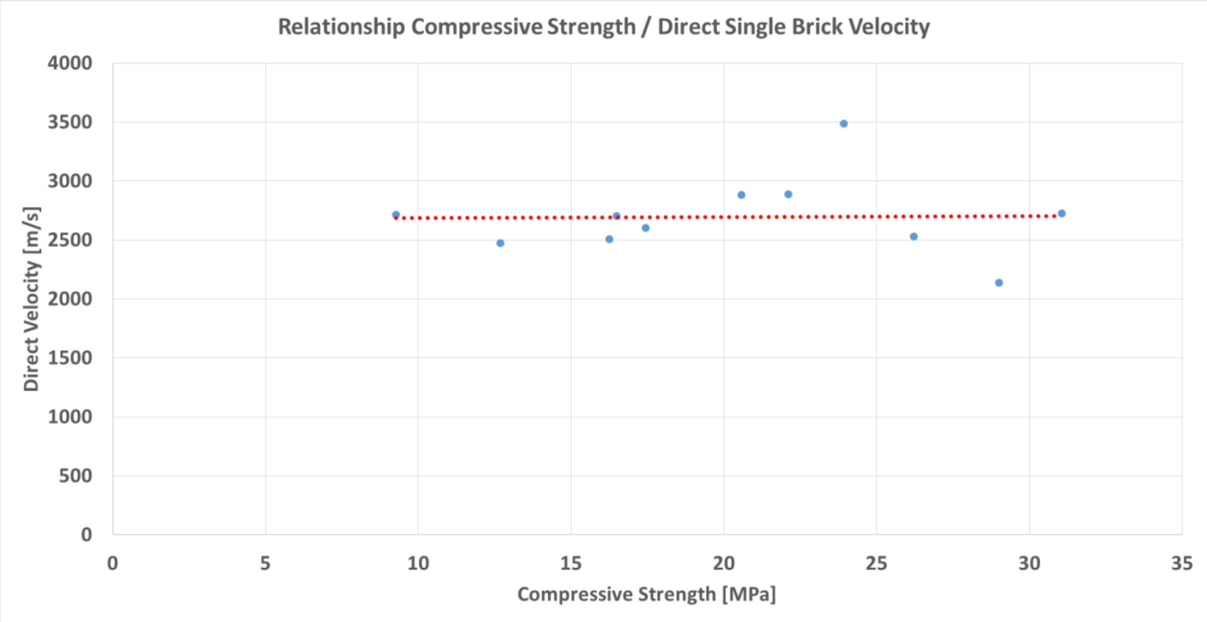


Figure 44. Correlation between the results from Compression Test on masonry units and the results of Ultrasonic Test on a single brick indirect configuration.

5.4.3 Correlation between Bond Wrench Test and Shear Triplet Test

Finally in Figure 45 the correlation between the bond wrench test and the cohesion obtained from laboratory Shear Triplet Test is presented. Despite the dispersion of the results a certain trend is observable, it is anyway difficult to establish a strong correlation especially for the limited number of samples available.

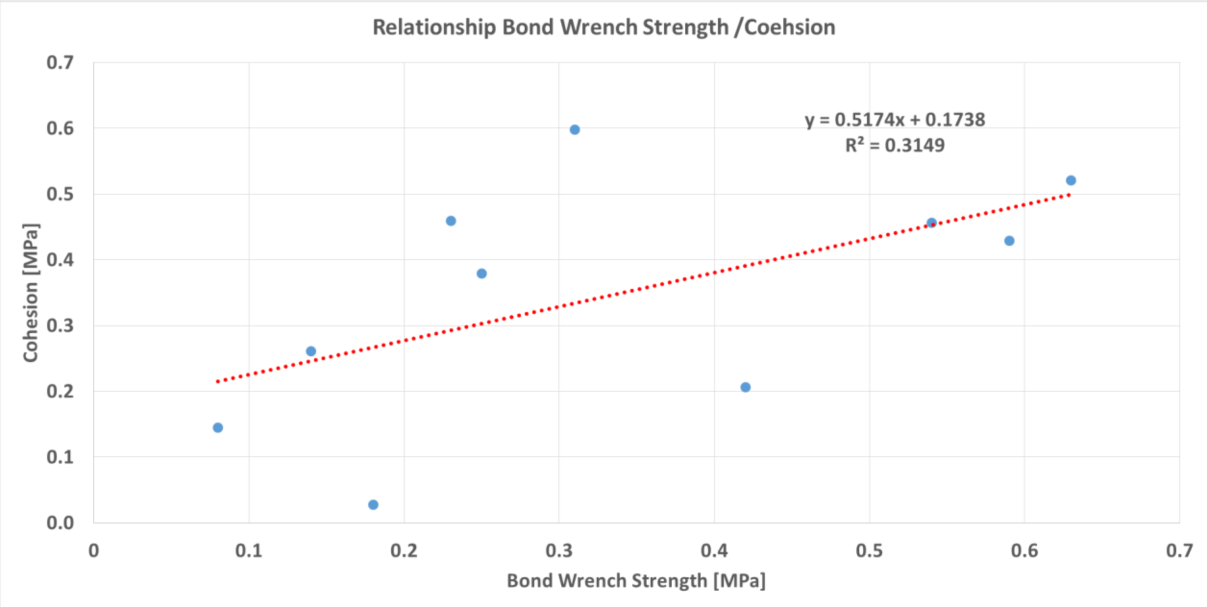


Figure 45. Correlation between the results from the Bond Wrench Test and the Cohesion.

6 Masonry Abacus

This section is intended to provide, for each masonry typology, the range of variation of the most important mechanical properties which are necessary for the vulnerability analyses or assessment of existing masonry structures.

The mechanical parameters are presented from Table 59 to Table 63 for the four main masonry typologies identified at the beginning of the project as well as for the Concrete masonry typology (future versions of the report may consider different sub-typologies). Each table provides a full set of mechanical parameters including both parameters from in-situ and laboratory testing. For each parameter the average value and coefficient of variation obtained from testing are given as well as the maximum and minimum value recorded.

For each material typology three values of vertical elastic modulus of the material are provided. The firs of the three, $E_{m,v(30\text{-}70)}$, is the value obtained from the Vertical Compression Test performed in laboratory. The name derives from the fact that the elastic modulus is evaluated as the secant modulus from the points at the 30% and 70% of the maximum compressive strength of the masonry (future versions of the report may consider an elastic modulus differently interpreted). The second value, $E_{m,v(LIN)}$, is still obtained from the Vertical Compression Test where the modulus is evaluated as the slope of the most linear part of the stress-strain curve. The third and last value provided, $E_{m,v(IS)}$, is the value obtained from in-situ Double Flat Jack Test. Generally in-situ it is not possible to reach such high values of compression in the masonry therefore the elastic modulus is the secant modulus at a lower range of compression with respect to the laboratory one. Therefore, the elastic modulus obtained in-situ tend to be higher than the one from laboratory evaluated in the 30%-70% strength range whilst is should be more compatible with the modulus evaluated as most linear part of the stress-strain curve since this is usually observed a lower level of vertical stress.

Concerning the shear mechanical parameters one value of friction is given while two values of cohesion are reported. The friction coefficient, μ, is the one obtained from Shear Triple Test in laboratory, except for Calcium Silicate < 1985 masonry typology where no masonry samples were available. The provided values of the friction coefficient is the residual one, ultimate values can be found in paragraph 5.2.7. In term of cohesion, $\tau_{0,(LAB)}$ is the value obtained from Shear Triplet Test in laboratory while $\tau_{0,(IS)}$ is the value from in-situ Shove Test. The idea of providing both the values is due to the fact that the new procedure of interpretation of the Shove Test is still a validation process while there are still some uncertainties related to the interpretation of the laboratory test.

The last seven mechanical parameters of the tables were directly taken from the TU Delft material report since none of those could be directly evaluated from in-situ testing, therefore direct comparison from in-situ and laboratory results were not possible.

Table 59. Mechanical properties resume for Calcium Silicate < 1985 masonry typology.

		CALCIUM SILICATE < 1985			
		AVG	**COV [-]**	**MIN**	**MAX**
$E_{m,v(30\text{-}70)}$	**[MPa]**	**5918**	0.52	1659	8906
$E_{m,v(LIN)}$	**[MPa]**	**7177**	0.35	2476	11481
$E_{m,v(IS)}$	**[MPa]**	**4439**	0.54	950	7785
$f_{m,v}$	**[MPa]**	**10.76**	0.37	5.42	15.78
μ	**[-]**	**0.65**	0.12	0.57	0.72
$\tau_{0,(LAB)}$	**[MPa]**	**0.14**	0.71	0.03	0.22
$\tau_{0,(IS)}$	**[MPa]**	**0.19**	1.16	0.00	0.91
$f_{bu,c}$	**[MPa]**	**15.37**	0.27	5.64	23.37
$f_{mu,t}$	**[MPa]**	**4.44**	0.36	1.16	8.36
$f_{m,h}$	**[MPa]**	**6.26**	0.26	3.55	8.39
$G_{f\text{-}c,h}$	**[N/mm]**	**41.35**	0.36	17.51	69.32
f_{x2}	**[MPa]**	-	-	-	-
f_{x3}	**[MPa]**	**0.36**	0.63	0.13	0.76
$f_{b,bj}$	**[MPa]**	**0.18**	0.33	0.08	0.23

Table 60. Mechanical properties resume for Calcium Silicate > 1985 masonry typology.

		CALCIUM SILICATE > 1985			
		AVG	**COV [-]**	**MIN**	**MAX**
$E_{m,v(30-70)}$	**[MPa]**	-	-	-	-
$E_{m,v(LIN)}$	**[MPa]**	-	-	-	-
$E_{m,v(IS)}$	**[MPa]**	**4830**	0.27	3947	6721
$f_{m,v}$	**[MPa]**	-	-	-	-
μ	**[-]**	**0.67**	0.21	0.49	0.83
$\tau_{0,(LAB)}$	**[MPa]**	-	-	-	-
$\tau_{0,(IS)}$	**[MPa]**	**0.03**	1.62	0.49	0.09
$f_{bu,c}$	**[MPa]**	-	-	-	-
$f_{mu,t}$	**[MPa]**	-	-	-	-
$f_{m,h}$	**[MPa]**	-	-	-	-
$G_{f-c,h}$	**[N/mm]**	-	-	-	-
f_{x2}	**[MPa]**	-	-	-	-
f_{x3}	**[MPa]**	-	-	-	-
$f_{b,bj}$	**[MPa]**	-	-	-	-

Table 61. Mechanical properties resume for Clay < 1945 masonry typology.

		CLAY < 1945			
		AVG	**COV [-]**	**MIN**	**MAX**
$E_{m,v(30\text{-}70)}$	**[MPa]**	**3469**	0.86	765	9784
$E_{m,v(LIN)}$	**[MPa]**	**5346**	0.60	1269	10548
$E_{m,v(IS)}$	**[MPa]**	**5072**	0.75	411	11665
$f_{m,v}$	**[MPa]**	**8.91**	0.52	3.09	15.84
μ	**[-]**	**0.66**	0.18	0.51	0.82
$\tau_{0,(LAB)}$	**[MPa]**	**0.28**	0.26	0.17	0.38
$\tau_{0,(IS)}$	**[MPa]**	**0.08**	0.96	0.00	0.17
$f_{bu,c}$	**[MPa]**	**25.58**	0.23	16.24	41.19
$f_{mu,t}$	**[MPa]**	**6.43**	0.64	0.71	17.35
$f_{m,h}$	**[MPa]**	**10.86**	0.11	9.99	11.73
$G_{f\text{-}c,h}$	**[N/mm]**	**83.09**	0.14	74.78	91.39
f_{x2}	**[MPa]**	**0.83**	0.47	0.55	1.28
f_{x3}	**[MPa]**	**0.61**	0.45	0.29	1.12
$f_{b,bj}$	**[MPa]**	**0.33**	0.69	0.03	0.71

Table 62. Mechanical properties resume for Clay > 1945 masonry typology.

		CLAY > 1945			
		AVG	**COV [-]**	**MIN**	**MAX**
$E_{m,v(30\text{-}70)}$	**[MPa]**	**6355**	0.45	2236	12105
$E_{m,v(LIN)}$	**[MPa]**	**7141**	0.48	1199	15604
$E_{m,v(IS)}$	**[MPa]**	**8986**	0.49	3469	18972
$f_{m,v}$	**[MPa]**	**15.12**	0.47	7.35	28.60
μ	**[-]**	**0.72**	0.07	0.66	0.79
$\tau_{0,(LAB)}$	**[MPa]**	**0.45**	0.57	0.15	0.84
$\tau_{0,(IS)}$	**[MPa]**	**0.11**	0.85	0.00	0.38
$f_{bu,c}$	**[MPa]**	**22.06**	0.40	9.40	48.10
$f_{mu,t}$	**[MPa]**	**4.69**	0.4	1.75	8.79
$f_{m,h}$	**[MPa]**	**11**	0.23	7.41	14.23
$G_{f\text{-}c,h}$	**[N/mm]**	**47.59**	0.3	29.22	70.96
f_{x2}	**[MPa]**	**1.22**	0.28	0.59	1.68
f_{x3}	**[MPa]**	**0.76**	0.44	0.25	1.4
$f_{b,bj}$	**[MPa]**	**0.43**	0.51	0.12	0.95

Table 63. Mechanical properties resume for Concrete masonry typology.

		CONCRETE			
		AVG	**COV [-]**	**MIN**	**MAX**
$E_{m,v(30-70)}$	**[MPa]**	**4286**	0.13	3659	4726
$E_{m,v(LIN)}$	**[MPa]**	**5229**	0.10	4688	5674
$E_{m,v(IS)}$	**[MPa]**	**8310**	0.13	7222	9462
$f_{m,v}$	**[MPa]**	**5.57**	0.15	4.60	6.12
μ	**[-]**	**0.71**	-	-	-
$\tau_{0,(LAB)}$	**[MPa]**	**0.39**	-	0.39	-
$\tau_{0,(IS)}$	**[MPa]**	-	-	-	-
$f_{bu,c}$	**[MPa]**	-	-	-	-
$f_{mu,t}$	**[MPa]**	**1.27**	0.61	0.37	2.39
$f_{m,h}$	**[MPa]**	-	-	-	-
$G_{f-c,h}$	**[N/mm]**	-	-	-	-
f_{x2}	**[MPa]**	-	-	-	-
f_{x3}	**[MPa]**	**0.31**	0.09	0.28	0.33
$f_{b,bj}$	**[MPa]**	**0.23**	0.56	0.13	0.47

7 Conclusion and Recommendations on way forward

The performed experimental campaign allowed the collection of data for the evaluation of the mechanical parameters of the existing masonry categories available in the Groningen area.

The experimental campaign included both in-situ and laboratory testing, whose results are reported in this report, which allowed a first evaluation of the mechanical parameter of four main masonry categories.

The main observation drawn during the experimental campaign are resumed in the following points:

- A limited number of samples, both for in-situ and laboratory testing, is available for any of the masonry typologies (especially for Calcium Silicate > 1985). Such a limited sample cannot be considered fully relevant from a statistical point of view. It was therefore a conscious choice not to provide any distribution for the mechanical parameters presented in this paragraph. The authors decided then to provide not only the average value and the coefficient of variation but also the minimum and maximum. It is idea of the authors that at this stage, due to the limited amount of samples, the best fit for the variation of the mechanical parameter is considering the as uniformly distributed between the provided minimum and maximum value.

- The possibility of performing further testing could probably allow the definition of more precise distribution for the mechanical parameters. This admitting that a significant number of samples will be available for each material typology. Further test should, above all, aim testing those masonry typologies for which few test results are available, e.g. Calcium Silicate > 1985.

- The double interpretation of the Vertical Compression Test showed that evaluation the elastic modulus as the slope of the most linear part of the stress-strain curve rather than the secant modulus in the range of 30% to 70% of strength leads to results which are more compatible for the comparison with the in-situ results.

- Future versions could benefit of further validation of the Shove Test interpretation procedure since it was observed that the cohesion is underestimated for values higher than 0.3 MPa. Therefore, also additional Shear Triple Test would be necessary. The latter could benefit of possible improvement of the test set-up which would allow a more trivial interpretation of the results. Firstly, a set-up designed to keep the horizontal compressive force in the masonry specimen would be ideal. Secondly, a more refined sampling rate, in this campaign 1Hz was used, could allow a better understanding of interaction between shear and compressive force at the ultimate condition when the masonry sample fails in shear. Finally, the presence of head joints in the sample should be better investigated. In fact it was observed that when the latter are not properly filled the application of the shear load leads a compression of these joints and a redistribution of the shear forces in the sample which does not correspond to the in-situ condition.

- The available data, as previously indicated, suggest the possibility of identifying sub typologies. In general this is due to two factors: strong influence of mortar joint quality, presence (especially for clay bricks) of a wide range of different type of units. However, due to the limited number of samples, the authors finally decided to define mechanical parameters only for the four main typologies identified at the beginning of the project.

The subdivision of the latter in further sub typologies would lead to the definition of ranges of parameter with no statistical relevance. In a second stage of the project, if more test will be performed, a revision of the abacus could be considered. In the new abacus the subdivision of the material typologies could be usefully coupled with a detailed photographic documentation.

- It is known that masonry is characterized by a significant sample to sample variability. The limited number of available samples do not allow to understand if the high variability observed in the results is due to a high variation of the masonry material from one building to the other or if it is related to the intrinsic variability of the problem of testing masonry material. A larger number of samples could provide more information in this direction.
- The performed experimental campaign underlined how in-situ and laboratory test are both beneficial. The intrinsic variability related to testing masonry material is such that laboratory test are necessary to support the observations from in-situ test and vice versa. If the experimental campaign will extend furtherly it is suggest to keep parallel testing effort: in-situ and laboratory. In terms of in-situ testing it is suggested to keep performing both non-destructive and slightly destructive tests. Slightly destructive test are necessary for the investigation of the main mechanical parameters. Non destructive test, despite not providing direct estimation of mechanical parameters, provide useful information on the homogeneity of the masonry quality and can be a useful tool in the interpretation of the results from slightly destructive test in-case of disputable results. In terms of laboratory test priority should be given to Vertical Compression Test and Shear Triplet Test which provide the most important mechanical parameters and a direct comparison with the results of in-situ test.
- The indications provided in the report should be of use to the parts involved in the project and should not considered as a tool to be addressed to professional in the assessment/analyses of existing masonry buildings. The latter should follow indication provided by national guidance. Indeed, the results and indications contained in the report could be used as a starting point for the formulations of new guidelines under the supervision of expert technicians.