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Durability Evaluation of Strengthening Mortars Applied to Historical Masonry Structures

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INTRODUCTION

The restoration of historical masonry buildings is a complex process, in that the choice of the most compatible strengthening materials plays a basic role for the durability of reinforced structures.

Their long-term behaviour remains unknown in several aspects, especially when they are applied to deteriorated historical masonry structures, whose mechanical behaviour is often difficult to analyse.

Testing a new material → his ultimate strenght

SERVICE LIFE? FATIGUE BEHAVIOUR?

INTERACTION WITH PRE-EXISTING MATERIALS?

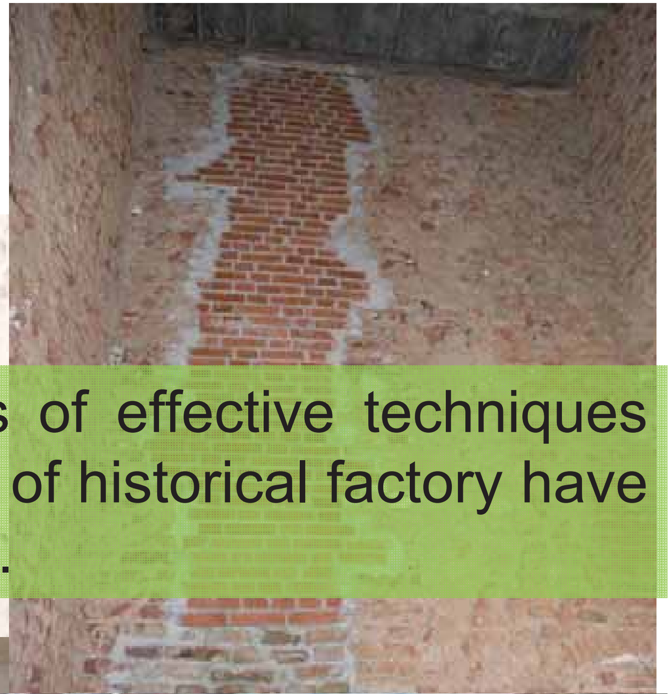
Preliminary laboratory tests to pre-qualify the most compatible product for a specific restoration work

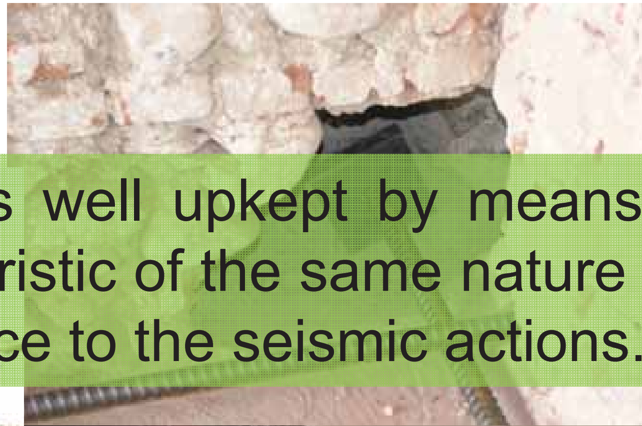
INTRODUCTION

The recent earthquakes have shown the clear failure of the restoration works performed with the use of concrete materials. The original constructive characters of historical masonry buildings have been upset.

SUSTAINABLE AND DURABLE RESTORATION WORKS

- ✓compatibility and durability
- ✓integration and not alteration of the structure
- ✓respect of conception and original techniques
- ✓not much invasive
- ✓reversible



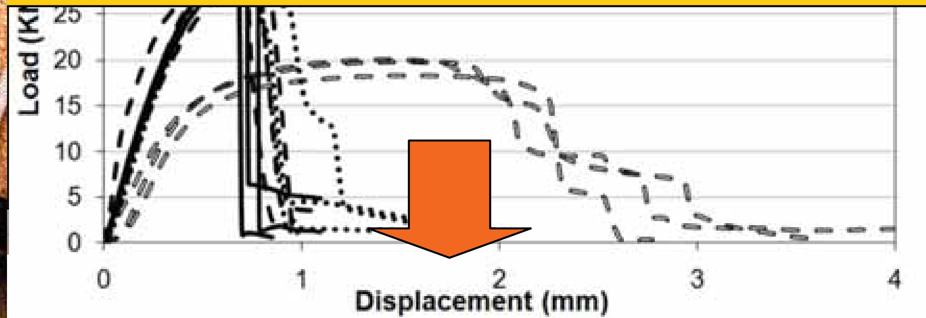


The masonry buildings well upkept by means of effective techniques and materials characteristic of the same nature of historical factory have shown a great resistance to the seismic actions.

Today the restoration knowledge has finally understood the good effectiveness shown by the lighter and less invasive technologies.

The Non-Destructive Testing Laboratory - Politecnico di Torino

CHANGE IN THE TIME OF MECHANICAL CHARACTERISTICS IN SINGLE MATERIAL



UNEXPECTED CHANGE IN THE TIME OF MECHANICAL BEHAVIOUR AND COMPATIBILITY IN STRENGTHENED MASONRY

The pur gy to be used in laboratory tests as a preliminary design stage for structural interventions, in order to pre-qualify the strengthening mortars and be able to formulate y and long-term behaviour when applied to historical masonry walls

PROBLEMS OF DURABILITY

THE RESTORATION BUILDING SITE

La Venaria Reale

The most significant restoration project in Europe

EXPERIMENTAL LABORATORY and IN SITU TESTS

Injection technique? **Jacketing technique?**

The modern lime mortars have a composition similar to those historical and good mechanical characteristics. They can to strengthen the masonry structures through reinforcement of vaults or jacketing walls that don't result too much stiff compared to the same manufactured by concrete mortars.

La Venaria Reale

LABORATORY TESTS

1st stage: SINGLE MATERIALS and MIXED TEST PIECE

- Historical bricks from the Royal Palace of Venaria (LT);

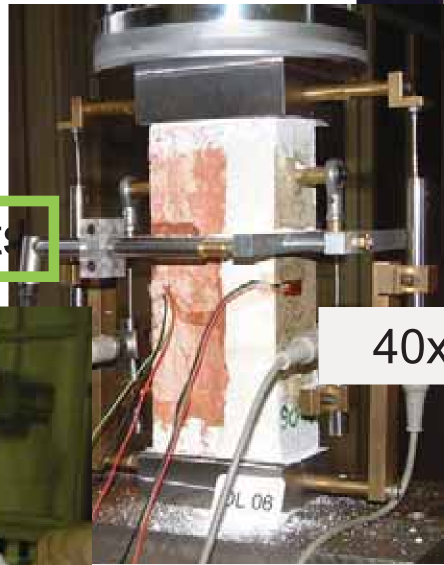
4 types of strengthening mortars:

- AM - reinforcement by structural plaster
- BM - consolidation by grout injection
- CM - reinforcement by structural plaster
- DM - jacketing of walls or reinforcement of vaults

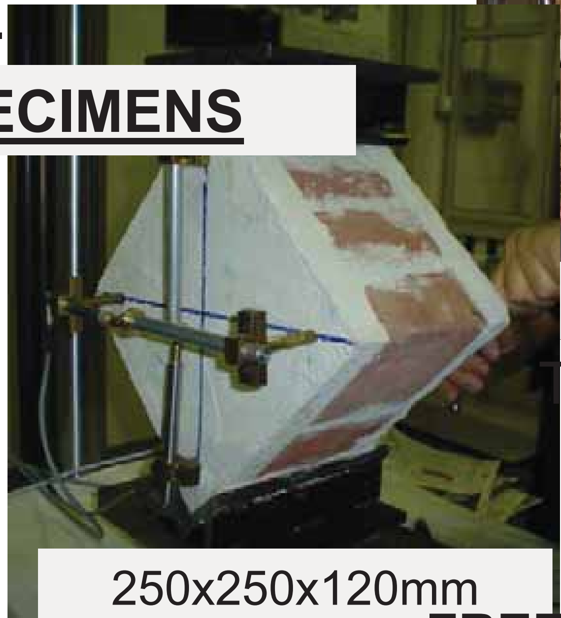
2nd stage: BRICKWORKS

3rd stage: MASONRY SPECIMENS

40x40x160mm



223x57x83mm



250x250x120mm

800x800x400mm

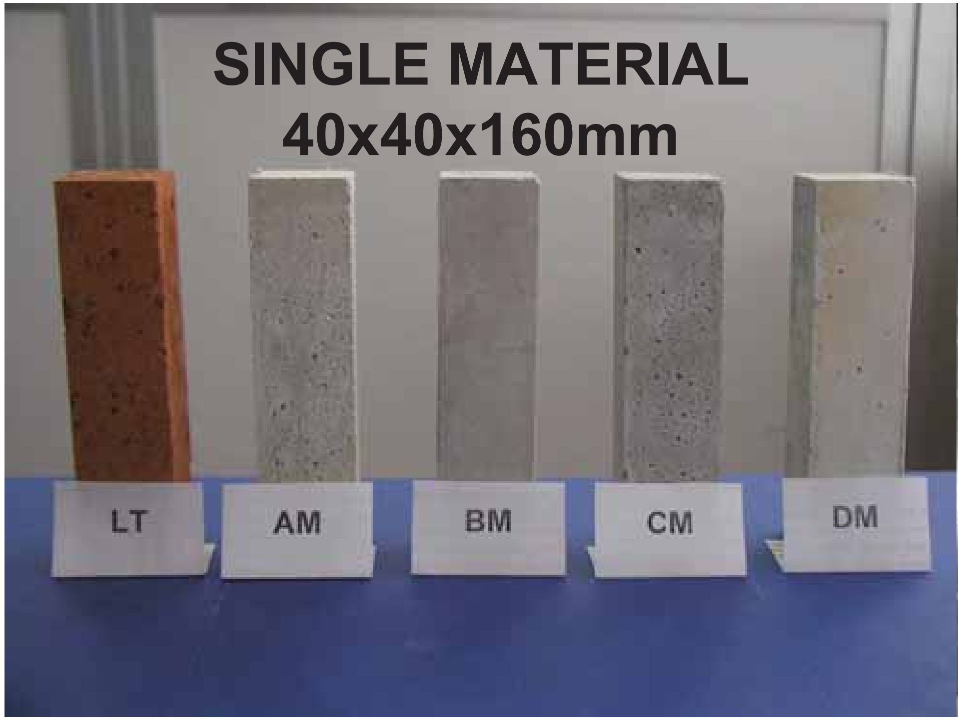
The choise of the most compatible mortar

STATIC TESTS
FREEZING-THAWING TESTS
CYCLIC LOADING TESTS

EXPERIMENTAL LABORATORY TESTS

1st stage: SINGLE MATERIALS and MIXED TEST PIECES

Static, cyclic loading and freezing-thawing tests are carried out on the single materials and on the first scale dimension mixed test pieces in order to study in small scale the interaction fatigue problems between strengthening mortar and historical bricks.

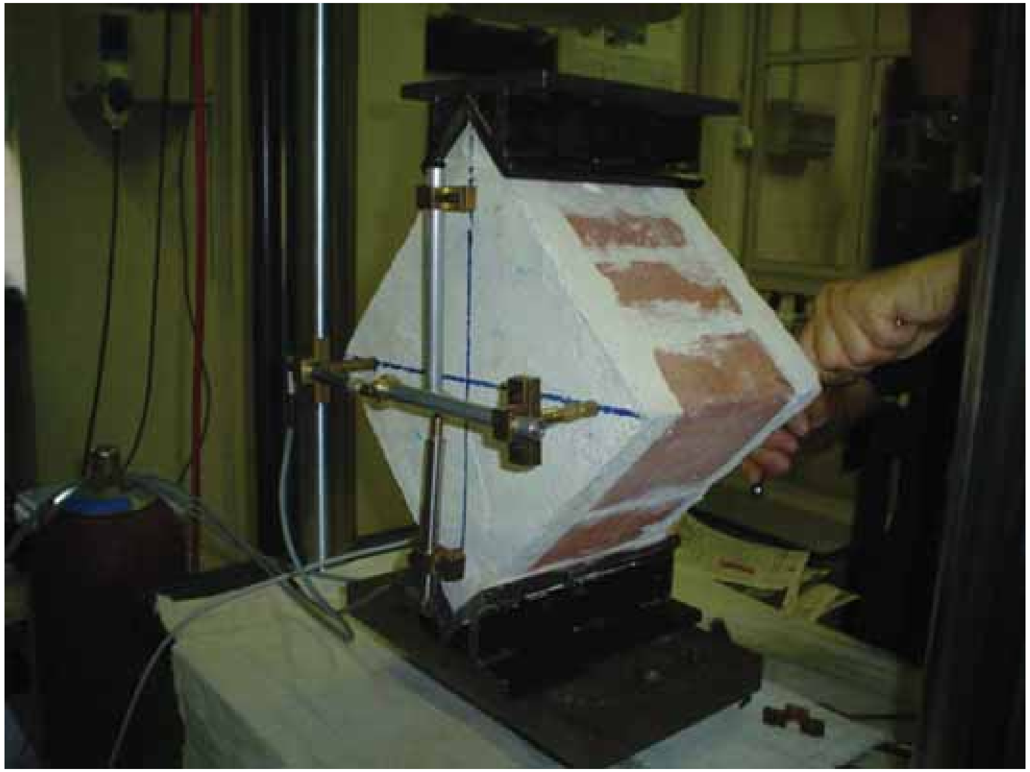


EXPERIMENTAL LABORATORY TESTS

2nd stage: BRICKWORKS

From the experimental results of the first stage, a typology of mortar is chosen to continue the experimental study through the brickworks. Static, cyclic loading and freezing-thawing tests are carried out by diagonal compressive test.

BRICKWORKS
250x250x120mm



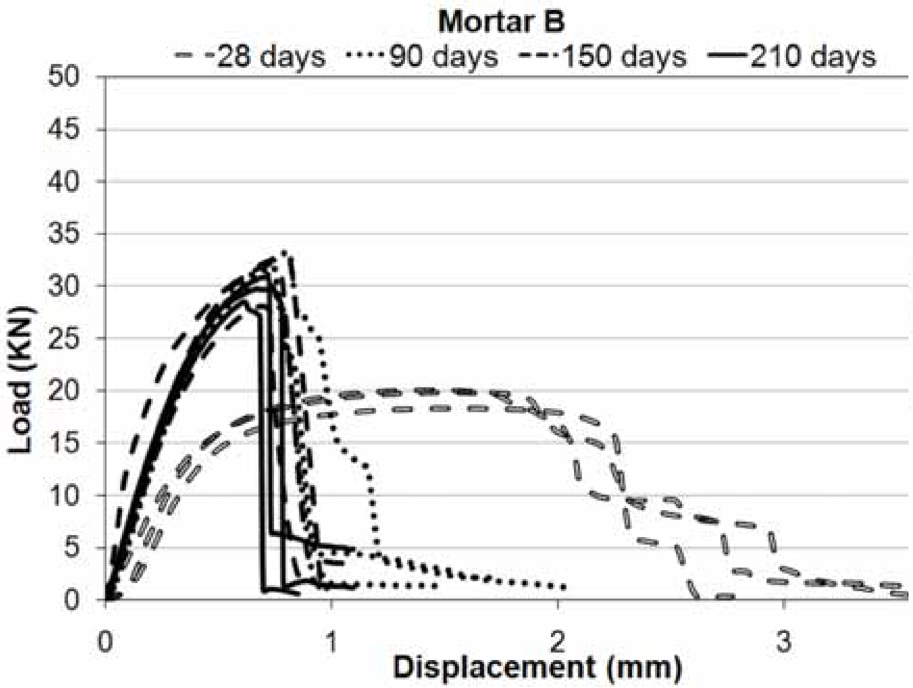
EXPERIMENTAL LABORATORY TESTS

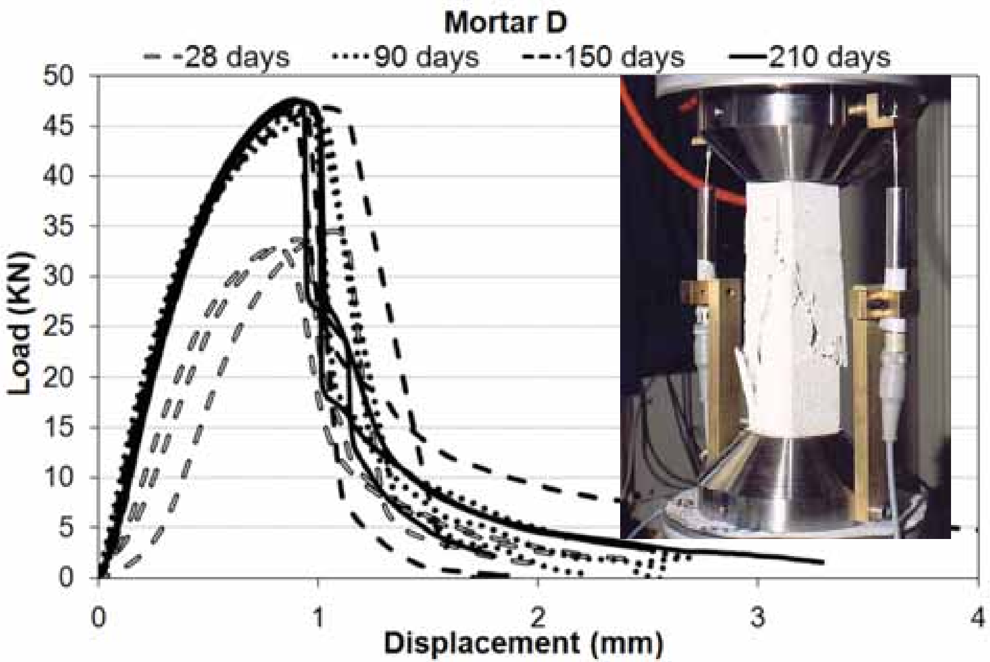
3rd stage: MASONRY SPECIMENS

The effectiveness of the same chosen strengthening mortar is analysed by means of static compressive test on the masonry specimens, in order to simulate in large scale the real behaviour of the jacketing technique.

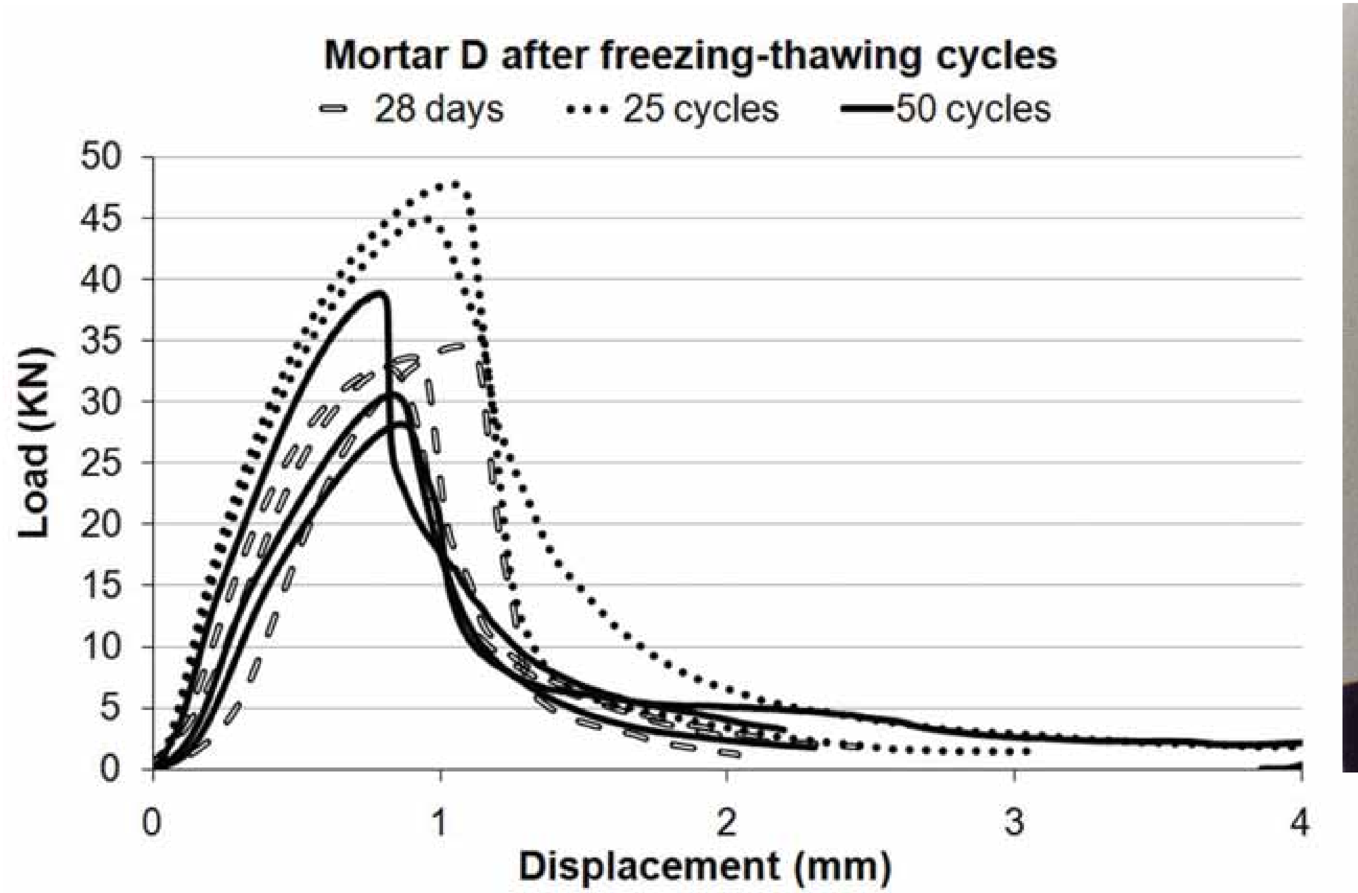
1st stage: SINGLE MATERIALS

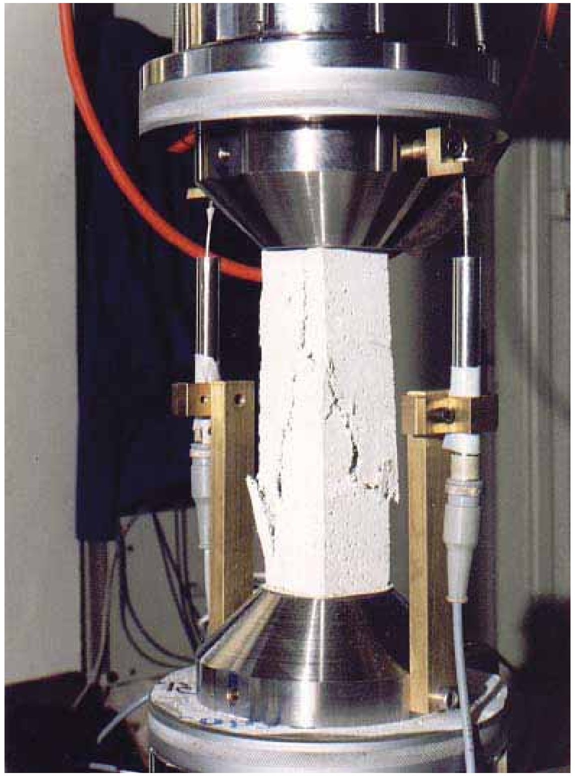
Material	$E_{average}$ (N/mm²)	$\nu_{average}$	$\sigma_{average}$ (N/mm²)	$\Delta\%\ \sigma$ (6 months)
Mortar A	6208	0.12	8.27	-7.50
Mortar B	7534	0.19	10.91	+111.55
Mortar C	12678	0.23	10.34	+146.39
Mortar D	12274	0.32	24.95	+57.47
Historical Brick	4099	0.08	8.09	-





1st stage: SINGLE MATERIALS





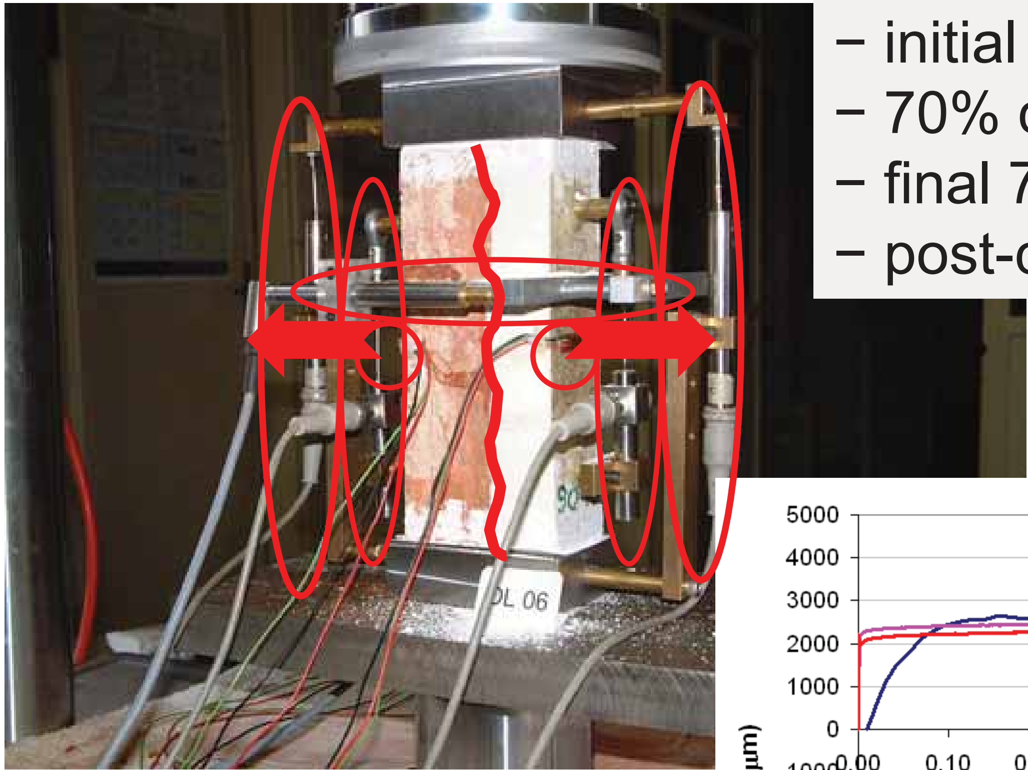
1st stage: MIXED TEST PIECES

Series	Test piece	P_{max} (KN)	σ_{max} (N/mm²)	$\sigma_{average}$ (N/mm²)	E (N/mm²)
AL	AL02	102.75	19.30	15.40	11988
	AL04	59.76	11.49		14157
BL	BL01	108.51	22.17	16.89	16940
	BL02	52.30	11.60		4400
CL	CL01	40.78	9.71	12.58	6597
	CL02	76.98	15.46		12478
DL	DL01	58.50	12.10	12.04	6191
	DL02	60.45	11.98		8106

Series	Test piece	Condition	P_{max} (KN)	σ_{max} (N/mm²)	$\sigma_{average}$ (N/mm²)	Δσ %	E (N/mm²)
AL	AL03	cracked	95.54	19.78	15.88	+3.15	10050
	AL06	detached	81.00	15.83			8151
	AL08	detached	59.30	12.03			6701
BL	BL07	cracked	76.30	14.23	13.88	-17.81	6250
	BL10	cracked	66.50	13.52			6582
CL	CL06	whole	104.50	19.92	15.52	+18.25	10604
	CL08	whole	54.62	11.13			7191
DL	DL08	whole	107.40	21.52	22.87	+89.93	35358
	DL07	whole	129.30	24.22			16249

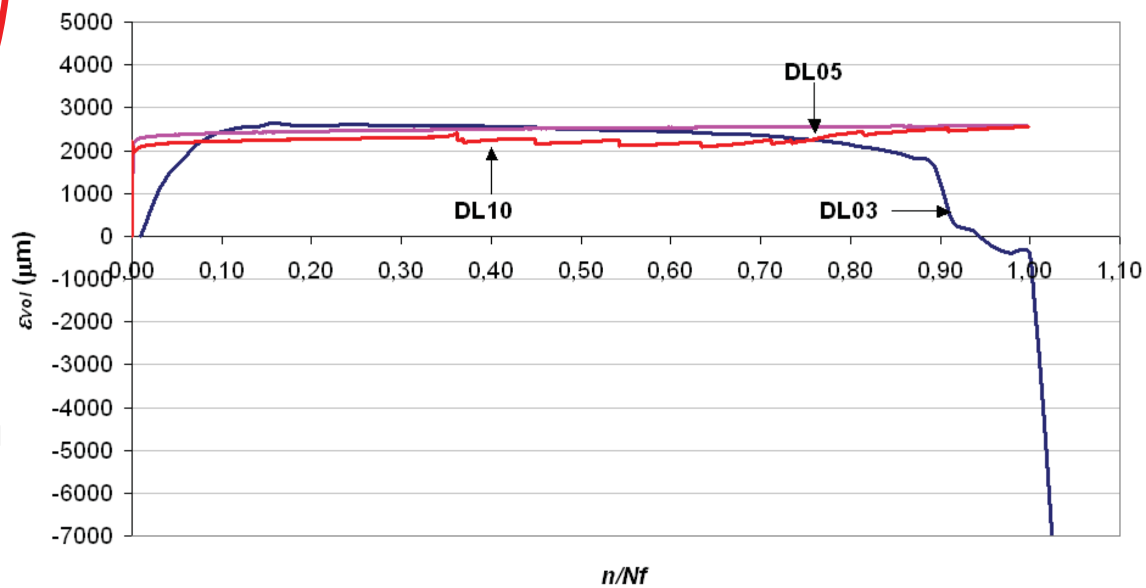
1st stage: MIXED TEST PIECES

Cyclic tests 70% of the static load – 100000 cycles

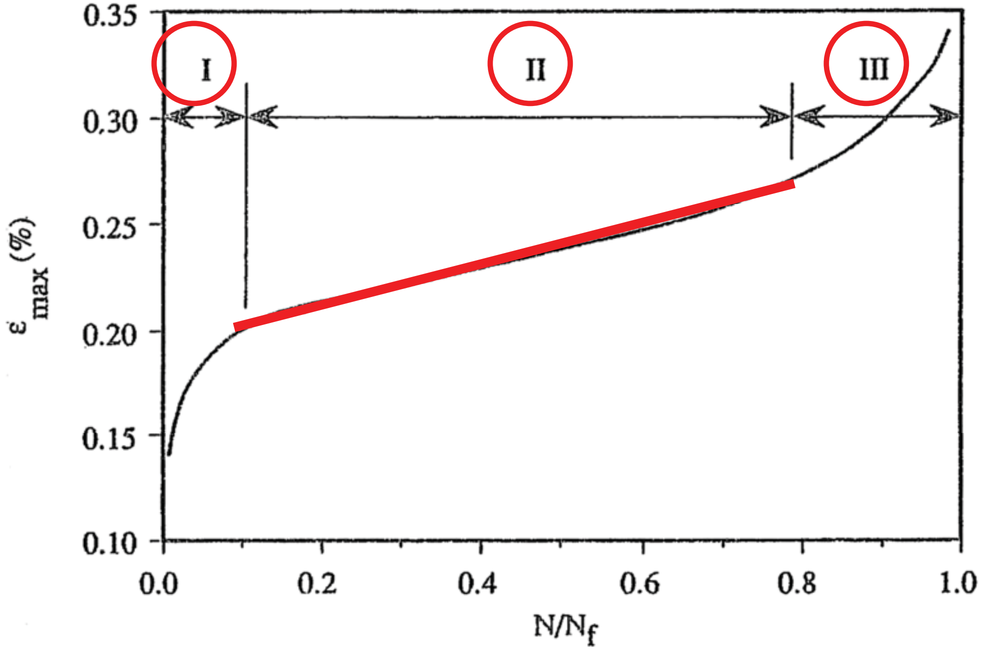


- initial 70% loading-unloading test;
- 70% cyclic test (100000 cycles);
- final 70% loading-unloading test;
- post-cyclic compression test to failure

Volumetric deformation

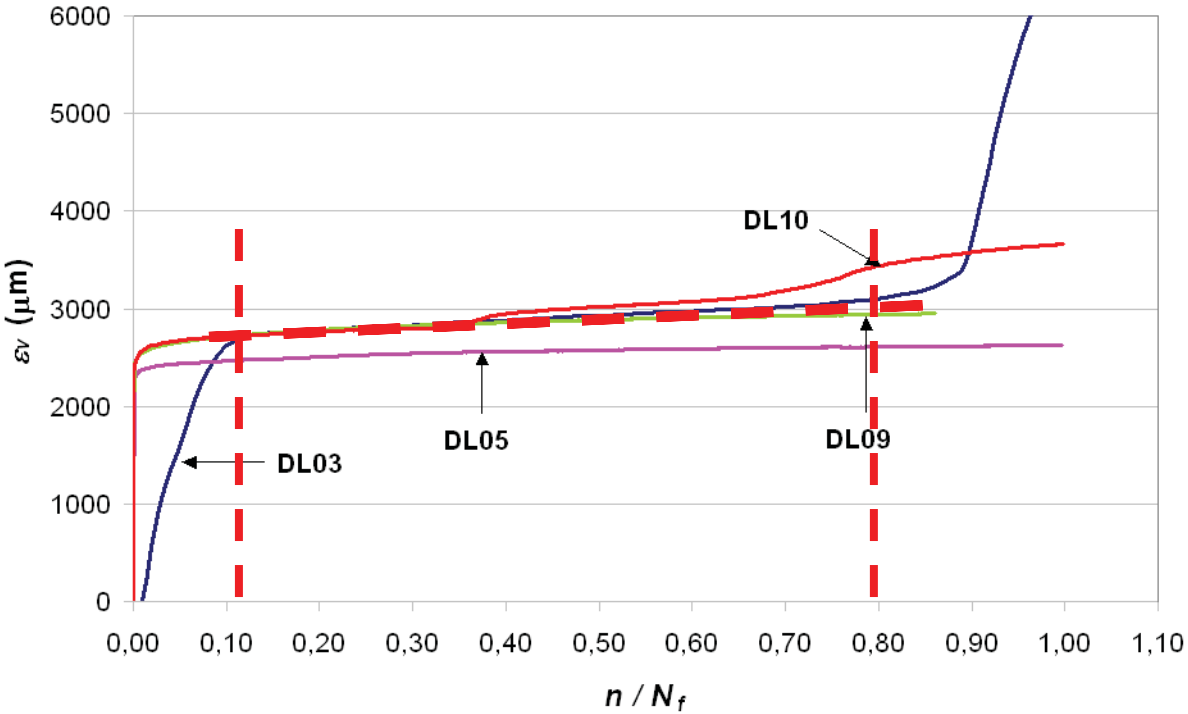


1st stage: MIXED TEST PIECES



TALIERCIO, GOBBI (1996) – MINH-TAN et al. (1993) – MU, SHAH (2005)

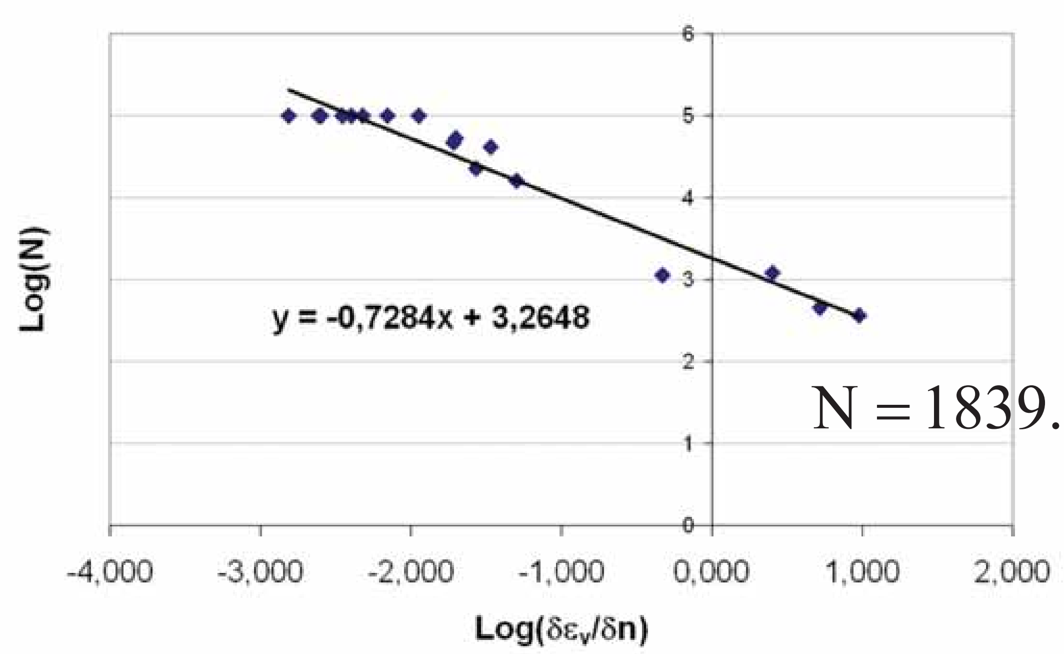
1st stage: MIXED TEST PIECES



By analogy with the method suggested for concrete (Taliercio and Gobbi 1996), the evolution of vertical deformations over time is analysed as the primary parameter for predicting and quantifying the fatigue strength of the material.

Through linear interpolation between the 20% and 80% deformation values (secondary creep), the $\partial \varepsilon_v / \partial n$ derivatives were worked out.

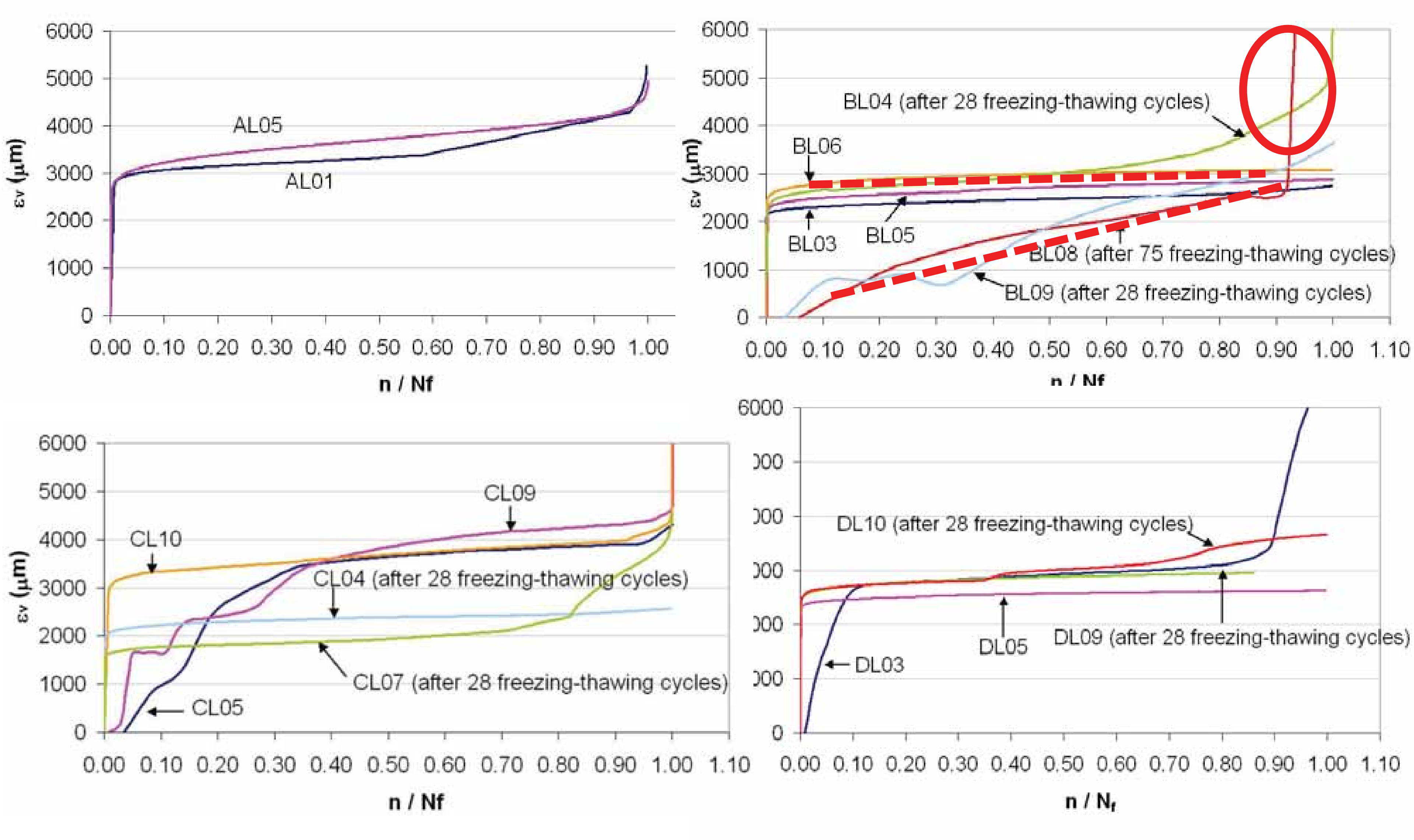
1st stage: MIXED TEST PIECES



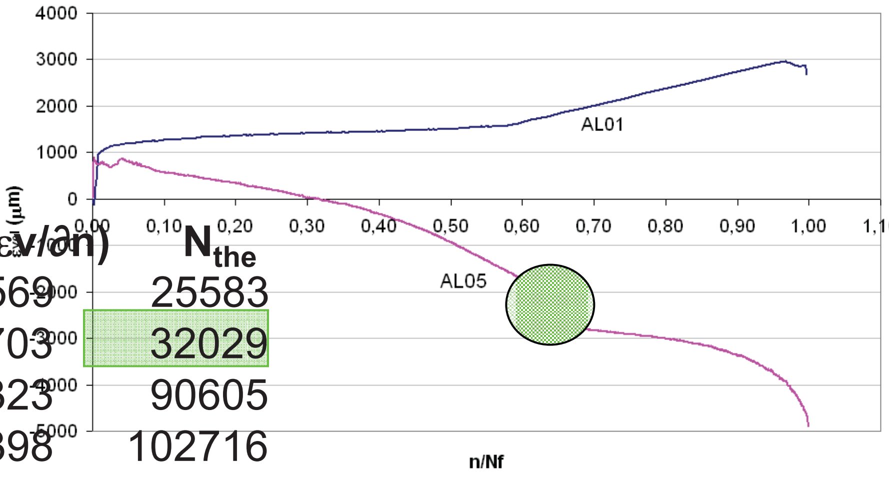
$$N = 1839.92 \cdot \left(\frac{\partial \varepsilon_v}{\partial n} \right)^{-0.7284}$$

A valid correlation was established between secondary creep rate ($\partial \varepsilon_v / \partial n$) during stage II and fatigue life (number of cycles to failure, N). By performing a number of cycles on a consistent number of masonry specimens, it is possible to predict fatigue life.

1st stage: MIXED TEST PIECES Cyclic tests

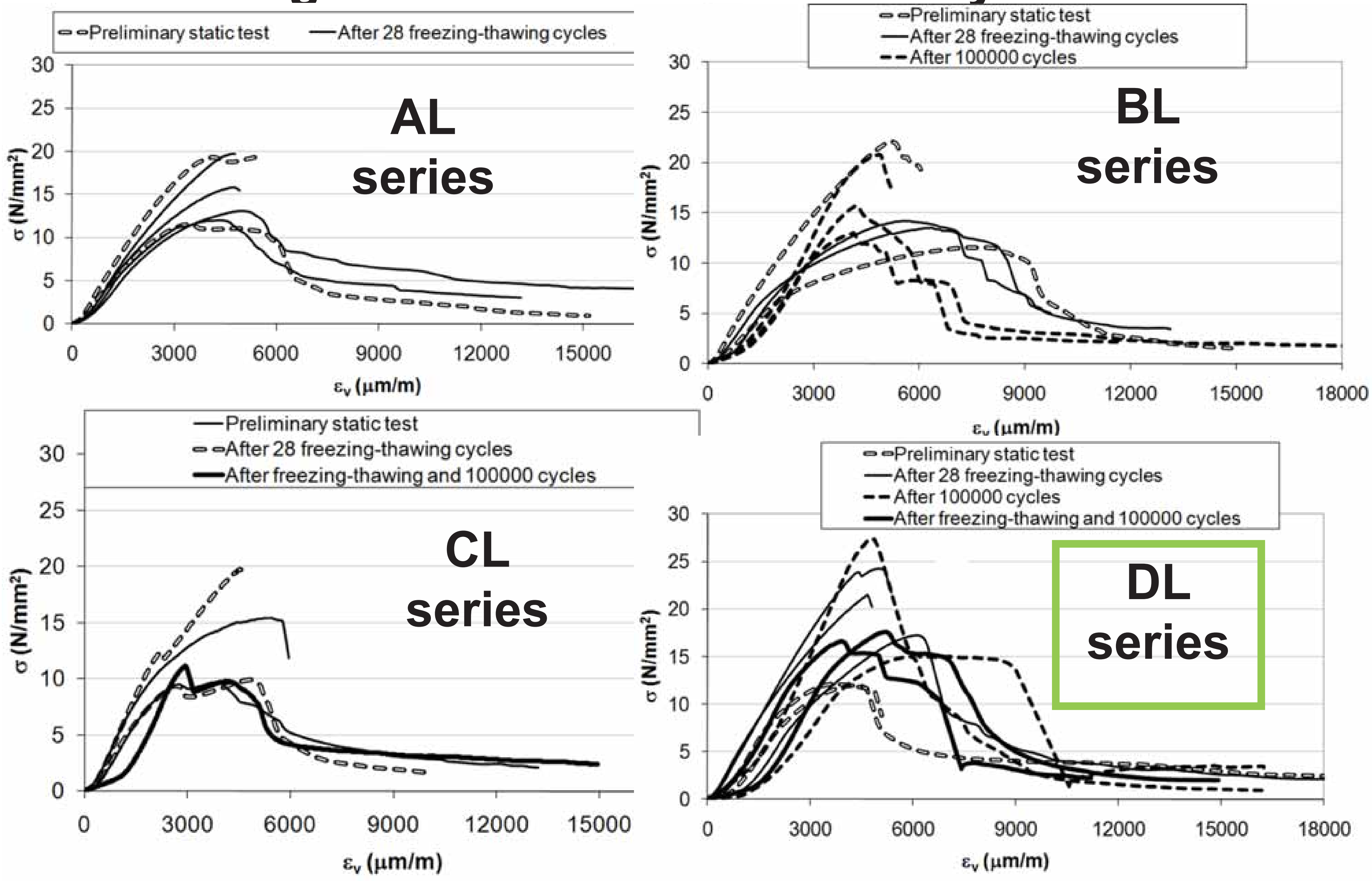


1st stage: MIXED TEST PIECES Cyclic tests



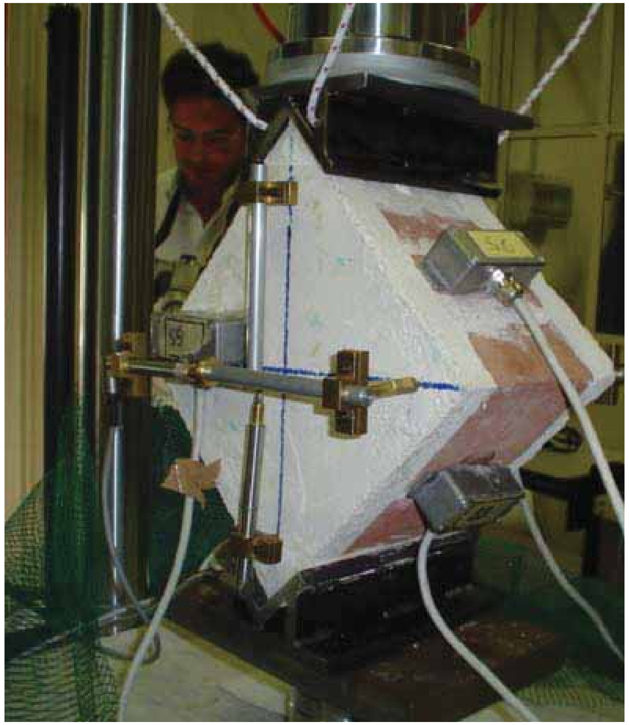
Test piece	n	$\partial\varepsilon v/\partial n$	LogN	$Log(\partial\varepsilon v/\partial n)$	N_{the}
AL01	22380	0.0270	4.350	-1.569	25583
AL05	53465	0.0198	4.728	-1.703	32029
BL03	100000	0.0047	5.000	-2.323	90605
BL05	100000	0.0040	5.000	-2.398	102716
BL06	100000	0.0024	5.000	-2.612	147056
CL05	461	5.1818	2.664	0.714	555
CL09	1223	2.5110	3.087	0.400	941
CL10	15835	0.0501	4.200	-1.300	16294
DL03	1149	0.4704	3.060	-0.328	3187
DL05	100000	0.0015	5.000	-2.813	206028
DL06	100000	0.0070	5.000	-2.155	68328
BL04	40993	0.0340	4.613	-1.469	21612
BL09	360	9.4729	2.556	0.976	358
CL04	100000	0.0035	5.000	-2.454	112832
CL07	46622	0.0192	4.669	-1.717	32795
DL09	100000	0.0025	5.000	-2.594	142671
DL10	100000	0.0113	5.000	-1.947	48171

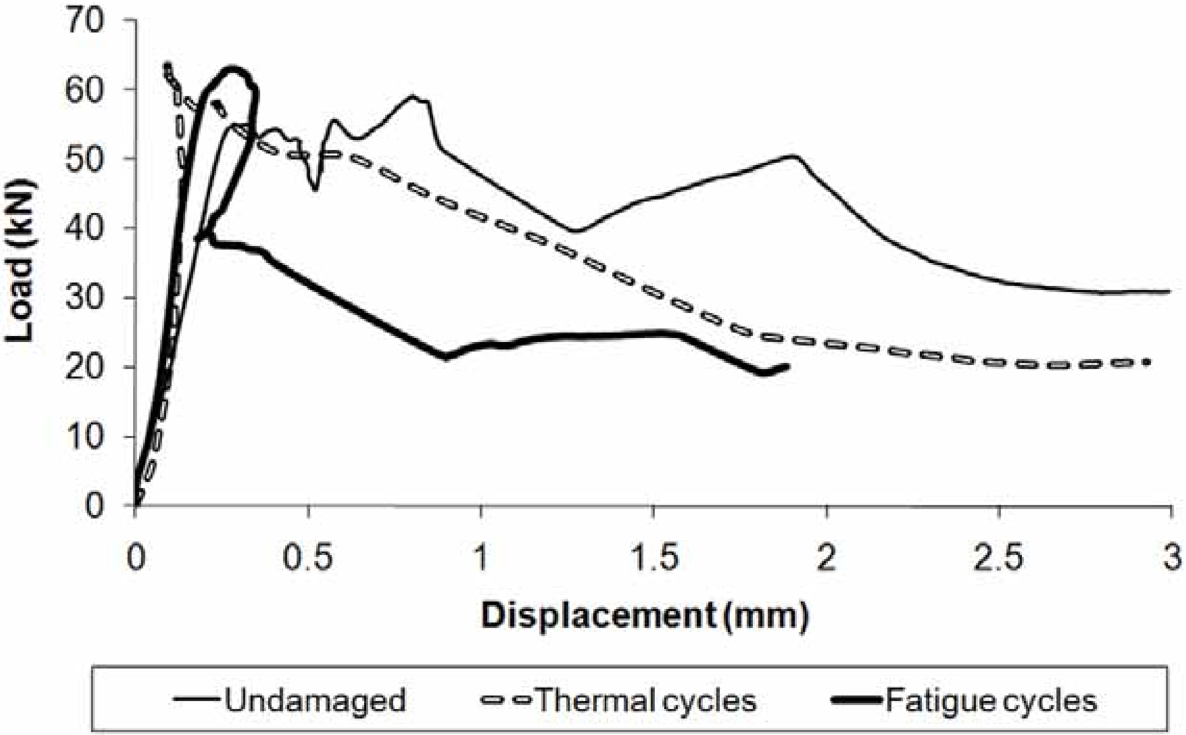
1st stage: MIXED TEST PIECES Cyclic tests



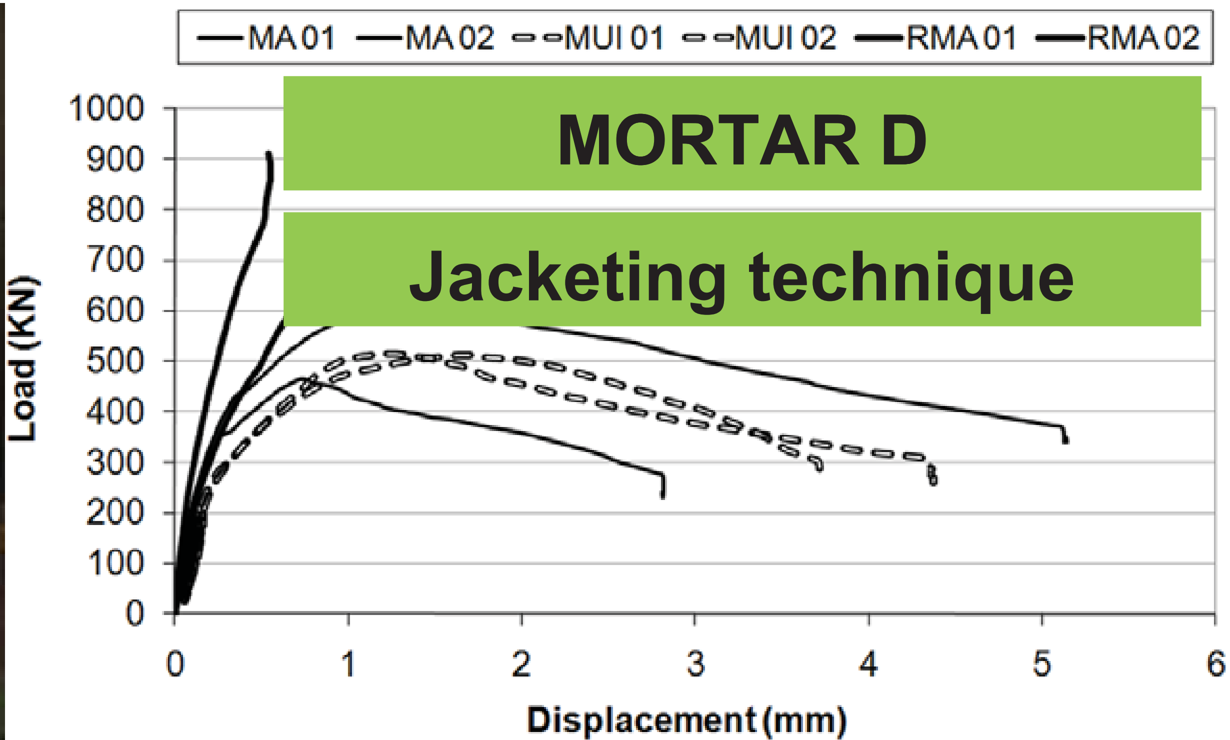
2nd stage:BRICKWORKS

MORTAR D





3rd stage: MASONRY SPECIMENS



Specimen	Typology	P_{max} (KN)	$P_{average}$ (KN)	E (N/mm^2)	$E_{average}$ (N/mm^2)	K (N/mm)	$K_{average}$ (N/mm)
MA 01	Historical masonry	600.69	532.37	7062	7147	1126705	1117404
MA 02	Historical masonry	464.04		7231		1108102	
MUI 01	Injected masonry	515.95	**514.05**	4913	**4435**	1287808	**1283092**
MUI 02	Injected masonry	512.14	***-3.44%***	3956	***-37.95%***	1278376	***+14.83%***
RMA 01	jacketing walls	769.75	**869.04**	5931	**6940**	1099971	**1306238**
RMA 02	jacketing walls	968.33	***+63.24%***	7948	***-2.90%***	1512505	***+16.90%***

CONCLUSIONS

The experimental procedure has allowed to select the most compatible and durable restoration product and technique for the strengthening works. From a range of alternatives, tested in laboratory through fatigue tests, a mortar, suitable for the jacketing technique, have shown to possess constant mechanical performances in the time under different mechanics and termo-higrometric stress.

The evolution in the time of the mechanical characteristics, due to maturation, thermo-hygrometric and fatigue loading condition has been investigated through static, cyclic loading and freezing-thawing tests on different reinforced masonry specimens.

The methodology is useful to identify a number of key parameters for interpreting the fatigue behaviour of historical brick-strengthening mortar system, in order to avoid the errors associated with materials that are not mechanically compatible and to guarantee the durability of strengthening works.

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