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Consolidation of 'Fill Layer' Masonry Structures

Consolidation des structures en maçonnerie avec matériau de remplissage

Festigung eines 'Füllschicht'-Mauerwerkbaus

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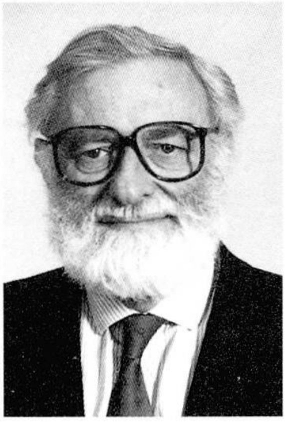

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SUMMARY

A new technology for the consolidation of "fill layer" masonry is proposed: the incoherent material is injected with an inorganic hydraulic binder and is confined by means of connectors with valves. Test results have been satisfactory and encouraging, showing increased strength and essentially unaltered stiffness after consolidation. The type and properties of the materials adopted also ensure the durability of the measure.

RÉSUMÉ

Une nouvelle technique pour la consolidation de la maçonnerie avec matériau de remplissage est proposée: le matériau incohérent est injecté avec des liants hydrauliques à base inorganique, à l'aide de canalisations dotées de vannes. Les résultats des essais sont satisfaisants et encourageants; ils montrent une résistance accrue et une rigidité pratiquement inchangée après la consolidation. Le type et les propriétés des matériaux adoptés assurent également la longévité de l'intervention.

ZUSAMMENFASSUNG

Vorgestellt wird eine neue Technologie zur Konsolidierung von 'Füllschicht'-Mauerwerk: Durch Einspritzen von anorganischem hydraulischen Bindemittel in Verbindungsröhren, die mit Ventilen ausgestattet sind, wird dem Lockermaterial eine Kohäsion verliehen. Testergebnisse waren zufriedenstellend und ermutigend. Nach dem Erhärten konnte eine gesteigerte Festigkeit bei grundsätzlich unveränderter Steifigkeit festgestellt werden. Art und Eigenschaften der verwendeten Werkstoffe garantieren eine dauerhafte Sanierung.

1. AIM OF THE INVESTIGATION

As is widely known, historical buildings undergo a structural deterioration process (micro-climate aggression, vibrations caused by vehicle traffic, heavy utilisation conditions) and it becomes necessary to take action in order to maintain adequate safety coefficients and to improve a building's load-bearing capacity in relation to actual utilisation conditions. When selecting an adequate consolidation technique, an essential factor not to be overlooked, is the need to forestall possible chemical-physical interactions between newly added material and the existing ones. Another prerequisite is not to alter the shape and appearance of a building. Finally, ease and speed of execution should also be taken into account.

In this investigation, special attention has been devoted to the so-called "fill layer" structures (whether piers, columns or walls), that is to say, structures consisting of facing walls (brick courses with joints of mortar, mostly of the air-hardening type) and a fill layer of incoherent material (building site rubble, such as sand, earth, brick fragments). When dealing with these structures, it may prove important to be able to consolidate this fill layer so that it will contribute to the enhancement of overall strength.

Account taken of these needs, a new technique has been developed to meet such needs. It consists of injections of hydraulic mortar (made of suitable inorganic substances) combined with the application of specially designed connectors to serve as confinement elements.

To this end, test pieces were produced from samples of historical materials: following an initial loading cycle carried on till an advanced state of cracking, the specimens were repaired and their strength was assessed through additional tests.

2. SUMMARY DESCRIPTION OF THE HISTORICAL MATERIALS AND TEST PIECES

2.1 Bricks

As was to be expected, the bricks, taken from the baroque structure of the Castello della Venaria Reale in Piedmont, revealed highly scattered geometrical, physical and mechanical characteristics which, however, were comparable to those gathered from the material in the State Archives of Turin (see [5]). Significant test results are listed in Table 1.

Compressive strength N/mm^2	nominal dimensions of area in compression 60 x 250 mm	nominal dimensions of area in compression 125 x 125 mm	
		dry	soaked
No. of specimens	8	8	4
mean value	14.79	10.78	6.01
s. d.	5.06	5.55	—

Table 1. Compressive strength [N/mm^2] (strength values were calculated by assessing the effective area in compression of each specimen).

2.2 Joint mortar

To simulate as closely as possible the composition and behaviour of historical materials, mortar was produced with sand and binder in a 4 to 1 ratio, the binder consisting of air-hardening lime and hydraulic lime in 1 to 1 proportions.

Table 2 lists flexural strength values as measured on specimens sized 40x40x160 mm and compressive strength values as obtained on each pair of test piece produced by the bending test.

Mortar strength N/mm^2	Bending		Compression		
	at 14 days	at 28 days	at 7 days	at 14 days	at 28 days
No. of specimens	3	3	6	6	6
mean value	0.46	0.63	0.41	0.45	0.59
s. d.	–	–	0.015	0.020	0.085

Table 2 Mortar strength [N/mm^2]

2.3 The test pieces

Fig. 1 clearly shows the shape and geometry of the columns. The fill layer was reproduced with rubble taken from the Castello della Venaria. Grain size is described in fig. 2.

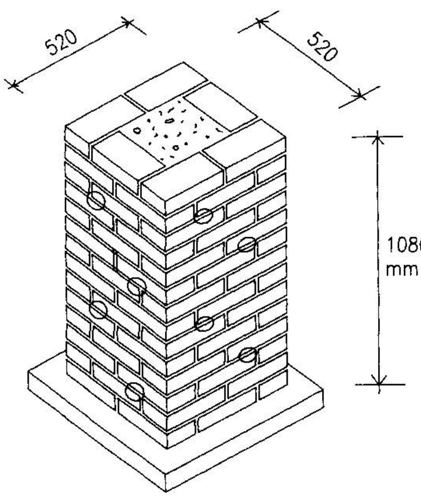

Fig. 1 Test column showing arrangement of connectors

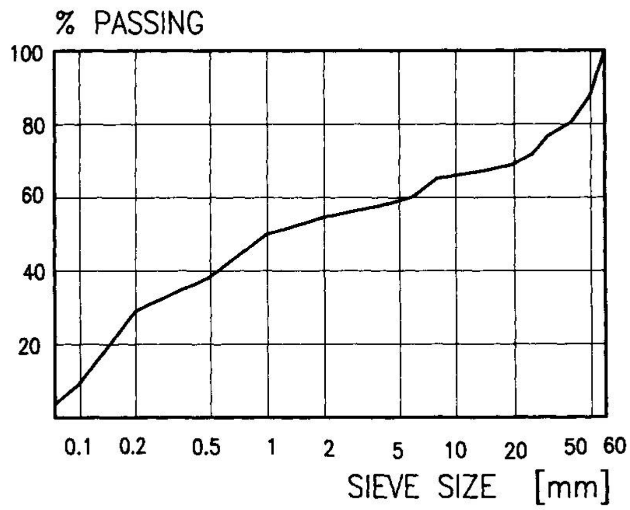

Fig. 2 Grain size of the fill material

3. DESCRIPTION OF THE CONSOLIDATION TECHNOLOGY AND THE MATERIALS EMPLOYED.

The consolidation process takes place in two distinct stages. The first consists in making holes in the structural element by means of a 50 mm diameter core drill. Through holes, spaced 45 cm apart, are made in the brickwork, and, to make sure they are not obstructed by fill material when the drilling equipment is pulled-out, a temporary pipe-shaped support is inserted, enabling the special connectors with valves to be inserted. After that, the elements are wetted with a mixture of water and surface-active agents so as to avoid the dilution and dissipation of existing mortar and to prevent soluble salts from surfacing. At this point, injection operations get underway, the aim being: a) to bind together the incoherent fill layer material, b) to provide anchorages for the connectors in the outer brickwork. Finally, the heads of the holes are filled with the material taken out, so as to conceal the damage in the best way possible.

3.1 Materials employed

The injected material is a hydraulic binder with an inorganic base which is chemically compatible with the original materials, especially with regard to the possible presence of sulphates, since the latter may trigger the deterioration/destruction of the brick-joint-binder chain.

Their salient physical-mechanical properties are:

- mix water: 37% - weight/volume: 1900 kg/m3
- pot life: > 2 h
- cone emptying time (according to the Italian Motor-way Authority's method for grouting material):
  at the time of mixing: 24.5 seconds after 30 minutes: 24.5 seconds
- hardening time:
  hardening begins: 16 h hardening ends: 20h

- mechanical strength (N/mm²) at	1 day	3 days	7 days	28 days
in compression	15	30	38	46
in tension by bending	2.8	4.0	4.4	5.6

- elastic modulus at 28 days: 1500 N/mm²
- pull-out test (performed through the connector adopted): 7 N/mm²

3.1.2 Connectors with valves

These consist of:

a) a pipe with valves, of DURVINIL PVC, 21 mm in diameter and long enough to match the element's size, fitted with three manchette-type 30 mm long polyester elastomer DUR-O-RING valves, with opening pressure < 1 bar;

b) two circular cross-section bars with nominal diameter of 5 mm, made of parallel aramidic fibres impregnated with an epoxy-based compound and coated with the same compound with the addition of fine silica sand (grain size between 0.125 and 0.25 mm);

c) two (or more) spacers-centering pieces of polypropylene, 37 mm in diameter and 60 mm in length.

The physical-mechanical properties of the connecting bars are:

- specific gravity: 1250 kg/m³

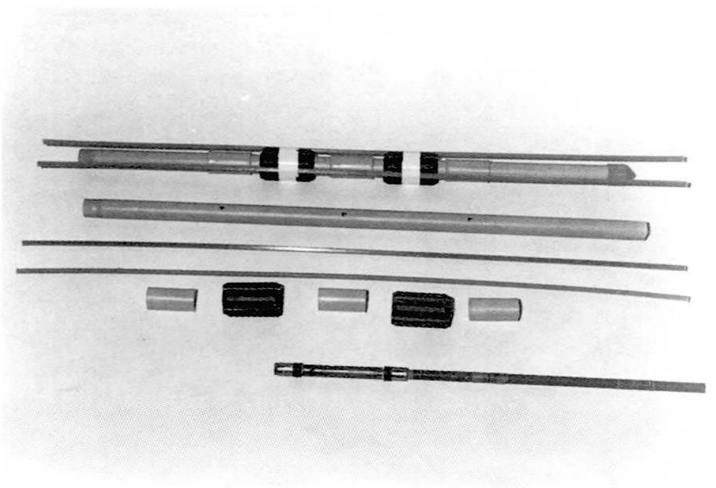

Fig. 3 Detailed view of connector

- tensile strength (referred to the section measured): 1150 N/mm^2
- elastic modulus: 56.3 kN/mm^2.

3.2 Specific consolidation technologies

The need to bind together the incoherent rubble filling the inside of the column (which includes fine grained material) made it necessary to adopt specially developed grouting techniques. The operation was performed from the bottom up in two stages. During the first stage, macro cavities were saturated with a 0.4 ratio water-binder mixture; after that, micro cavities were filled with 0.50 water-binder proportions.

Fig. 4 Inside view of consolidated column with the connectors in place.

The alternate use of individual valves, obtained with the aid of a special hydraulically sealed piston sliding inside the duct, made it possible to reach high pressures (up to 3 atm.) at the injection point without making any further damage to the test pieces.

Individual valves were used and - thanks to the grouting mixture's long pot-life - the injection time was graduated so as to be able to diffuse the mixture better and to control the quality of the materials introduced.

Confinement is obtained through a pair of bars - made of aramidic fibres impregnated with an epoxy based compound - featuring high mechanical strength. These bars are arranged on the outside of the injection pipes and are anchored by bonding to the two opposite facing layers. The presence of reinforced connectors is shown in fig. 4, where it is also possible to observe the effects of the consolidation of the fill material.

4. TESTING PROCEDURE

4.1 Specimen manufacture

The materials described above were used to manufacture 20 specimens sized 52x52x108 cm, hollow inside and subsequently filled with the material as per para. 3.3.1. The heads of the columns were then smoothed with mortar before the application of metal plates for the distribution of the test loads.

4.2 Damaging cycle

After about 30 days of ageing at 20°C temperature and 65% humidity, the specimens were subjected to centred compressive tests up to advanced cracking. For each load level, strains were measured by means of 16 potentiometric transducers on 250 mm gauges, arranged as shown in fig. 5.

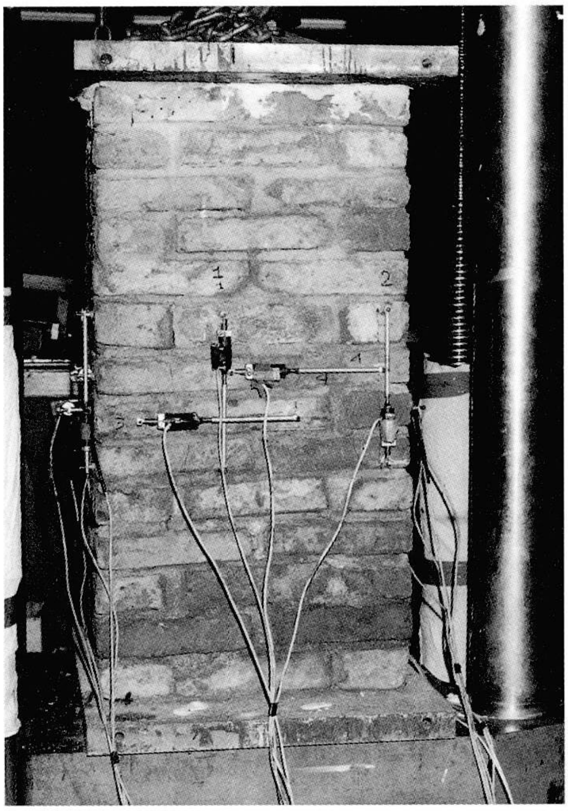

Fig. 5 Arrangement of the strain gauges

A load-strain diagram is shown in fig. 6. Transverse strains are shown on the left, and it can be seen that vertical cracks appeared at a load level of about 220 kN and then continued to increase in width with increasing load. It should be noted that at the maximum load reached at this stage (400 kN) the width of the main crack was about 3.75 mm: in actual practice, this corresponds to the specimen's maximum bearing capacity, as was also confirmed by the value of residual strain after the removal of the load. A subsequent loading cycle showed that the slope of the axial load-strain diagram, shown in the right-hand side of the diagrams in fig. 6, was greater than in undamaged specimens. This aspect must be taken into account when comparing the deformability of consolidated specimens.

4.3 Load tests on consolidated masonry

Consolidated specimens were tested until failure by the same procedure employed in the earlier series of tests. Figs. 7 and 8 reproduce the diagrams for two representative specimens. Lines a) refer to the damaging cycle and lines b), c) and d) refer to the subsequent application of the load to the consolidated specimens.

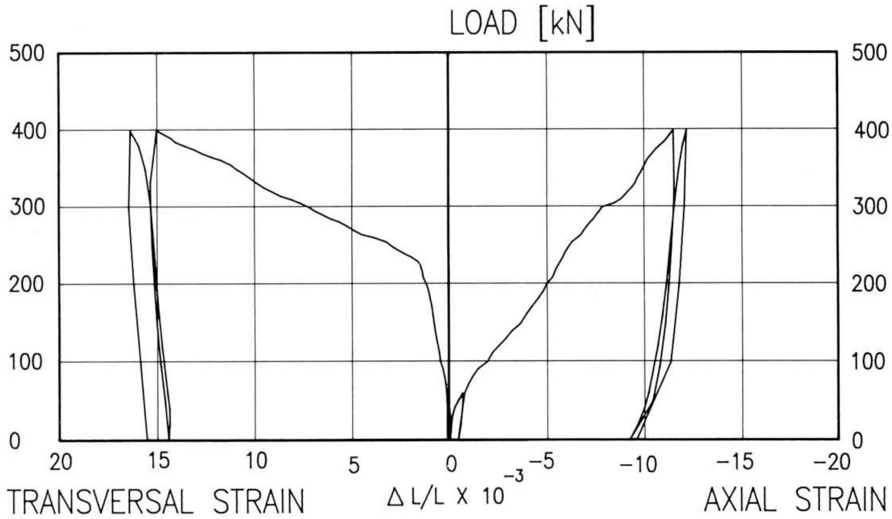

Fig. 6 Load-strain diagram, specimen No. 12

5. DISCUSSION OF TEST RESULTS

All consolidated test pieces displayed a significant increase in their load-bearing capacity, from 70 to 75% higher than the initial values.

The analysis of the load cycles, denoted by letter b), makes it possible to discern an elastic relationship between axial and transverse strains at the initial stage. The appearance of significant lesions, as revealed by transverse strains, takes place under loads about 60% higher than those applied in the first loading cycle.

The slope of the load-strain curves obtained from the consolidated structures can be compared to the load removal curves obtained during the damaging cycle. This means that the stiffness of the structural elements remains substantially unaltered after the intervention.

Finally, it can be pointed out that the action of the connectors makes it possible to obtain wide load-strain cycles; this suggests that the chosen consolidation method may be able to cope with considerable energy dissipation and hence can be effectively applied in seismic areas.

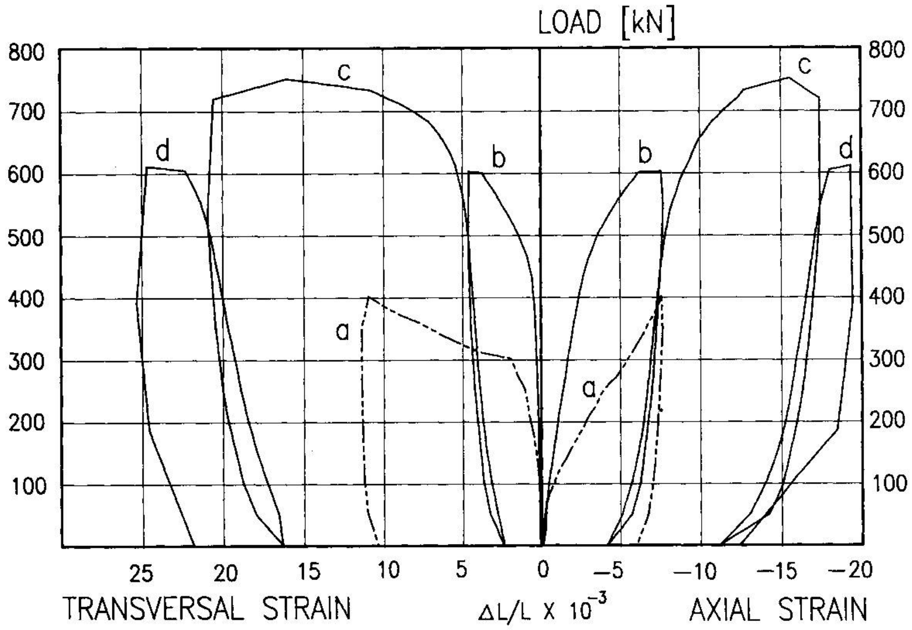

Fig. 7 Load-strain diagram, specimen No. 6

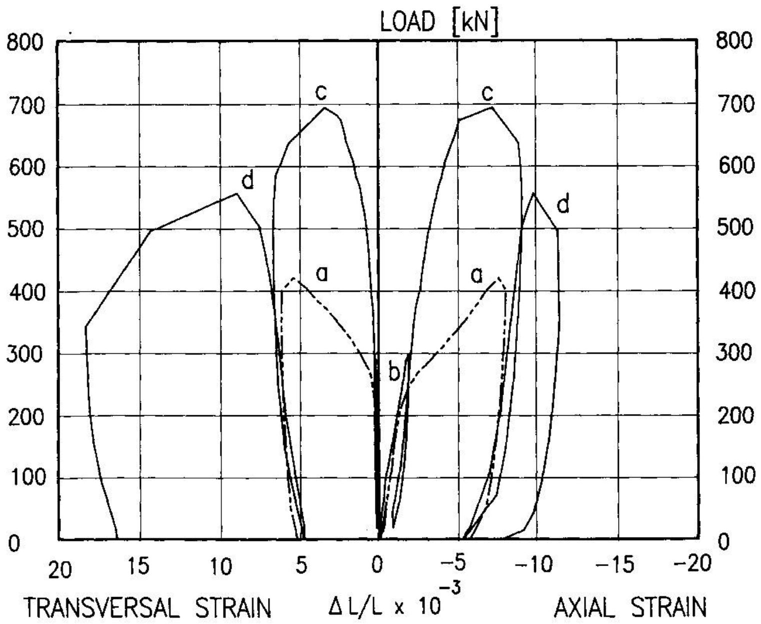

Fig. 8 Load-strain diagram, specimen No. 7

6. CONCLUSIONS

The investigation was meant to verify the validity of a new fill layer masonry consolidation technique by which the incoherent inner material is bound together through the injection of chemically compatible mortar and confined by fitting special high mechanical strength connectors designed to ensure satisfactory bond with the grouting material and not to react with the micro-climate in serviceability conditions.

The results obtained are quite encouraging: strength is seen to increase by about 65-70% compared to the initial values and the stiffness of consolidated elements remains essentially unaltered compared to that of the cracked specimens; energy dissipation and durability are also satisfactory. These results confirm the validity of the proposed technology

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