TESTS ON THE ARCHITECTURE OF ADOBE IN CALABRIA

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Abstract
This work on the constructive techniques for the buildings constructed in raw earth in the city of Lamezia Terme (CZ), has been completed with an experimental part, focused on the study of the mineralogical composition and the characterization (specific weight, granulometry, plasticity) of 8 bricks of earth withdrawn in different buildings of the centre part of the city. Two samples have been extracted from each brick and they have been subjected to a uniaxial test of compression. The result pointed out an heterogeneity of the behavior of the single sample, and low values of compression resistance. After these first experiments the samples have been kneaded to homogenize the preparation in comparison to the percentage of water of the mixture, to the compaction of the samples and the ageing. The results from this second cycle have shown a better resistance at the compression force, but still below average, and a good ductility already present in the preceding samples.
Subsequently have been created two scale 1:8 models of an existing wall with the double purpose:
- to appraise the compression behavior of the masonry;
- to use traditional techniques and materials for the conservation of the mansory

The masonry has been submitted to two cycles of load,the first one with concentrated loads: to simulate the load of the attic that unloads through the girders on the brickwork; the second with a distributed load: to simulate the load of the upper masonry. Both cycles have produced lesions and limited collapses of small areas of the models. The intervention for the reparation was made through a particular technique (called "*cuci-scuci*") that is based on unplug old deteriored bricks and insert some new in the most damaged parts,There was planned another intervention on the lesions consisted of injections of earth, aerial lime and water, elements that are already present in the traditional wall. The models after the reparation have been submitted to another distributed load bringing the brickwork to the collapse. From this test has emerged that the interventions of restoration with proper elements of the masonry, has had a positive result, the compression resistance after the restoration is improved around 1/3 in comparison to the initial resistance of the masonry. We can conclude that the masonries as the single bricks previously tested, despite a low compression resistance, and have a good ductile behavior.

1. INTRODUCTION

Many factors come into play when it comes to buildings made of adobe, this is enhanced by the unknowns if we study historical buildings of which no trace remains of the practices implemented. The tests conducted in the laboratory were aimed at understanding the chemical and physical characteristic of different types of soil. The samples analyzed have produced different particle size distribution curves, the chemical composition of the clays present were so varied, that it brought the soil to behave in one way rather than another.
The number and complexity of these factors is so high to encourage research applied to the buildings to consider not only the classification of the earth according to their chemical and microstructural characteristics, but also according to the behaviour and data that more easily influence the performance of the entire artifact.

In the present work shows the results of an experiment carried out on scale models of walls in blocks of earth and listature clay,, that reproduced the actual recordings of the historical buildings in the centre of Lamezia Terme (CZ), where there is an interesting

heritage building, with tall buildings even 5 or 6 floors, built completely or for individual portions in the ground.

For the making of the models, were used blocks packed with soil previously analyzed and elements obtained by cutting baked bricks normally available on the market.

Both the panels were tested with a double load condition:

- Distributed across 4 segments equidistant from the higher edge, in order to simulate the actions transmitted from the rafters.
- Distributed across the surface of the higher edge of the panel, in order to simulate higher floors.

For the registration of the deformations were used displacement transducers placed on the test plan, and strain gauges placed in the longitudinal and transverse, on the lateral sides of the panel.
To achieve the restoration of continuity of the walls the procedure was replace the damaged blocks with elements of the same type, placed in the work with a mortar identical to that already used, made of earth, lime and water. The portions(which were eventually plastered with lime mortar, earth and air) subjected to interventions of consolidation were again subjected to compression testing.

The mechanical tests performed on the panels in scale had another good motivation: to record the behaviour and verify the applicabilityin the walls of earth, of the consolidation technique known as "*cuci-scuci*" (see abstract). This technique requires that in cases of damaged or deteriorated masonry in small areas, is to restore continuity of the wall by incorporating elements of the same type, put in place in the same way as those removed. It may be noted that the intervention of structural restoration carried out by the technique of "*cuci-scuci*" resulted in a reacquisition of the original bearing capacity of the panel. Even the post-peak behaviour showed a good reserve of ductility.

2. TESTS OF THE MATERIAL OF THE EARTH

In Calabria the installations were distributed, above all, on the terrace type of sediments that were welded to massive crystalline schist, often results in characteristic alignment of the towns that follow one after the other, a short distance from each other. This phenomenon is repeated for the whole region with morphology, constituted precisely by terracing.
The soil used to produce bricks of raw earth is indeed clay, in as much as it lends itself largely to be worked plastically. If the presence of clay in the soil is excessive it is verified by the cracks during the drying, to overcome this phenomenon, one can add straw, sand or other inert of large dimensions to better the cohesion of the mixture. The earth is a mixture of clay minerals and other minerals usually largely distinguishable; they can be distinguished on the basis of diameter of the granules:
Clay: diameter < 2 micron;
Slime: from 20 micron to 2 mm;
Gravel: > 2 mm.

2.1 Tests of the characterisation of the specimens

The tests performed in the laboratory were aimed to characterise, physically and mechanically the material and be able to identify and classify.
The tests of classification performed taking into account the rules CNR-UNI, allowed them to recognize the quality of the soil identifying the nature of the physico-mechanical characteristics.
The soil samples analysed were 8 in total, of which 7 were bricks taken *in situ*, and a sample of soil taken from the city of Lamezia Terme. The first test which was submitted from all the samples is about the mineralogical composition.

Subsequently, the samples were classified according to the analysed size for screening (Norma CNR-UNI A. V N.23), which subdivides the soils into classes or groups, identifying the dimensions of the single grains, from which derived it's rheological behaviour. This type of analysis can be conducted in a dry or in a humid way: given that the soils being tested presented a negligible percentage of silty clay, the test was conducted in a humid way.
Of all the samples, given the high percentage of material passing through a sieve n.200 (75 micron), it was decided to continue the study of the grading curve with the test of the hydrometer. Of these same samples even the specific gravity was determined.
For further identification of the soil they determined the limits of consistency (or of Atterberg) to verify the liquid limit, plastic limit, index plastic and withdrawal limit.

Particle size analysis conducted on samples from the same physical characteristics show a rather homogeneous earth. This analysis is highly significant in regards to the single rocks, because it can be determined from the dimensional point of view of the lithic particles that make up the ground (in micron for those that are smaller, in millimetres for those that are bigger) and through the diagram of Winkler the subdivision is indicated, understanding the best use of the material as a function of particle size distribution. According to the convention of the A.G.I (Italian Geological Association), all the soils examined were classified into gradings of sandy soil-gravelly weak clay. The clays resulted in organic, low plasticity.

2.1.1 Considerations

Particularly important is the knowledge of the plasticity index, that allows the stability of the behaviour of the soil to the atmospheric actions and to define the critical value that allows the stability suitable of the given soil to the production of raw bricks.
In all cases, index plasticity varied from IP 9.7% to 15.6% and between 35% and 43% of WL was included. After having determined the limits of consistency, these analysis were integrated with the mineralogical analysis. However, to fully appreciate the existing construction technique in Calabria, it is necessary not to limit these analysis to samples of material prevailed directly from the existing constructions, in which, the materials put in the work hide part of the oral knowledge, not only for the construction technique, but also for the manufacturing of the bricks. The bricks used were always the result of an elaborate "recipe" of the *mastro* who knew the exact consistency required for the material, the percentage and the typological substances to be amalgamated for the requirements. For this reason the analysis it's also about the soil's natural, not worked, to identify the quality of the calabrian earth in the better way.

The mineralogical analysis highlights the homogeneity percentage of minerals of quartz, feldspars, and if one excludes the value of 34% of only one sample, all the others have the percentage of clay minerals in excess of 50%, two samples reaching a threshold of 70%.
To make the investigation more reliable and precise, whereas the high percentage of clay minerals,, phyllosilicates were examined: the kaolinite results in a smaller quantity of water withdrawal of hydration, thus promoting dryness (value between 20% and 35%). The chlorite, for its fine particle size and composition of the crystal lattice, has a greater percentage of water hydration, and therefore a greater withdrawal in the case of drying (value absent in two samples, present in quantities of 10% in all samples except one, equal to 5%). The illite, instead, presents an intermediate behaviour (values ranging between 55% and 70%).

2.2 Mechanical Tests

Fig.1 – Sample after uniaxial compression test.

After conducting preliminary analysis on different samples, the focus is shifted to the mechanical characteristics of the bricks taken in the town of Lamezia Terme, through uniaxial compression tests on six groups of two cubic specimens obtained by cutting a part of the original brick.
This allows to determine various mechanical characteristics of the earth. These analysis are monotonous of destructive typeand consist to take on the samples increasing loads over time until exceeding the tensile strength, allowing to determine the maximum compressive strength, stiffness and ductility of the material.
From each brick were taken two samples; the dimensions of each specimen was different. Given the excessive friability and the presence of inerts of sizeable dimensions within the bricks, it has been preferred to focus on the parallelism of the faces rather than a perfect cube shape of the sample. From the compression tests it was revealed that there was a different resistence of the samples although from the same brick, therefore, the pieces of brick leftover were again mixed with a percentage of water equal to 15% and compacted by hand inside wooden cubic forms of 4.5 cm per side. For each brick were made 3 samples, which were left to mature for 30 days and subsequently tested for uniaxial compression; the average resistance of the samples performed better than the average resistance of the samples obtained from the original bricks.

2.2.1 Considerations of the test results

PROVINO dimensioni	area (cmq)	h (cm)	Vm (µ)	Vl' (µ)	Fm (kg)	σr (kg/cmq)	ET (kg/cmq)	Vu (µ)	µc	µcd
ST1c 4,8x5x5	24	5	637,25	429,25	281	11,71	1.148,23	4236	1,48	6,65
ST1d 4,6x4,8x5	22,18	5	1328	951,5	261	11,77	828,25	4291,7	1,40	3,23
ST1e 4,8x5x4,85	24	4,85	1039,25	295,5	241	10,04	1.896,38	3424,5	3,52	3,30
ST2c 5,02x4,95x5,09	24,85	5,09	455,75	262,25	206	8,29	2.008,21	5328	1,74	11,69
ST2d 5,08x4,9x5,07	24,89	5,07	1247,25	738,5	392	15,75	985,29	5684,5	1,69	4,56
ST2e 5,08x5x5,12	25,40	5,12	767,25	418	301	11,85	1.482,17	2853	1,84	3,72
ST3c 5,13x4,77x5,12	24,47	5,12	329,75	76,5	95	3,88	1.004,33	2060	4,31	6,25
ST3d 4,95x5,16x5,04	25,54	5,04	1281,5	235	80	3,13	717,53	1813,5	5,45	1,42
ST3e 5,17x4,59x5	23,73	5	706,75	134	65	2,74	814,30	2331	5,27	3,30
ST4c 4,8x5x4,6	24	4,6	968,75	418	392	16,33	1.610,00	2775,5	2,32	2,87
ST4d 4,56x4,82x4,4	21,98	4,4	522,5	250,25	337	15,33	2.814,54	4027,8	2,09	7,71
ST4e 4,96x4,82x4,6	23,91	4,6	425	274,75	256	10,71	1.554,58	3526	1,55	8,30
ST5c 4,8x4,7x5	22,56	5	1243	264,25	558	24,73	3.859,99	2782,3	4,70	2,24
ST5d 4,68x4,63x5,05	21,67	5,05	1359,25	546,25	543	25,06	1.926,10	3668,3	2,49	2,70
ST5e 4,71x4,66x5,02	21,95	5,02	547	426,25	513	23,37	2.221,06	2251,3	1,28	4,12
ST7c 4,8x4,7x5	23,62	5,11	651,25	236,5	145	6,14	958,87	2520	2,75	3,87
ST7d 4,86x4,76x5,02	23,13	5,02	830	375	155	6,70	863,07	34855	2,21	41,99
ST7e 4,79x4,87x4,98	23,33	4,98	1098	381	196	8,40	1.212,98	3111,3	2,88	2,83
ST8c 4,91x5,09x5,13	24,99	5,13	940,25	209,25	326	13,04	2.219,10	2889	4,49	3,07
ST8d 4,89x5,2x5,18	25,43	5,18	1511	436,25	417	16,40	1.665,57	3518	3,46	2,33
ST8e 4,89x5,19x5,21	25,38	5,21	1283,25	294,5	432	17,02	3.072,32	3270	4,36	2,55
St4a 4,68x4,74x4,97	22,18	4,97	1001,25	279,75	422	19,02	2.987,25	3695,5	3,58	3,69
St4b 4,88x4,84x4,93	23,62	4,93	1295,25	229,5	412	17,44	2.995,21	3098	5,64	2,39
St4c 4,84x4,78x4,84	23,14	4,84	1215,75	901,25	457	19,75	1.081,00	3448	1,35	2,84

Fig.2 – Brochure table of values for each samples.

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Analysing the graphs, and observing the table of values obtained from the individual samples it is impossible to draw some meaningful information. The results showed high differences in the reaction of the individual samples, either about the movement of the graph and the values obtained. This could depend on the working processes and from the unexpected factors that occurred during sample preparation. Faced with an overall shortage of resistance to compression it was found a high ductility of the samples analysed.

From a preliminary analysis there is a greater homogeneity in the results of individual class of samples, although the behaviour of the chart is different for each individual sample. The average resistance of the samples that were remix is about double that obtained when the bricks were originally cut, this may depend on several factors linked to age and the implementation of the use of the bricks, the state of conservation, but also from the cut caused by the preparation of the test samples. Another determining factor is the handmade compacting in wooden forms, and a rough selection of earth to be used for the mixture, as the formwork had cubic shape of about 5 cm sides. Even in this second case, against a low resistance to compression, however, it is reported high ductility of the samples analysed.

2.3 Conclusion

For the current legislation in Italy, as long as the raw earth is a suitable material to build, it is necessary that its characteristic resistance to compression is greater than or equal to 30 kg/cm^2. To ensure in any case such level of performance it is necessary that the production process be controlled to provide a product of equal and constant composition; to this must be added only when the influence that each component of the mixture and its precise doses impact on the mechanical characteristics of the finished product. The determination of the influence that various factors have on the mechanical properties, can be assessed only by experience. Although, from these initial results it's possible to see the requirements to improve technical quality of the material which has intrinsic good strength and ductility characteristics which are fundamental for buildings constructed or to be erected in seismic zones.

3. MODELS OF EARTH

Fig.3 – 1:8 scale model.

The decision to construct two models have been applied first to test the influence of the behavior of the masonry on the strength of the structure, and secondly to verify the validity of consolidation techniques above described and already widely used for interventions of the ordinary masonry.

To realize the wall hangings, an investigation was done directly on the spot, based on the information gathered by local craftsmen, were used mud-bricks specially made to scale 1:8 closely matches the traditional building techniques.
The two models represent an existing wall in the isolated subject of the study: it is located on the fourth floor above ground, and it is characterized by walls thickness due to the positioning of the bricks, placed the horizontally, and the presence of irregular stripes of baked brick.
The second model differs from the first only for the actions put in brick work at regular intervals every three rows of mud brick. This choice has resulted in taking a cue from legislation dating back to 1908 (art. 8, paragraph b).

3.1 Methods of realizing.
The baked bricks were specially made to scale closely matches the traditional techniques. The earth did not have any special treatment, it is only to dispose the aggregates larger than 5-6 mm.
The soil was mixed with 15% water, left for 24 hours and then formed into formwork of 17x17x34 mm.
The bricks were prepared in June and the maturation lasted for a month, and were prepared by cutting a common brick in the size of 5x15, 6x31, 2 mm.
The mortar for the brick wall was carried out, according to the mineralogical analysis conducted by the CNR, supported by indications of local workers. According to testimonies, the mortar was composed from 1 part lime and 3 of sand, the latter coming from the quarries or sandy soils, was not sieved, so there can be found different size of the stones in the mortar.
The rows of bricks were alternated to avoid alignment of the mortar joints. It was taken special care to achieve the Jack arch above the opening, which from a study done on the spot, seeing the photos afterwards, and also assessing the state of degradation, it was decided to put a plank of wood on the opening setting and above that was made a rib lose with adobe specially shaped and broken beked bricks; after about 24 hours was built a Jack arch by alternating brick raw and cooked, while the key is made of beked bricks.
After the completion of the models, we are left to mature about 60 days, after that it was applied a layer of plaster made from a ratio of 3:6, , of lime and earth n.40 sifted through a sieve (425 microns).

3.2 Running the Test
To detect the deformation, there were applied electrical resistance strain gauges on the both sides of the models. To measure the overall lowering of the upper part of the models there were used 4 displacement transducers placed on the loading plate.
During the test it was possible to follow the deformation process, and the trend of the graph "load-displacement".
After the test, uniaxial compression, it was desired to test the applicability, even in the buildings of adobe, of the traditional methods of consolidation already spread to the walls in brick. After submitting the specimen to axial concentrated on regular wheelbase 12 cm load transmitted from the rafters that rest on the attic wall - and distributed loads, there have been repaired the injuries, inflicted by the evidence, by injecting a binding mixture at low pressure to restore continuity in the system of the walls.
The technique of consolidation with the injection usually takes place in the presence of stone walls, bricks wall or mixed. It also applies for resolving the problems of loss of membership and mutual cooperation among the constructive parts with the consequent reduction of mechanical strength of the collection. The use is suitable in irregular equipment and uneven walls, and in the presence of the visible lesions. whenever it was possible, when the bricks were too damaged, it was also used the "*cuci-scuci*" method above described.

Fig.4 – Illustrated intervention.

The second model was positioned under the press with the same procedures used before. To compare two models, there were same types and models of proof for both panels. The uniaxial compression test conducted on both models after the repair has taken place with distributed load over the entire upper surface (area of 270 cm2).
After reaching the maximum load (1116 kg for the first model, 1343 kg for the second), it was decided to leave it to avoid the deformation for the next 24 hours.
Injuries have manifested themselves in new sections of the wall and the load dropped by about 500 kg. there were further loading to bring the models to collapse, for the first model was discontinued the trial to achieve a slump since the transducers were out of the race.
For the second model, however, the part which was collapsed of the embankment, was the left part of the door, and then the left side divides in two architrave which remained in place thank to the wooden table. The right side of the model did not have any particular damage.

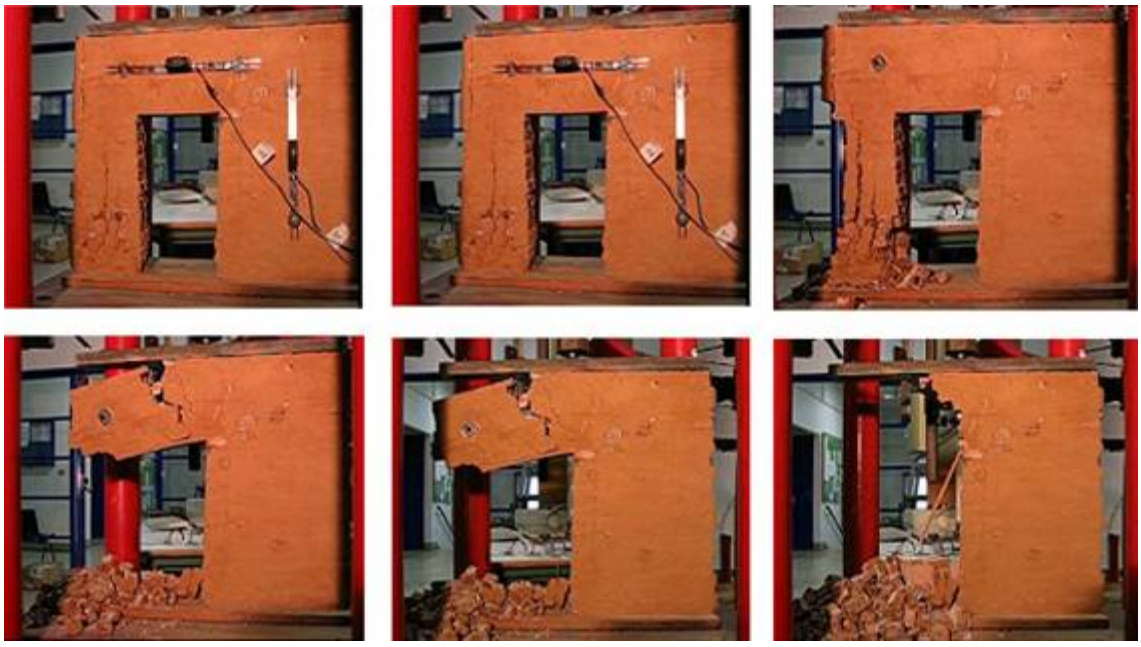

Fig.5 – Model crash.

4. TECHNICAL CONSIDERATIONS ON THE EARTH STRUCTURES

The ground material has insulating capacity and thermal inertia compared to the specific weight, excellent hygroscopic capacity of abandoning or taking water steam adjusting microclimate housing, keeping the humidity to have a suitable level of living.
The earth is a porous material and so it is breathable and it defines a notable ventilation through the pores and a subsequent purification of the air. Furthermore, the

clay is sound proof, in fact you can get a soundproof equal to 48 dB with a wall of adobe of 15 cm thick (it would be half the thickness if the same wall was made of baked bricks).
The surfaces of a building allow only a certain amount of heat, humidity, sound, light and air, and only materials that have the same characteristics of a membrane are able to provide a comfortable environment.
The historic house not only arouses interest in formal element of the landscape, but has value like an expression of ecological solutions, economic situations, popular traditions of labor relations. The house is the element of an economic and a social structure within which to be studied.
The earth, the building materials are also recyclable during the preparation of the bricks, they do not produce harmful substances, and after the sale of a building, all the material earth can be used for a new cycle production, or re-introduced into the environment without generating environmental shocks.

The material requirements of the earth can be renewed or to be processed with cutting down transportation costs. Compared with a baked brick, brick made of raw earth enables energy savings of 90% why not subjected to baking, resulting in further reduction of production costs.

5. CONCLUSIONS

Values results from different load tests were lower than those obtained from similar tests conducted on other models on the earth.
We had to consider that the uniaxial compression tests conducted on different samples made by the bricks taken in site, gave low results, lower than the average. Furthermore, regarding to the first model, we detect a certain geometric imperfections under construction that certainly has influenced the final result.
The geometric imperfections of the model N.1, don’t permited to evaluate very well the effect of cooked, but in terms of ductility you can say that the models tested exhibited good behavior post-peak, showing a good reserve of strength even after you download the test machine.
Another remarkable result was achieved in the second part of the test, thanks to the choice of the intervention of consolidation.
Consolidating the model with ground lime and water, and where possible, replacing the brick with other brick earth was a choice due to three fundamental factors:
- Compatibility / Sustainability;
- Validity;
- Economy.
The simulated repair in the laboratory, the well managed one, could be brought on full-scale buildings of "folk architecture" that possess a dignity and a history that is well respected, so we chosen to these buildings, a scientific approach also from the point of view of the art of the restoration and we can summarized the intervents in five points:
- Observe the monument and the environment, the character and appearance of the city, particularly near the monuments ;
-paying attention to the maintenance and the consolidation of the works;
-give importance to keep a certain artistic value for the elements;
-insert new elements in works of art only if it is really indispensable, and with the intention of not creating a false document.
- Supporting the introduction of new construction techniques if the storical techniques is no longer suitable.

We observe that old brick walls, at times, have internal voids and discontinuities, formed due to geological instability or deterioration phenomena due to the different causes, these cavities are the breaks in the field of building structures and determine a lower capacity to resist, especially if they are subjected to increased loads, or a

different distribution or concentration of weight caused by disruptions or alterations in the old sections bearing. According to the results obtained, the injections have filled the gaps generated from injuries, increasing the surface resistance of the masonry, welding fully disconnected parts.
It was always wanted to regain the full bearing capacity of the buildings which were originally equipped. This result, which seems important according to scientific world that has promoted the problem of energy saving and eco-sustainability, highlighted the importance of maintaining and preserving the built heritage in raw earth through actions that don't change the nature of artifacts and thus allow to convey to future generations the materials and construction techniques that are part of the history of the popular press.

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