EASY AND RELIABLE REMOVABLE EQUIPMENT FOR IN-SITU COMPRESSION AND SHEAR TESTS ON LARGE MASONRY SAMPLES

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ABSTRACT:
The strong earthquake which demaged many buildings in the regions Emilia Romagna, Lombardia and Veneto on May 2012, induced severe damages on the supporting masonry structures of the Church of St. Felice sul Panaro, built in XIV century. The upper part of the lateral walls collapsed together with the vault. In order to define the reconstruction and strengthening interventions of the supporting structures of the Church, it was necessary to determine the compression and shear characteristics of the masonries. For this purpose, large scale masonry samples were cut from the portions of the collapsed walls. The compression and shear tests were carried out in-situ by using easy and reliable removable equipment, which allowed to carry out each test within few hours. The testing technique and the results of the tests are described, as well as the technique for cutting and setting the masonry samples.

INTRODUCTION:
The church of San Felice sul Panaro was built in several phases, starting from the end of XIV century when the first church, with a rectangular plant, and the bell-tower were built. In the second construction phase, between 1500 and 1650, the church was enlarged and a first chapel was built. In the third phase, between 1650 and 1730, the church was affected by an architectural renovation and the lateral chapels were built. This renovation process continued until the beginning of XIX century. The last intervention dates back to the end of XIX century with the construction of a new façade.
The Church of San Felice sul Panaro was severely damaged by the earthquake of May 2012, which irreversibly altered and undermined its supporting structures in such a way that it can now be considered as an archaeological remain.
In Figure 1 the church after the collapse is shown together with the drawing of the church before the earthquake.
Awaiting the definition of the reconstruction design of the church, provisional and removable strengthening structures were designed in order to guarantee the safety of the remaining structures of the church in the short period (2 to 5 years). The purposes of this provisional strengthening intervention were:

- to guarantee the maximum conservation, through the strengthening and protection, of the remain structural elements of the church;
- to set up some operations which could be used for the final design of restoration and reuse of the church.

Before the seismic event of 2012, the church of San Felice sul Panaro showed a high seismic vulnerability due to the interventions of enlargement and increase in height.
During the earthquake, 21 failure mechanisms were activated. The provisional strengthening interventions started in 2013 and were carried on throughout 2013 and 2014, under the supervision of the Ministry of Culture. These works included: the removal of the ruins, the strengthening of the remaining masonry structures and their protection against atmospheric agents through the construction of a structure able to guarantee the complete covering of the church. These structures were designed in order to guarantee the protection and conservation of the remaining structures in compliance with the principles of reversibility and removability, which are necessary to avoid any preclusion for future design solutions.

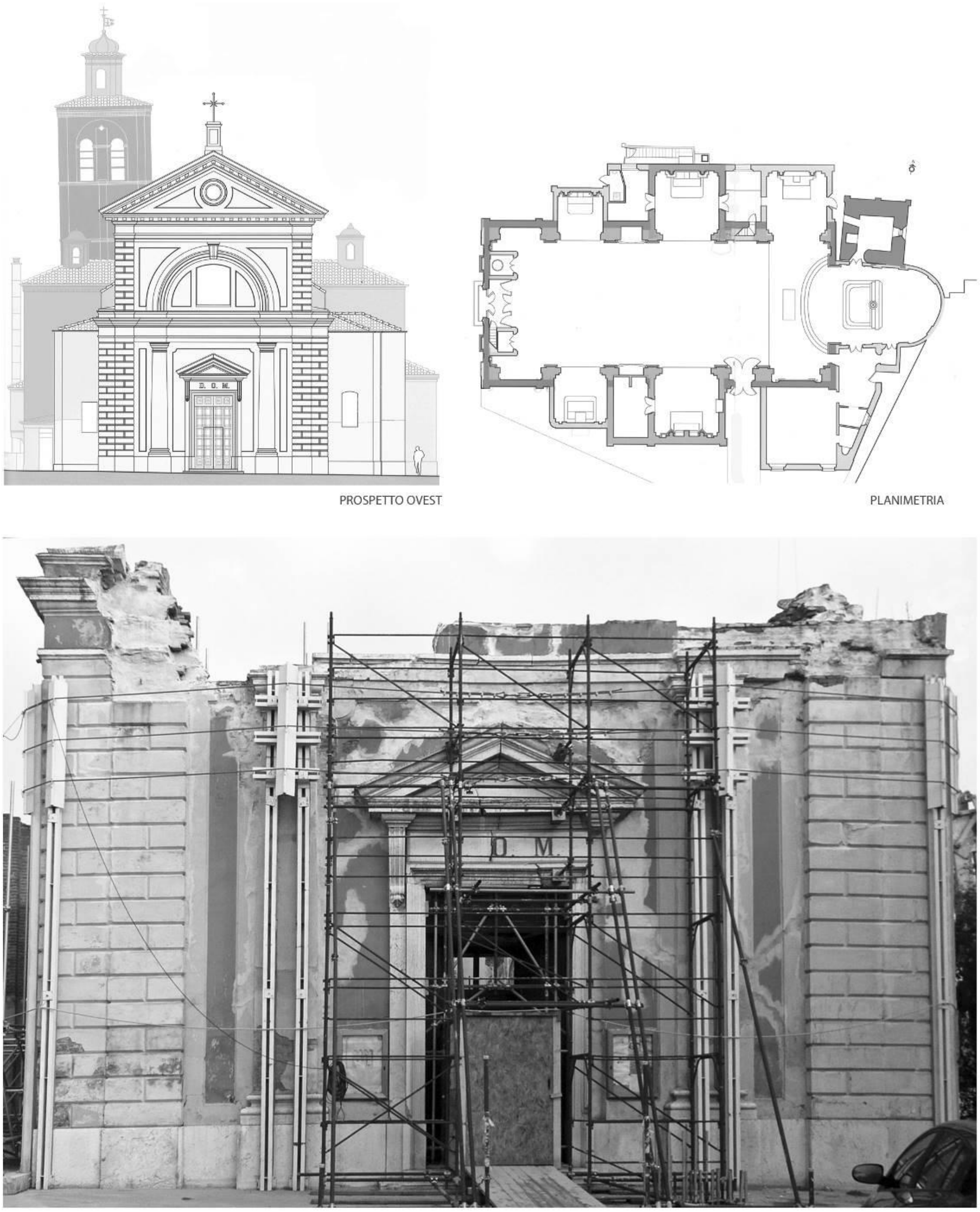

Figure 1. San Felice sul Panaro Church before and after the earthquake

The remaining unconnected and unstable masonry walls were connected by means of steel chains at two different levels (5 and 7.5 meters) in order to avoid collapse due to lateral inflexion. All the cracked masonry structurers were consolidated with lime mortar grouting and “scuci-cuci” method using recovered bricks. The aim of these interventions was to re-establish the shear strength characteristics of the masonries.
The vaults and the architraves were consolidated by grouting with local insertion of stainless steel bars. The heads of the masonry walls were protected by a layer of lime mortar with reinforcing steel mesh.
A steel reticular structure was chosen, for its structural flexibility, to sustain the covering structure of the church and to support in the meantime the lateral walls of the church.
The characteristics of the intervention and the material used, clearly indicate that the intervention is provisional and needs periodical survey. Within a period of about 10 years, a definitive design solution must be found for the reconstruction of the church. In Figure 2, a view of the provisional covering structure, is shown.

The provisional supporting structures of the covering were installed outside the walls of the church in order to allow possible occasional use of the inner space for religious or cultural events.
In this complex scenario, it was extremely important, for the analysis of the safety conditions in the short period and for the final design, to know the mechanical characteristics of the remaining masonry structures. For this reason, mechanical test were set up directly in the site, to determine compression and shear strength on large size masonry specimens which did not suffered any damage during the collapse.

Figure 2. View of the provisional covering structure.

EXPERIMENTAL ANALYSIS OF THE MECHANICAL CHARACTERISTICS OF THE MASONRY

In order to avoid any damage to the masonry specimens, due to the transport from the site to the laboratory, it was decided to carry out the compression and shear tests directly in the site. This decision required the construction of a removable testing machine with a limited weight and easy to be assembled in short time. The testing equipment, which was installed in the working area in front of the church, was especially designed in order to combine the reliability of the tests with the simplicity and rapidity of installation. The masonry specimens (50 x 50 x 50 cm) were cut and prepared very close to the loading frame and for the execution of the tests only slight movement of the specimens was required.

Preparation of the specimens

A large masonry block, which fell down during the earthquake from a lateral wall of the church, was chosen for the preparation of the specimens. The masonry block, with a thickness of about 50 cm, is shown in Figure 3.
By using a cutting chain provided with diamond tools, large size specimens (50 x 50 x 50 cm) were obtained. In order to avoid damages and release of the masonry, (5 mm thick) steel plates were installed on the opposite faces of each specimen and connected each other by means of steel tendons. Only after the connection of the two plates with the tendons, the specimen was completely isolated from the masonry block by cutting the last face with the diamond chain. The cutting and preparation phases of the specimens for the compression test are shown in Figure 4.
It must be pointed out that, before the installation of the two steel plates, a thin layer of mortar was applied on both faces of the specimen in order to eliminate the irregularities of the masonry and to

guarantee the parallelism of the lower and upper faces. The same cutting procedures were used to prepare the specimen for the diagonal compression test which was used for the determination of the shear strength of the masonry.

Figure 3. View of the masonry block collapsed during the earthquake and used for the compression and shear tests.

Figure 4. Cutting of the large size masonry specimens for the compression and shear tests. The steel frame used in the cutting phase is shown.

Testing equipment

The loading machine used for the determination of compression and shear strength of the masonry is shown in Figure 5.

A simple and removable steel frame was set up. In order to reduce the weight of the equipment as much as possible, the lower and upper loading plates were made with some IPE profiles welded each other. Four steel columns at the corners support the compression load applied by the double-effect hydraulic jack. After the installation of the masonry specimen on the basement steel plate, the assembling of the loading machine was completed, as shown in Figure 6.

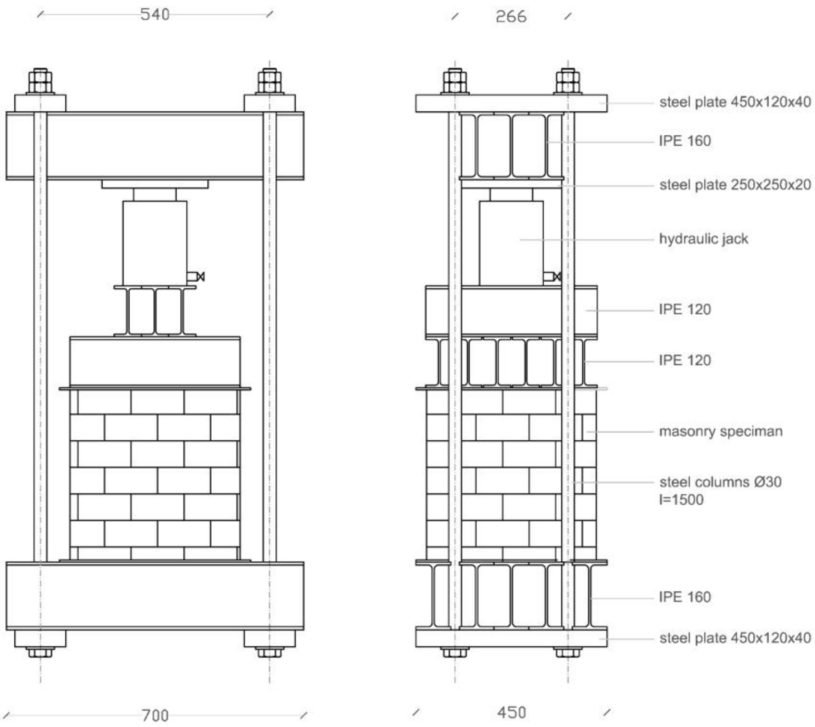

Figure 5. Scheme of the removable loading machine used for the compression and shear tests.

Figure 6. Phases of installation of the loading machine for compression test.

The same equipment used for the determination of the compression strength was used also for the determination of shear strength, by using a diagonal compression test. In figure 7, the setting of the equipment for the diagonal compression test, is shown. The detail of figure 8 shows the two steel devices which apply the diagonal load to the opposite edges of the specimen.
The deformations of the specimen during compression and shear test were measured by means of displacement transducers, connected to an automatic data acquisition system. The instruments installed on both faces of the specimens during compression and shear tests, are shown in figure 9.
Before the installation of the instruments, sonic velocity tests were carried out on the masonry specimens, as shown in figure 10. In the same figure, the values of sonic velocity measured in several points of the specimen, are shown. A good homogeneity of the results, with high values of sonic velocity, can be observed. These values were compared with the sonic velocity values measured in several points of the perimetral walls of the church.

Figure 7. Setting of the loading machine for shear test through diagonal compression.

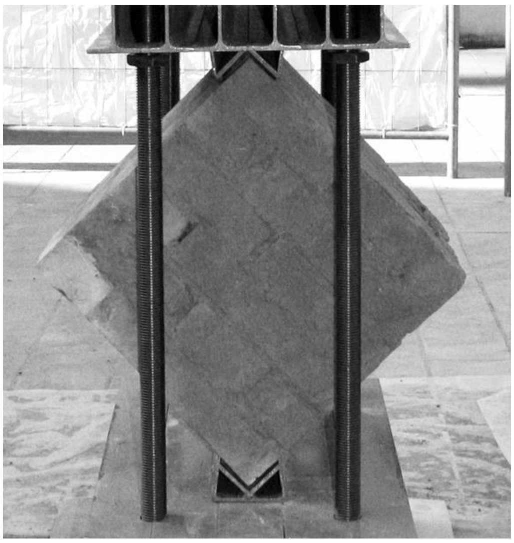

Figure 8. Particular of the masonry specimen during the diagonal compression test for the determination of the shear strength. The two steel plates for applying the diagonal compression to the opposite edges of the specimens are shown.

Figure 9. The deformations of the masonry specimens during compression and shear tests are measured by electrical transducers connected to an automatic acquisition system.

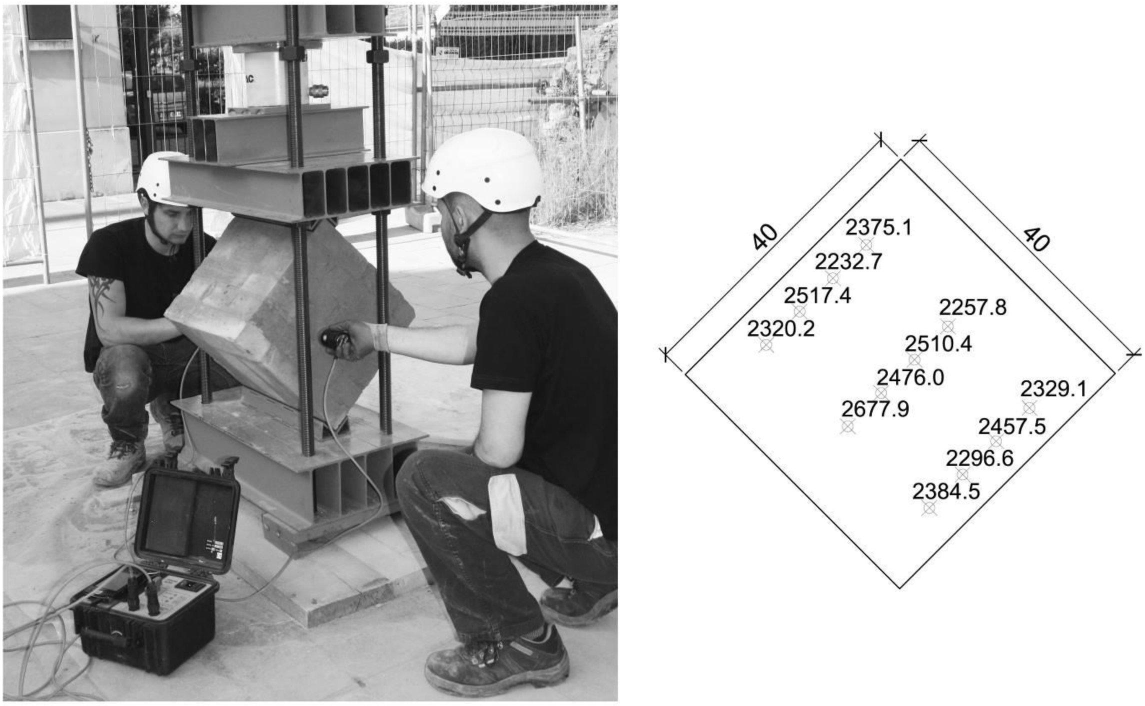

Figure 10. Measure of the sonic velocity in several points of the masonry sample.

COMPRESSION TEST RESULTS

The compression test for the determination of the deformability modulus (E) and the compression strength (fm) was carried out by increasing load levels up to the failure of the specimen. Figure 11 shows the behaviour of axial and transversal deformations of both faces of the specimen, as well as the average curves. It can be observed that the axial deformations of the two faces are very close to each other also after the limit of elastic behaviour. As regards the transversal deformations, it can be observed that the behaviour of the two faces is quite the same up to the limit of the elastic behaviour of the masonry. Over

this limit, a sudden diversion of the two curves is observed, with face B showing a much higher transverse deformation than face A.
The deformability moduli are shown in Table 1.
The compression strength was 2.83 MPa.

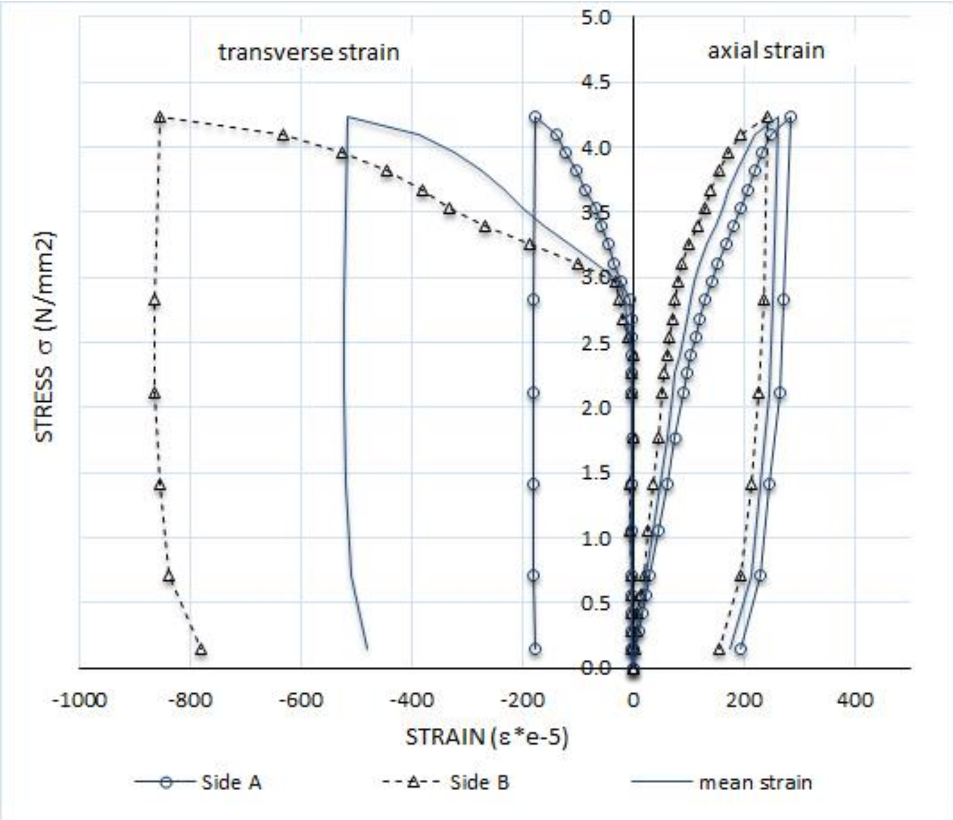

Figure 11. Axial and trasverse deformation of the specimen during compression test.

Stress σ (MPa)		Modulus (MPa) E	E 1-2	E 3-4
0.28	1.06	2685.7	2024.8	3987.0
1.06	2.83	2647.0	2132.6	3488.6
2.83	3.39	1259.7	1119.2	1440.5

Table 1. Summary of deformability moduli. E: mean modulus; E1-2, E3-4: modulus of side A and side B

SHEAR TEST RESULTS
The diagonal compression test for the determination of the shear strength of the masonry specimen was carried out with increasing load levels up to failure. The shear moduli values are shown in Table 2
The shear strength obtained is ft = 0.16 MPa.
A detail of the sample after the shear failure is shown in figure 12.

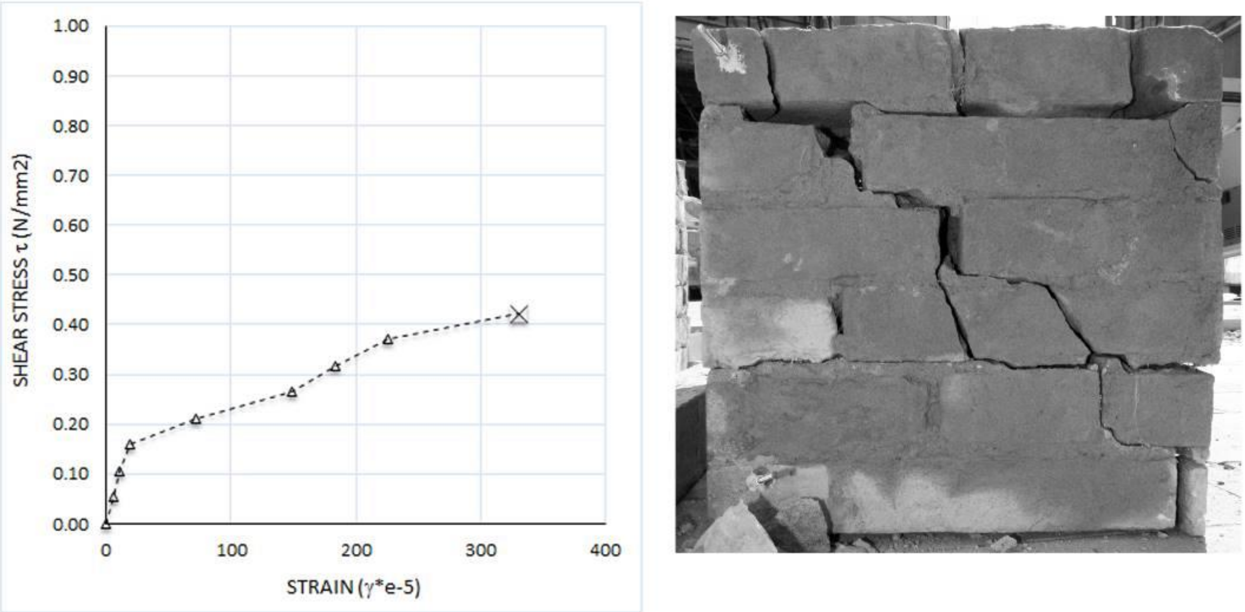

Figure 12. Shear stress-strain diagrams and detail of the masonry after the shear failure.

Shear stress τ (MPa)		Modulus (MPa) **G**
0.06	0.16	768.0
0.16	0.37	102.3
0.37	0.42	50.7

Table 4. Summary of deformability shear moduli

CONCLUSIONS

The removable equipment that was set up to carry out compression and shear tests, proved high reliability. It is very simple to be dismounted and assembled and transport is easy because its components are not bery high. Also the testing procedure, including the cutting and the preparation of the specimens, is very simple and tests can be carried out in a very short time.

The compression and shear tests that were carried out on the specimens extracted from the masonries of the lateral walls of the church of S. Felice sul Panaro, took only two days, including cutting and the preparation of the specimens.

The instruments installed on the specimens and the automatic acquisition system, were able to follow the deformations of the specimens during the whole duration of the test up to failure and the results obtained can be considered fully satisfactory.

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