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AE Characterization of Brick Masonry Walls Mechanical Behavior: The Case-Study of Alessandria and Boves Barracks

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Keywords. Acoustic Emission; Non-destructive monitoring; Masonry structure; Flat-jack test; Emitted energy; Kaiser effect; Damage analysis.

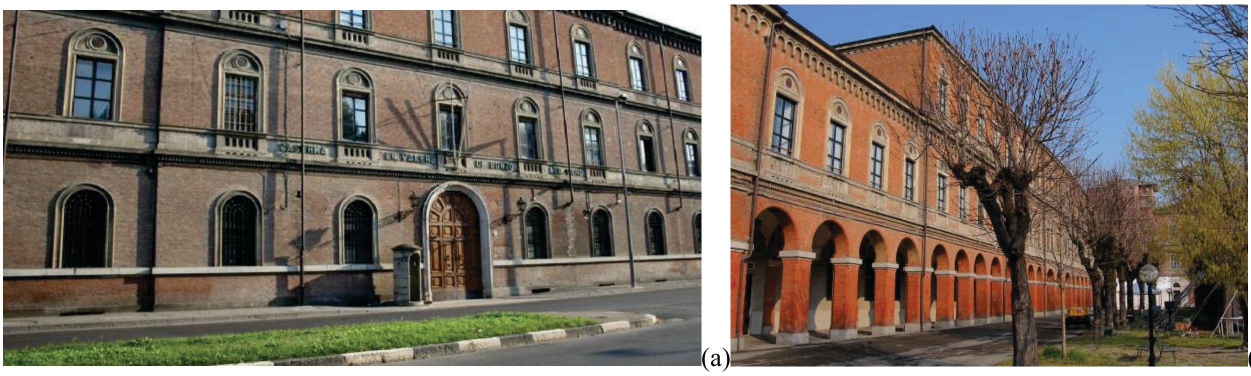
Abstract. In the present study, Acoustic Emission (AE) monitoring technique is applied in order to characterize the brick masonry of two important military buildings located in Northern Italy: the barracks of Alessandria and Boves. The internal brick masonry walls of the two barracks object of the study are tested by two double flat-jack systems, in order to analyze the compressive strength of the structural material. During the tests, the stress-strain relationship of the masonry is determined by gradually increasing the pressure applied by the flat-jacks in the course of three loading-unloading cycles. Moreover, AE technique is coupled to the flat-jack testing, in order to assess the extent of damage in the masonry texture. Thus, AE technique makes it possible to highlight critical phenomena and fracture mechanics scale effects in the masonry by identifying the critical conditions, not entrusted to an analysis of the loading process (compression or shear), rather depending primarily on the distribution and evolution of crack patterns.

Introduction.

Acoustic Emission (AE) is a non-invasive and non-destructive monitoring technique ideally suited for use in the assessment of historic and monumental structures that are subjected to high, long-term or cyclic loads, or, more in general, are exposed to seismic risk [1-6]. Having identified the fractured or damaged portion of a structure, it is possible to evaluate its stability from the evolution of damage, which may either gradually come to a halt or propagate at an increasingly fast rate [7,8]. Moreover, if the position of the defects is not known to begin with, it can be located by making use of a multiplicity of sensors and by triangulation, prior to assessing the stability of a structure based on the evolution of damage phenomena [9,10].

In order to investigate a wide series of structural problems related to masonry structures. AE technique has been used to assess the damage evolution and to analyze the residual capability of ancient brick masonry under loading, or to evaluate the reliability of reinforcing techniques employed in historical bearing structures [4].

Within this work, the masonry buildings of Alessandria and Boves barracks, located in Piedmont, Italy, have been monitored by means of the AE technique. The barrack of Alessandria, named after General Leopoldo Valfré di Bonzo, winner of the Crimean War as Commander of the Artillery, is a wide complex of brick masonry buildings dating back to XIX century, and located in the city center of Alessandria (Fig.1,2).



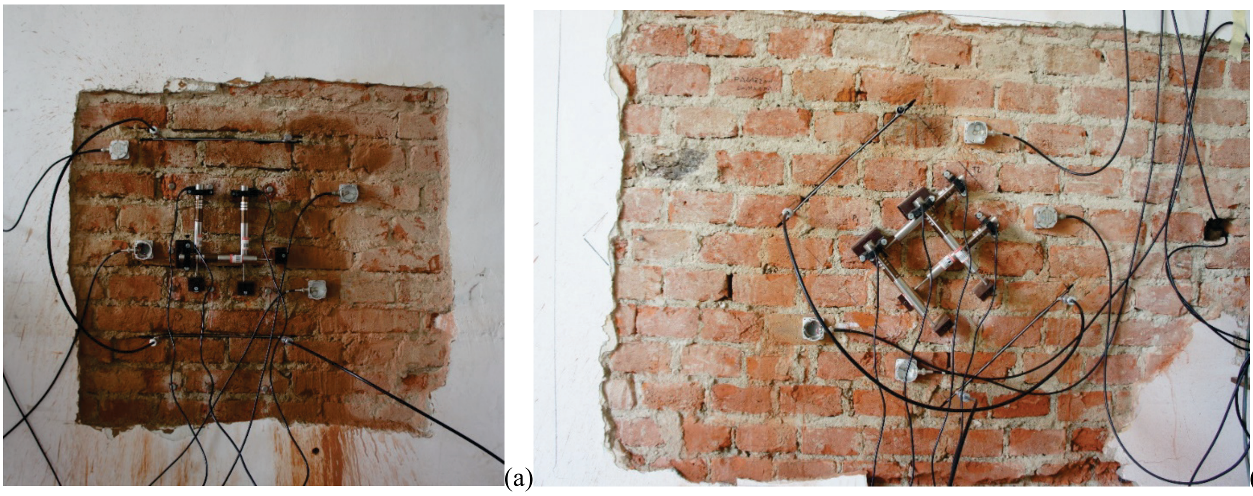
(a) (b)

Figure 1. Valfré Barrack, Alessandria: (a) Main entrance; (b) Main Building from the inner courtyard.

The barrack of Boves, near the town of Cuneo, is named after the Alpine Major-sergeant Giovanni Cerutti, missing in Russia during II World War. This brick masonry structure was built between 1938 and 1939 for the quartering of the Alpine Artillery Corps.

Flat-Jack Tests and AE.

The internal brick masonry walls of the two barracks object of the study are tested by two different double flat-jack systems, the standard double flat-jack test [11,12], and an innovative inclined flat-jack test (Fig.2). These tests, coupled with the single flat-jack test, are designed to evaluate the mechanical characteristics of the masonry [13].



(a) (b)

Figure 2. Valfré Barrack: (a) Double flat-jack test; (b) Inclined double flat-jack test.

Flat-jack testing is a versatile and powerful technique that provides significant information on the mechanical properties of historical constructions. The first applications of this technique on some historical monuments clearly showed its great potential [14,15]. The flat-jack technique is only slightly destructive and classified as a minor destructive test (MDT). The standard double flat-jack test works according to the same principle as a standard compressive test allowing to determine the Young's modulus and estimate the compressive strength of the masonry. The difference is that it is performed in situ and the load is applied by means of two flat-jacks instead of the loading platens. The inclined flat-jack test aims to evaluate the shear modulus and the tensile strength of the sample. During the tests, the stress-strain relationship of the masonry is determined by gradually increasing the pressure applied by the flat-jacks in the course of three loading-unloading cycles. Table 1 lists the values of mean Young's modulus, as determined with flat-jacks applied to the walls. In all cases, different tests in different positions of the buildings are considered.

Table 1.

Barrack	Young's Modulus [MPa]
Valfré (Alessandria)	1850
Cerutti (Boves)	1740

In all the tests, AE data are gathered continuously using a leading edge equipment described in the following. AE monitoring technique takes advantage of the elastic energy emitted after crack propagation events [3,16,17]. The micro-motion of the tip of the crack excites elastic waves which are acquired by sensors on the surface of the material. The number of recorded signals during loading is connected to the number of active sources within the material [3]. Additionally, the signals depend on their source, and specifically the intensity and the mode of fracture. Therefore, key waveform features, like the amplitude, energy and frequency carry information from the damage mode and the fracture process. In general, tensile mode of failure typically develops before shear; therefore, the characterization of cracks as to their mode provides a warning before failure. The received wave depends on the motion of the crack tip, as well as on the orientation of the crack relatively to the receivers and the distance between the cracking source and the sensor.

When a cracking event occurs, all possible wave modes (longitudinal, transverse and Rayleigh if the crack is surface breaking) are excited. A tensile cracking incident (Mode I) excites most of the energy in the form of longitudinal waves. Therefore, most of the energy arrives in the initial part of the acquired waveform since longitudinal waves are the fastest type. When shear cracking occurs (Mode II), the percentage of energy emitted in the shear wave mode is increased resulting in a delay of the main energy cycles of the waveform. This leads in a long rise time (RT), and quite low rise angle of the waveform [3]. AE duration is the time delay between the first and last threshold crossings. Amplitude, A is the maximum voltage of the waveform, and "AE energy" is the area under the rectified signal envelope. Some frequency features of interest, derived after fast Fourier transformation of the signals are the central frequency (CF) and the peak frequency (PF). Central frequency is the centroid of the spectrum while PF is the frequency with the highest magnitude [3].

Within the monitoring campaign described in the present work, the leading-edge equipment here adopted consists of four piezoelectric transducers (PZT) calibrated over a range of frequency between 50 kHz and 800 kHz. The obtained signals are transferred to a PC Oscilloscope for multi-channel data processing. Micro and macro-cracks evaluation can be performed from this elaboration and the damaging condition of the monitored specimen can be determined. In the analyses, which also could include crack classification methods [3], the effects of distortion of the ultrasonic waves on the AE parameters must be taken into account [4,17].

Moreover, the acoustic data are processed for all the tests in the form of events made up of multiple signals, each consisting of a number of counts. A signal was considered to have started once the hit from a transducer exceeded a pre-set threshold level (2 mV) and ended when the hit fails to exceed that level within a pre-settable time window. Source location by utilizing signals received at 3 or more transducers from the same event is possible but effective only in a few instances due to attenuation over the path length in masonry [4,17,18].

In the following, the results concerning the Valfrè Barrack are discussed. Signal analyses concerning the West Building are considered. The positions for AE sensors are represented in Figure 2. The sensors were attached through a stiff bi-component glue to the masonry surface, in order to minimize the signal damping.

The result of the double flat-jack test and AE monitoring are reported in Figure 3 and 4 in terms of stress applied to the masonry by means of flat-jacks (σ), strain (ε_v), and cumulative AE curve (N_{AE}). The cumulative total events from all sensors was taken as a more meaningful acoustic signature than from pattern recognition based on data from individual sensors [18]. This parameter is used for all tests in the present work.

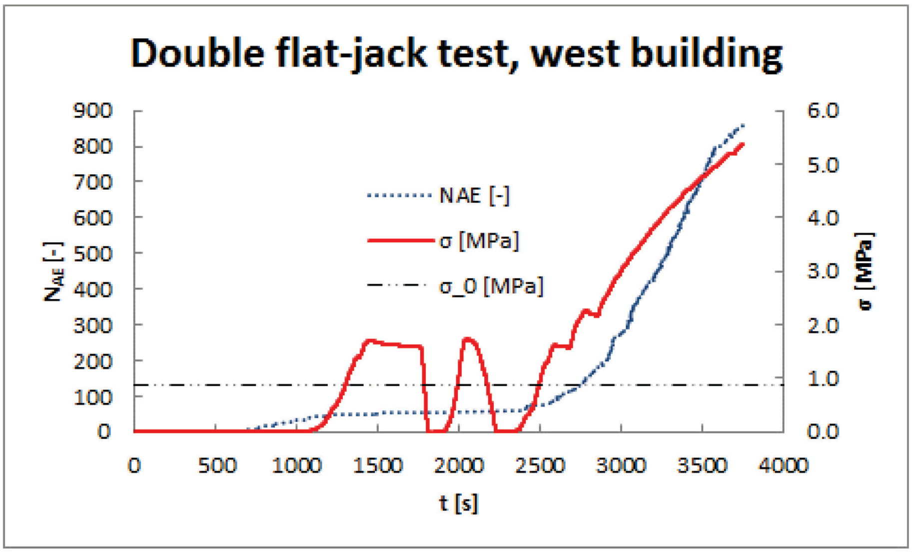
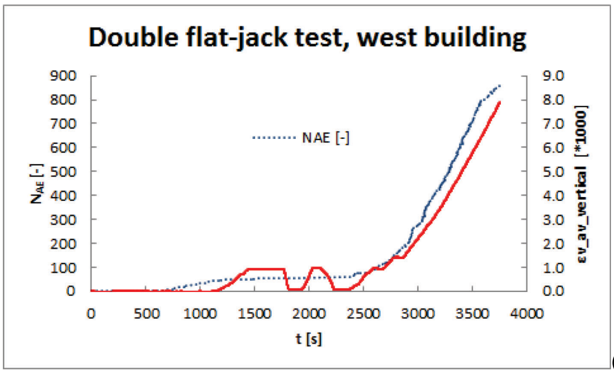
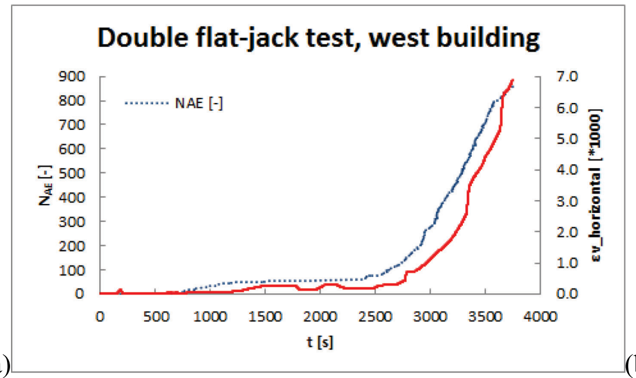


Figure 3. Double flat-jack test performed in the West Building, Valfré Barrack: Flat-jack Induced Stress vs Cumulative AE.



(a)



(b)

Figure 4. Double flat-jack test performed in the West Building, Valfré Barrack: (a) Flat-jack Induced Vertical Strain vs Cumulative AE; (b) Flat-jack Induced Horizontal Strain vs Cumulative AE.

In Figure 3, AE activity increases in correspondence to the σ_0 level −pointed out by a dotted line− that is the previously existing stress level in the masonry measured with the single flat jack test. For an AE-based damage quantification, Kaiser Effect is well known for the analysis of progressive damage in aggregative materials under cyclic compressive loads. The working principles are based on the detection of AE activity resulting from the stress induced fracture. Kaiser Effect is defined as the absence of AE activity until the loading exceeds the previously applied maximum load [19]. In some way, Kaiser Effect indicates the ‘‘stress memory” in a material, evidencing an occurred micro-structural damage before the actual load. The AE behaviour shown in Figure 3 can be referred to the Kaiser Effect, and reveals the previously existing stress level in the monitored masonry wall.

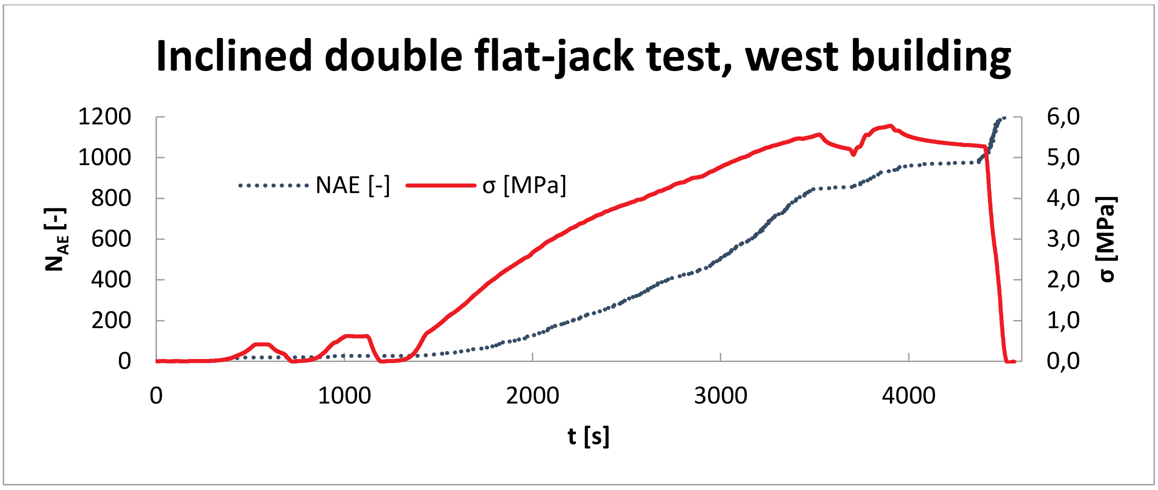


Figure 5. Inclined double flat-jack test performed in the West Building, Valfré Barrack: Flat-jack Induced Stress vs Cumulative AE.

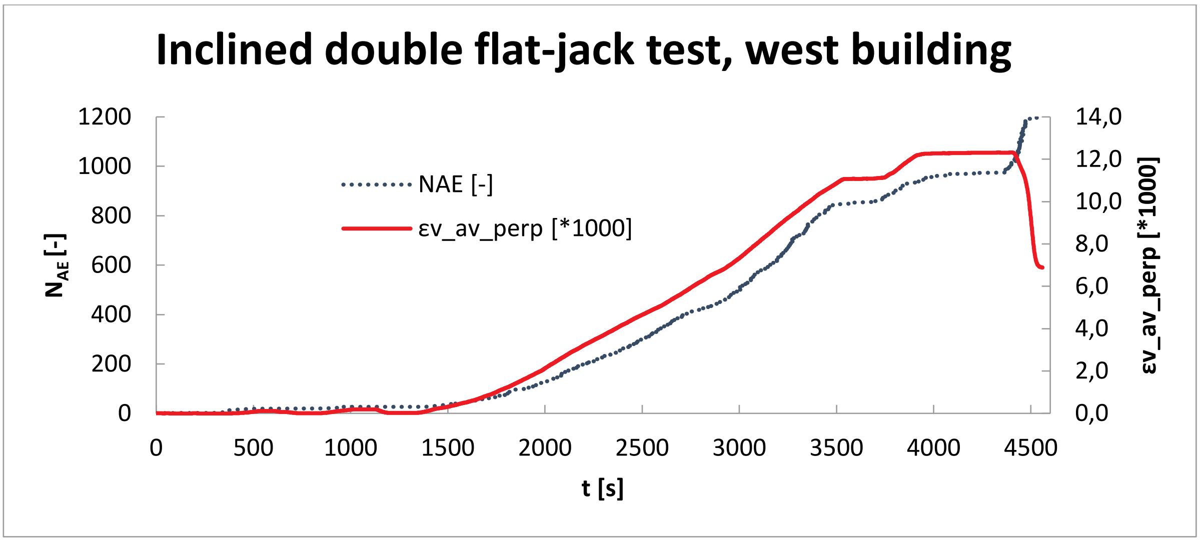


Figure 6. Inclined double flat-jack test performed in the West Building, Valfré Barrack: Flat-jack Induced Perpendicular Strain vs Cumulative AE.

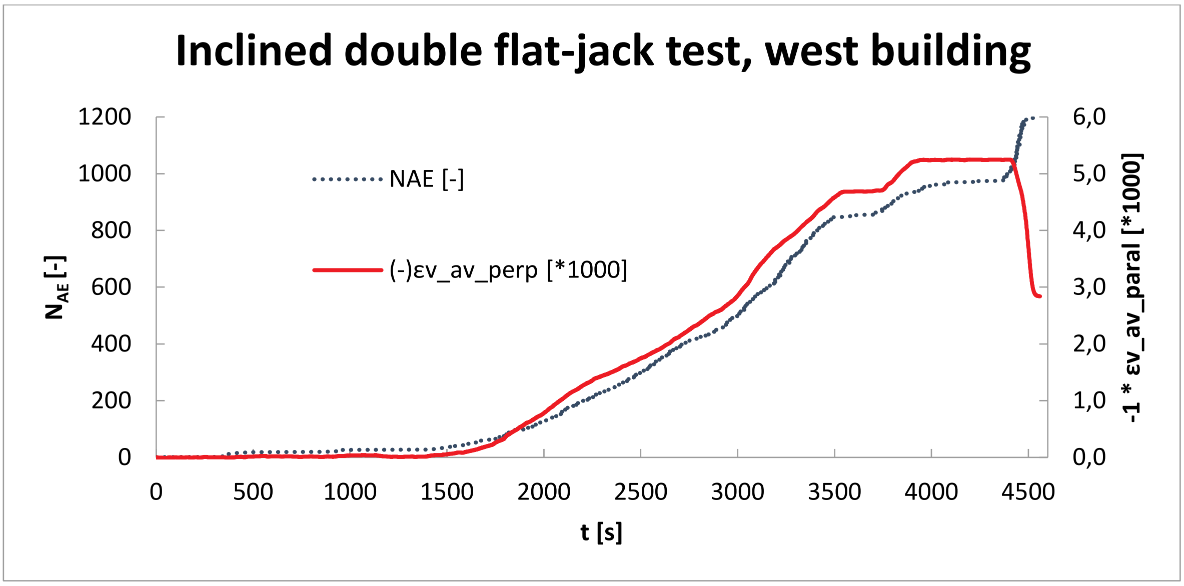


Figure 7. Inclined double flat-jack test performed in the West Building, Valfré Barrack: Flat-jack Induced Parallel Strain vs Cumulative AE.

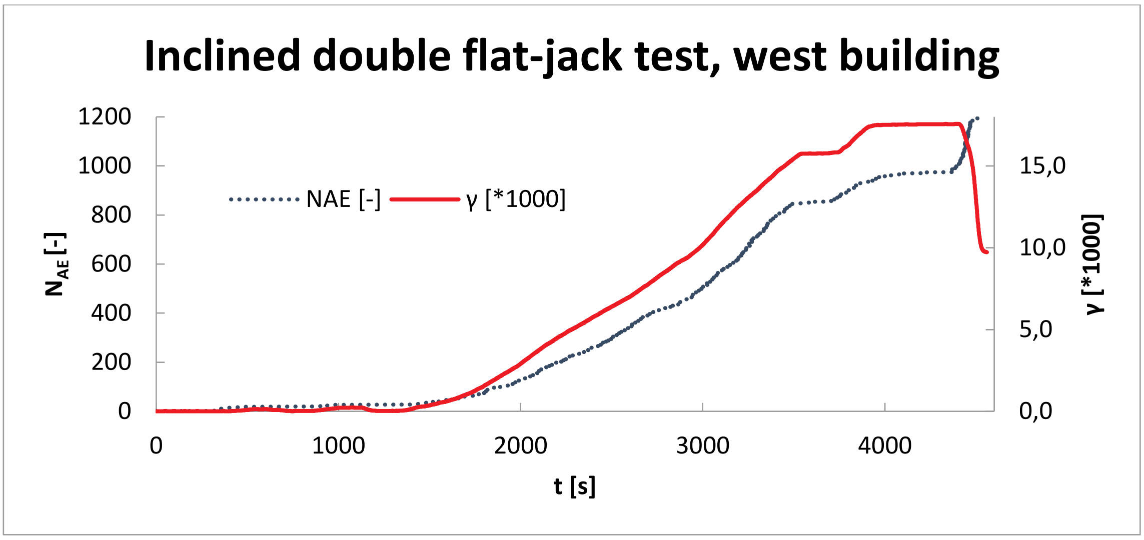


Figure 8. Inclined double flat-jack test performed in the West Building, Valfré Barrack: Flat-jack Induced Shear Strain vs Cumulative AE.

Within the results obtained by the inclined double flat-jack test, and concerning the West Building (Figs. 5-8), the general pattern is that the emission grew as load increased, the main activity stemming from the load point considered as the previously existing stress level in the masonry. Also in this case, the cumulative total events from all sensors was taken as a meaningful acoustic signature: it is quite clear from Figs. 6-8 that the total events parameter has some definite correlation with deformation, there being a marked similarity between the two [18].

This remarkable similarity between strain and AE behavior recalls the strict dependence of these latter to the damaging process in brittle materials [16,20]: this process occurs with an increase in strain coupled with global or local drops in the load carrying capacity, and the resulting emitted energy appears with an increase in the AE cumulative curve. Also for a globally smooth loading branch, small snap-back instabilities hided in the loading process [20] cause a smooth AE cumulated curve similar to the deformation trend (Figs. 6,7).

Moreover, it is worth noting that at the end of the strain process, during the unloading phase (Fig.5), a burst in AE appears, suggesting a final damage increase in the masonry [21]. Even if slight part of the emissions recorded here could be produced by slippage between the flat-jack and the surface of the cut in the masonry, the ratio of re-emission load to previous peak load, termed Felicity Ratio [7], for magnitudes significantly less than unity, is indicative of permanent damage having occurred. The micro-cracking process, induced here by flat-jack testing, is only slight destructive but lasting in masonry structures [22].

Finally, an example of AE signal analysis is provided in Figure 9: a typical AE signal taken from the monitoring of the Valfrè West Building is shown, characterizing a dominant Mode I fracturing process (RT= 25 μs; RA= 0.006 s/V).

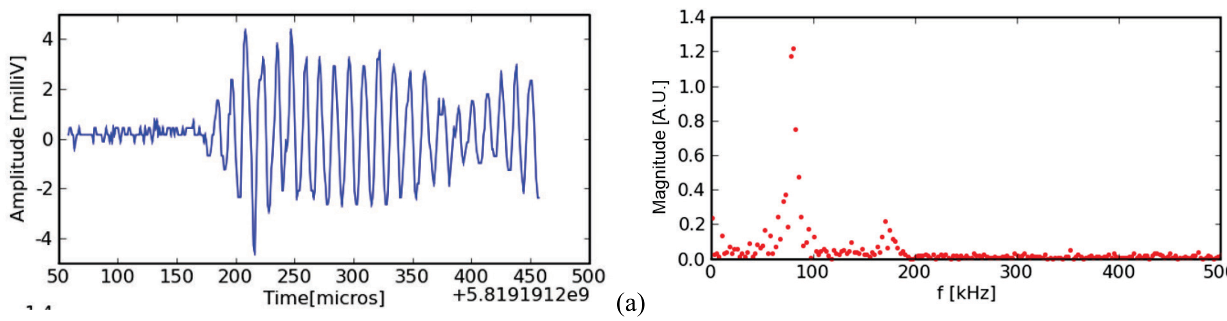


Figure 9. (a) Typical AE signal representative of Valfrè West Building Monitoring (Mode I): RT= 25 μs; RA= 0.006 s/V; (b) Signal FFT.

Concluding remarks. In the present study, Acoustic Emission monitoring technique is coupled with an innovative double flat-jack testing, in order to characterize the brick masonry of two important military buildings located in Northern Italy: the barracks of Alessandria and Boves. Among the principal results presented within this work, it is worth noting that the added value of employing AE technique leads to the following findings: the similarity between the strain process and the damage increase monitored by AE, which points out the strict dependence of the emitted energy to local mechanical instabilities hided in the loading process; the increase of AE activity in correspondence to the previously existing stress level in the masonry (Kaiser Effect); the burst of AE during the unloading phase, which is indicative of permanent damage having occurred in the masonry (Felicity Effect).

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