ACOUSTIC EMISSIONS IN COMPRESSION OF BUILDING MATERIALS: Q-STATISTICS ENABLES THE ANTICIPATION OF THE BREAKDOWN POINT

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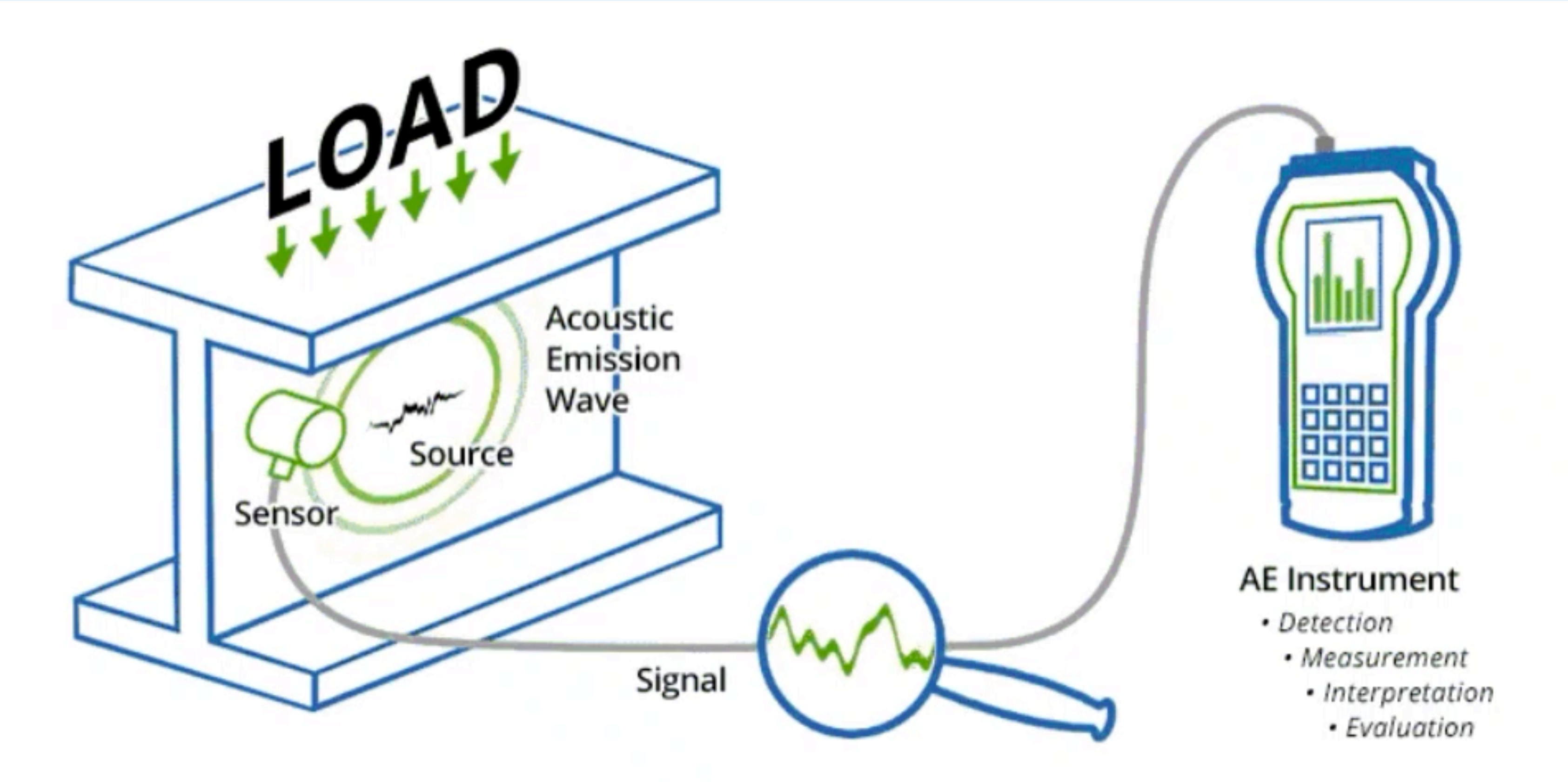
OVERVIEW

Acoustic Emission Analysis and Nonextensive Statistical Mechanics

The study of Acoustic Emission (AE) due to applied loads is a powerful technique for deeply understanding the dynamics of the fracture processes and the behavior of damage propagation in different kind of materials approaching failure.



OVERVIEW

Acoustic Emission Analysis and Nonextensive Statistical Mechanics

The investigation in controlled laboratory tests allows obtaining valuable information which could be very important in a health monitoring strategy of large structures (buildings, bridges, highways, etc…).

Oggi a € 1,50 Salute

Martedì 26 novembre 2019

la Repubblica

Fondatore Eugenio Scalfari — Direttore Carlo Verdelli

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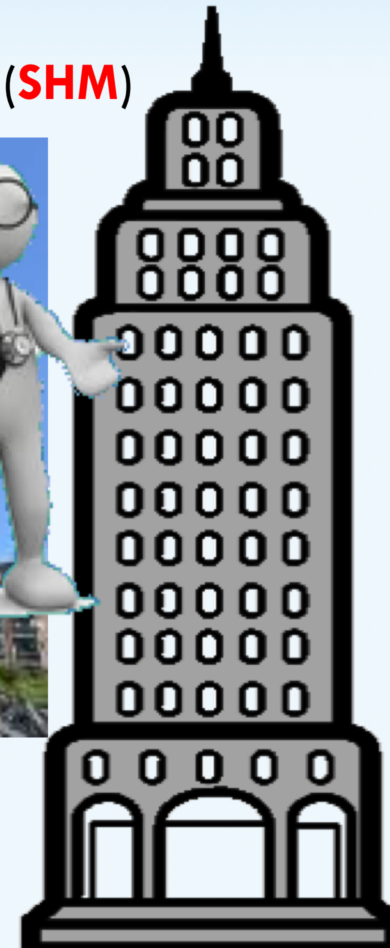
DISASTRO ITALIA

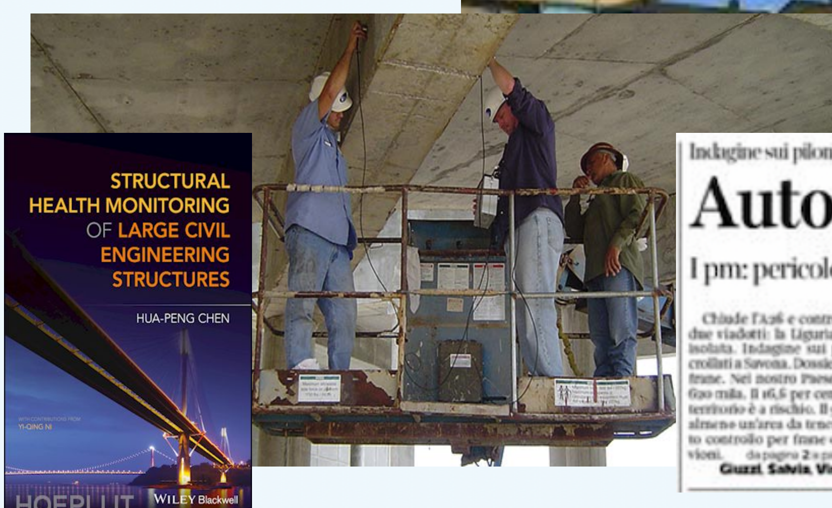
Genova ancora più sola

Dopo l'ultimo crollo, chiusi altri due ponti alle porte della città

"Pericolo rovina", la Procura ordina blocchi sulla A26. Interrotta nei due sensi la Torino-Savona. Allarme porto: "Così non si resiste"
Il dossier dei ritardi sul dissesto: un miliardo bloccato, 354 cantieri fermi. Le carenze dei concessionari nella manutenzione

Structural health monitoring (SHM)





Indagine sui piloni crollati a Savona. Dossier sulle frane: sono 620 mila, a rischio il 16,6% del Paese

Autostrade, Liguria isolata

I pm: pericolosi due viadotti. Dopo il Morandi e l'A6 ora chiude l'A26

Chiude l'A26 e controlli su due viadotti: la Liguria resta isolata. Indagine sui piloni crollati a Savona. Dossier sulle frane. Nel nostro Paese sono 620 mila. Il 16,6 per cento del territorio è a rischio. Il 91% ha almeno un'area da tenere sotto controllo per frane o alluvioni.

Giannelli

CRISI DELL'ILVA: TRATTATIVA CON MITTAL

LE CONSEGUENZE PER IL PORTO DI GENOVA

Una regione bloccata «Tornati agli anni 30»

di Marco Imarisio

OVERVIEW

Acoustic Emission Analysis and Nonextensive Statistical Mechanics

In the last decades several studies have shown the potential of time series statistical analysis in several fields, such as earthquakes dynamics, crumpled plastic sheets and financial time series.

epl A LETTERS JOURNAL EXPLORING THE FRONTIERS OF PHYSICS

Long-term memory in earthquakes and the distribution of interoccurrence times

S. Lennartz[1], V. N. Livina[2], A. Bunde[1] and S. Havlin[3]

Published 22 February 2008 • Europhysics Letters Association

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Triggering Processes in Rock Fracture

Jörn Davidsen, Grzegorz Kwiatek, Elli-Maria Charalampidou, Thomas Goebel, Sergei Stanchits, Marc Rück, and Georg Dresen

Phys. Rev. Lett. **119**, 068501 – Published 8 August 2017

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Earthquake-like patterns of acoustic emission in crumpled plastic sheets

R. S. Mendes[1,2], L. C. Malacarne[1], R. P. B. Santos[1], H. V. Ribeiro[1] and S. Picoli jr.[1]

Published 22 October 2010 • Europhysics Letters Association

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Memory effects in the statistics of interoccurrence times between large returns in financial records

Mikhail I. Bogachev and Armin Bunde

Phys. Rev. E **78**, 036114 – Published 22 September 2008

OVERVIEW

Acoustic Emission Analysis and Nonextensive Statistical Mechanics

More recently the use of electrical and acoustic signals emission as fracture precursors when geomaterials are subjected to mechanical stress can be found in several papers.

Engineering Failure Analysis 35 (2013) 454–461

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Electrical and Acoustic Emissions in cement mortar beams subjected to mechanical loading up to fracture

C. Stergiopoulos [a], I. Stavrakas [a,*], G. Hloupis [a], D. Triantis [a], F. Vallianatos [b]

Engineering Structures 32 (2010) 1704–1714

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Acoustic emission monitoring of bridges: Review and case studies

Archana Nair, C.S. Cai *

...iana State University, Baton Rouge, LA 70803, United States

Latin American Journal of Solids and Structures

Acoustic Emission Analysis of Cement Mortar Specimens During Three Point Bending Tests

Acoustic emissions and pressure stimulated currents experimental techniques used to verify Kaiser effect during compression tests of Dionysos marble

Ilias Stavrakas

Laboratory of Electronic Devices and Materials, Technological Educational Institute of Athens, 12210, Athens, Greece

ilias@ee.teiath.gr, http://research.ee.teiath.gr/

OVERVIEW

Acoustic Emission Analysis and Nonextensive Statistical Mechanics

In these contexts, Tsallis' non-extensive generalized statistical mechanics has also proved to be particularly effective in describing universal features of complex systems emerging at criticality or at the edge of chaos.

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Analysis of self-organized criticality in the Olami-Feder-Christensen model and in real earthquakes

F. Caruso, A. Pluchino, V. Latora, S
Phys. Rev. E **75**, 055101(R) – Publi

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Editors' Suggestion

Experimental Validation of a Nonextensive Scaling Law in Confined Granular Media

Gaël Combe, Vincent Richefeu, Marta Stasiak, and Allbens P. F. Atman
Phys. Rev. Lett. **115**, 238301 – Published 1 December 2015

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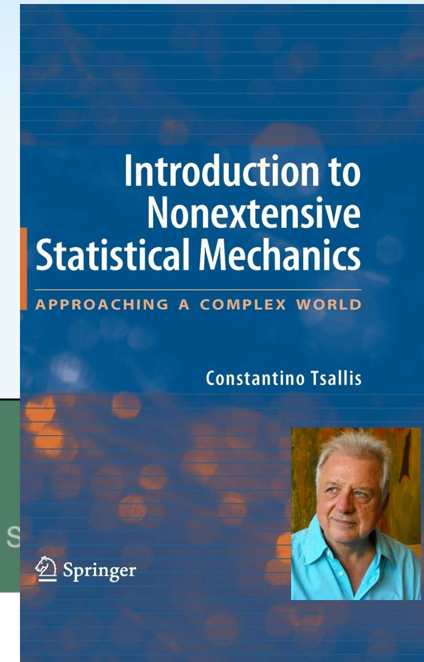
Highlights Recent Acce

Noise, synchrony, and correlations at the edge of chaos

Alessandro Pluchino, Andrea Rapisarda, and Constantino Tsallis
Phys. Rev. E **87**, 022910 – Published 19 February 2013



C.T., J. Stat. Phys. **52**, 479 (1988)

OVERVIEW

Acoustic Emission Analysis and Nonextensive Statistical Mechanics

In these contexts, Tsallis' non-extensive generalized statistical mechanics has also proved to be particularly effective in describing universal features of complex systems emerging at criticality or at the edge of chaos.

TYPICAL SIMPLE SYSTEMS:

$$W(N) \propto \mu^N \quad (\mu > 1)$$

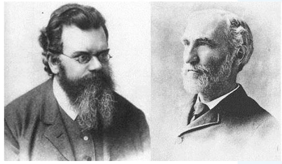
Short-range space-time correlations

Markovian processes (short memory), Additive noise

Strong chaos (positive maximal Lyapunov exponent), **Ergodic**, Riemannian geometry

Short-range many-body interactions, weakly quantum-entangled subsystems

Linear and homogeneous Fokker-Planck equations, Gausssians



→ **Boltzmann-Gibbs entropy (additive)**

→ **Exponential dependences (Boltzmann-Gibbs weight, ...)**

TYPICAL COMPLEX SYSTEMS:

$$\text{e.g.,} \quad W(N) \propto N^\rho \quad (\rho > 0)$$

Long-range space-time correlations

Non-Markovian processes (long memory), Additive and multiplicative noises

Weak chaos (zero maximal Lyapunov exponent), **Nonergodic**, Multifractal geometry

Long-range many-body interactions, strongly quantum-entangled sybsystems

Nonlinear and/or inhomogeneous Fokker-Planck equations, *q*-Gaussian

→ **Entropy S_q (nonadditive)**

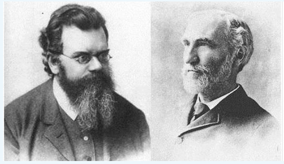
→ ***q*-exponential dependences (asymptotic power-laws)**

OVERVIEW

Acoustic Emission Analysis and Nonextensive Statistical Mechanics

In these contexts, Tsallis' non-extensive generalized statistical mechanics has also proved to be particularly effective in describing universal features of complex systems emerging at criticality or at the edge of chaos.

	equal probabilities	*generic probabilities*
BG entropy $(q=1)$	$k \ln W$	$k \sum_{i=1}^{W} p_i \ln \frac{1}{p_i}$
entropy S_q $(q \in R)$	$k \ln_q W$	$k \sum_{i=1}^{W} p_i \ln_q \frac{1}{p_i}$



C.T., J. Stat. Phys. **52**, 479 (1988)

DEFINITIONS : *q − logarithm* : $\ln_q x \equiv \frac{x^{1-q}-1}{1-q} \quad (x>0;\ \ln_1 x = \ln x)$

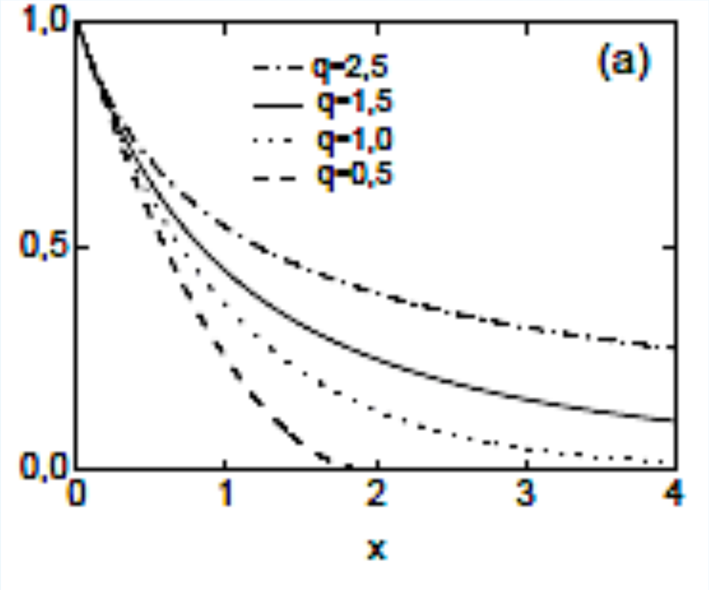
q − exponential : $e_q^x \equiv [1+(1-q)\,x]^{\frac{1}{1-q}} \quad (e_1^x = e^x)$

OVERVIEW

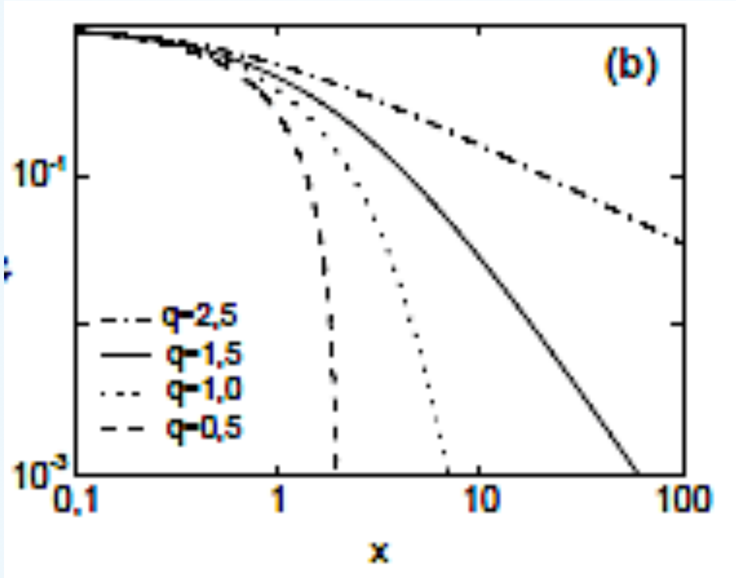
Acoustic Emission Analysis and Nonextensive Statistical Mechanics

In these contexts, Tsallis' non-extensive generalized statistical mechanics has also proved to be particularly effective in describing universal features of complex systems emerging at criticality or at the edge of chaos.

Linear scale



Log-Log scale



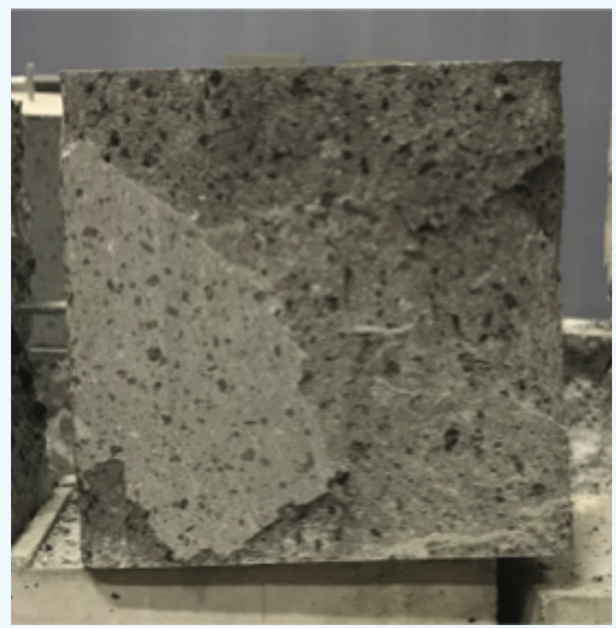
$q-exponential:$ $\quad e_q^x \equiv [1+(1-q)\,x]^{\frac{1}{1-q}} \quad (e_1^x = e^x)$

EXPERIMENTAL SETUP

In this study we perform a statistical investigation of AEs occurring in relatively small cubic specimens of 150 mm side, made of concrete and basalt, and subjected to compressive cyclic loadings.

CONCRETE is an artificial conglomerate consisting of a mixture of binder (cement), water and fine and coarse aggregates (sand and gravel) according to appropriate ratios. It is characterized by having an excellent compression behavior, resistance to water and atmospheric agents, while it has low tensile and flexural strength.

BASALT is an effusive rock of volcanic origin, resulting from the escape of magma. The rapid reduction in pressure and the cooling caused by contact with the atmosphere gives this rock a very compact structure. Basalt has excellent technical characteristics, high degree of compactness with excellent resistance to mechanical stresses and impacts, low gelling.



EXPERIMENTAL SETUP

The COMPRESSION TESTS on the cubic specimens were performed in a Laboratory of the Department of Civil Engineering and Architecture of the University of Catania. Acoustic emissions during the tests were measured through a "Piezotron Acoustic Emission Sensor", protected against external noise and capable to measure emissions of surface and longitudinal waves over a broad high frequency range, 50-400 kHz. The sensor was mounted with a stud onto the surface of the specimen and a thin layer of silicone grease was put between the coupling surfaces.

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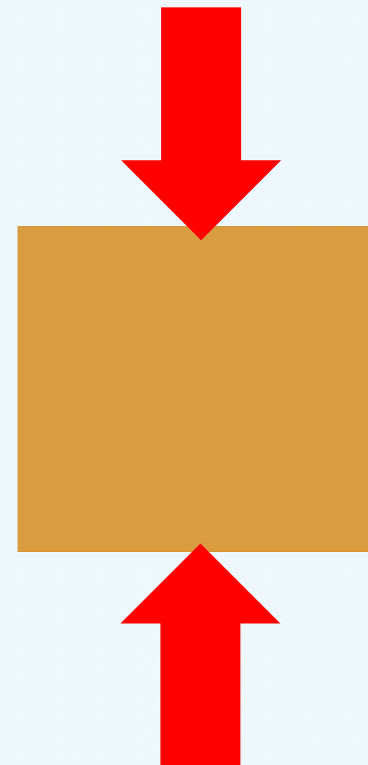
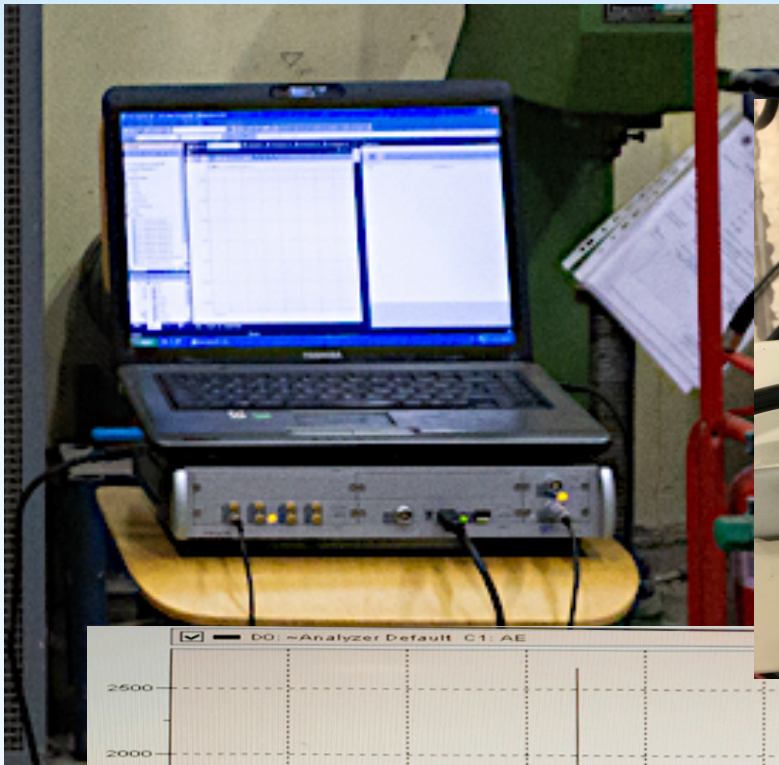
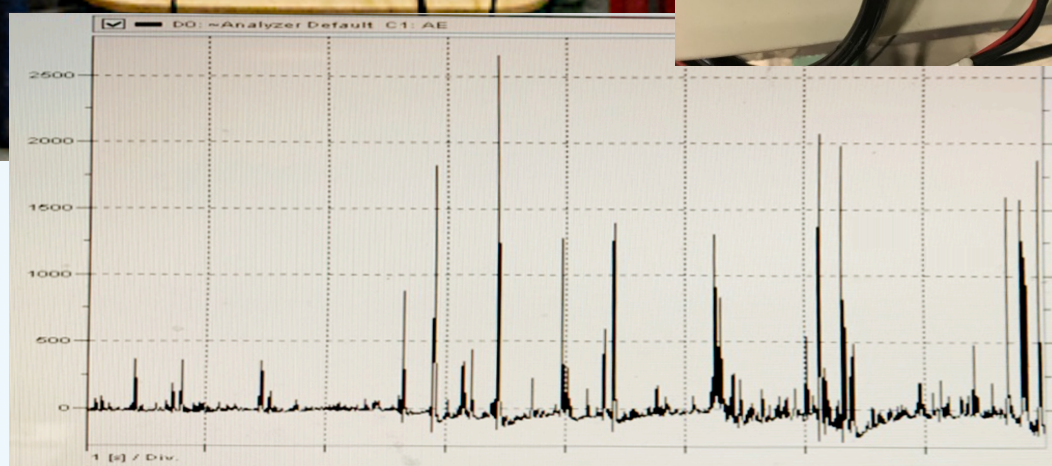


EXPERIMENTAL SETUP

The analogic output RMS signal (linear voltage), obtained with 1.2 ms integration time constant, was recorded by a data acquisition front end and post processed later.

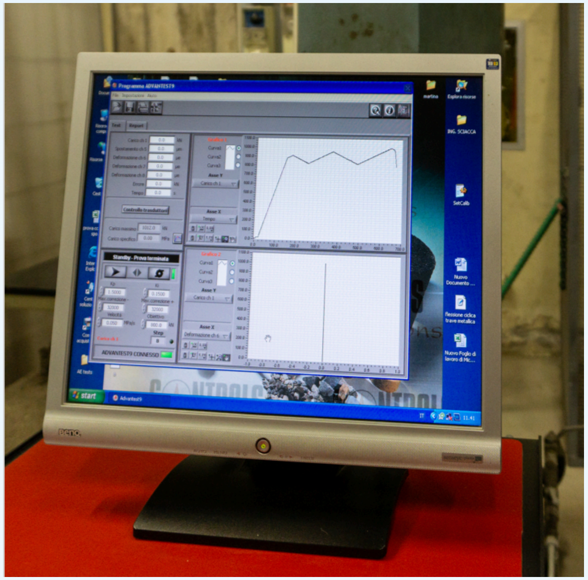


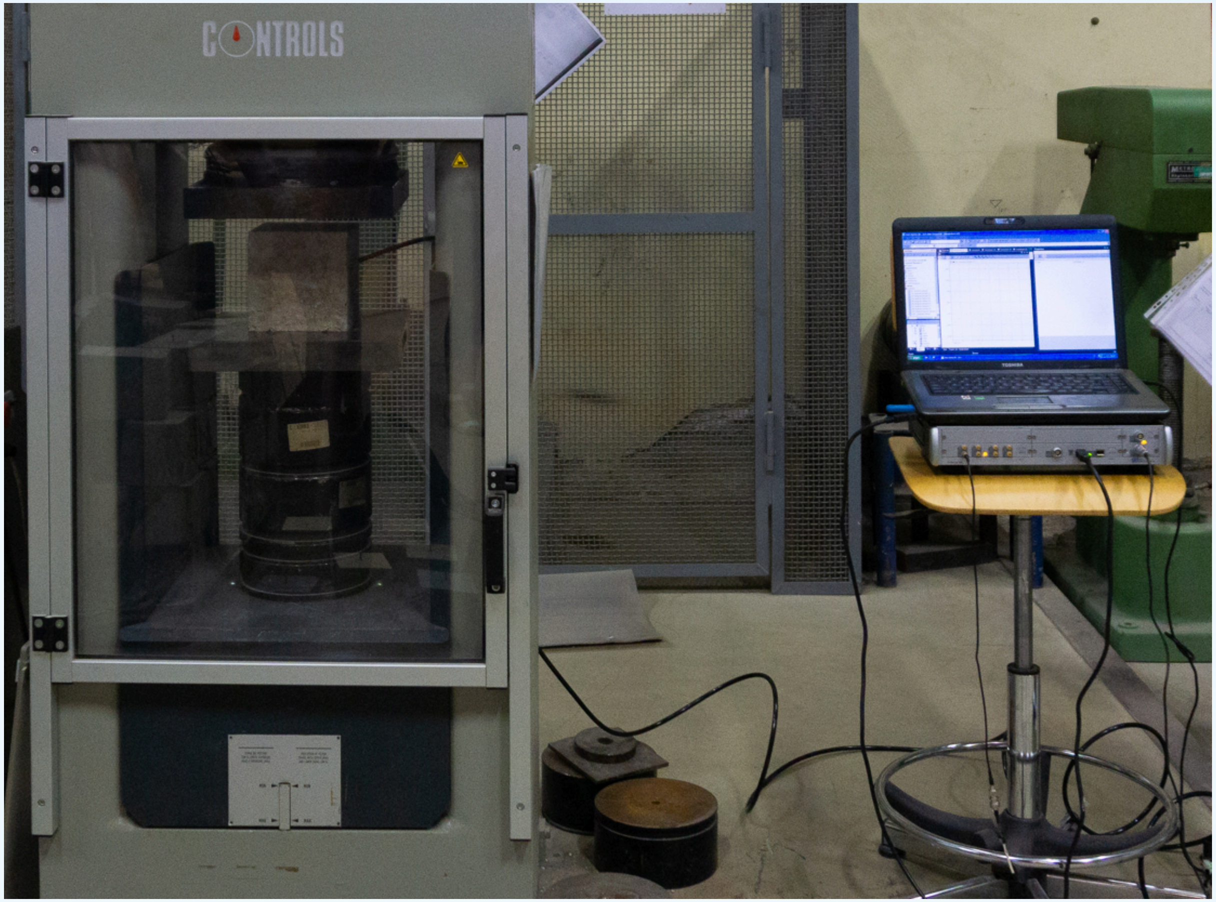
ACOUSTIC EMISSIONS



EXPERIMENTAL SETUP

The cyclic compression tests, with load control, have been performed on the cubic specimens by using a 5000 kN hydraulic press connected to a data acquisition unit. The software allows to set all the necessary test parameters, such as the values of the load sequence, its speed of application and the peak sensitivity.

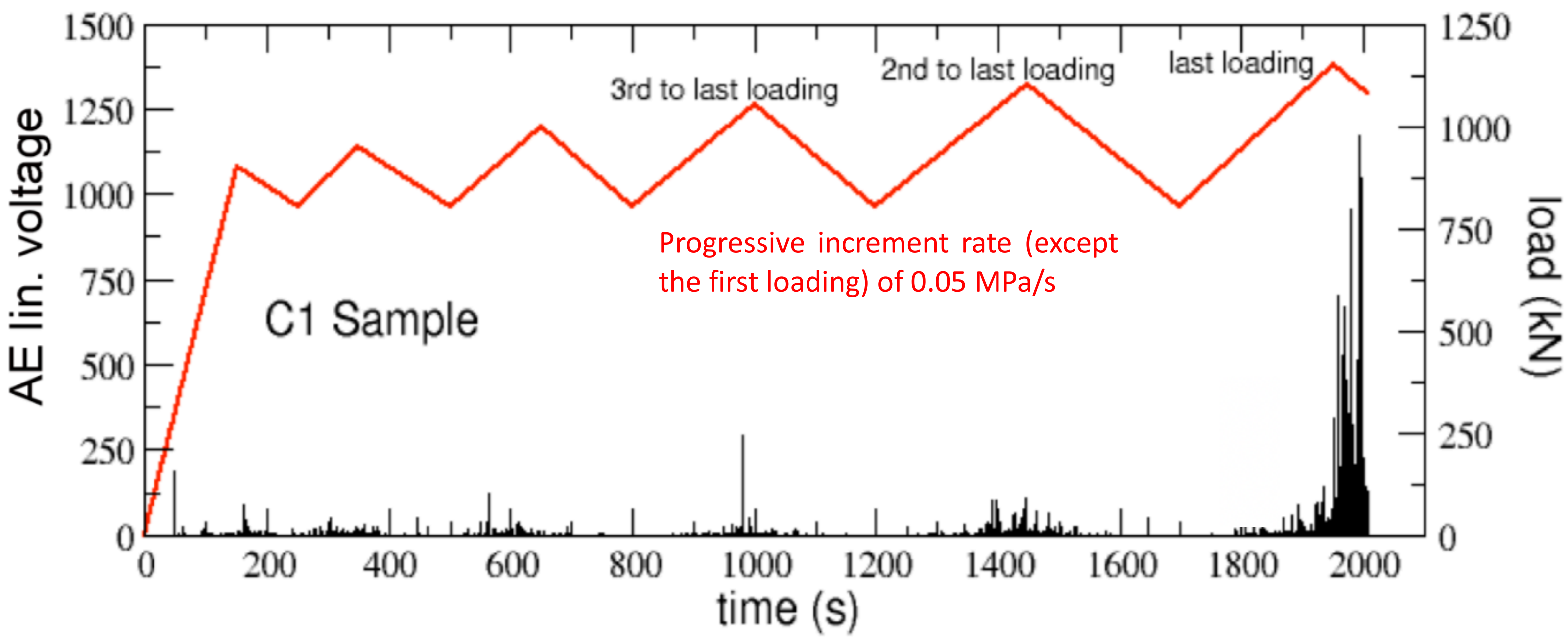




COMPRESSION TESTS

CONCRETE SPECIMENS: the acoustic emissions started from high values of the applied load and were concentrated at the load peaks. The failure for the considered sample does occur after 2007 seconds at a load value of 1080 kN.

Material	Load step (kN)	Average Failure load
Concrete	0 - > 900 -> 800 -> 950 -> 800 -> 1000 -> 800 -> 1050 -> 800 -> 1100 -> 800 -> 1150 -> 800 -> 1200	1154



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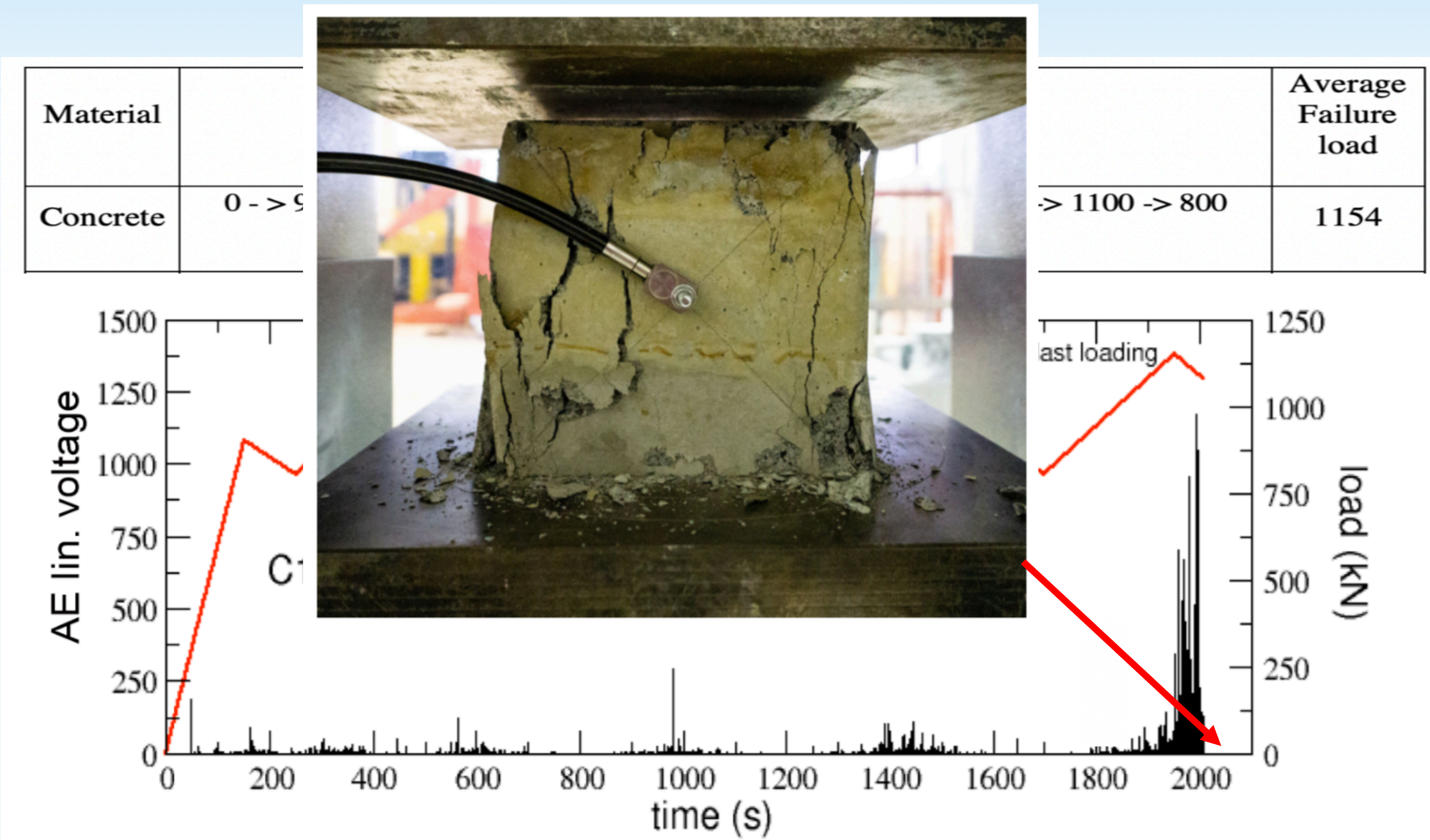
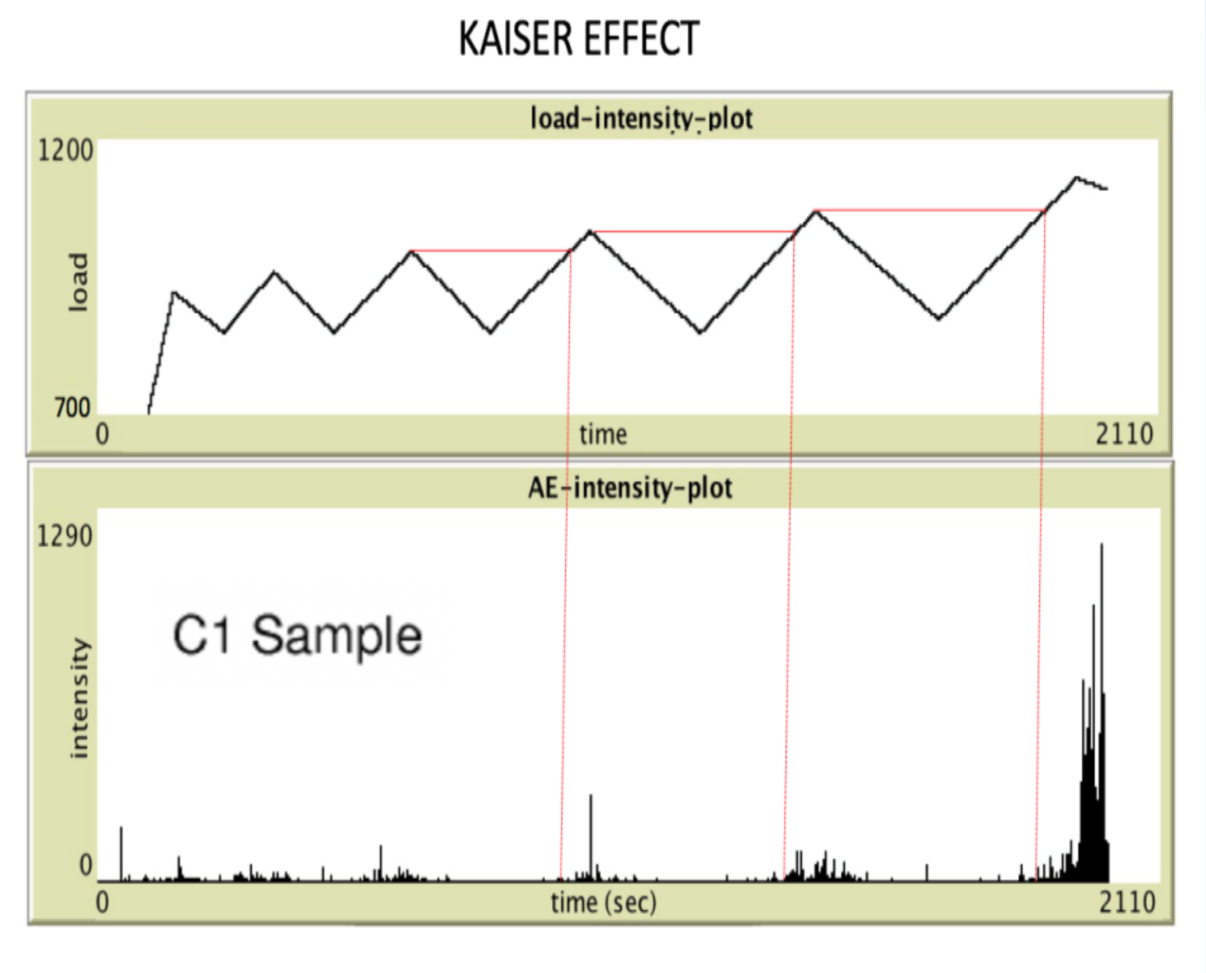


COMPRESSION TESTS

CONCRETE SPECIMENS: the acoustic emissions started from high values of the applied load and were concentrated at the load peaks. The failure for the considered sample does occur after 2007 seconds at a load value of 1080 kN.

Observing the graph, it is evident that, during each load cycle, very few emissions are recorded until the load value corresponding to the previous peak is exceeded.

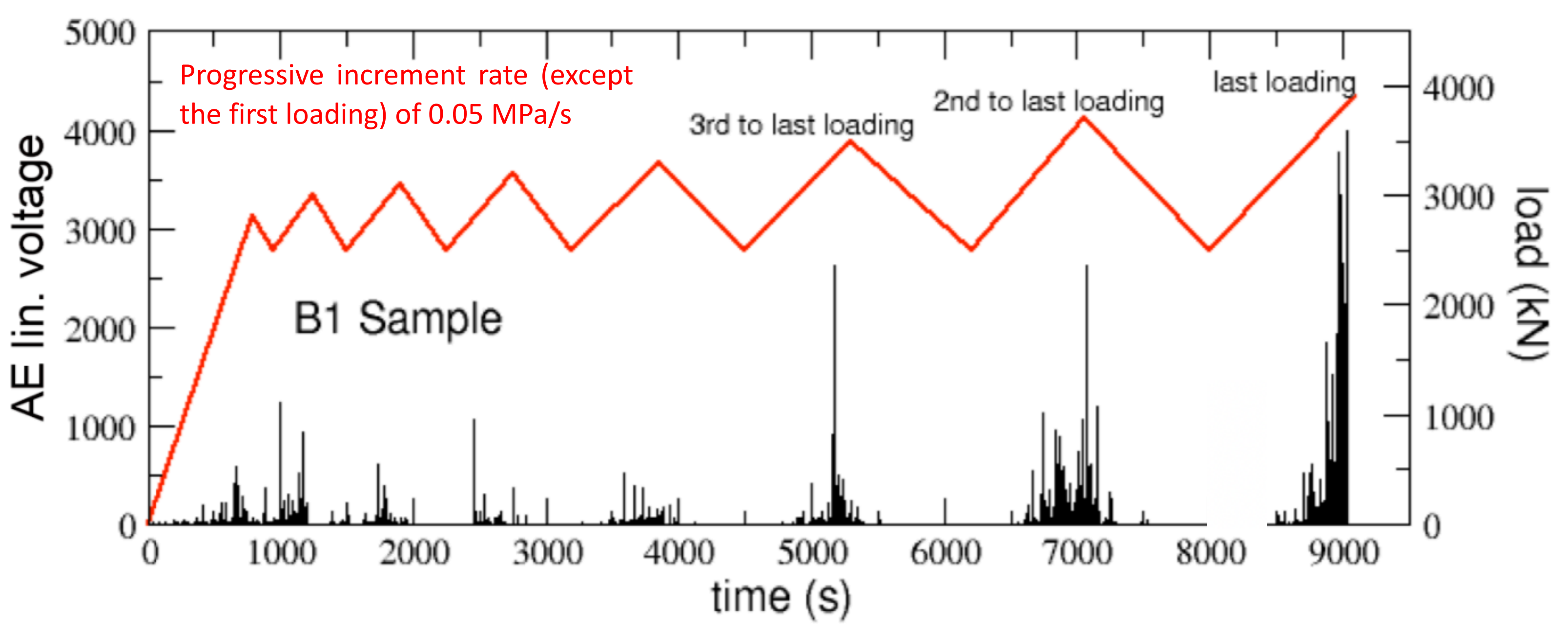
This is a confirmation of the well known Kaiser effect, following from the fact that the microcracks opened in the material during the loading phases do not propagate until a load intensity greater than the one previously experienced is reached.



COMPRESSION TESTS

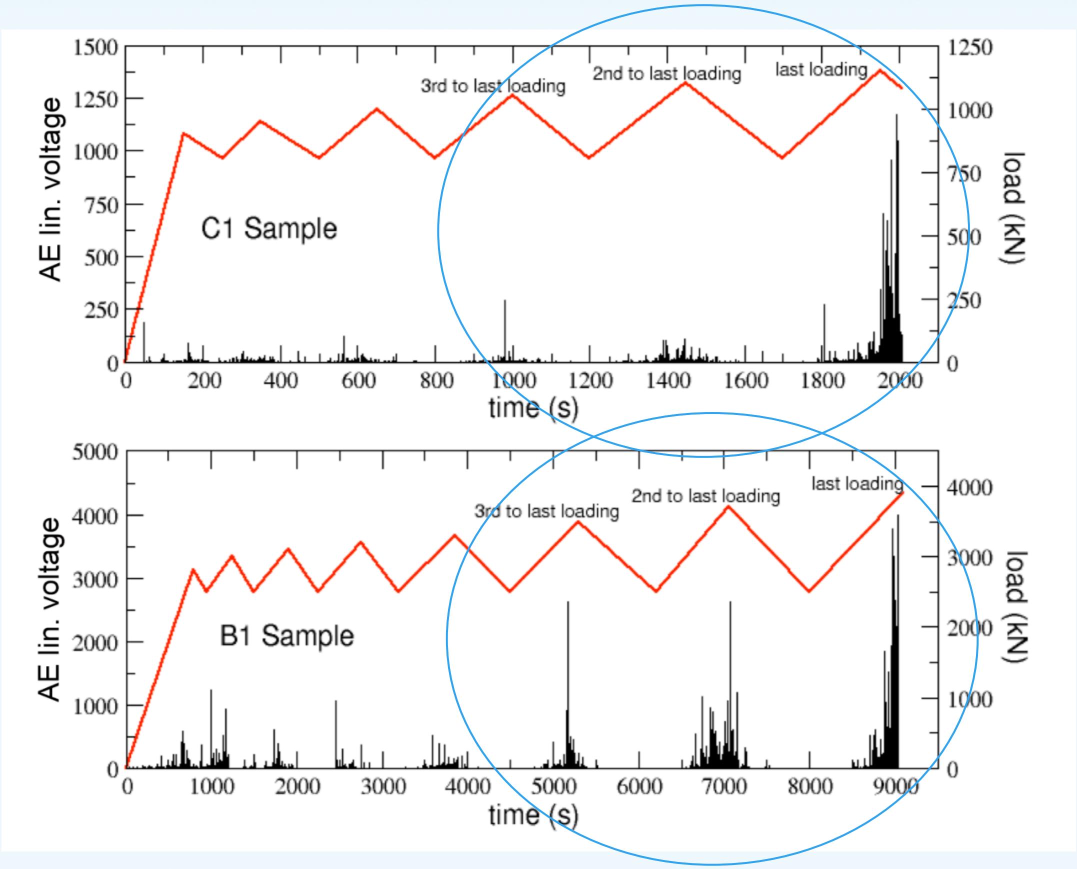
BASALT SPECIMENS: high intensity emissions started immediately after the application of the first loading and lasted throughout the tests. The failure for the considered sample do occur after 9101 seconds at a load value of 3902 kN.

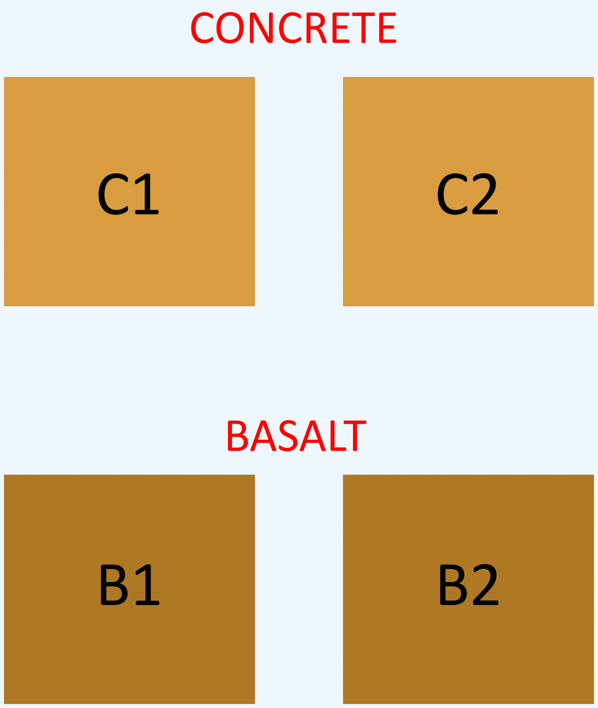
Material	Load step (kN)	Average Failure load
Basalt	0 -> 2800 -> 2500 -> 3000 -> 2500 -> 3100 -> 2500 -> 3200 -> 2500 -> 3300 -> 2500 -> 3500 -> 2500 -> 3700 -> 2500 -> 3900 -> 2500 -> 4000	3829



INTER-EVENT TIME ANALYSIS

Let us investigate, now, the inter-event time series of the AE recordings during the compression tests on some of the considered specimens. In particular, we perform our analysis on two concrete specimens, namely C1 and C2, and on two basalt specimens, B1 and B2 and we consider only the last three loadings, being the latter those with the best statistics.





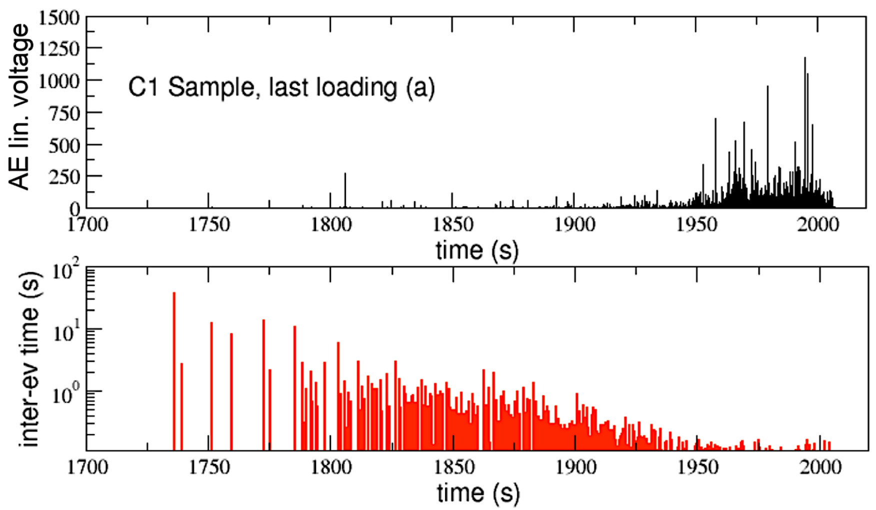
INTER-EVENT TIME ANALYSIS

The inter-event time $\delta\tau(t)$ is defined as the time interval between two consecutive recordings AE(n) and AE(n- 1). In other words:

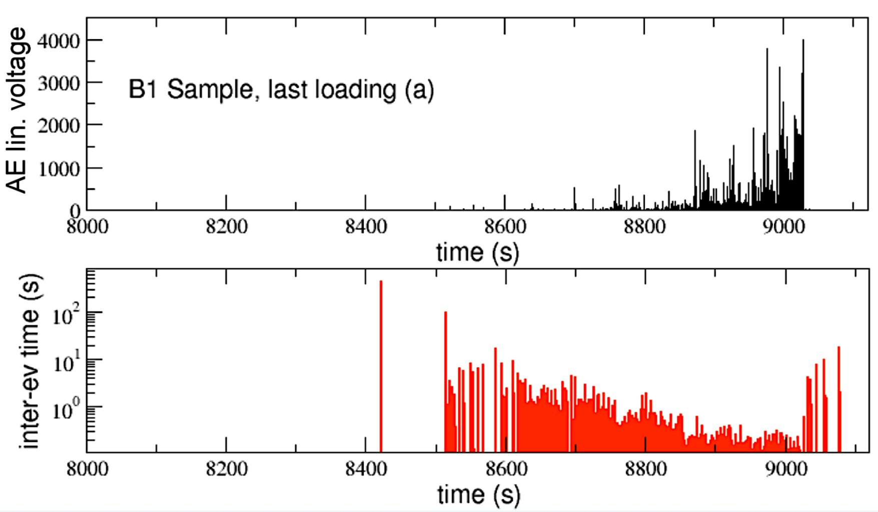
$$\delta\tau(t) = t_{AE(n)} - t_{AE(n-1)}$$

where $t_{AE(n)}$ is the time at which the n-th AE event does occur and $t_{AE(n-1)}$ the time of the previous event.

CONCRETE



BASALT



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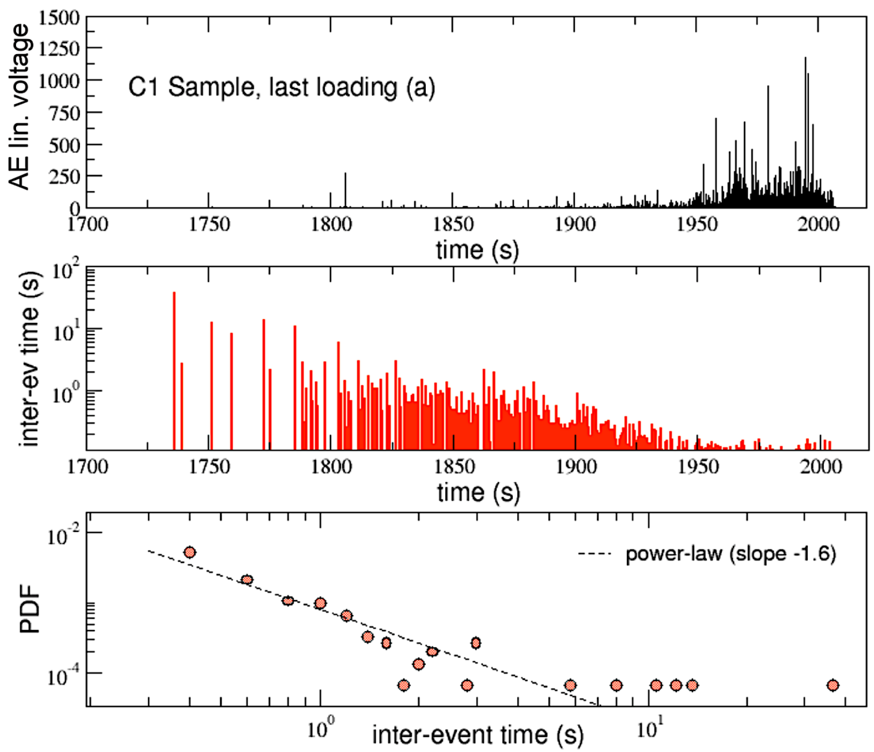
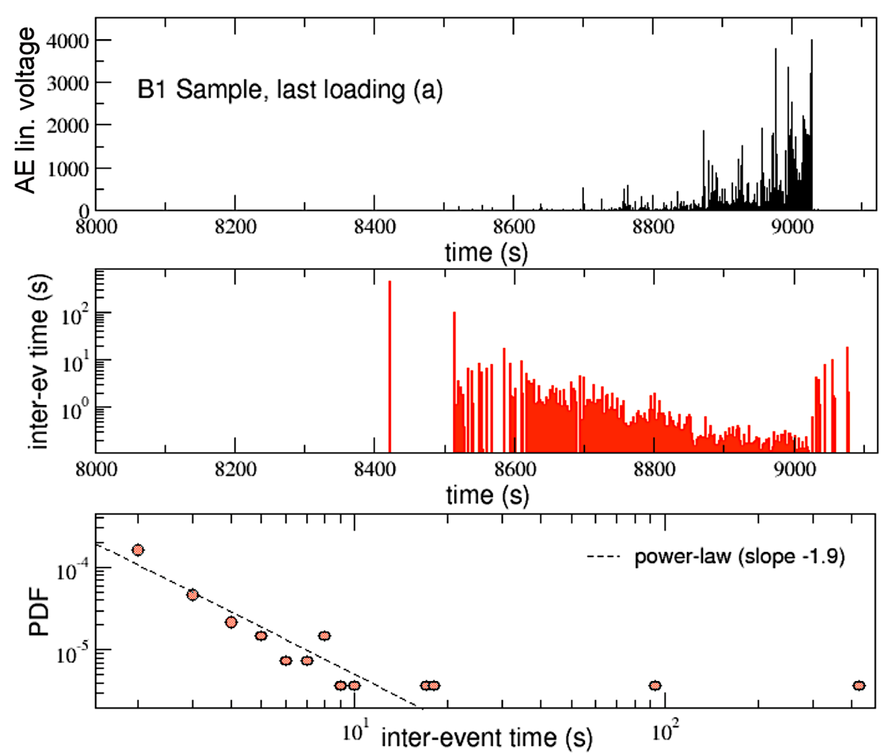


BASALT



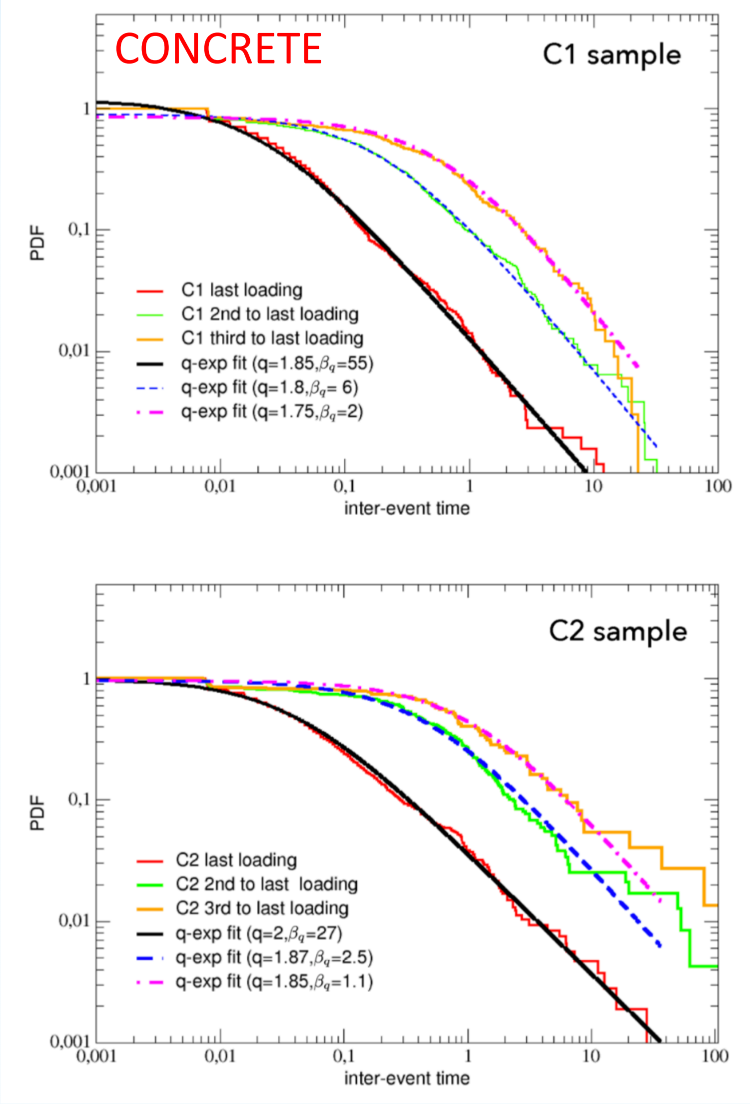
INTER-EVENT TIME ANALYSIS

The complementary cumulative distribution P (> δτ) of the inter-event time series reports, for each value of δτ in the interval [0,500], the fraction of inter-event times greater than that value.

This behavior can be very well reproduced by means of a decreasing q-exponential function $e_q(\delta\tau)$:

$$e_q(\delta\tau) = [1 - (1-q)\beta_q \ \delta\tau]^{1/(1-q)}$$

where the entropic index q is considered as a measure of the strong correlations present in the system (q = 1 means no correlations) while the relaxation parameter β_q is a sort of inverse temperature, therefore its reciprocal $1/\beta_q$ indicates the level of noise in the analyzed process.



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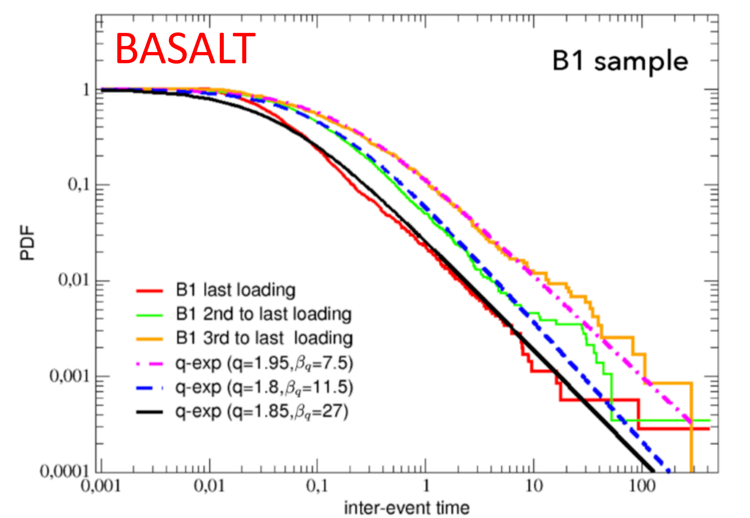

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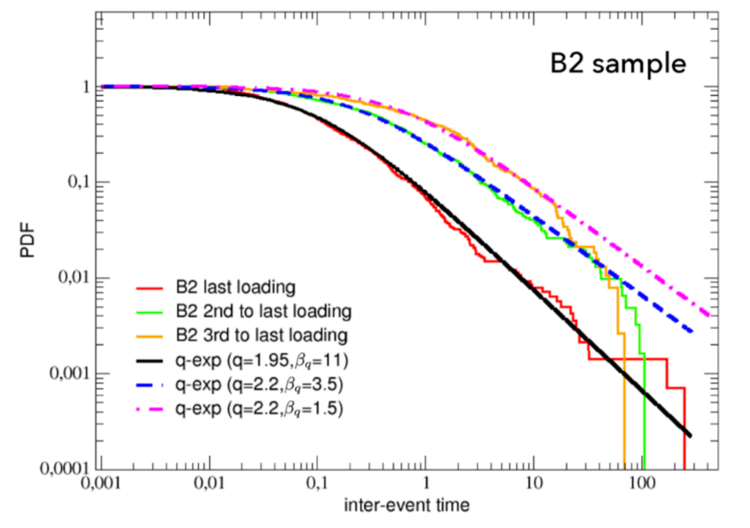
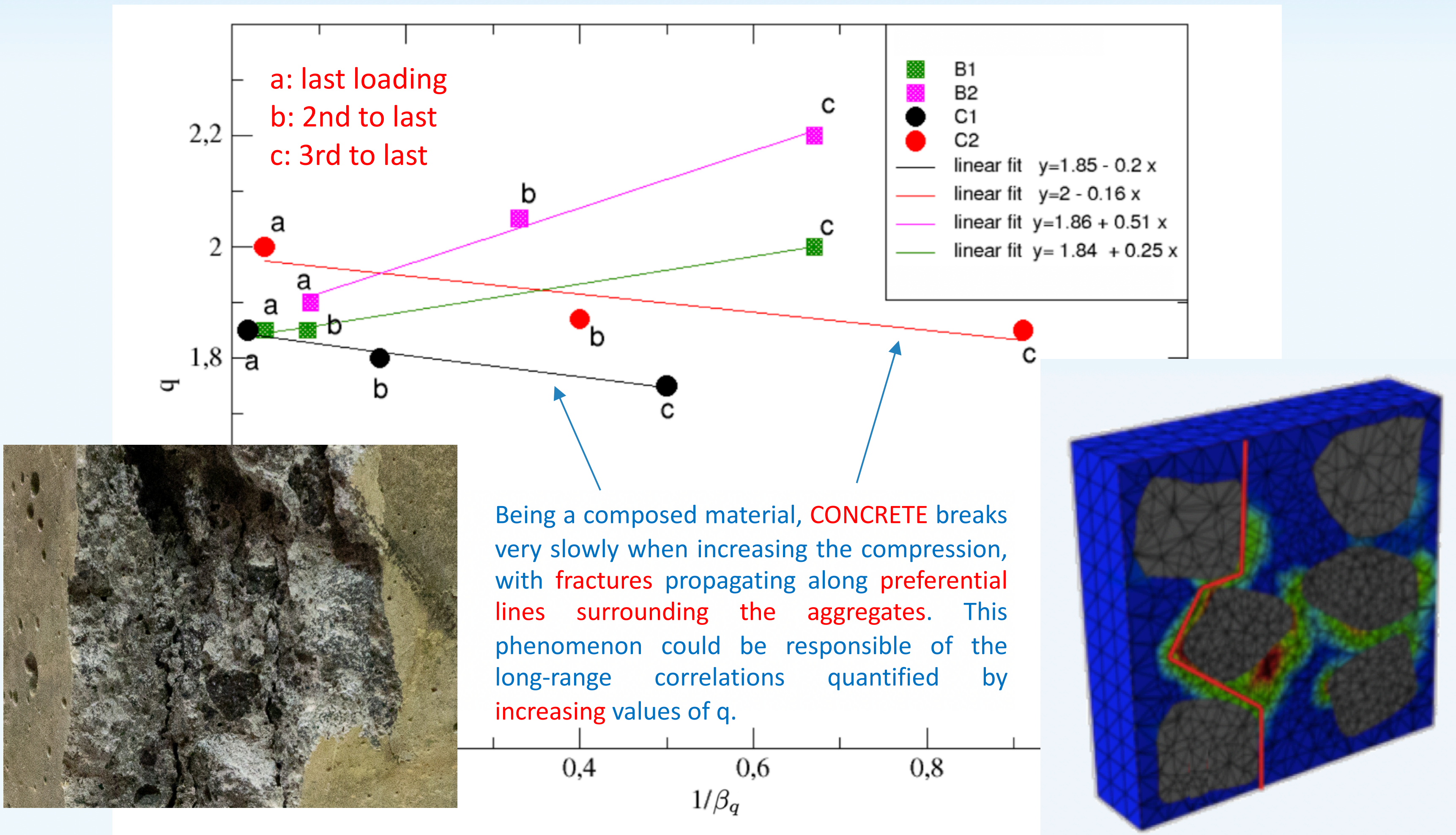


INTER-EVENT TIME ANALYSIS

For all the specimens we find that, approaching the failure, while $1/\beta_q$ tends to zero, the entropic index q goes towards a value in between 1.8 and 2.0. On the other hand, the trend of the linear fit is not the same for the two considered materials: in particular, approaching the failure point, it is increasing for the concrete specimens and decreasing for the basalt ones.



Being a composed material, CONCRETE breaks very slowly when increasing the compression, with fractures propagating along preferential lines surrounding the aggregates. This phenomenon could be responsible of the long-range correlations quantified by increasing values of q.

INTER-EVENT TIME ANALYSIS

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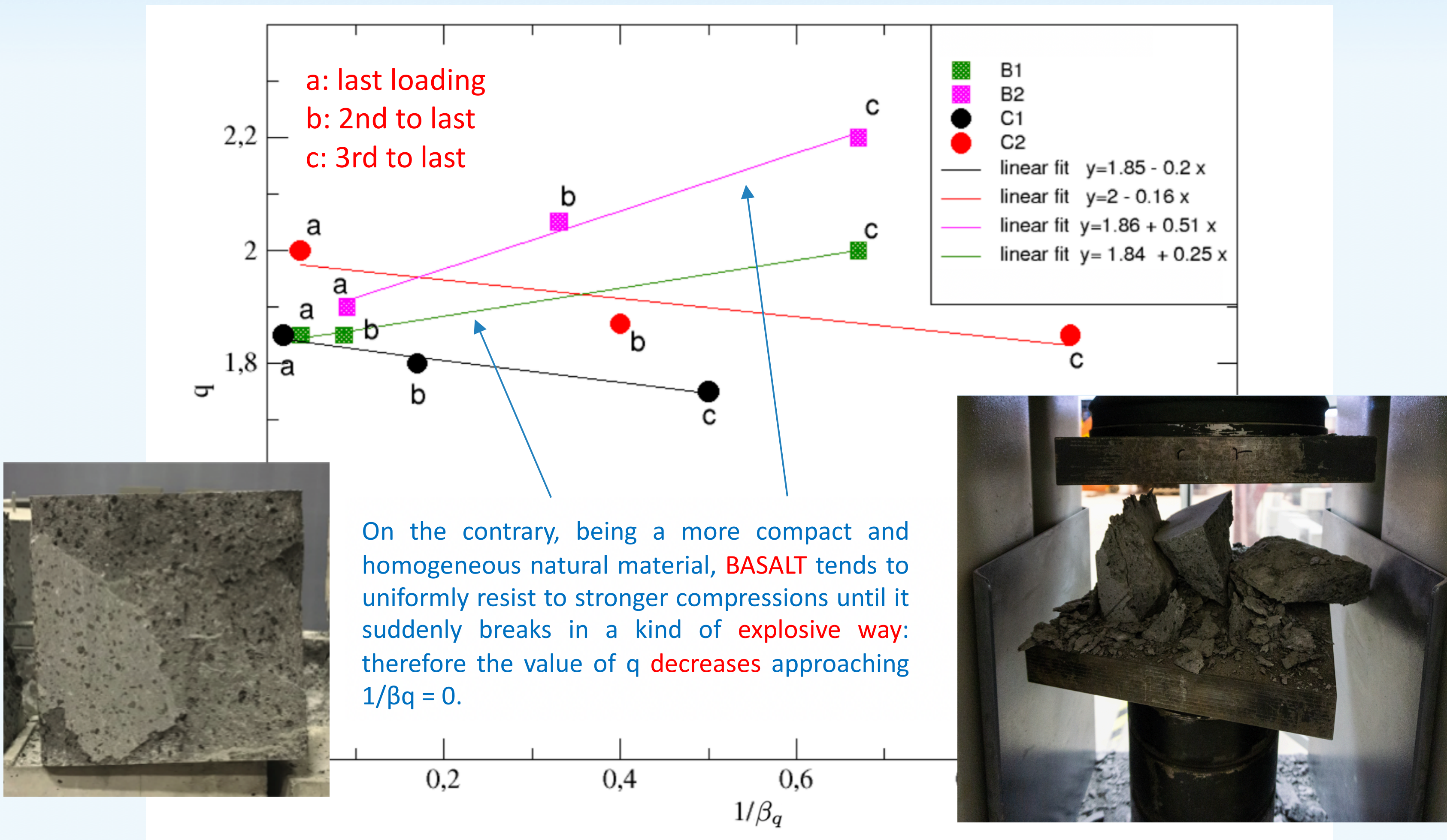
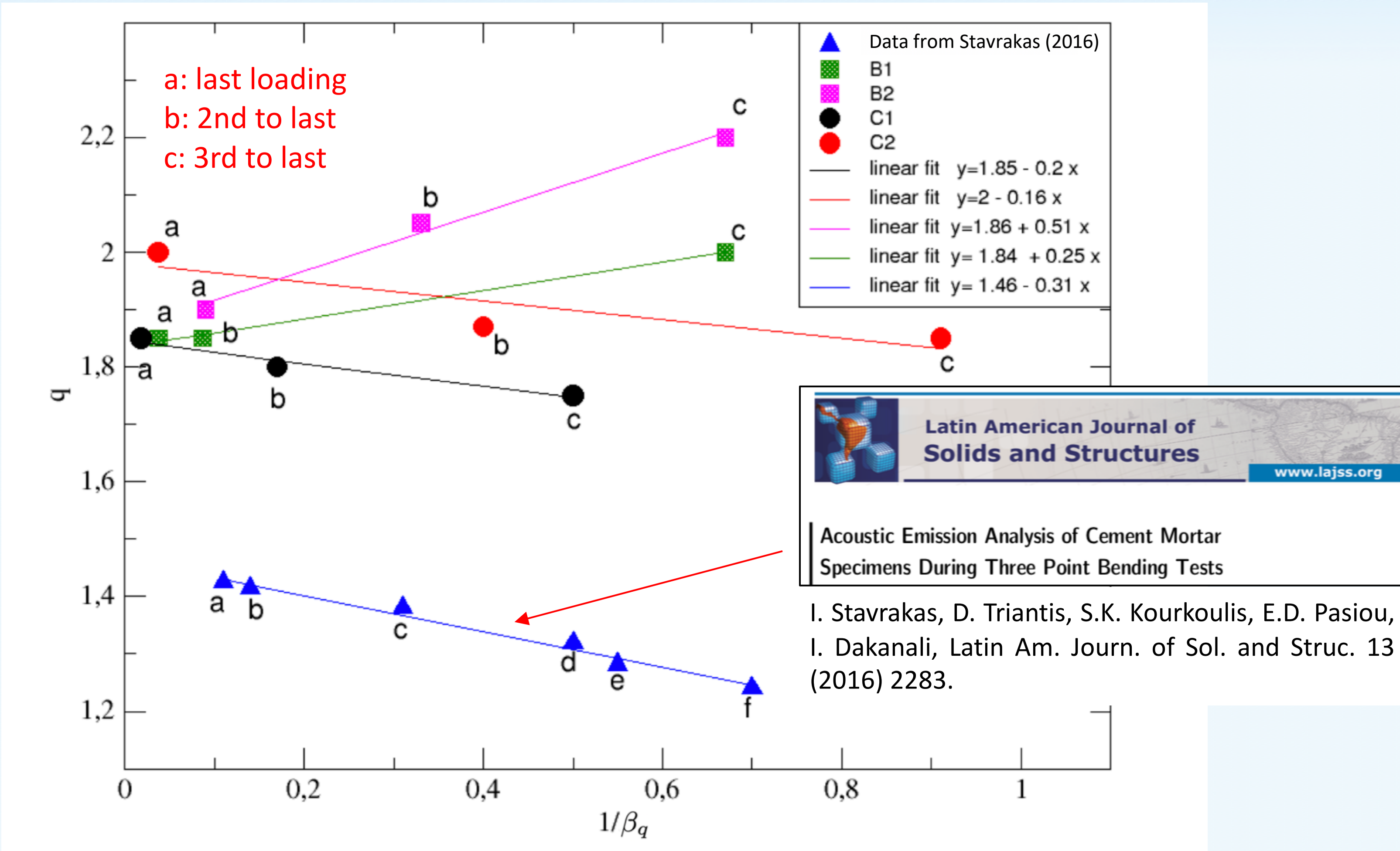


On the contrary, being a more compact and homogeneous natural material, BASALT tends to uniformly resist to stronger compressions until it suddenly breaks in a kind of explosive way: therefore the value of q decreases approaching $1/\beta q = 0$.

INTER-EVENT TIME ANALYSIS

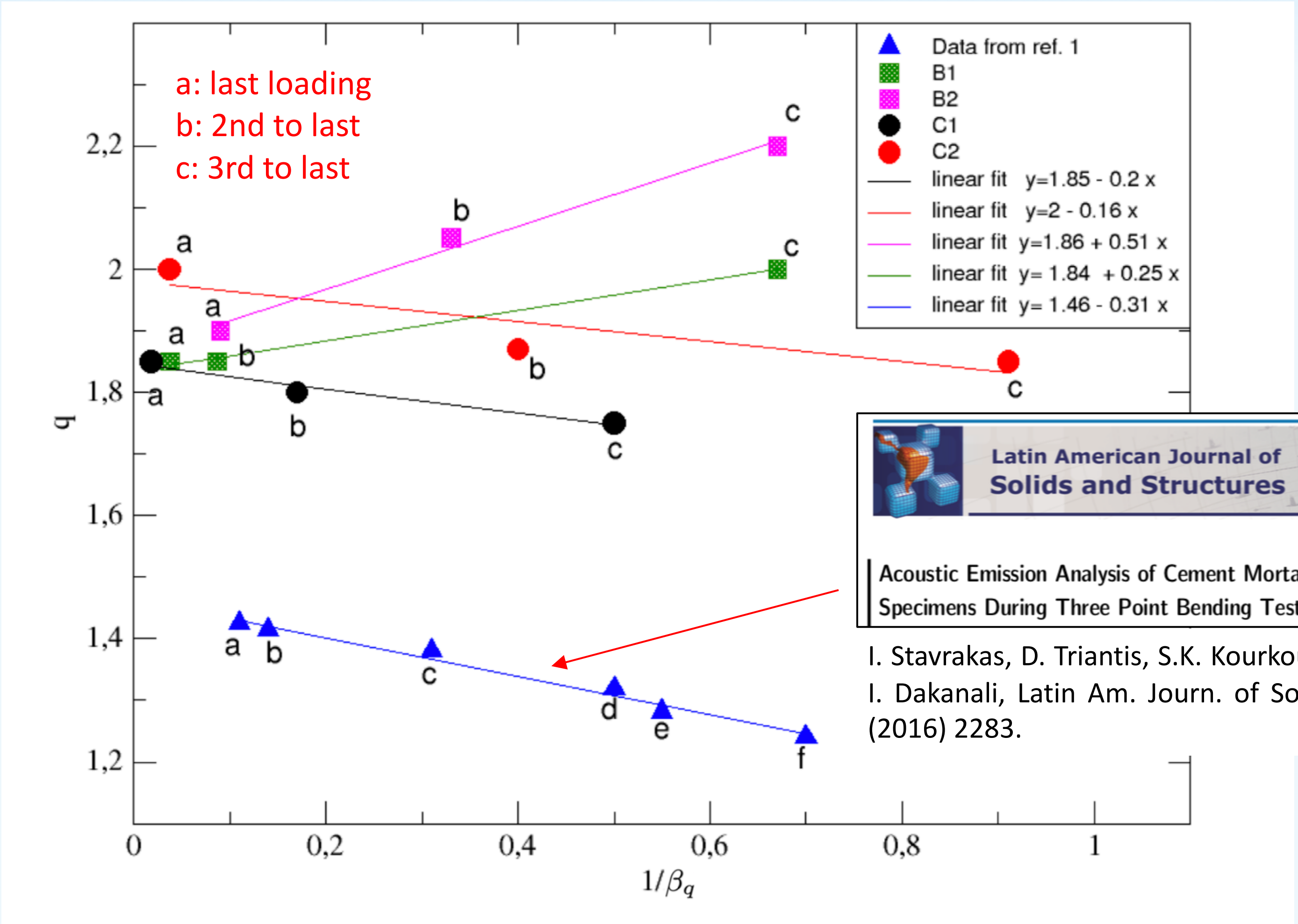
It is interesting to compare these results with data extracted from an analogous study of Stavrakas et al (2016). In fact, the linear fit of the q-exponential data for white cement mortar shows a slope similar to that obtained in the present study for concrete specimens, even if the asymptotic value of q for vanishing $1/\beta_q$ stays quite below the interval 1.8-2.0.



I. Stavrakas, D. Triantis, S.K. Kourkoulis, E.D. Pasiou, I. Dakanali, Latin Am. Journ. of Sol. and Struc. 13 (2016) 2283.

INTER-EVENT TIME ANALYSIS

This result can be due to the fact that both materials are composed by a mixture of binder and aggregates which can drive the propagation of cracks along the preferential directions. These statistical regularities seem to suggest the existence of different classes of materials parametrized by q and $1/\beta_q$. In order to assess the universality of the observed results further investigations would be useful...



I. Stavrakas, D. Triantis, S.K. Kourkoulis, E.D. Pasiou, I. Dakanali, Latin Am. Journ. of Sol. and Struc. 13 (2016) 2283.

IN CONCLUSION

The present generalized statistical analysis provides an insight on the warning signs of the incipient failure of building materials and could therefore be used in a health monitoring strategy on existing structures such as buildings and bridges.

THAN-q
FOR YOUR ATTENTION!

REFERENCE

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