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PIEZONUCLEAR REACTIONS IN COMPRESSED SOLIDS



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Introduction

Neutron emission measurements by means of helium-3 neutron detectors were performed on solid test specimens during crushing failure.

The materials used were marble and granite, selected in that they present a different behaviour in compression failure (i.e., a different brittleness index) and a different iron content. All the test specimens were of the same size and shape.

Neutron emissions from the granite test specimens were found to be about one order of magnitude larger than the natural background level at the time of failure.

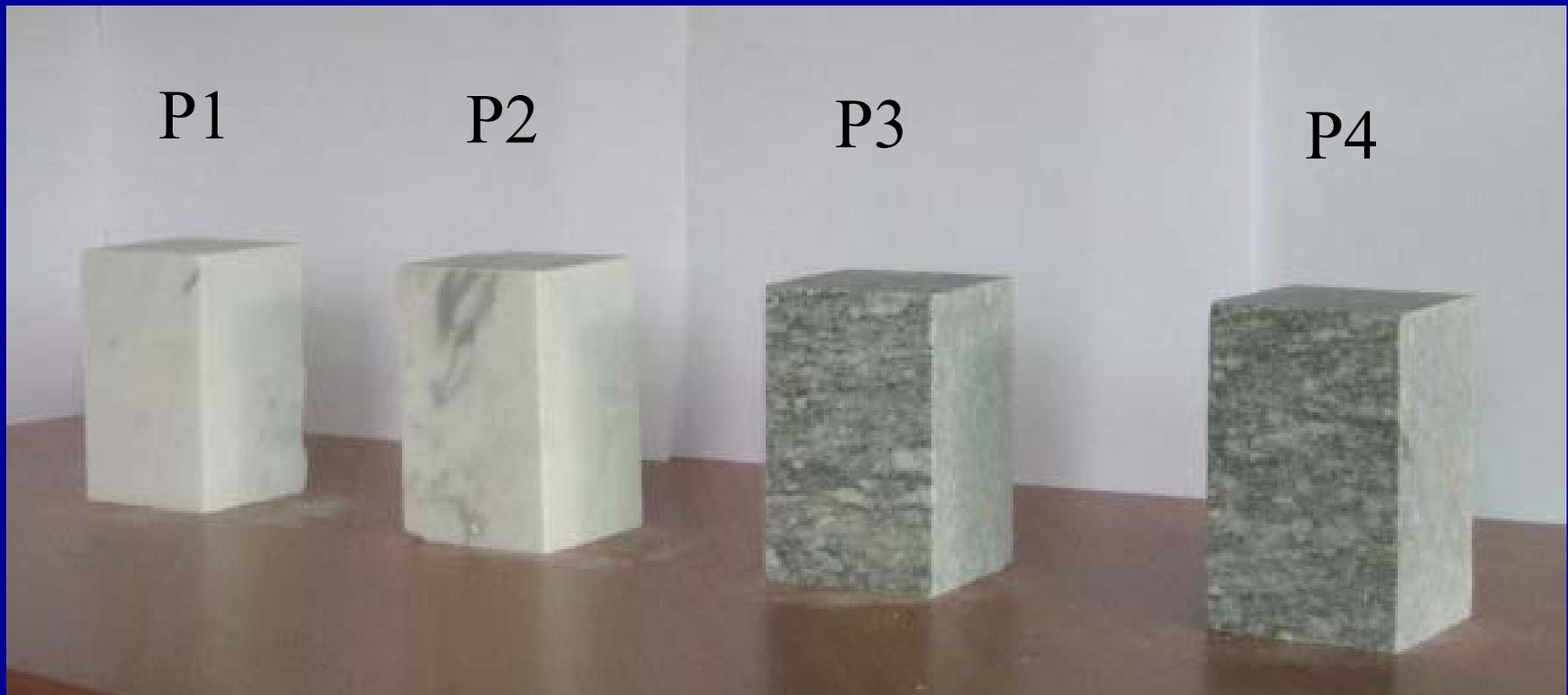
These neutron emissions were caused by piezonuclear reactions that occurred in the granite, but did not occur in the marble.

Experimental set-up

During the experimental analysis four test specimens were used:

- two made of Carrara marble, calcite, specimens P1 and P2;
- two made of Luserna granite, gneiss, specimens P3 and P4;
- all of them measuring $6 \times 6 \times 10 \text{ cm}^3$.

This choice was prompted by the consideration that, test specimen dimensions being the same, different brittleness coefficients would cause catastrophic failure in granite, not in marble.





The same testing machine was used on all the test specimens: a standard servo-hydraulic press Baldwin with a maximum capacity of 500 kN, equipped with control electronics.

The tests were performed in piston travel displacement control by setting, for all the test specimens, a velocity of 10^{-6} m/s during compression.

Neutron emission measurements were made by means of a helium-3 detector placed at a distance of 10 cm from the test specimen.

The detector was enclosed in a polystyrene case to prevent the results from being altered by acoustical-mechanical stresses.



Neutron emission measurements

Before the loading tests

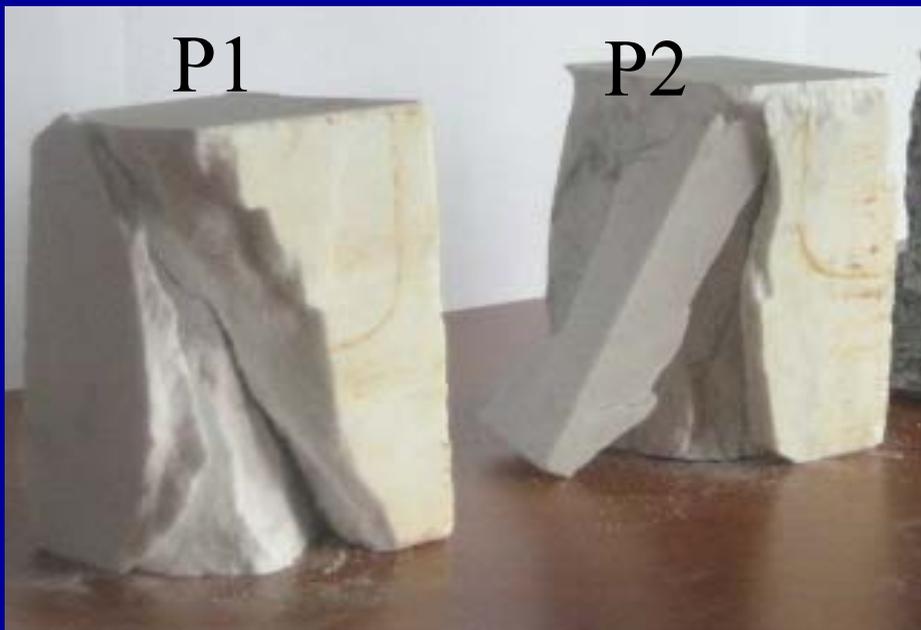
The neutron background was measured at 600 s time intervals to obtain sufficient statistical data with the detector in the position shown in the previous figure.

The average background count rate was:

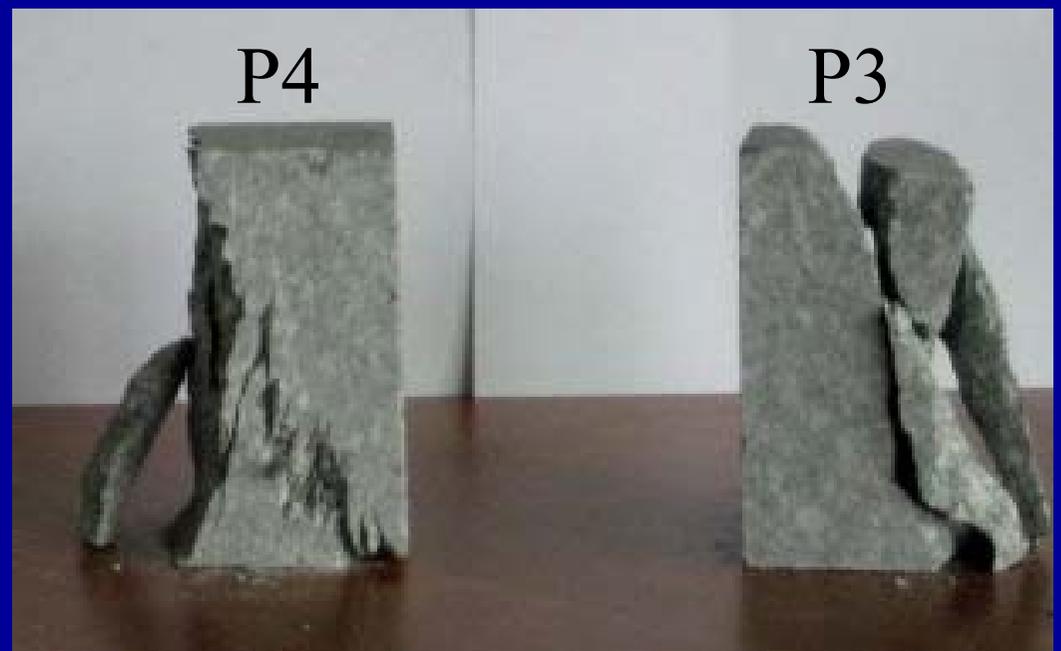
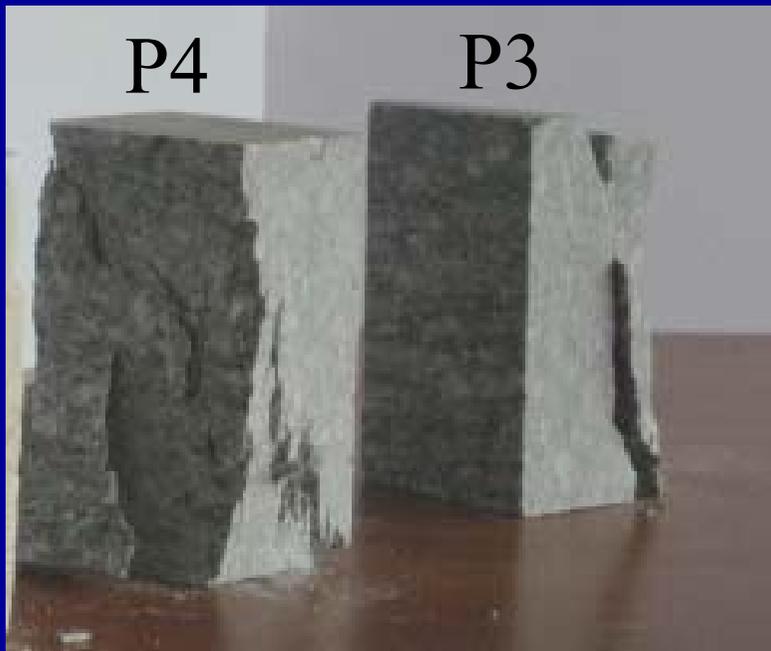
$$3.8 \times 10^{-2} \pm 0.2 \times 10^{-2} \text{ cps.}$$

During the loading tests

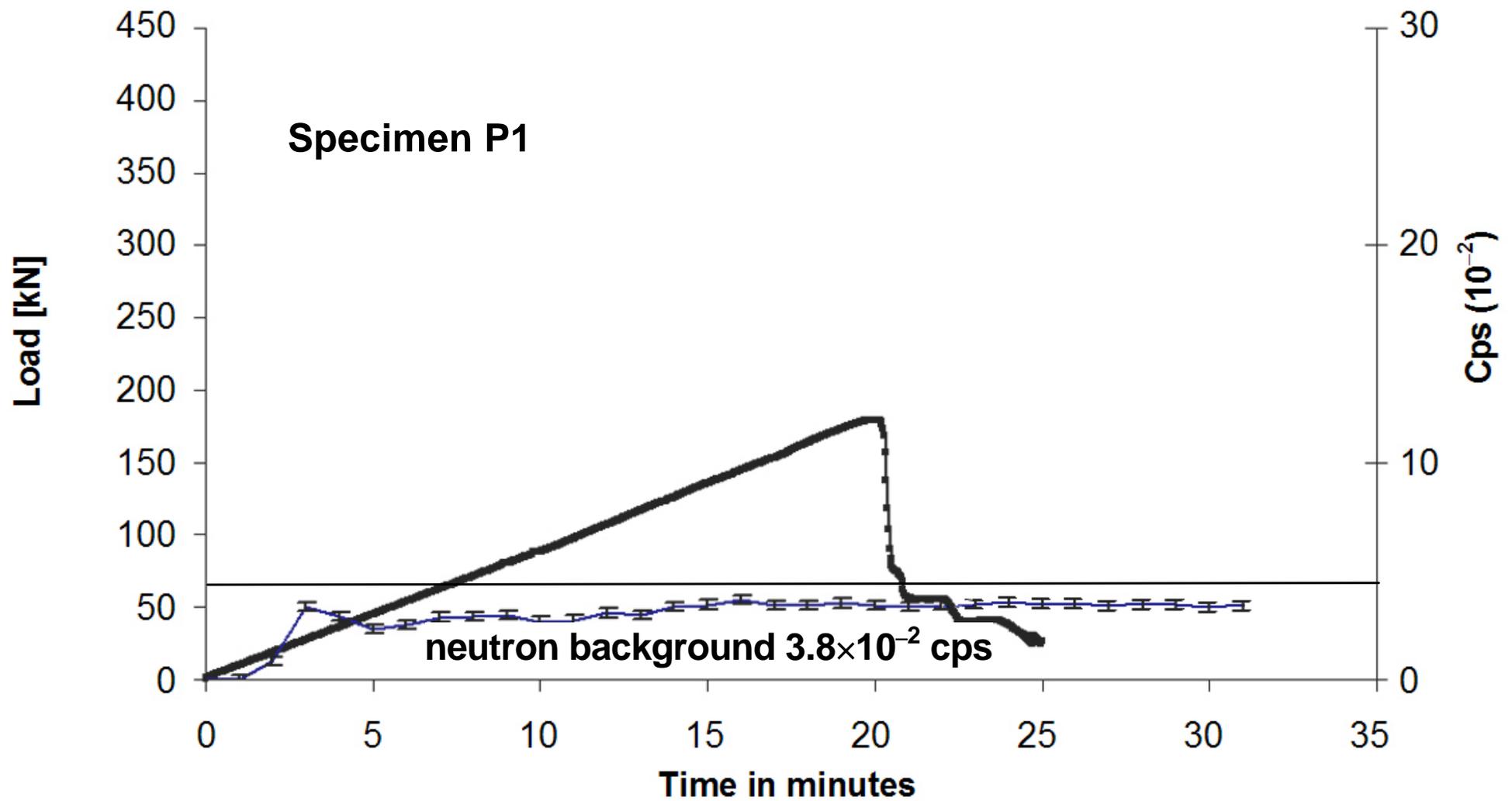
- The neutron measurements obtained on the two Carrara marble specimens yielded values comparable with the background, even at the time of test specimen failure.
- The neutron measurements obtained on the two Luserna granite specimens, instead, exceeded the background value by about one order of magnitude at the test specimen failure.



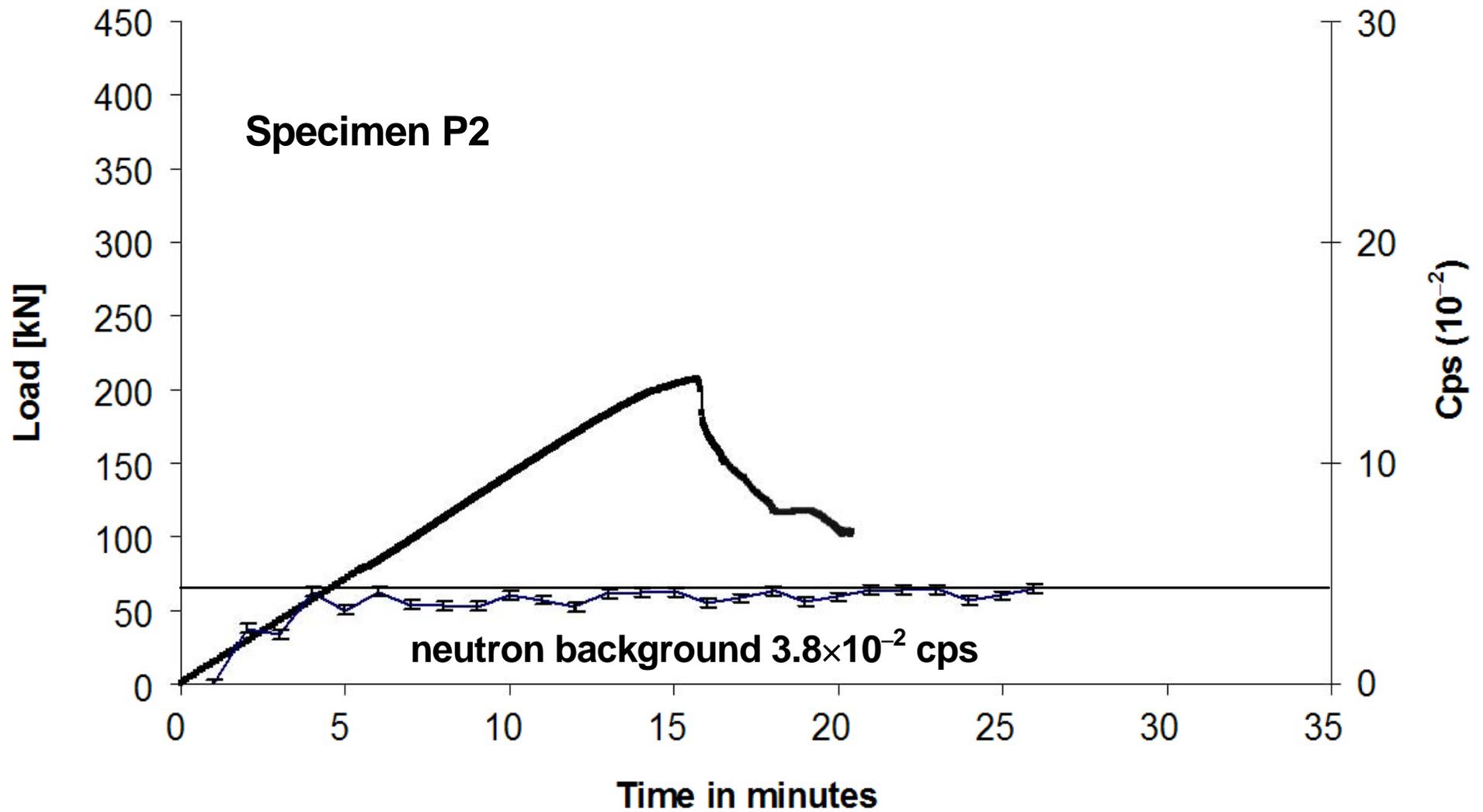
Specimens P1 and P2 in Carrara marble following compression failure.



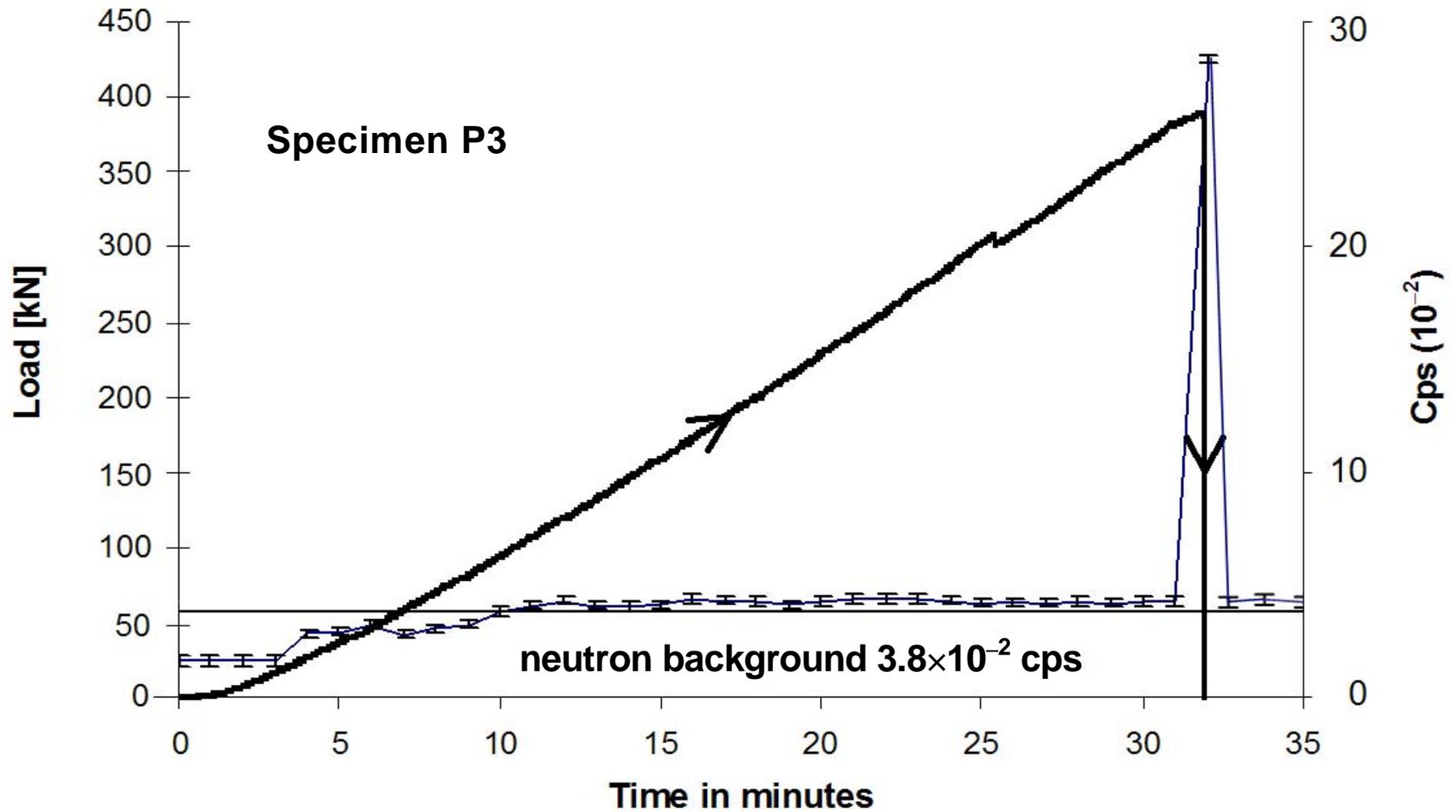
Specimens P3 e P4 in Luserna granite following compression failure.



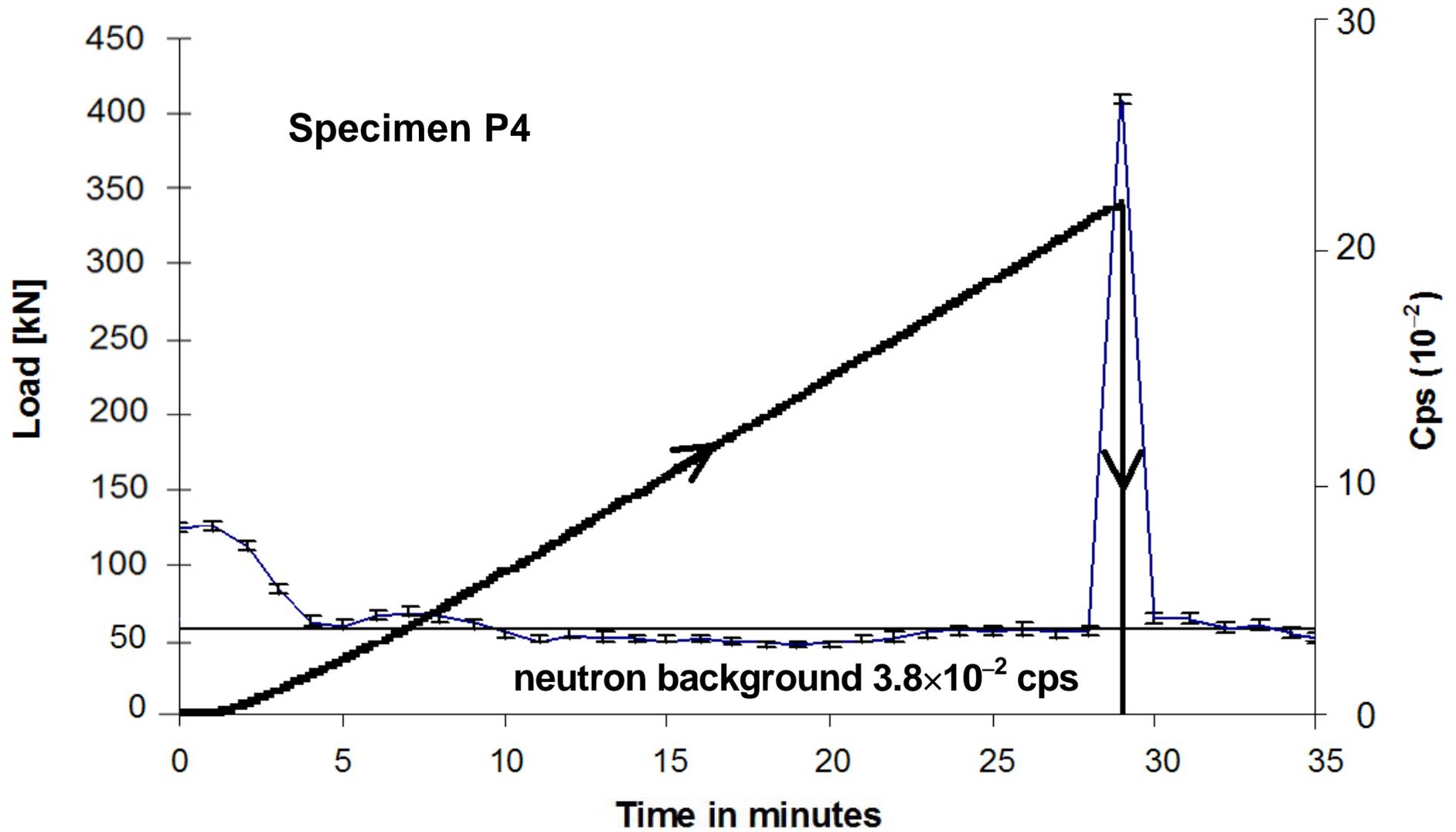
Load vs. time and cps curve for P1 test specimen in Carrara marble.



Load vs. time and cps curve for P2 test specimen in Carrara marble.

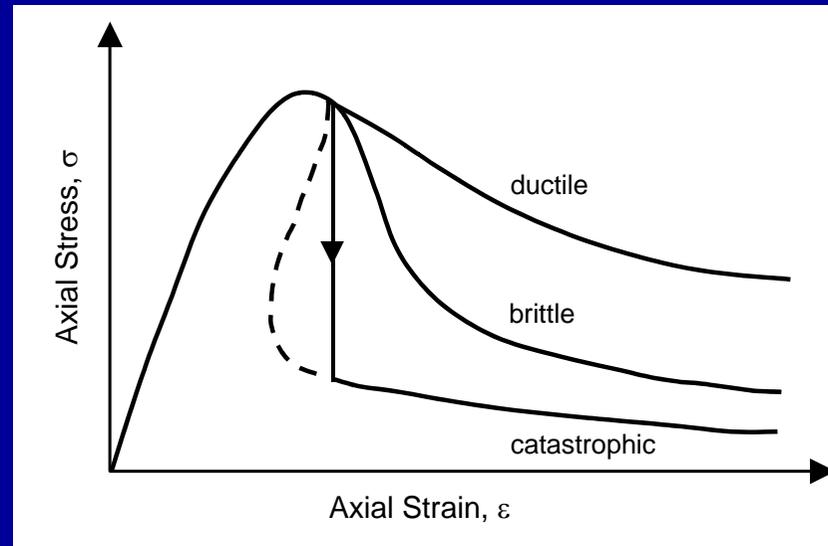


Load vs. time and cps curve for P3 test specimen in Luserna granite.

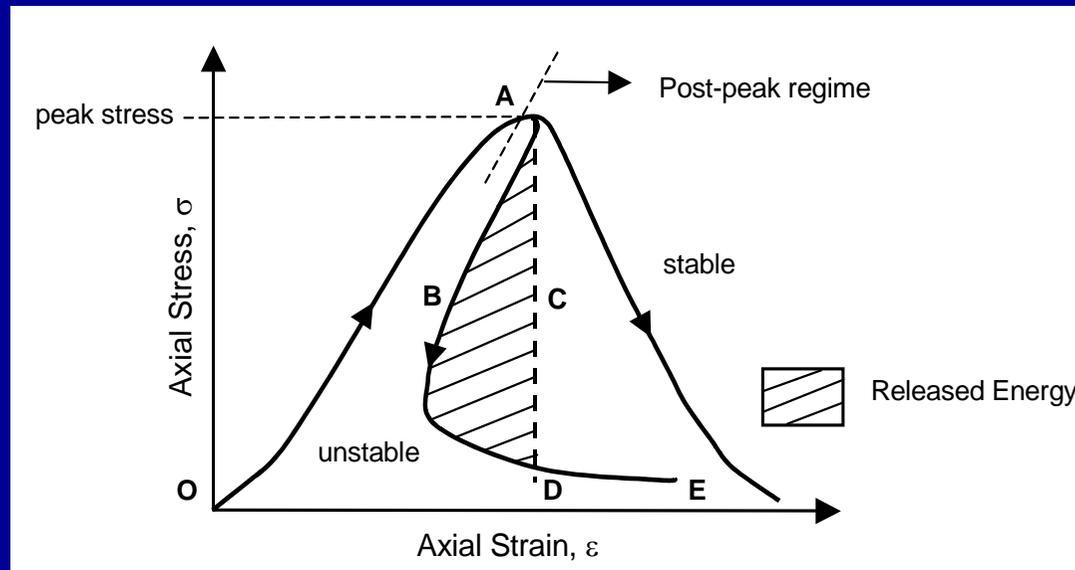


Load vs. time and cps curve for P4 test specimen in Carrara marble.

Factors involved in controlling rock failure

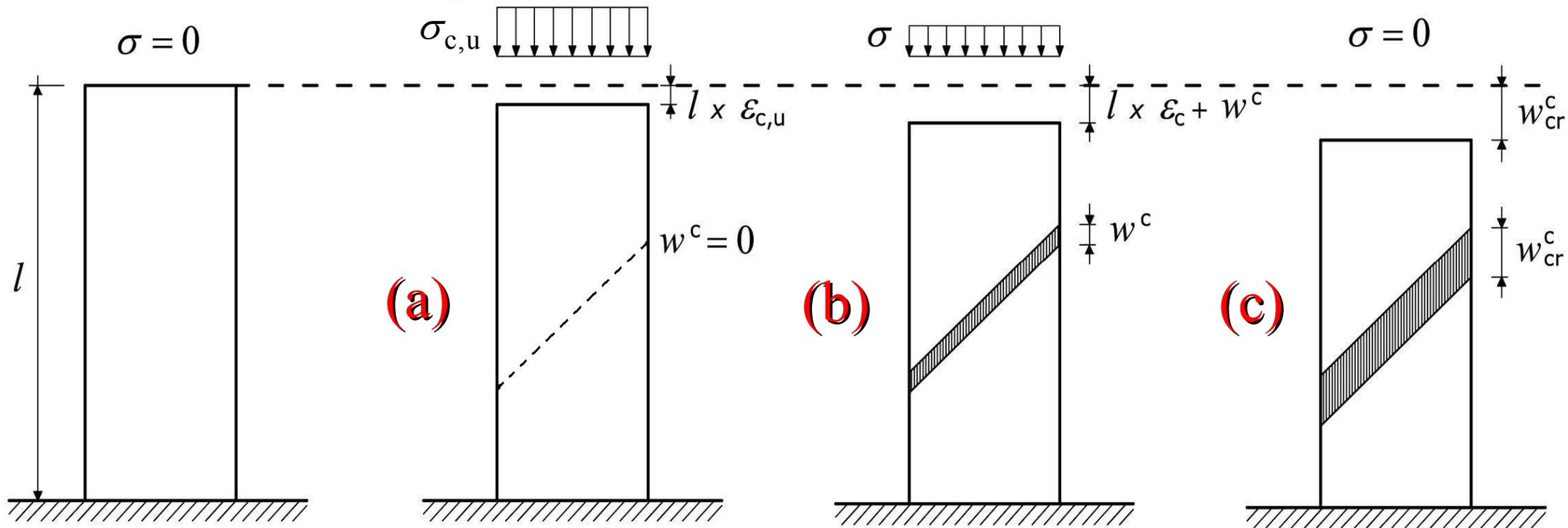


Ductile, brittle and catastrophic behaviour



Energy release and stable vs. unstable stress-strain behaviour

Subsequent stages in the deformation history of a specimen in compression^(I) (II)



$$\delta = \varepsilon_c l = \frac{\sigma_c}{E} l;$$

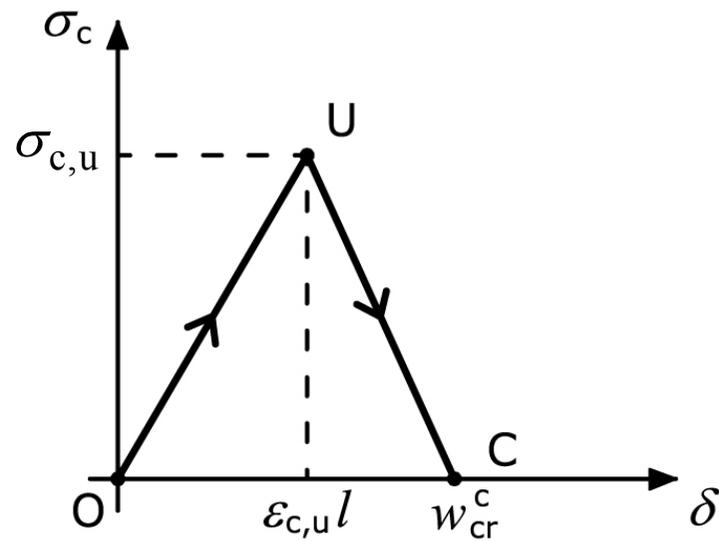
$$\delta = \frac{\sigma_c}{E} l + w^c;$$

$$\delta \geq w^c_{cr}.$$

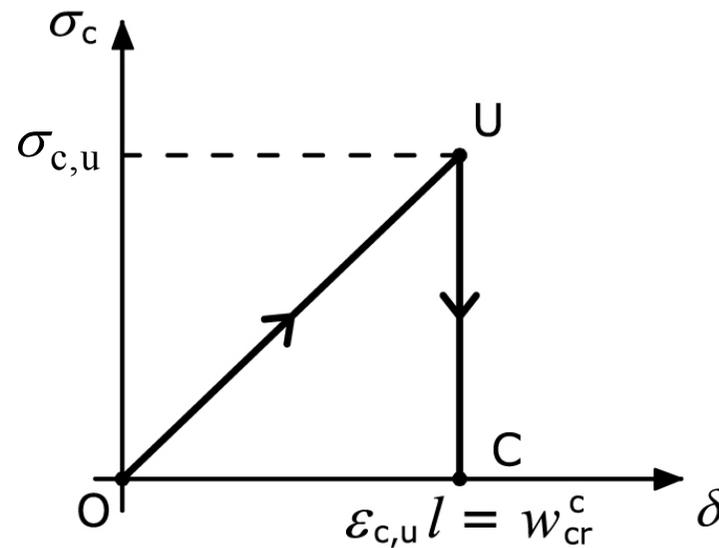
^(I) Carpinteri, A., "Cusp catastrophe interpretation of fracture instability", *J. of Mechanics and Physics of Solids*, 37 (5), 567–582 (1989).

^(II) Carpinteri, A., Corrado, M., "An extended (fractal) overlapping crack model to describe crushing size-scale effects in compression", *Eng. Failure Analysis*, in print.

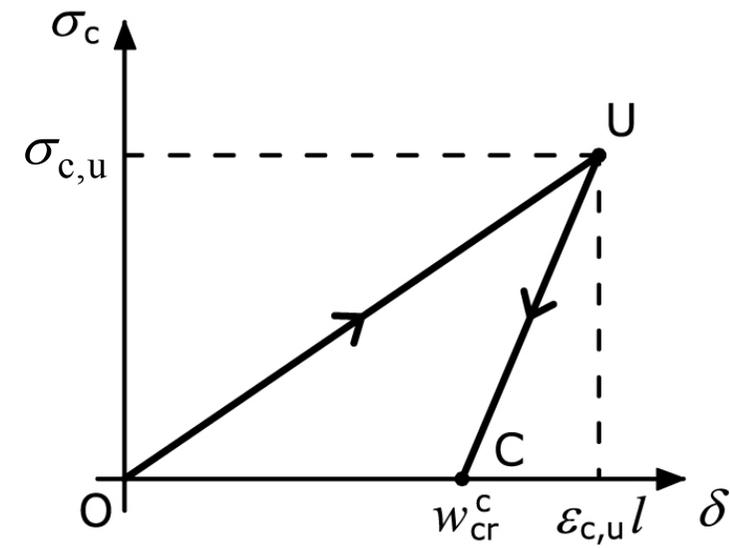
Stress vs. displacement response of a specimen in compression



**Normal
softening**



**Vertical
drop**



**Catastrophic
behaviour**

Elastic strain energy at the peak load, ΔE

| Test specimen | Material | ΔE [J] |
|---------------|-----------------|----------------|
| P1 | Carrara marble | 124 |
| P2 | Carrara marble | 128 |
| P3 | Luserna granite | 384 |
| P4 | Luserna granite | 296 |

Threshold of energy rate for piezonuclear reactions ^(III) ^(IV):

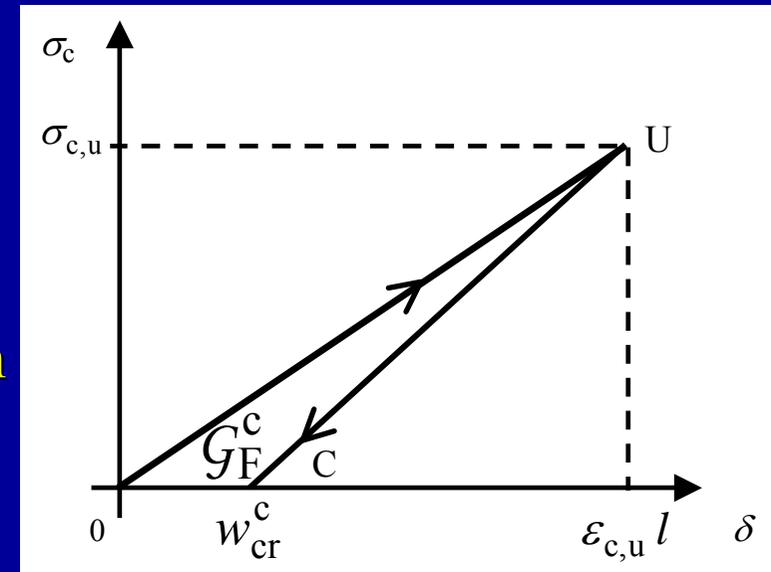
$$\frac{\Delta E}{\Delta t} \sim 7.69 \times 10^{11} \text{ W} \rightarrow \Delta t \sim 0.5 \text{ ns}$$

Extension of the energy release zone:

$$\Delta x = v \Delta t \sim 4000 \text{ m/s} \times 0.5 \text{ ns} \sim 2 \mu\text{m}$$

Comparison with the critical value of the interpenetration length:

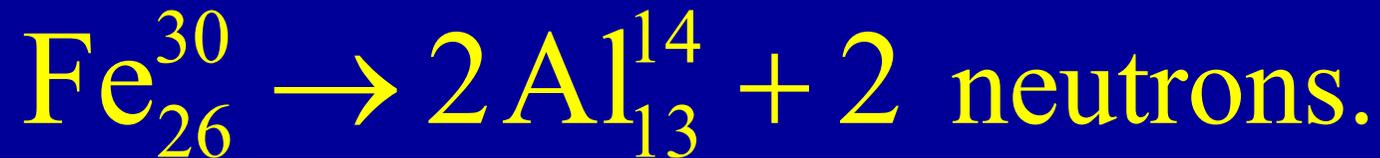
$$\Delta x \sim w_{\text{cr}}^c ?$$



^(III) Cardone, F., Mignani, R., “Piezonuclear reactions and Lorenz invariance breakdown”, *Int. J. of Modern Physics E, Nuclear Physics*, 15 (901), 911–924 (2006).

^(IV) Cardone, F., Mignani, R., *Deformed Spacetime*, Springer, Dordrecht, 2007, chaps 16 –17.

Based on the appearance after the experiments of aluminium atoms, our conjecture is that the following nucleolysis or piezonuclear “fission” reaction could have occurred:



The present natural abundance of aluminum (7-8% in the Earth crust), which is less favoured than iron from a nuclear point of view, is possibly due to the above piezonuclear fission reaction.

This reaction—less infrequent than we could think—would be activated where the environment conditions (pressure and temperature) are particularly severe, and mechanical phenomena of fracture, crushing, fragmentation, comminution, erosion, friction, etc., may occur.