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DAMAGE EVALUATION OF POST-TENSIONED CONCRETE VIADUCT BY AE DURING PROOF LOADING

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Abstract

Recent collapses of civil structures (reinforced concrete, prestressed concrete or mixed steel structures, i.e. buildings, bridges, dams, and so on) have demonstrated once again the need for reliable tools for an early monitoring of damage progression. Damages due to deterioration processes, overload, bad design, poor material quality, can grow subcritically until final collapse. Acoustic emission has been successful used for more than 20 years in industry for monitoring metal equipments (pipelines, pressure vessels, gas tanks, etc.) and the technology is quite mature. The application of the AE technique in the civil engineering requires however the overcoming of several problems related to structural complexity, material inhomogeneity and the high attenuation factor for high-frequency acoustic waves in concrete, and environmental noise. A great effort yet has to be done on data handling and data interpretation.

We have used AE technique for damage evaluation of two severely deteriorated viaducts during proof loading. The viaducts, made at the end of the 1950's along the national road 114 in Sicily (Italy), consist of several spans. Each span was built in a post-tensioned concrete girder configuration. The load test consisted basically of 5 loading steps and 5 unloading steps. For each load test step, it has been possible to evaluate the displacements in the middle, in the border and in the center of the span. It was observed that, during loading phase, the mean AE hits rate, corresponding to a minimum in the mean amplitude, reached a maximum at an intermediate load, while at higher loads a reduced number of AE hits characterized by high mean energy was recorded. AE behavior was asymmetric with respect to the loading sequence (relaxation dominant), indicating the advanced degradation status of the viaducts.

Keywords: Concrete structures, bridge, proof loading, corrosion

Introduction

Segmental cast-in-place post-tensioned structures were extensively used in Italy during the reconstruction processes soon after the Second World War, as innovative design solutions adopted for a rapid and economical building of bridges. After 50 years, most of those structures have formally concluded their design service life, but social and economic reasons frequently force their owners toward rehabilitative solutions instead of undertaking demolition and rebuilding. The rehabilitation project and the evaluation of the residual load-carrying capacity involves the solution of unusual problems arising during the degradation assessment step linked to the peculiar geometry and to the structural weakness of such constructions. For such structures, the main concern is the status of prestressing or post-tensioning cables.

The evaluation of corrosion of the post-tensioning cables (usually grouted in ducts placed in box girder walls) required the use of new, but not yet well established, techniques such as those based on magnetic induction, while indirect techniques such as impact echo could locate grouting defects, but not give any information about cable conditions.

Since the difficulties in accessing to cable anchorage and the impossibilities to re-tensioning cables themselves the evaluation of mechanical characteristics and performance of the viaducts could be estimated on the basis of a dynamic behavior analysis, whose main limit is however the definition of the right theoretical model. AE technique seems to be very promising in this field since it is not invasive, allows a volume evaluation and at the same time has the possibility to locate discrete defects. AE was however introduced very recently in the field of health assessment of reinforced concrete structures notwithstanding some difficulties to be overcome in the field of data handling and analysis. Relationship between AE signal parameters and failure processes that produce these signals have in fact to be properly defined for example by means of the development of pattern recognition techniques. With the same aim, several health indices as well as "Load ratio", "Calm ratio", "Felicity ratio" or "Historical index" have been defined [1-2].

Experimental

The Agrò and Fiumedinisi viaducts, on the national road number 114 on the eastern coast of the Sicily Island were designed in 1954 by Riccardo Morandi and built during 1955-56. They are 13- and 8-spans viaducts, respectively, with the span length of ~22 m. The viaducts are segmental cast-in-place post-tensioned prestressed concrete box girder type, characterized by a five-cell longitudinal trapezoidal void section box girder. Four cast-in-place diaphragms were provided at each end and along each span of the bridge. An 11-cm-thick top concrete slab was monolithically cast-in-place. The post-tensioning ducts of 40-mm diameter were drilled in-place and the post-tensioning internal tendons consisted of 5-mm wires bundle. Following detailed visual and instrumental inspection, which showed a critical degradation status due to seaside vicinity and to the "advanced" age [3], it was decided to evaluate damage effects on structural behavior by means of proof-loading test and a simultaneous AE monitoring.

The set-up of the AE system involved a long series of calibration tests on concrete samples at rest, carrying out the scratching and breaking of pencil-leads of different hardness and dimensions on the surface of samples; these tests have been carried out in different environments to test the effectiveness of filter system and to calibrate the "trigger threshold" suitable to extract the significant components of AE signals.

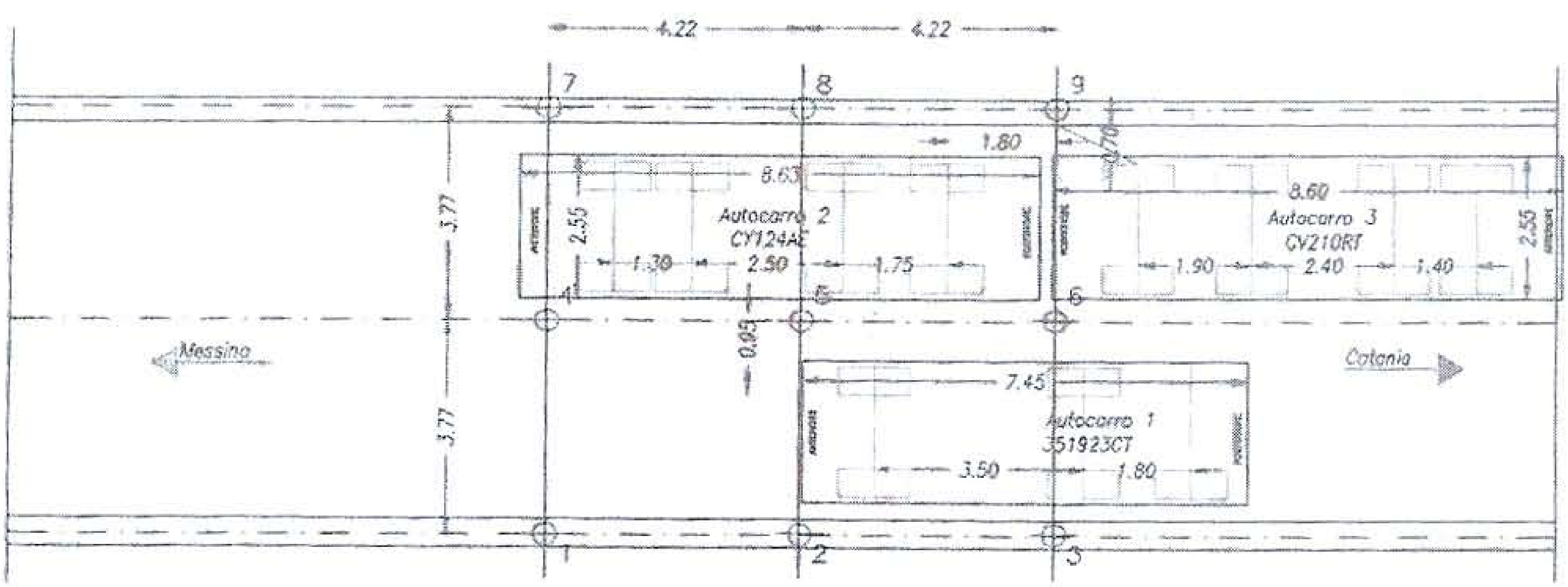

Fig. 1. Scheme of the static loading condition during the fourth loading step.

The proof loading test consisted basically of 5 load steps:

I° load test step: the load was produced by a 30 tons (0.3 MN) truck set in the middle of the span;

II° load test step: the load is produced by a 30 tons truck set in the middle and by a 20 tons

(0.2 MN) truck set on the parallel lane; Total = 0.5 MN

III° load test step: the load is produced by two 30 tons trucks set on the same lane; 0.6 MN

IV° load test step: the load is produced by two 30 tons trucks set on the same lane and a 20 tons truck set on the parallel lane; 0.8 MN

V° load test step: the load is produced by two 30 tons (0.3 MN) trucks set on the same lane and a 20 tons (0.2 MN) truck plus 30 tons (0.3 MN) truck set on the parallel lane; 1.1 MN.

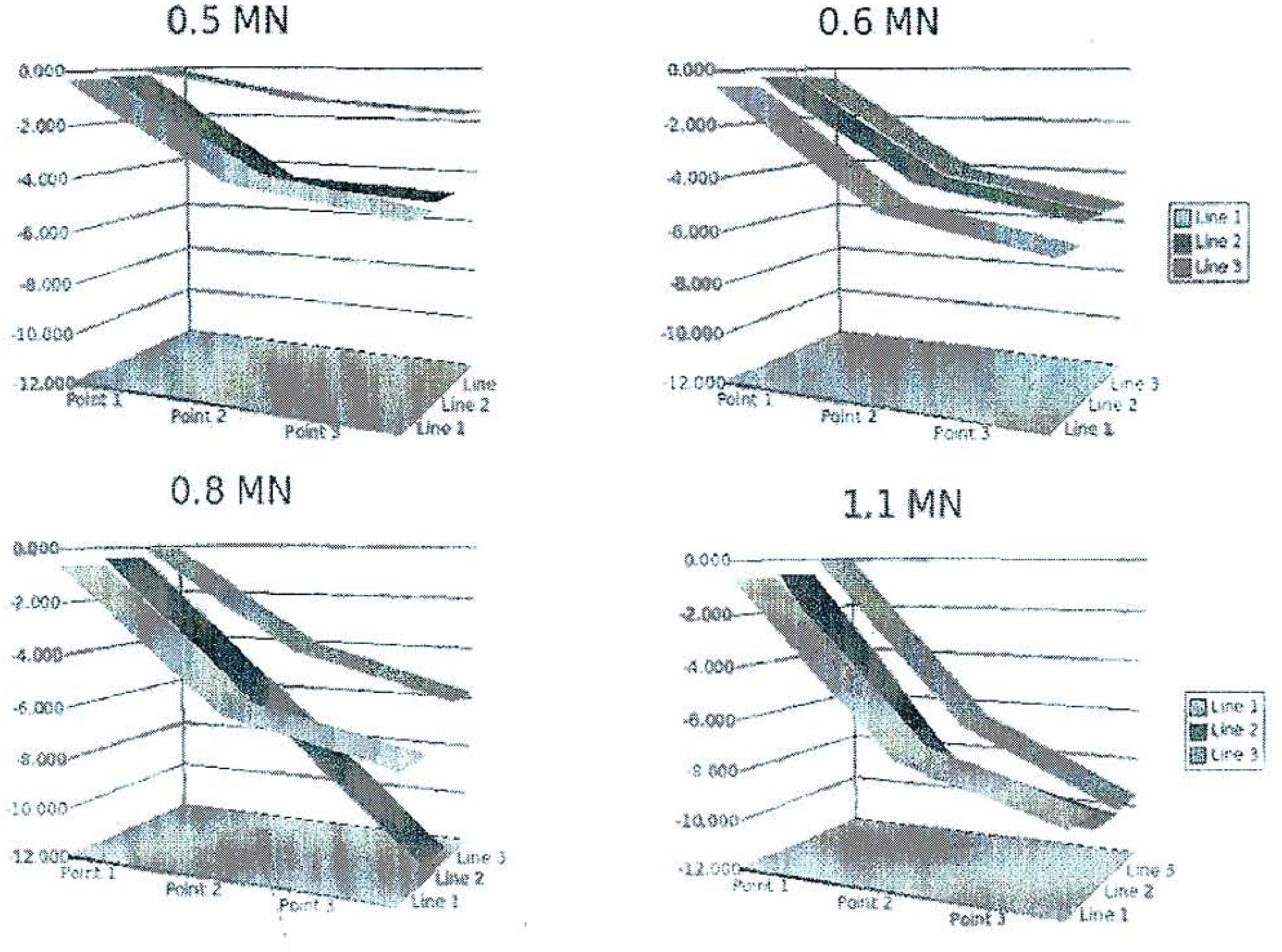

Fig. 2. Displacement of the measuring point (Fig. 1) on the viaduct span during proof loading.

A scheme of the 4th load test step with the indication of displacement measurement points is reported in Fig. 1. For each load test step, it has been possible to evaluate the displacements in the middle of the span in the border and in the center (Fig. 2). AE sensors adopted were VS30-V flat response type (23-80 kHz bandwidth, 140 pF capacitance), a total of ten sensors were used and positioned on the lateral side of different segments of box girders as shown in Fig. 3.

Results

The AE application has proven effective to detect vibration phenomena produced by trucks crossing on the structure, and the intense AE activity recorded was connected to the residual stress in the structure induced by the post-tensioning system, while the events recorded during the first phase seems to be connected with the phenomena of internal rearrangement of pre-existing defects.

Considering the huge amount of data recorded, only a limited amount of available results are reported here and related to span No. 12 of the Agrò viaduct. Hits, energy and amplitude of AE events have been reported as mean values of the total amount of events recorded during a specific loading step (i.e., within a specific time interval).

An example is reported in Fig. 4 and refers to the second load step. One of the main aspect that must be highlighted is that the great amount of hits have been recorded during transient phases (loading and unloading), while, at the maximum load, the structures remained almost silent (Fig. 4A). On the contrary, the energy of the AE events reached the maximum value at the intermediate loading (0.3 MN) as reported in Fig. 4B. It is important to keep in mind that by considering the specific loading procedure, which considered the presence of asymmetric loads, the maximum displacements of all the measuring points of the side beams do not correspond to the maximum load applied (Fig. 2). In Fig. 5, relationship between AE parameters for sensors 7 and displacements measured at the nearest measurement points (3 and 6) are reported.

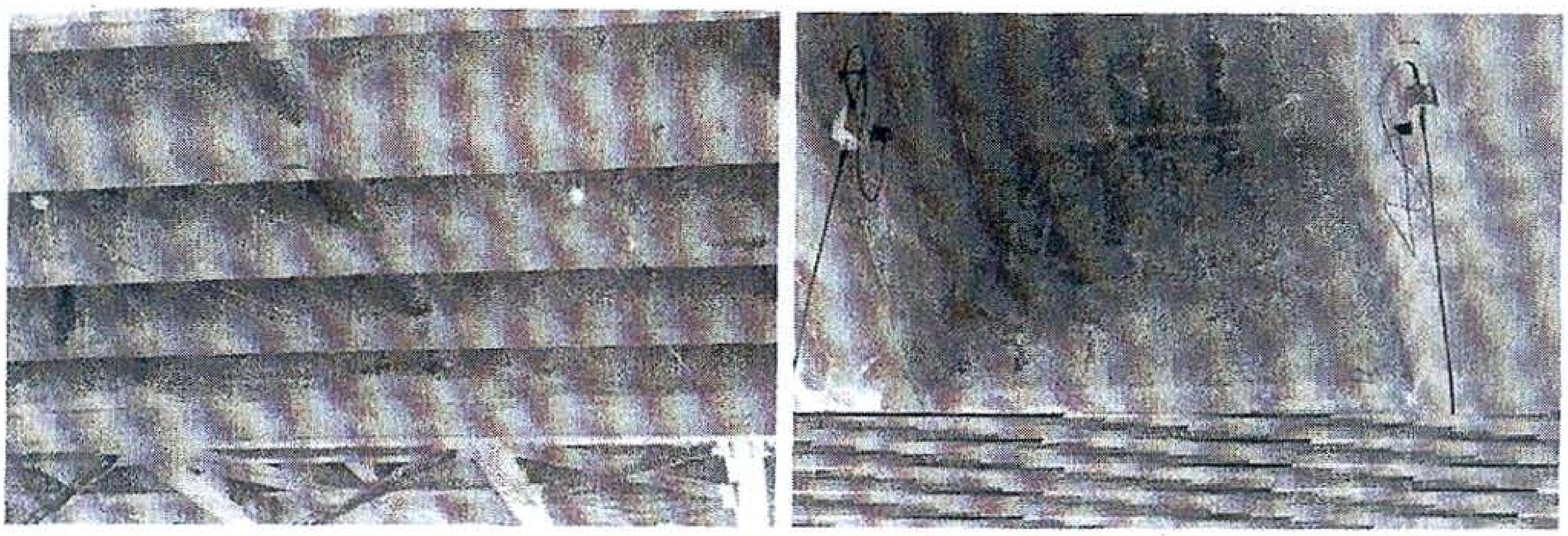

Fig. 3. AE sensors positioning on box girders.

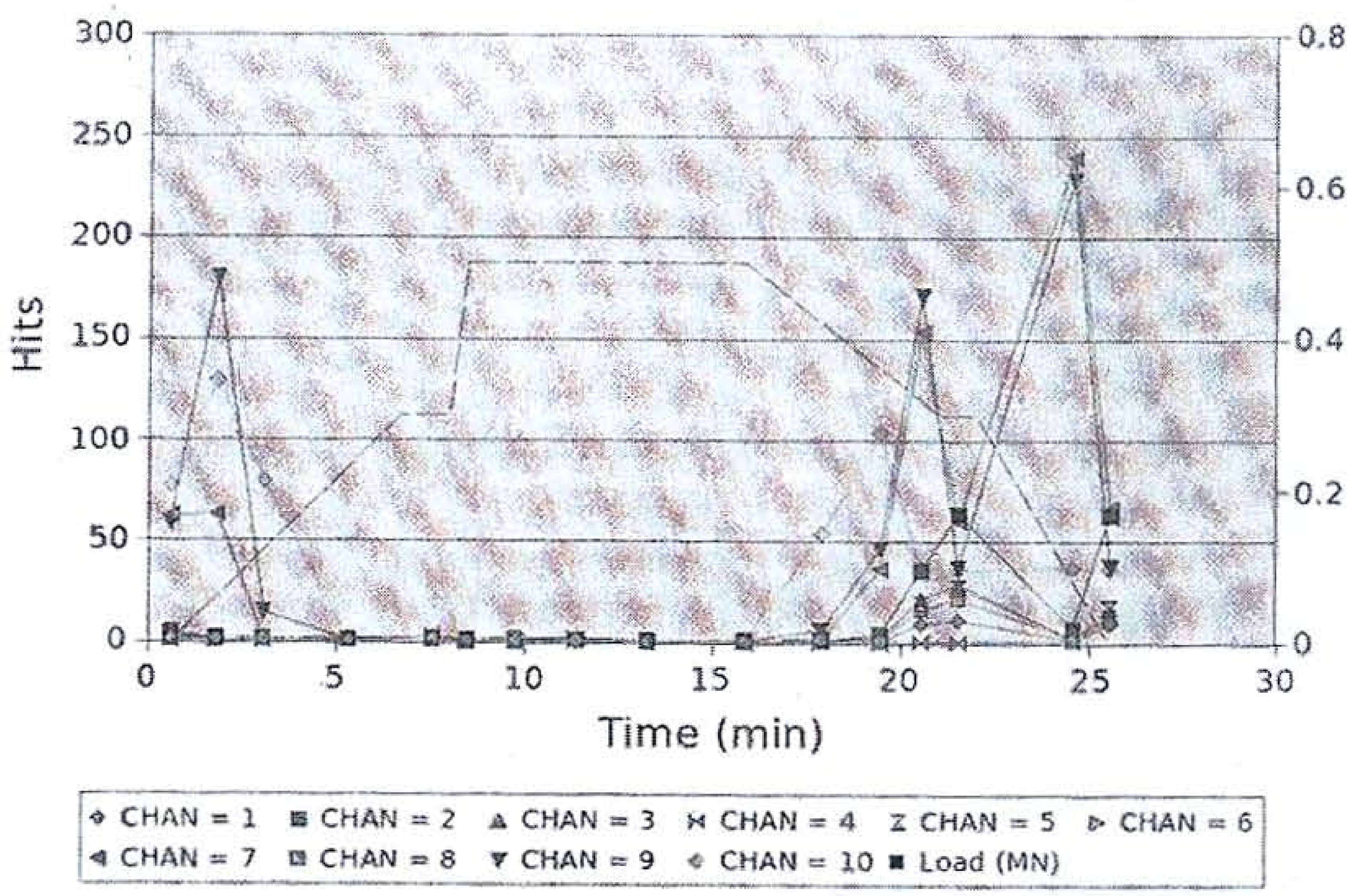

Fig. 4A. Mean numbers of hits for all channels vs. time for the second load step (load: dashed line; load scale on the right side in MN).

As a further evaluation of the degradation status of the viaduct, we carried out a relaxation ratio analysis [4]. Relaxation ratio is defined as the ratio of the average energy during unloading phase to the average energy during loading phase. Considering that AE activity during the unloading process is generally an indication of structural instability [5], a relaxation ratio greater than one (relaxation dominant) implies a defective structure.

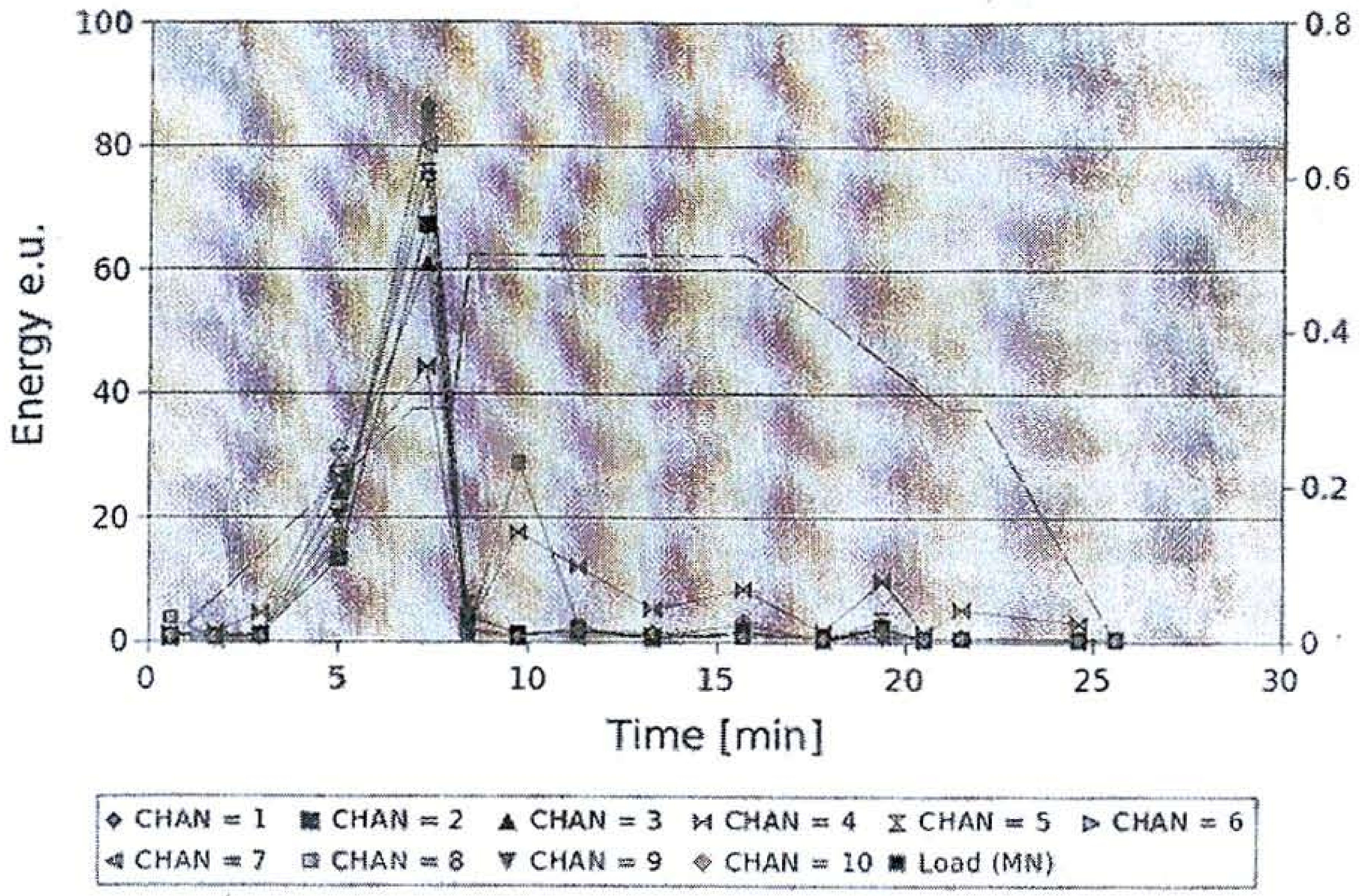

Fig. 4B. Mean energy for all channels vs. time for the second load step (1 eu=10^{-14} V^2s; load: dashed line; load scale on the right side in MN).

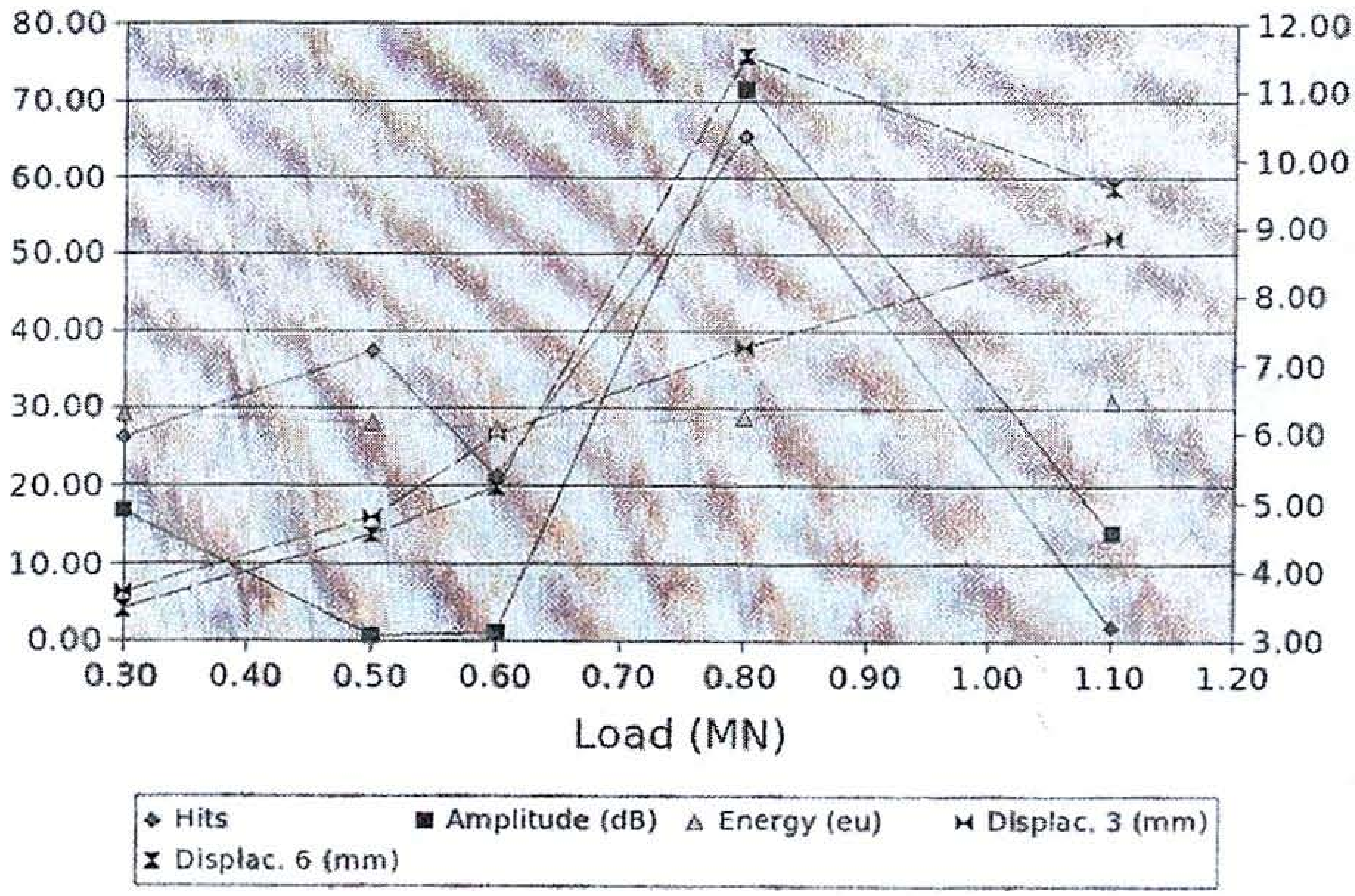

Fig. 5. Mean hits, amplitude and energy for channel 7 during loading steps matched with effective displacement measured at points 3 and 6 (Displacement scale on right side).

In Fig. 6, results obtained on the second box girder are reported. A strong peak in the relaxation ratio during the third loading condition is evident for channels 3, 8 and 9 (on the same box girder side), while at higher load condition (0.8 MN) the peak was recorded on channel 4 (on the opposite side of the box girder).

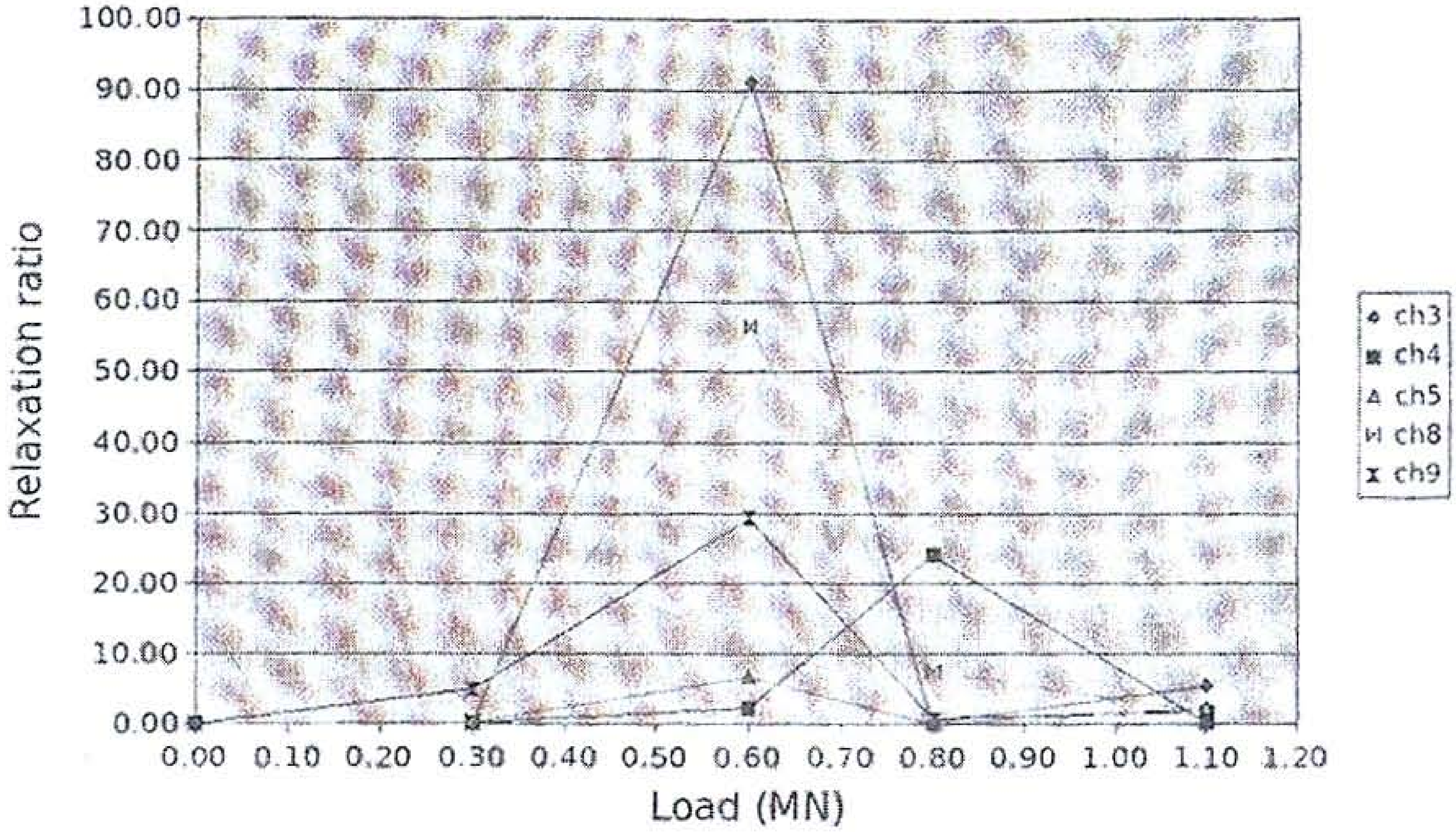

Fig. 6. Relaxation ratio for channels 3-4-5 and 8-9 on box girder No. 2.

Conclusions

We used AE technique for damage evaluation of two severely deteriorated viaducts during proof loading. The viaducts, made at the end of the 1950s along the national road 114 in Sicily (Italy), consist of several spans. Each span was built in a post-tensioned concrete girder configuration. It was observed that during loading phase, the maximum mean AE hits rate, corresponding to a minimum in the mean amplitude, was reached at an intermediate load, while at higher load a reduced number of AE hits characterized by high mean energy was recorded.

The application of the relaxation ratio analysis indicated the structural instability (relaxation dominant) of the two viaducts.

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