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NON–LINEAR SOURCE PROCESSES UNDER TENSILE LOAD REGIME?

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ABSTRACT. In the past years the non–linearity of the processes was detected and verified during which – under compressional loading the solid body – elastic waves were radiated. In the paper presented an attempt is made to find out whether also radiation from a solid body (steel string) subjected to tension loading displays non–linear behaviour as well. The first results obtained indicated the existence of non–linear component of such a source of radiation.

1. INTRODUCTION

The potential non–linear character of radiation from an earthquake focus has been subjected to intensive study in the last years, since especially this approach allows us to explain the substantional increase of energy release not only by increasing seismic volume/dimensions as suggested in classical source models based on linear physics, see [Keilis–Borok 1990].

Non–linear approaches to seismic source are based on the concept that the stress concentration in a seismic focus and the consequent seismic energy release can be considerably enlarged by additional loading with complementing, confining compression. This additional compressive force can possibly result in a special kind of focus self–organizing reflected in coherent wave radiation and wave (self)–modulation.

Considering n oscillators creating a seismic source, the released seismic energy E is proportional to n^2, ($E \simeq n^2$) for coherent energy radiation while the same energy E is proportional only to n, ($E \simeq n$) for non–coherent radiation expressed by the terms of linear physics, see [Poincaré 1928], [Mandelshtam 1950] and [Nicolis 1986].

Assessment of a maximum energy which can be released from a given seismic source volume are closely linked to regional seismicity patterns and to the seismic risk of a given region. Importance and weight of these parameters increase when large and costly industrial complexes (e.g. nuclear power plants, water dams or chemical plants etc.) are built in a region endangered by strong earthquakes.

An increase of seismic energy release explained by means of non–linear dynamics was studied in the Institute of Rock Structure and Mechanics in the past years, see [Aksenov et al. 1991; 1992; 1993].

It was revealed and verified on extensive series of laboratory tests on rock samples subjected to bi–axial compression, that when increasing the confining pressure, the natural acoustic emission (AE) gradually displays non–linear behaviour. Such radiation transformation was clearly reflected in the frequency spectra of AE impulses shape and/or in the frequency changes. Results of the tests on magnesite and sandstone samples demonstrated non–linear features of the treated structures, the degree of which was growing when increasing the confining pressure value.

In the above mentioned papers by [Aksenov at al.] an attempt was made to trace non–linearity of seismic foci also in field conditions; it was found and confirmed – by the FFT analysis – for a series of rockbursts in the Ostrava Coal–Basin and also for sallow earthquake aftershock series [Oroville 1975; Spitak 1988].

Our interest in the non–shear component of a loaded seismic source was not evoked by chance. A large series of laboratory tests performed on physical models under compression demonstrated that besides the shear displacement also smaller tensional seismogenic component can occur in a seismic source. This tensional component was also detected in the focal mechanism of several shallow earthquakes, see [Kozák et al. 1983], [Kozák et al. 1984], [Csikos et al. 1985]. Likewise, by analyzing the records of rockbursts occurring in coal mines, an additional small implosive source component was detected, see [Rudajev et al. 1984], [Kozák et al. 1985], [Šílený et al. 1985]. In this stage of research a question has arisen whether the non–linearity of a seismic source occurs due to source additional confining compression only, or whether it is a function of common source load.

For testing the potential non–linear behaviour of seismogenic structures under tension, we made a series of laboratory tests on steel strings.

2. THE EXPERIMENT

Three series of steel strings having diameters of 0.8, 1.2 and 2.0 mm and the uniform length of 170 mm were loaded up to their strength values. In five levels of constant load (a step of app. 20 % of σ_{str}) the strings were sounded by a mechanical impact of a steel hammer. The resulting string vibration (sound) was picked up by an ultrasonic receiver and records subjected to FFT.

The results can be summarized as follow:

1) With all the tested strings (of all three diameters) the frequency of the maximum spectral amplitude increased with string tension. This frequency shift (if we compare the load level of ca 20 % σ_{str} with ca 100 % σ_{str}) were characterized by a coefficient with the value of 1.5 – 1.7.
2) In contrast to frequency changes, the spectral amplitude values of maximum spectra component A_{max} displayed a different pattern in the course of loading. In the first half of the loading cycle (app. to 50 % of σ_{str}) a more or less regular growth of this amplitude was observed; the maximum values occurred at app. 75 % of σ_{str}. During the last loading stage (ca 85 – 100 % of σ_{str}), an amplitude

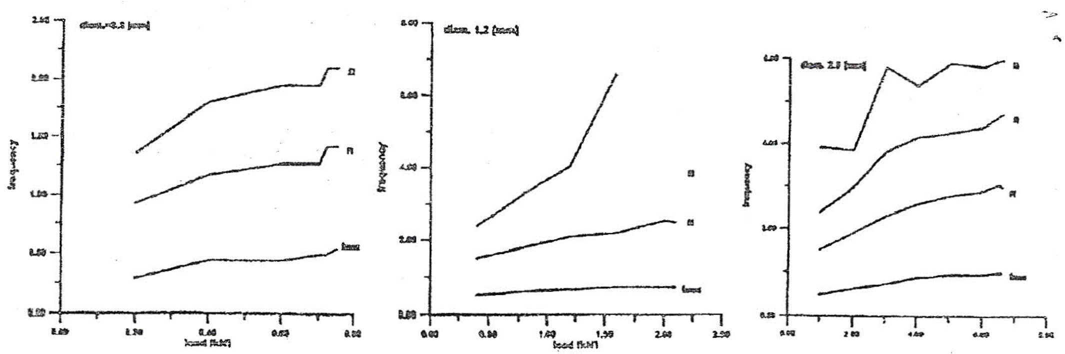

FIG. 1. Pulse frequencies as a function of tension load. A_{max} – frequency of the maximum spectral component, A_1, (A_2) – frequency of the first (second) spectra maximum harmonics. All spectra were constructed by analyzing the pulse first wave–lengths only.

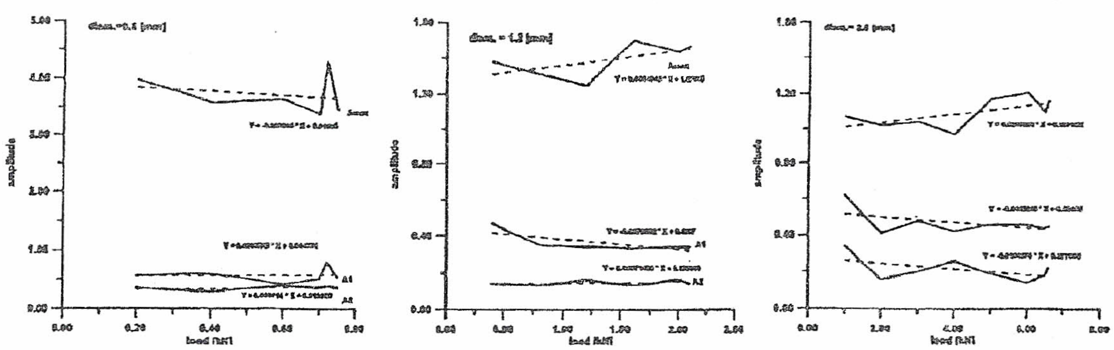

FIG. 2. Spectral amplitudes as a function of tension load. A_{max} – amplitude of the maximum spectral component, A_1 (A_2) – amplitudes of the first (second) spectrum harmonics. Dotes lines represent a straight line approximation, see the coefficients of equations.

decrease was recorded, see Fig. 2. This amplitude decrease corresponds to the situation in which the frequency of this spectral amplitude does not grow any more. This irregularities can be explained by the non–reversible material changes of the treated strings when approaching the σ_{str} value.

3) Let us have a closer look at the development of spectral changes with increasing load. Let us denote the maximum spectral amplitude by A_{max} and the two next local spectra (higher harmonics) amplitudes (shifted always to higher frequencies compared to A_{max}) we shall denote by A_1 and A_2. The pattern of their mutual relations, namely A_{max}/A_1 and A_{max}/A_2, invariably displayed a notoriously growing tendency with increasing string tension, see Fig. 3. It clearly indicated that with increasing tension the sounded strings radiated more and more monochromatic signals; other secondary maxima in the pulse spectra (e.g. A_1 and A_2) disappear or diminish while the maximum spectral component grows.

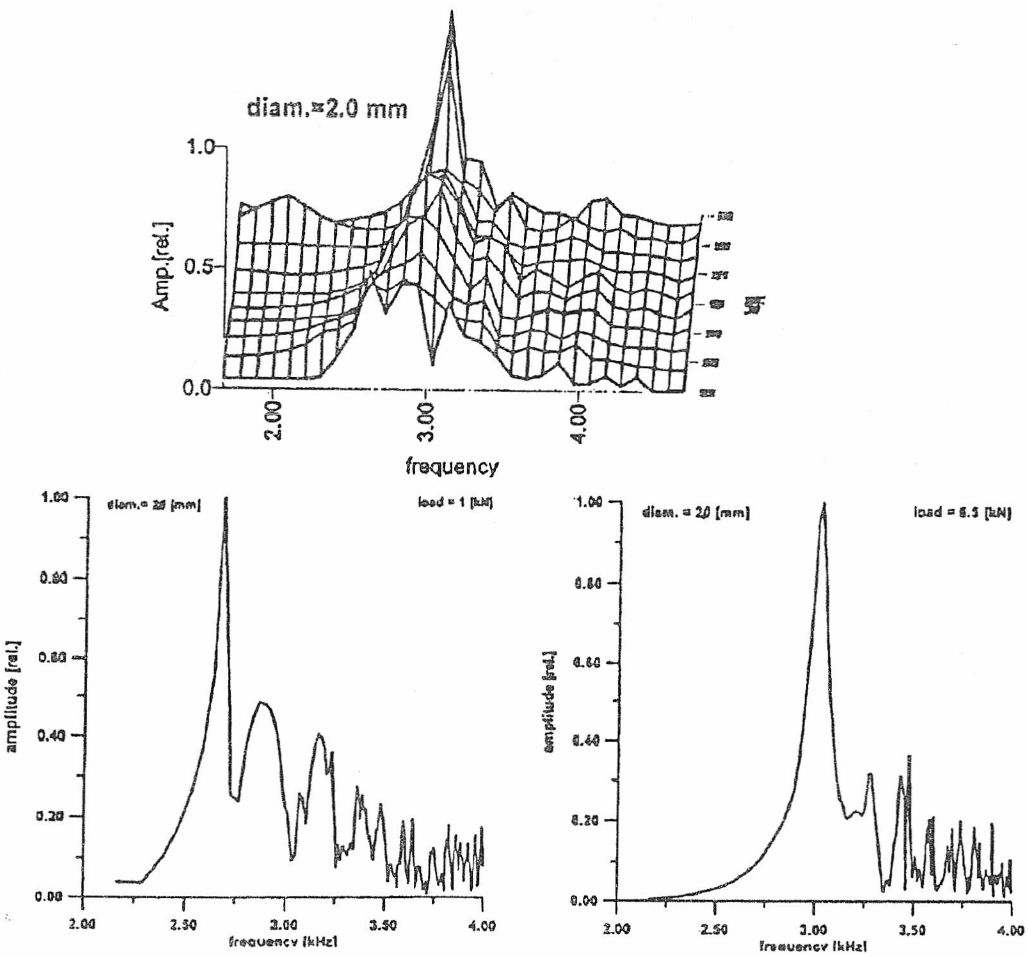

FIG. 3. Amplitude changes in the spectra for treated strings of a diameter $d = 2$ mm sounded for 10 tension values level (top). These spectra are shown in the picture bottom for a minimum tensile load (1 kN) and for a maximum tension level (6.5 kN).

3. DISCUSSION

On the one hand, the above experiments could be interpreted as a confirmation of non–linear processes in structures loaded by tension. On the other hand, however, an extrapolation of the physical relations obtained by Aksenov et al. on rock samples under biaxial compression can hardly by extended also to "negative compression", i.e. to tension loading.

First, the rock samples of a composite character radiating natural impulses under compression differ considerably from quasi–homogeneous steel strings which had to be artificially sounded by external impact to produce elastic waves. Further, it is well known that the tension strength of rock is much lower than that of steel. Moreover, the treated strings were loaded by pure uniaxial tension in contrast to rock samples by Aksenov et al. which were – expect for uniaxial compression

– loaded also by confining pressure which is believed to be responsible for the occurrence of non-linear processes. However, the first results obtained from the recent measurement with steel strings indicate that a kind of selforganizing or a certain degree of non-linearity could exist even in structures loaded by tension. More experiments will have to be conducted to prove or disprove this idea.

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