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ACOUSTIC EMISSION ACCOMPANYING STABILITY LOSS OF COMPRESSED RODS

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1. Introduction

In metal rod structures more than 90% of failures are caused by different forms of stability loss of elements. From the point of view of effects of stability loss, rod structures can be divided into two groups:

Group 1, in which the stability loss of a single element in the system causes a stability loss of the system. This concerns rod frame systems and grids which contain rods compressed in minimal critical sets of size 1 [1], and therefore it also concerns all statically determinable structures.

Group 2, in which a stability loss of single elements (or local stability loss in surface structures) does not cause exhaustion of the structure load bearing capacity. This concerns a considerable number of statically indeterminable structures known from load bearing capacity reserves in extracritical state. In such cases, a new statical form of the structure equilibrium occurs after stability loss which gives an opportunity to save it. A particular significance of protection against overload occurs in large excavators [2].

In real rods classical stability loss does not occur due to geometrical imperfections which decrease the critical load bearing capacity of rods (and also shells). The more geometrical imperfections are in the rod, smaller is its load bearing capacity, and acoustic signals are to be expected under a smaller load.

In the same rod systems imperfections of fixing and fixing through friction occur, as well as change in conditions of fixing throughout loading which is accompanied by a change of static friction into kinematic.

It should be added that friction has a considerable influence on the critical load bearing capacity of compressed rods fixed in joints [5, 6].

A stability loss of single rods in the elastic area in the elastic-plastic area is qualitatively different, and therefore a change in characteristics of acoustic emission is to be expected together with a change in the slenderness of the investigated rods.

From the initial investigation it is possible to predict on the basis of EA the degree of the danger of a structure caused by a stability loss, and also it is possible to estimate the history of the structure load.

The above premises and experience from projects for industry [1] prompted the present authors to carry out an AE investigation which accompanies a stability loss of rods of different slenderness.

This paper presents the results of the investigation of acoustic emission which accompanies a stability loss of compressed rods of different slenderness made of low carbon steel of the group ST3S.

2. Experimental

Compact rods of a rectangular intersection 10 × 20 mm were investigated. Intersections were obtained by machining (milling and grinding) from steel flat bars made of low-carbon steel of the group ST3S with a long plastical stop.

The characteristic of steel obtained from the present authors' own investigation is as follows: Young's modulus $E = 209$ GPa, upper boundary of plasticity $R_e^g = 350.43$ MPa, lower boundary of plasticity $R_e^d = 329.6$ MPa, elastic strain boundary $\varepsilon_s = 1.600\%$, plastic strain boundary $\varepsilon_{pl} = 1.875\%$ corresponding to the upper plasticity boundary, Poisson's elastic coefficient $\nu = 0.292$.

An inventory of the geometry of the investigated rods was made. Deviations from the straight line axis of the rod was measured. It was described by the terms from Fourier's series [5]. Rods of nominal slenderness 50, 75, 100, 150 three pieces of each range of slenderness, were tested.

Rods were fixed in the hydraulic gripping jaws of the testing machine MTS, the investigated models of rods being rigidly fixed.

The testing machine controlled by a computer made it possible to carry out the tests when the rod ends were mutually displaced longitudinally by the computer (axial shortening Δl). The displacement rate was 0.05 mm/s for slender rods ($\lambda = 50, 75$)and 0.025 mm/s for slender rods ($\lambda = 100$ and 150), and it approached the lower limit of possible rates of displacement in order to obtain quasi-static load.

The hydropulsating testing machine manufactures by the MTS Company (ASSY system No.921.06–01) is a PDP–11/04 computer-controlled machine with an operating memory of 16kb with the attached soft-disc station (8") and a copier.

In the analog part controlled by the machine, it is possible 1) to choose the control factor (force, displacement or strain), 2) to choose the length interval of a given factor, e.g., the smallest range 0–25 kN, or the greatest range 0–250 kN for force, 3) to introduce the value limits of the factor in order to protect the tested element from destruction. The theoretical accuracy of the machine is 0.024 mm for displacement in the range 0–50 mm. On account of the level of electronic noises in the control system, the actual accuracy is estimated to be 2/2047 of the maximum value of a chosen range. The parameters of acoustic emission were measured with an analyzer of acoustic emission

EA-3 produced by IPPT in Warsaw, which was coupled an IBM computer by an interface. The density of AE countings and the momentary values of the RMS parameter of the acoustic emission signal were measured. A piezoelectric transducer of a resonance frequency of 500 kHz and counting range 0.1 s was used.

One free channel of the acoustic emission analyzer was used in order to make a simultaneous measurement of the longitudinal force acting on the investigated rod. The axial force which corresponds to the controlled mutual shortening of the length between the rod ends was automatically digitally recorded during the tests.

A set of procedures written with the help of a TURBO PASCAL compiler version 4 was used for recording and processing of measurement data.

The program PIZAZZ of the Application Techniques Inc. was used to transfer the graphs to the printer. The above-mentioned procedures and programs were developed and tested by Z. RANACHOWSKI of IPPT in Warsaw [4].

3. Results

Using the procedures [4] of visualization of the experimental data, the results of the investigation for the particular tests from no.3 to no.15 are graphically presented. For example, Fig. 1 shows the course of counting density in the function of time *s*, elongation Δl and static equilibrium path $F(\Delta l)$ for test no.4 ($\lambda = 50$). Plot $F(\Delta l)$ was recorded by the testing machine which controlled displacement Δl. Figure 2 shows analogously the course of the power parameter RMS in the function *s* and Δl for test 4 ($\lambda = 50$), on which the plot $F(\Delta l)$ was also superimposed. Figure 3 shows the counting density with summing in the function *s* and Δl for test 4 ($\lambda = 50$). Figure 4 shows the course of a power parameter RMS with summing in the function *s* and Δl for test no.4 ($\lambda = 50$). In Figs. 3 and 4 we see a synchronized plot of force $F(\Delta l)$ – SEP. Some coordinates of the static equilibrium path SEP and characteristics *AE* have an essential significance for the signalization of the loss of load carring capacity of structural elements.

Tables 1 through 4 contain the maximal coordinates (s, n), (s, P), (s, RMS), $(s, \max \sum N)$ of the investigated rods denoted * in Fig. 1 through 4.

4. Discussion of the investigation results

It follows from an analysis of the coordinates contained in Tables 1 through 4 that there occurs displacement between the coordinates of maxima of the static equilibrium path SRS and maxima of the AE characteristics. Displacement of the maxima of AE characteristics in relation to the coordinates of limit load bearing capacity of a rod calculated from the formula (1) is shown in Table 5

$$\Delta\overline{S} = \overline{S}_i - \overline{S}_{gr} \tag{1}$$

It follows from an analysis of the results contained in Table 5 that there occurs a delay in peaks in the course of counting density and in the course of RMS, and also in

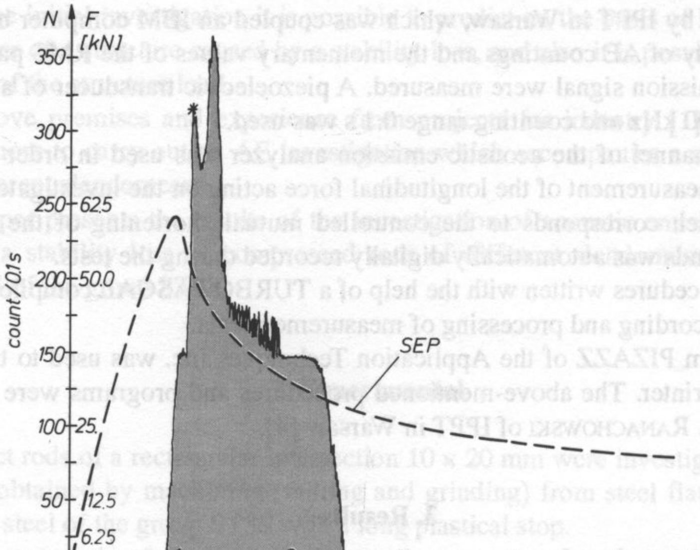

FIG. 1. Course of counting density for test 4 ($\lambda = 50$).

FIG. 2. Course of the power parameter RMS for test 4 ($\lambda = 50$).

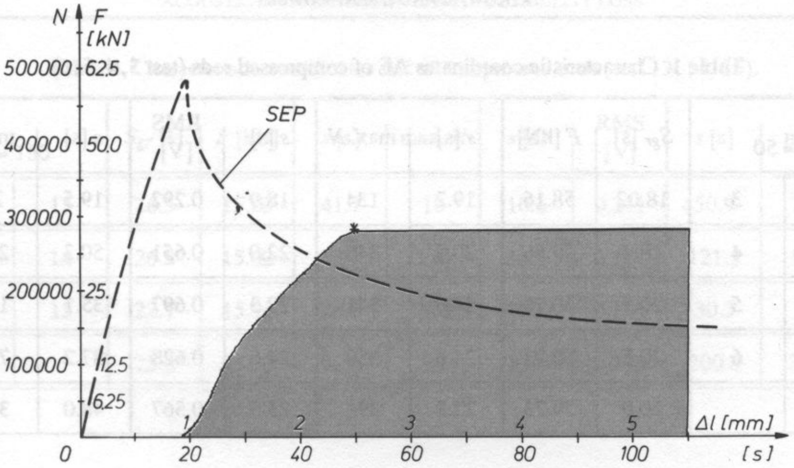

FIG. 3. Course of counting density for test 4 ($\lambda = 50$).

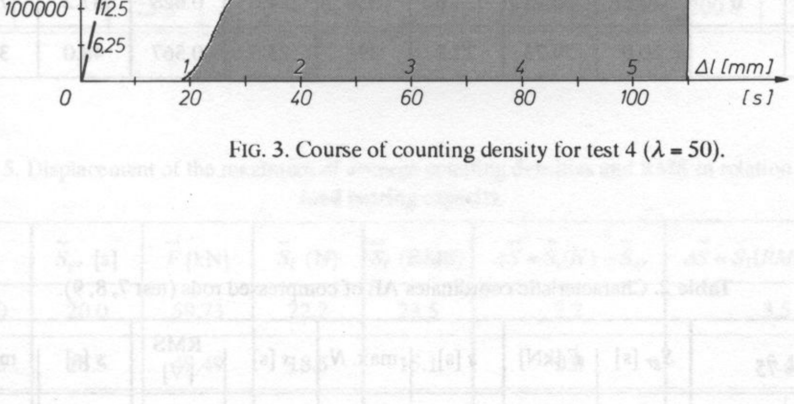

FIG. 4. Course of the power parameter RMS with summing for test 4 ($\lambda = 50$).

Table 1. Characteristic coordinates AE of compressed rods (test 3, 4, 5, 6).

$\lambda = 50$		S_{gr} [s]	F [kN]	s [s]	max. N	s [s]	RMS [V]	s [s]	max ΣN
test	3	18.02	58.16	19.2	134	18.9	0.292	19.5	21000
	4	18.4	59.66	20.4	340	22.0	0.651	50.3	282000
	5	20.7	60.10	24.6	341	28.3	0.697	35.1	198000
	6	20.7	60.98	24.6	350	24.6	0.628	87.2	721000
mid.		20.0	59.73	22.2	291	23.5	0.567	48.0	305500

Table 2. Characteristic coordinates AE of compressed rods (test 7, 8, 9).

$\lambda = 75$		S_{gr} [s]	F [kN]	s [s]	max. N	s [s]	RMS [V]	s [s]	max ΣN
test	7	17.8	48.61	14.4	3	15.1	0.199	24.8	206800
	8	21.2	53.20	21.9	82	19.2	0.220	21.9	2100
	9	16.4	49.49	19.2	147	10.9	0.574	155	678000
mid.		18.5	50.43	18.5	77	15.1	0.331	100.6	296000

Table 3. Characteristic coordinates AE of compressed rods (test 10, 11, 12).

$\lambda = 100$		S_{gr} [s]	F [kN]	s [s]	max. N	s [s]	RMS [V]	s [s]	max ΣN
	10	30.82	31.82	33.2	149	39.1	0.231	56.8	84800
	11	49.74	37.10	56.4	6	46.4	0.165	401.2	710000
	12	33.22	28.90	33.2	3	28.4	0.094	158.7	310000
mid.		37.99	32.60	40.9	53	38.0	0.163	123.4	368000

Table 4. Characteristic coordinates AE of compressed rods (test 13, 14, 15).

λ = 150		S_{gr} [s]	F [kN]	s [s]	max. N	s [s]	RMS [V]	s [s]	max ΣN
test	13	26.5	15.03	41.7	10	10.6	0.211	450.9	710000
	14	26.5	15.02	27.7	136	11.4	0.187	121.3	160000
	15	22.7	15.91	26.5	122	15.2	0.196	30.3	20000
mid.		25.2	15.32	32.0	93	12.4	0.198	200.8	330000

Table 5. Displacement of the maximum of average counting densities and RMS in relation to limit load bearing capacity.

	$\bar{S}_{gr}$ [s]	$\bar{F}$ [kN]	$\bar{S}_i$ (N)	$\bar{S}_i$ (RMS)	$\Delta S = \bar{S}_i(N) - \bar{S}_{gr}$	$\Delta S = \bar{S}_1(RMS) - \bar{S}_{gr}$
λ = 50	20.0	59.73	22.2	23.5	2.2	3.5
λ = 75	18.5	49.49	18.5	15.1	0.0	-3.4
λ = 100	37.9	32.60	40.9	38.0	3.0	0.1
λ = 150	25.2	15.32	32.0	12.4	6.8	-12.8

the counting density with summing in the relation to the limit load bearing capacity of compressed rods.

Classical AE characteristics cannot be obtained from the known AE analyzers and cannot be used for predicting the safety of structures containing compressed rods.

It follows from an analysis of the relations between the abscissas of the maxima of the static equilibrium path SEP and the maxima of acoustic emission characteristics that it is possible to forecast a stability loss on the basis of the rate of the increase in the peaks of counting density. Therefore, it is possible to make warning signalization against the stability loss of structure by means of an additional, digital processing of data from the analyzer AE according to the above-given idea, or it is possible to build a special analyzer to accomplish this purpose.

A more precise analysis requires the development and implementation of analytic programs based on a correlational spectrum analysis, nonstationary stochastic process, or to build new analyzers. The investigation aimed at advances techniques of measurement and processing of signals AE is carried out by the present authors.

5. General conclusion

Exhaustion of the load bearing capacity of compressed rods is accompanied by a change in the value of AE characteristics.

The investigation results obtained indicate that there is a possibility of using AE in practice to monitor the hazard of structures susceptible to buckling and which gives an opportunity to save the structure. It requires the introduction of additional AE characteristics. It will be the subject of a separate publication.

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