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ORIGINAL RESEARCH PAPER

THE EFFECT OF LOADS SUPERPOSITION ON TECHNICAL STRUCTURES, ENVIRONMENT AND LIVING ORGANISMS

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Abstract: The current state of calculation the result of the superposition of loads, or their effects, on a material body is analyzed. The limits of the current calculation methods, based on strength theories, in the case of technical structures are shown. The results of experimental research that refer, in general, to the superposition of two loads of the same nature and without addressing problems of loads of a different nature (mechanical, chemical, electrical, magnetic, radioactive etc.), in the case of technical structures and the environment is analyzed.
Starting from the principle of critical energy, which is based on the concepts of the total specific energies' participation of the loads and of the critical participation, general relations are deduced for these concepts, in the case of the nonlinear behavior of matter, as a function of power. These results are applied to the calculation of the superposition of loads of different nature on a technical structure, the environment and living organisms, taking into account the deterioration of matter. The influence of the loading speed (static, shock ...) is taken into account based on the value of the exponent in the behavior law, which was not possible in the previous calculation methods. From the analysis of the results obtained in the paper, it is found the utility and the high degree of generality of the principle of critical energy and of the concept of the specific energy participation.

Keywords: *critical participation, deterioration of matter, loads, principle of critical energy, specific energy participation*

INTRODUCTION

A material body of given geometry, or a delimited part of the environment, can be exposed to one or more actions. These, subsequently referred to as loads, may be of the same nature but of different types, or of a different nature. Also, they can be permanent, or temporary. The temporary ones can be of short duration, accidental or of a shock nature.
The main effect of a load may be of the same nature as the load or of a different nature.
In the case of a single stress S, with a single main effect, the condition of preserving the integrity of the material body results from the relation $S < S_{cr}$, where S_{cr} is the critical value of the load in the analyzed case. If $S \geq S_{cr}$, the material body goes through excessive deformation or is destroyed. In the case of the environment or living organisms S_{cr} means destruction, excessive toxicity etc.
To avoid such situations, it is practically required that $S \leq S_{al}$, in which S_{al} is the allowable load, calculated as a function of the critical load, $S_{al} = S_{cr}/c_S$, where $c_S > 1$ is the safety coefficient in relation to the critical state.
If a material body is simultaneously or successively exposed to several loads, the previous relations are not sufficient. This is the case of multiple pollution of the environment with pollutants of the same or different nature, or of the living organism suffering from several diseases (comorbidities), or of technical structures subject to multiple loads.

MATERIALS AND METHODS

The problem of superposition loads/effects

The problem of superposition loads, or the superposition of the effects of loads, is encountered in all chapters of science. In general, this kind of problem is evaluated experimentally in the case of the application with only two loads.
Empirical results of superposition only two distinct loads have been obtained [1 – 10]. Research has highlighted the effects of the superposition of the following mechanical stresses: bending and pressure [2], external pressure and axial tension [3], compression and bending [4], bending and shearing [5], shearing and torsion [6], biaxial loading [7]. Also, experimental results were obtained for some mechanical fatigue stresses under creep conditions [8, 9].
In only a few cases there are theoretical solutions to this problem. For example, in Mechanics of Deformable Solid and Strength of Materials it is calculated: - *equivalent stress of the effects* (stresses on the principal directions) caused by an external load; - *equivalent load* induced by a bending moment and a torsional moment or *equivalent stress* induced by a normal stress and a torsional stress. Only that!
These equivalent quantities are calculated based on strength theories. Since each strength theory relies on a distinct concept, in different units of measurement (maximum normal stress, strain, tangential stresses, total strain energy, shape variation energy), the expressions of equivalent stresses differ. The choice of a particular strength theory for practical calculations is based on some experimental observations, introducing a certain subjectivity into the decision-making process of the engineer or designer of a technical structure.

The method of equivalent stresses, based on classical strength theories, is applied only to materials with linear-elastic behavior. Consequently, it is not permitted for the equivalent stress to exceed the elasticity limit or, by convention, the yield stress ($\sigma_{ech} \leq \sigma_Y$).

- The *single-load condition* is considered first. For example, a thick-walled body subjected to internal pressure, p_i. The pressure generates in the body (on the main directions, θ; z; r) main stresses σ_θ, σ_z, σ_r. These are the *effects of the load*.

The strength condition *for loading* is expressed as,

$$p_i \leq p_{i,al} \tag{1}$$

where $p_{i,al}$ is the allowable internal pressure. The strength condition *for* the *effect of loading* is,

$$\sigma_{ech} \leq \sigma_{al} \tag{2}$$

in which σ_{ech} is the equivalent stress, calculated with one of the strength theories and σ_{al} – allowable stress for the material from which the thick-walled body is constructed.
In general, relation (2) is used in design, which is based on the effects of loading. For example, according to the theory of maximum tangential stress (Coulomb, Guest, Tresca),

$$\sigma_{ech} = \sigma_{max} - \sigma_{min} \tag{3}$$

Since in the analyzed case $\sigma_\theta > \sigma_z > \sigma_r$, means that the maximum stress $\sigma_{max} = \sigma_\theta$ and the minimum stress $\sigma_{min} = \sigma_r$. Result,

$$\sigma_{ech}(p) = \sigma_\theta - \sigma_r \tag{4}$$

When simultaneously loaded with a bending moment M_b, which produces the maximum normal bending stress σ_b, and with a torsional moment M_t, which produces the maximum tangential stress τ_t, according to the theory of the maximum tangential stress [11], it results:

- the equivalent bending moment,

$$M_{b,ech} = (M_b^2 + M_t^2)^{\frac{1}{2}} \tag{5}$$

- the equivalent bending stress,

$$\sigma_{b,ech} = (\sigma_b^2 + 4 \cdot \tau_t^2)^{\frac{1}{2}} \tag{6}$$

This is the only case of calculating the effect of simultaneous loading with two different loads, namely of the same nature (mechanical) but of different types. Strength theories do not allow the calculation of the equivalent stress in the case of stresses of a different nature (mechanical, chemical, electromagnetic, thermal etc.).
Relation (6) can, however, be extended to the situation where the normal bending stress is replaced by a normal stress produced by:

- an axial force, F,

$$\sigma_{F,ech} = (\sigma_F^2 + 4 \cdot \tau_t^2)^{\frac{1}{2}} \tag{7}$$

- internal pressure, p_i,

$$\sigma_{p,ech} = \left(\sigma_p^2 + 4 \cdot \tau_t^2\right)^{\frac{1}{2}} \tag{8}$$

where σ_F = F/A is the axial stress produced by the axial force F on the transverse surface A and σ_p is the circumferential normal stress produced by the internal pressure.

- In the Mechanics of Rigid Bodies, the superposition of the loads of certain forces F_i is done by summing the vectors of these forces, according to *the principle of the independence of the actions of the forces* [12]: "*If several forces acts simultaneously on a body, each force produces its own acceleration independently of the other forces, the resulting acceleration being the vector sum of the individual accelerations*".
- In Mechanics of Deformable Solids, with linear behavior, of general form,

$$Y_i = C \cdot X_i \tag{9}$$

in which Y_i is the load, X_i – the effect of the load, C – a constant of the material under load, the total effect of the superposition of the loads is obtained by algebraic summation of the individual effects,

$$X_T = \sum_i X_i \tag{10}$$

The relation (10) expresses the essence of the *classical principle of superposition* according to which [13], "for *a linear system the net response caused by two or more loads is equal to the sum of response caused by each load individually*".

This principle and therefore relation (10) can *only be used if* the effects X_i are of *the same nature and are measured with the same units of measurement*.

Currently, the superposition of loads of different natures is possible by resorting to the concept of *specific energy participation*, a dimensionless concept introduced by *the principle of critical energy* [14 – 16]. Based on this, problems regarding the superposition of loads from any chapter of science and engineering design can be solved, in the general case of considering the nonlinear behavior of matter.

The principle of critical energy and the specific energy participation

According to the principle of critical energy [16], "*In the development of a phenomenon or process, some critical state is reached when the total specific energies participation of action becomes equal or higher to the critical participation*".

The total specific energies participation is

$$P_T = \sum_i P_i \tag{11}$$

where P_i it is the specific energy participation of the load Y_i,

$$P_i = \frac{E_{S,i}}{(E_{S,i})_{cr}} \cdot \delta_i \tag{12}$$

a dimensionless quantity.

In the relationship (12), $E_{s,i} = E_i/V$. It is the specific energy introduced into the material body by load Y_i, which transfers the volume V of the body, the energy E_i. From the point of view of the analyzed process/phenomenon, $(E_{s,i})_{cr}$ is the critical specific energy corresponding to the interaction between the material body and load Y_i.

The factor δ_i = 1 if Y_i acts in the direction of the development of the process/phenomenon and δ_i = -1 otherwise.

In the case of nonlinear behavior of the material body under the action of the load Y_i,

$$Y_i = C_i \cdot X_i^{k_i} \tag{13}$$

where X_i is the effect produced; C_i and k_i – material constants.

From relations (11)-(13) results the total specific energies participation in relation to the critical state,

$$P_T = \sum_i \left(\frac{Y_i}{Y_{i,cr}}\right)^{\alpha_i+1} \cdot \delta_i \tag{14}$$

where $Y_{i,cr}$ is the critical value of load Y_i in the analyzed case and $\alpha_i = 1/k_i$.
In general [4 – 6], the value of α_i depends on the load rate ($v_Y = dY/dt$). For static loading $\alpha_i = 1/k_i$, while for shock loading $\alpha_i = 0$. For linear behavior $k_i = 1$.
The specific energies participations in the case of nonlinear behavior, as a function of power (13), being dimensionless quantities, can be algebraically summed, although the total effect X_T is different from the algebraic sum of the individual effects ($X_T \neq \sum_i X_i$).
In the following, the use of the specific energy participation concept is exemplified in three different cases: - technical structure exposed to loads of different nature; - multiple pollution of the environment; - living organism with comorbidities.
According to the principle of critical energy, the critical state is reached when [15]

$$P_T(t) \geq P_{cr}(t) \tag{15}$$

where $P_{cr}(t)$ is the critical participation (dimensionless quantity), dependent on time, matter and its deterioration. The loading is not critical if,

$$P_T(t) < P_{cr}(t) \tag{16}$$

Where, in general [16],

$$P_{cr}(t) = \begin{cases} P_{cr}(0) \text{ - for undeteriorated structure;} \\ P_{cr}(0) - D_T(t) - P_{ase} + P_{tr}(t) \text{ - for living organisms;} \\ P_{cr}(0) - D_T(t) \text{ - for the environment and deteriorated, structures,} \end{cases} \tag{17}$$

where $P_{cr}(0)$ is the critical participation at t = 0. Generally $P_{cr}(0) \in [P_{cr,min}(0); P_{cr,max}(0)]$, with $P_{cr,min}(0) > 0$ and $P_{cr,max}(0) \leq 1$.
$P_{cr}(0) = 1$ – if one considers a unique, deterministic value of the each physical characteristic involved in the process, or in the case of natural phenomena.
$D_T(t)$ is the total deterioration at time *t*,

$$D_T(t) = \sum_k D_k(t) \tag{18}$$

Deterioration $D_k(t) \in [0;1]$ is a dimensionless variable. $D_k(t) = 0$ for undeteriorated structure/environment/living organisms, $D_k(t) = 1$ if the structure/environment/living organism is damaged/unusable/is dead.
The deterioration may be due to: – *external actions* like mechanical forces, electric current, chemical pollution, radioactive pollution, ultrasounds, electromagnetic radiation, viruses, bacteria, toxins etc.; – *internal imbalance* in the case of living organisms from lack or insufficiency of some important internal components of the living organism (like nutrients, vitamins, etc.).
In the case of living organisms: – the adaptive – adjustment specific energy participation (through homeostasis) is denoted $P_{ase}(t)$ – a time dependent *t*, dimensionless variable; – $P_{tr}(t)$ – medical treatment specific energy participation, time dependent dimensionless variable; it may help to increase the organism resistance.
If the limit state is considered the allowable state, then it is necessary that,

$$P_T^*(t) \leq P_{al}(t) \tag{19}$$

where $P_T^*(t)$ is calculated with relation (14) with respect to the allowable state at a given time *t* (it is replaced $Y_{i,cr}$ whith $Y_{i,al}$) and P_{al} is the allowable participation dependent on time *t,* and dimensionless [13 – 16].

- Based on relations (16), (17) and (19), relationships were obtained for the critical and allowable loads with consideration of the influence of total damage, $D_T(t)$ [17 – 21]:

- the critical load of the deteriorated material,

$$Y_{cr}(D;t) = Y_{cr}(t) \cdot [1 - D_T(t)]^{\frac{1}{\alpha+1}} \tag{20}$$

- the allowable load of the deteriorated material,

$$Y_{al}(D;t) = Y_{al}(t) \cdot [1 - D_T(t)]^{\frac{1}{\alpha+1}} \tag{21}$$

in which $Y_{cr}(t)$ and $Y_{al}(t) = Y_{cr}(t)/c_Y$ are the critical and allowable load respectively for the undamaged material and $c_Y > 1$ – the safety coefficient in relation to the critical state.

The actual load Y(t) at time *t* must satisfy the condition,

$$Y(t) \leq Y_{al}(D;t) \tag{22}$$

If $Y(t) \geq Y_{cr}(D;t)$ excessive deformation or breaking of the technical structure occurs, the death of the living organism, or the environment becomes "toxic", dangerous or unusable.

RESULTS AND DISCUSSION

Technical structure subjected to various types of loads

It is considered a joint 1 of a pipe 2, subjected to the internal pressure p_i, with the bending moment M_b and the torsional moment M_t, under creep conditions and in a corrosive environment (Figure 1).

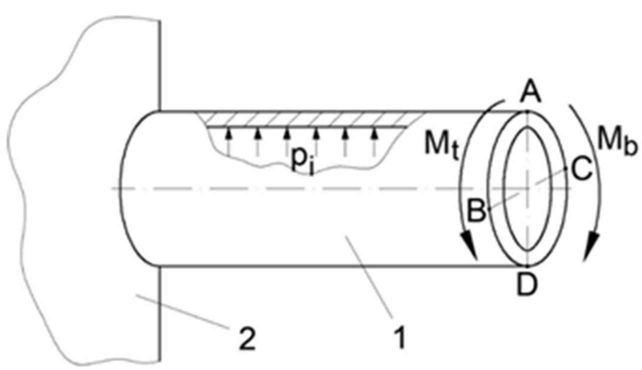

Figure 1. *Joint 1 of pipe 2, subjected to internal pressure, p_i, bending moment, M_b and torsional moment, M_t*

To the three mechanical loads are added the thermal stress at a temperature higher than the creep temperature and a chemical load, corrosion.

The general case of the nonlinear behavior, as a function of power, of the joint material (13) is considered. The specific energies participations of the three mechanical loads result through particularizations from the general relation (14), by replacing Y_i in turn, with p_i, M_b and M_t:

$$\left.\begin{aligned} P(p_i) &= \left(\frac{p_i}{p_{i,cr}}\right)^{\alpha+1} \\ P(M_b) &= \left(\frac{M_b}{M_{b,cr}}\right)^{\alpha+1} \cdot \delta_b \\ P(M_t) &= \left(\frac{M_t}{M_{t,cr}}\right)^{\alpha+1} \end{aligned}\right\} \tag{23}$$

where the critical quantities $p_{i,cr}$, $M_{b,cr}$ and $M_{t,cr}$ have the following meaning: each of them, individually, can destroy/break the joint 1. The factor $\delta_b = 1$ – at generators above section BC and $\delta_b = -1$ at generators below section BC.

In creep conditions, the specific strain increases slowly over time, t, in the stabilized creep region, extending up to time t_c. The specific energy participation under creep conditions is [15],

$$P(T) = \frac{t}{t_c} \tag{24}$$

where $t < t_c$ and T – temperature higher than the creep temperature.

The material's potential energy lost through corrosion is directly proportional to the duration *t* of corrosion. The specific energy participation corresponding to corrosion has the expression [17],

$$P(t_{cr}) = \frac{t}{t_{cs}} \tag{25}$$

where t_{cs} is the duration corresponding to the corrosion of the pipe throughout the thickness.

The total specific energies participation, according to relation (14) is,

$$P_T(t) = \left(\frac{p_i}{p_{i,cr}}\right)^{\alpha+1} + \left(\frac{M_b}{M_{b,cr}}\right)^{\alpha+1} \cdot \delta_b + \left(\frac{M_t}{M_{t,cr}}\right)^{\alpha+1} + \frac{t}{t_c} + \frac{t}{t_{cs}} \tag{26}$$

For a joint without damage, where the critical quantities are deterministic quantities ($P_{cr}(0) = 1$), critical participation is $P_{cr}(t) = 1$.

With this clarification, from relations (15) and (26) we obtain the expression of the duration until reaching the critical state of the joint, corresponding to $\delta_b = 1$,

$$t = \frac{1-\left[\left(\frac{p_i}{p_{i,cr}}\right)^{\alpha+1} + \left(\frac{M_b}{M_{b,cr}}\right)^{\alpha+1} + \left(\frac{M_t}{M_{t,cr}}\right)^{\alpha+1}\right]}{\frac{1}{t_c}+\frac{1}{t_{cs}}} \tag{27}$$

If the joint has a defect or a crack, then $P_{cr}(t) = 1 - D_T(t) < 1$, in which $D_T(t)$ is the deterioration. In this case, the duration until reaching the critical state becomes,

$$t(D) = \frac{[1-D_T(t)]-\left[\left(\frac{p_i}{p_{i,cr}}\right)^{\alpha+1} + \left(\frac{M_b}{M_{b,cr}}\right)^{\alpha+1} + \left(\frac{M_t}{M_{t,cr}}\right)^{\alpha+1}\right]}{\frac{1}{t_c}+\frac{1}{t_{cs}}} \tag{28}$$

It follows that in the presence of damage the time to reach the critical state decreases.
In the case of materials with linear-elastic behavior, k = 1 is replaced in relations (23), (26)-(28) and consequently $\alpha = 1/k = 1$.

Pollution of the environment with pollutants of different nature

Determine the total effect of environmental pollution if it is subjected to the simultaneous action of three chemical substances with concentrations $C_1(t)$, $C_2(t)$ and $C_3(t)$, the action of a radiation flux $\phi(t)$ and the action of some particles in suspension PM2.5.
The nonlinear behavior of the environment in relation to the action of pollutants is considered, according to the power function law (13), where Y_i is either the concentration $C_i(t)$, or the radiation flux $\phi(t)$, or the mass $m_{2.5}$ of particles PM2.5.
The specific energy participation introduced into the environment by each pollutant is of the form of the relationship (14), namely:

$$\left.\begin{aligned} P(C_i) &= \left(\frac{C_i(t)}{C_{i,cr}}\right)^{\alpha_{c_i}+1} \\ P(\phi) &= \left(\frac{\phi(t)}{\phi_{cr}}\right)^{\alpha_\phi+1} \\ P(PM2.5) &= \left(\frac{m_{2.5}}{(m_{2.5})_{cr}}\right)^{\alpha_m+1} \end{aligned}\right\} \tag{29}$$

Consequently, the total specific energies participation introduced locally in the environment is

$$P_T(t) = \left(\frac{C_1}{C_{1,cr}}\right)^{\alpha_{C_1}+1} + \left(\frac{C_2}{C_{2,cr}}\right)^{\alpha_{C_2}+1} + \left(\frac{C_3}{C_{3,cr}}\right)^{\alpha_{C_3}+1} + \left(\frac{\phi(t)}{\phi_{cr}}\right)^{\alpha_\phi+1} + \left(\frac{m_{2.5}}{(m_{2.5})_{cr}}\right)^{\alpha_m+1} \tag{30}$$

In relations (29) and (30) the denominators represent the critical values of the respective pollutant, i.e. that value of the pollutant that alone produces the dangerous pollution. The exponents in these relations may or may not be different. This depends on the interaction of the pollutant with the environment, but also on the rate of size variation that characterizes the pollutant ($v_C = dC_i/dt$; $v_\Phi = d\phi/dt$; $v_m = dm_{2.5}/dt$).
In the case of the linear behavior of the environment in relation to the pollutants, the exponents $\alpha_{Ci} = 1$, $\alpha_\phi = 1$ and $\alpha_m = 1$.
The specific energies participation $P_T(t)$ is compared to the critical participation according to relations (15) and (16), where $P_{cr}(t)$ is according to relation (17). For the undamaged environment prior to the time when the calculation is made, $D_T(t) = 0$.

Superposition of loads in the case of living organisms

The superposition of loads in living organisms have some aspects that differ from non-living matter [22 – 24].
Harmful effects on living matter can be produced by some *external factors*, such as: viruses, bacteria, pollutants, ultrasound, infrared ionizing radiation, toxins, stress etc.
On the other hand, some *internal imbalances* (small, insufficient concentration of some vitamins, nutrients, trace elements etc.) reduce the body's resistance to external actions.
The *external factors* that load the organism are introduced in the relation of the total specific energies' participation (14).

The *internal factors*, the internal imbalances, determine the damage to the organism and will be introduced into the total damage relation $D_T(t)$, according to the relation (18) and finally into the critical participation relation.

The critical participation in the case of living organisms (the second relation (17)) contains two terms specific to them, namely, $P_{ase}(t)$ and $P_{tr}(t)$. Through them, the body's resistance can be increased, which translates into increasing the value of critical participation.

For example [24], a monkey injected with a certain amount of poliomyelitis virus, $m_{p,cr}$, got polio, while injected with an amount $m_p < m_{p,cr}$, did not get sick. Subjected to a stress of intensity S_{cr}, the monkey died, while if the stress $S < S_{cr}$, the monkey did not die.

The question arises: what will happen to the monkey if it is simultaneously subjected to the action of the poliomyelitis virus $m_p < m_{p,cr}$ and to a stress of intensity $S < S_{cr}$?! Because the amount of virus administered and the intensity of the stress have different units of measurement, they cannot be summed.

If the virus and the stress act simultaneously, the result is evaluated by calculating the total specific energies participation corresponding to them. It is considered the general case where the interaction between the body and its loads is nonlinear, a power function (13). According to the general relation (14) it follows [24],

$$P_T = \left(\frac{m_p}{m_{p,cr}}\right)^{\alpha_p+1} + \left(\frac{S}{S_{cr}}\right)^{\alpha_S+1} \tag{31}$$

in which $\alpha_p = 1/k_p$ and $\alpha_S = 1/k_S$, where k_p and k_S have the meaning of the exponent k_i from the general law (13).

P_T is compared to $P_{cr}(t)$. If $m_{p,cr}$ and S_{cr} etc. have personalized values for each individual (taking into account age, antecedents, current state of health etc.), then $P_{cr}(t)=1$ can be accepted.

On the other hand, if the poliomyelitis virus acts slowly, while the stress acts by shock, instead of the relation (31) the following expression is used:

$$P_T = \left(\frac{m_p}{m_{p,cr}}\right)^{\frac{1}{k_p}+1} + \frac{S}{S_{cr}} \tag{32}$$

because in case of shock $\alpha_S = 0$.

If an amount of drug m_d is administered that opposes the action of the virus, then the critical participation increases, according to the second relation (17),

$$P_{cr}(t) = 1 - D_T(t) + \left(\frac{m_d}{m_{d,cr}}\right)^{\alpha_m+1} \tag{33}$$

where m_d is the amount of drug administered, $m_{d,cr}$ – the critical value of m_d and $\alpha_m = 1/k_m$ where k_m has the meaning of k_i from relation (13). The participation of adaptive self-regulation was neglected.

If the monkey's body was not damaged before the loading with the polio virus and the load S, then $D_T(t) = 0$ and

$$P_{cr}(t) = 1 + \left(\frac{m_d}{m_{d,cr}}\right)^{\alpha_m+1} \tag{34}$$

If $P_T > P_{cr}(t)$ – the monkey will die, while if $P_T < P_{cr}(t)$ the monkey will live!

The way to evaluate the loads of a certain living organism (P_T) and the resistance of a living organism ($P_{cr}(t)$), can be done by extending the calculation method presented.
Consider as an example a living organism in a radioactive environment with Radon, subjected to a flux of electromagnetic radiation $\phi_{em}(t)$, nitrogen dioxide, NO_2, of concentration C_{NO_2}, sulfur dioxide, SO_2, of concentration C_{SO_2} and a virus with mass m_v.
The behavior of the living organism in the interaction with various pollutants is considered nonlinear, according to the general law (13). The total specific energies participation of the pollutants is calculated based on the general relationship (14), where:

- the specific energy participation of Radon is,

$$P(Rn) = \left(\frac{A(t)}{A_{cr}(t)}\right)^{\alpha_R+1} \tag{35}$$

where *A(t)* is the Radon activity at time *t*, and $A_{cr}(t)$ is the critical Radon activity at time *t*. The exponent $\alpha_R=1/k_R$, where k_R has the role of k_i in the general behavior law (13);

- the specific energy participation of the electromagnetic flux is calculated with the second relation (29),

$$P(\phi) = \left(\frac{\phi_{em}(t)}{(\phi_{em}(t))_{cr}}\right)^{\alpha_\phi+1} \tag{36}$$

where the denominator represents the critical value of the electromagnetic flux;

- the specific energy participation of nitrogen dioxide has the expression,

$$P(NO_2) = \left(\frac{C_{NO_2}}{\left(C_{NO_2}\right)_{cr}}\right)^{\alpha_N+1} \tag{37}$$

where the denominator represents the critical value of the nitrogen dioxide concentration and the exponent $\alpha_N=1/k_N$, where k_N has the meaning of k_i in the relationship (13);

- the specific energy participation of sulfur dioxide, SO_2, is calculated with the relation,

$$P(SO_2) = \left(\frac{C_{SO_2}}{\left(C_{SO_2}\right)_{cr}}\right)^{\alpha_S+1} \tag{38}$$

where the denominator represents the critical value of the sulfur dioxide concentration and $\alpha_S=1/k_S$, in which k_S it has the role of k_i in the relationship (13);

- the specific energy participation of the virus present in the body and having the mass m_v is similar to that of the relation (31),

$$P(m_v) = \left(\frac{m_v}{(m_v)_{cr}}\right)^{\alpha_v+1} \tag{39}$$

in which $m_{v_{cr}}$ is the critical mass of the virus for that organism. The mass m_v is expressed per mass unit of the attacked organism. Exponent $\alpha_v=1/k_v$ where k_v is similar to k_i in the relation (13).
The total specific energies participation of the five pollutants that "load" the living organism, at a given time *t*, according to relation (14) is,

$$P_T(t) = P(Rn) + P(\phi) + P(NO_2) + P(SO_2) + P(m_v) \tag{40}$$

If condition (16) is met, the critical state of the organism is not reached. However, for reasons of safety for the organism, the condition is imposed not to exceed the allowable participation, according to the relationship (19). In the present case, the specific energies participation in relation to the allowable state results from relations (35)-(39), where the denominators are replaced by the allowable values, so that the total specific energies participation in relation to the allowable state becomes,

$$P_T^* = \left(\frac{A(t)}{A_{al}(t)}\right)^{\alpha_R+1} + \left(\frac{\phi_{em}}{(\phi_{em}(t))_{al}}\right)^{\alpha_\phi+1} + \left(\frac{C_{NO_2}}{(C_{NO_2})_{al}}\right)^{\alpha_N+1} + \left(\frac{C_{SO_2}}{(C_{SO_2})_{al}}\right)^{\alpha_S+1} + \left(\frac{m_v}{(m_v)_{al}}\right)^{\alpha_v+1} \quad (41)$$

In relation (41) the allowable quantities result from the critical quantities divided by a safety coefficient, respectively,

$$A_{al}(t) = \frac{A_{cr}}{c_A}; \quad (\phi_{em}(t))_{al} = \frac{(\phi_{em}(t))_{cr}}{c_\phi}; \quad (C_{NO_2})_{al} = \frac{(C_{NO_2})_{cr}}{c_N}; \ (C_{SO_2})_{al} = \frac{(C_{SO_2})_{cr}}{c_S};$$

$(m_v)_{al} = \frac{(m_v)_{cr}}{c_m}$, where $c_A > 1$; $c_\Phi > 1$; $c_N > 1$; $c_S > 1$ and $c_m > 1$ - are safety coefficients.

This approach allows: - the superposition of loads of a different nature, which until now was not possible; that is why, previously, each polluting agent was analyzed separately; - choosing safety coefficients with different values for each pollutant.

CONCLUSIONS

The paper analyzes the problem of superposition loads or their effects, on material bodies, with reference to technical structures, the environment and living organisms. It was found that:

- the classical principle of superposition is applicable only in the case of the linear behavior of matter and of some variables that are measured with the same unit of measure;
- for technical structures, the superposition of the effects is done with the help of strength theories, by calculating the stress or the equivalent stress;
- a number of experimental researches highlighted the result of superposition only of two different loads, for which empirical relationships were proposed;
- there are no relations for the calculation of the result of the superposition of the effects of loads of a different nature, comparable to a specified critical or allowable size, both for technical structures and for the environment or for living organisms.

By resorting to the principle of critical energy, based on the concept of specific energy participation, it is shown that it is possible to superposition the action of several loads, of the same nature or of a different nature (mechanical, thermal, electrical, magnetic, chemical, radioactive etc.). At the same time, this approach allows consideration of the critical state of each type of load, nonlinear behavior of matter, damage to the material, in general, not only that caused by cracks or defects.

The expressions for the total specific energy participation in the case of nonlinear power-dependent behavior of the matter were deduced, as well as some expressions of the individual specific energy participations.

The critical and allowable specific energies participations are defined for technical structures, the environment and living organisms. In this context, the problem of matter deterioration and the calculation of this concept is discussed. It should be noted that all the concepts used to evaluate the effect of superposition loads or their effects are dimensionless quantities, depending on the law of behavior of matter in the case of the examined load.

At the end of the paper, the general relations deduced are applied to the calculation of the superposition of loads of different nature on a technical structure, on the environment and on a living organism. These examples highlight the utility and high degree of generality of the critical energy principle and of the concept of specific energy participation introduced by this principle.

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