NATURAL DISASTERS AND STRUCTURAL SURVIVABILITY

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1. PROBLEM OF DISASTER'S PREDICTION

The term "disaster" is known to denote any environmental changes putting human lives under treat or materially deteriorating living conditions. A considerable part of disasters comprises natural calamities. These disasters can originate inside Earth (earthquakes, volcanic processes), near or on its surface (disturbance of slope stability, karsts, considerable changes in soil conditions and ground's settlements). The causes of disasters can as well be associated with a water, either at a liquid (flood, tsunami) or at a frozen state (complex or glacier avalanches), and, finally with atmospheric conditions. In many cases successions of interdependent disasters are possible, including these occurring in different media (earthquake-tsunami, earthquake-landslide, and lands-flood etc.).

The analysis of conditions associated with the onset and the development of the dangerous natural processes becomes at present the subject of both the natural research and the engineering analysis. New cities, industrial, power and other facilities are mostly erected in areas where natural calamities emerge. Environmental changes of natural or man-caused origin lead to disastrous effects in areas developed earlier, too.

It is always that the mechanisms of the dangerous natural phenomena can be represented by the direct cause-and –the effect relations. A prediction of the type, the time and the size of the expected disaster, even if practicable, can only be probabilistic. Therefore, for the analysis of the structures for the areas where natural calamities can take place the probabilistic approach and the use of the reliability theory can prove to be more efficient and necessary than in regular cases.

The level of the development of many problems concerning the comprehension of natural calamity's origination and hence, the level of the efficiency in predicting their time, conditions and the character of manifestation, as well as the development of measures for their prevention and mitigation of losses, leg behind with the practical needs of the national economy. To a certain extent, it can be accounted for by absence of common approaches to the constructing models of some natural disasters and the methods of their prediction.

To predict future events using statistical methods, we should dispose of information for rather a long time period. Practically, however, the prediction is based on limited information, due to which it is often imprecise and sometimes merely incorrect.

Prediction accuracy, however, fluctuates within a certain range, if the prediction is based on statistics alone. It implies that different methods should also be employed in prediction. For sufficiently substantiated prediction the following methods are generally used [2-6]: malty-dimensional regression analysis, theory of quantitative analysis, graph theory for error analysis, Delphi method (method of expert evaluation), and statistical analysis.

The latest research in the field of forecasting disastrous events and preventing the maximum risk and losses due to abnormal actions have shown that ever more widespread, together with the foregoing five methods, is becoming the approach based on the theory of fuzzy sets [7]. This can be accounted for by the fact that any classification, any algorithm, any rule of decision making, any model (theoretical or calculated) can be correlated with its fuzzy analogue. For example, classification implies the breakdown of a totality of elements into classes or groups of similar elements. Rigorous classification refers each element to a single definite class, whereas according to fuzzy classification it can belong to different classes depending to on certain conditions. The fuzzy classification is generally more realistic than the rigorous one. The use of the theory of fuzzy sets permits to elaborate, basing on fuzzy input data, a certain optimum solution setting applicability borders.

2. METHODOLOGICAL ASPECTS OF THE ANALYSIS

An engineering analysis proper is not aimed at evaluating of the probabilistic parameters that represent natural processes and, in theory; the engineer should obtain from experts in natural sciences properly represented statistical information. The task of the engineer is to assess, using this information, a risk associated with a particular structure, and to device measures of disaster protection of human life and property, efficient terms of the data available. In practice, however, similarly to the case of estimating disastrous wind's speed or water's pressure parameters, for example, when designing safe structures or estimating a stressed state of undisturbed soil's mass, engineers dealing with the theory of a structural analysis cannot count on obtaining the foregoing information "from the outside". Hence, an independent statistical analysis of available information is required, so that the data based on it should correspond to peculiarities involved in the engineering analysis. Moreover, sometimes it becomes necessary to describe, in terms of these peculiarities, mechanisms of natural phenomena and to reveal their quantitative characteristics determining the extent of a structural damage.

Another moment that should be born in mind is the comprehension that for not all natural disastrous effects structures can and must be designed and it is not always that engineering measures aimed to mitigating of the destructive effect of disasters can be designed and implemented. Design procedures envisaged in disregarding disastrous effects of an artificial origin. Similarly, when, for example, developing the code of design with due regard for the natural disasters one should not tackle an unsolvable problem of an analysis for all types or levels of the foregoing effects. In fact, there is nothing new about it: the same idea is employed in specifying the "assumed" seismicity for which the structures in the area are to be designed, whereas a higher-level earthquake motion is considered a "beyond-design" occurrence. Here the expected events can be classified as "design" or "beyond-design", according to the level of motion. Meanwhile, referred to "beyond-design" cases are, sometimes, entire types of events hard to predict or even quite unpredictable occurrences, as mentioned above. It needs to be said that the formal division of seismic effects upon structures and occurrences associated with them into "design" and "beyond-design" cannot be accepted, unless their consequences will be taken into account.

We know that in structural design for regular loads the term "failure" is generally used to denote a random event of realization of one of its damage states. The aim of a competent design consists in specifying of the structural parameters in a way that would exclude such failures due to design loads. In the design for natural disasters, however, the requirement of the inadmissibility of the failure in the foregoing sense can hardly be fulfilled and it should therefore be replaced by the requirement of the structural non-destructibility. Non-destructibility would imply the preservation of the main structure's member that would permit to retrofit the whole structure (building, for example). There are some types of structures or buildings, however, for which the foregoing consideration doesn't seem to be important. As far as structures whose failure presents a global threat to the environment are concerned, non-destructibility means, in this case, the prevention from the failure of structural members that contain or emit substances containing environment. This, however, applies to a design situation. As regards "beyond-design" situation, special engineering solutions are seemingly required for the above structures. The solutions should ensure, even in the case of the most improvable and unpredictable effects, spontaneous deviation from hazardous production processes and self-isolation of units containing detrimental or hazardous components.

3. STATITICAL EVALUATION OF NATURAL DISASTERS

The probabilistic approach proper employed in evaluating a possible level of any disastrous phenomenon in a particular area can also prove to be efficient and useful when the structure or soil are not supposed to be analyzed for the mentioned phenomenon. Therefore, when elaborating a probabilistic concept for natural disasters one should primarily consider in a general form the feasibility of using the statistical approach for representing the disastrous effects.

In principle the aim of the statistical analysis in terms of the problem being considered is the probabilistic prediction of the time and the place of a natural disaster or, on the contrary, for the given place and the service life of the structure – the probability of occurrence for the given period of a certain disaster's type.

Generally speaking, besides probabilistic prediction, direct forecasting based on warning signs can be used. Reliable warning signs, however, are often detected just before the disaster and cannot be taken into account in long-term prediction influencing engineering solution.

To have a prior notion of the frequency and the extent of disasters possible in a particular region is the reason, for which statistical methods are to be used. The analysis of observations for previous years can give the information of the frequency and parameters of disasters in the past. Assuming the probability of such events to be invariable in time, the same frequency that was in the past should be predicted for the future. This extrapolation, however, can prove to be rather conventional, since data obtained generally refer to a limited time range alone. For this reason the processing of the available data should be based on specially developed statistical models whose physical correspondence to the phenomena under consideration make the extrapolation trustworthy.

Since natural disasters are, this way or other, extreme occurrences (earthquake or/and tsunami of high intensity, landslide of a great amount of soil, karsts crater of a large diameter), their statistics has the character of "statistics of rare phenomena". The Poisson's distribution can be proposed in this case, and the time character of the disasters manifestations can be represented by the Poisson's process.

The specificity of the probabilistic approach to extreme values of the parameter referred to disastrous manifestations of the natural processes the Poisson's or other distributions that represent the statistics of the extremes take place [8]. The necessity in the accounting and description of the parameters of three-dimensional variability, as well as in the study of this variability at different scale levels is essential in terms of the determining, on the basis of observations, regions, where this danger should be allowed in the practical engineering analysis, i.e. solving the task of micro-zoning. For this purpose, as well as for a more detailed prediction of threatening occurrences, methods for optimum prediction of random fields should be employed.

Areas where dangerous phenomena can occur at intensity levels not yet realized (earthquake exceeding the design level, karsts crater over allowed dimensions), can be determined and assessed be the test's observations of the similar occurrences, however, of lower, pre-ultimate, intensity.

Meanwhile, to say nothing of the abovementioned incomplete trustworthiness of extrapolation, the notion of a somewhat mass scale of occurrences, though less intensive, but in any case, similar to "disasters", is far for being always correct.

There are, certainly, other types of dangerous phenomena, too, whose uniform realizations in the given area are of rather a mass scale; such are natural landslides or stonewalls on different slopes in mountainous areas or rock bursts in mining working; statistical data of these can also be obtained. Natural disasters of geotechnical origin, however, can be "unique"; hence, we must not rely upon full-scale data selection and processing, i.e. upon the so-called "objective analysis".

A specific feature of natural disasters (and man-caused disasters, too) is that they are practically in avoidable. Natural disasters are characterized by power and uncontrollability. Typical of man-cased events is that they result from the speedy development of super-modern technologies and a production whose management contains a weak link, that is, a man able to make with tragic consequences (Chernobyl, for example). The main task here is to predict possible disasters, localizing them and mitigating possible losses. The design of any structure should be preceded by the analysis of all possible types of natural or man-caused disasters in terms of the probability of occurrence, of the practicability of initiation, of some secondary disasters, of the practicability of the localization, of the preventive measures not connected with design methods, and, at last, of the damage in the case of occurrence.

4. SAFETY CRITERIA OF UNIQUE STRUCTURES

Before dealing with safety criteria we should clarify the notion of a unique structure and natural or other effects that, determining its vulnerability, are detrimental for human health. The notion of the structural uniqueness and that of the treat of the natural or other phenomena are interconnected. Considering the structural safety in terms of the treat to human life and health, we should not connect the uniqueness of the structure with its cost or with the expected material losses alone. The uniqueness should as well be linked with the level of the treat for people, irrespective of its probability and of factors causing it, such as: the function and the size of the considered building, the character of productions, the presence of the radioactive products, etc. Hence, unique structures are those whose damage or collapse, no matter how long their probability could be, threaten the life and the health of people, either inside or, which is more often, outside the building.

The foregoing definition of the structural uniqueness permits to refer to refer to such buildings projects of national economy (industry, energy, transport and others) and those of a social sphere, whose damage and collapse would entail threat to human life and health. Vulnerability of unique buildings exposed to disastrous natural effects and possibility of their damage or collapse depend on:

- The extent to which loads due to disastrous natural phenomena exceed standard loads.
- The influence of secondary factors (explosions, fires) due to disastrous natural phenomena.
- The errors involved in the design, analysis and the choice of location of a building and those made at the stage of maintenance.
- Poor workmanship, the discrepancy between the strength characteristics of building materials and the standards, strength degradation in the course of the maintenance.

Analyzing structural vulnerability or safety it is expedient to single out the so-called “critical” elements on which structural safety mostly depends. For many structures such are the bearing members of the buildings that determine their strength and stability (foundation, columns, floors, joints, supports, ets.). For other buildings “critical” elements will be those able to resist explosion or fire caused by natural cataclysms, ensuring a reliable operation of safety systems. For a number of unique buildings “critical” elements are associated with the radioactivity or with the insurance of radiation safety.

Differences in the character of the critical elements require performing, when choosing safety criteria of unique units, a systematic analysis in order to find these elements and to assess the consequences of their failure. The systematic analysis of structural safety should include the elaboration of the scenario of a natural effect, taking into account the specificity of the latter, the structure of the unique building, the presence and the character of the “critical” elements, the consequences of their failure, the nature of unit’s damage or collapse and their influence on the safety of people inside or outside the building and on the environment.

Generally speaking, every natural phenomenon and every unique building require a scenario permitting to take their specificity into account and to obtain statistical data for generalizing the consequences. The elaboration and the analysis of the scenarios require a great professional effort of people acquainted with the specificity of the branch and the particular unique building.

To specify qualitative and quantitative safety criteria of unique buildings exposed to any types of natural effects, an integrated approach should be recommended as based on:

- Systematic deterministic analysis of scenarios of the influence of natural disastrous factors on concrete unique buildings revealing particular quality criteria.
- Probabilistic risk analysis determining particular and general probabilistic safety criteria that include those for limit states representing the extent of the failure, and criteria for the personnel and other people in terms of the threat for human life and health (individual risk, collective risk, etc.).
- “Cost-benefit” analysis to define more exactly safety basing on optimization of investments for protection against unfavorable effects with due regard for socio-economic factors.

5. COMMENTS TO CODIFIED PROCEDURES

Among the codes on design of unique structures there are no codes of environment protection and the boundaries of homeostasis[1]of a living system as predominant in the process of determining the basis and analyzing structural strength, stability, durability. This kind of code should specify a limit state in terms of environment protection: in the result of investigation, construction and maintenance of structures the interface in the space of environmental parameters separating their domain, wherein a living system can exist, from the rest part of the space, should not surpass the boundary of the living system’s homeostasis.

The transition from homeostatic domain through its boundary means the termination of the existence of given organism, i.e. the given living system. To ensure homeostasis it is required: to determine its boundaries, to be able to assess the position of the whole living system with respect to the specified homeostasis boundary, e.g. to develop a specific informational system: sensors, gauges, monitoring, decision making procedures.

With codifying boundary protection and homeostatic boundaries of a unique structures living system, particular attention should be paid to geo-pathogenic[2] areas within the limits of design, construction and maintenance.

Geo-pathogenous zones result from the heterogeneous[3] structure of Earth’s Crust, that anomalous information fields, detrimental for the energy of bio-systems or objects of inanimate nature. It is not advisable to assembly in the geo-pathogenous zones structures, important in terms of economy and ecology. Codes specifying the contents of designs of unique systems should contain the section of analysis and evaluation of damage or failure probability of the structure being designed. This section should also contain appropriate scenarios for the operation of expert teams trained to eliminate damage, localize ecological losses and to rescue people, animals and the whole animate system in the region of disaster.

As concerns the abovementioned section, national data bank should be complied and constantly replenished; the data bank should contain information on the causes and the physical meaning of failures, systematic analysis, material and other losses and on methods of damage elimination and rescue of the animate system.

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[1] Relatively stable state of equilibrium.

[2] This term was coming from the world of Dowsing.

[3] Derved from the Greek, used to describe that has a large amount of variants.

Reliability is determined by the extent of structure's non-exposure to danger (in case under consideration, to elemental natural and elemental man-cause disasters), it being impracticable and inexpedient here to guarantee structural survivability as regards all, including almost improbable dangerous effects.

6. STRUCTURAL SYSTEM'S SURVIVABILITY[4]

Different situations in beyond-design states of structures can appear as a result of applying of natural or man-caused abnormal actions on building, which have not been foreseen in design. These states can be classified according to failure form, degree of damage and final state. The following forms of failure can be considered for ultimate limit state:

- Loss of strength in time of plastic, brittle, ductility or fatigue failure of elements.
- Elastic or inelastic buckling of structures.
- Loss of the stable equilibrium of the whole building.

According to the degree of the intensity it can be:

- Full progressive failure of the whole building. Such form of a failure is typical for brittle structures when a damage of separate elements can arouse dynamic effects in other elements of a structure.
- Little by little growing failure of accidental character as a result of plastic deformations accumulation. This situation will stop exploitation and demands restoration. This form of failure is typical for structures from elastic-plastic materials when failure of separate elements accompanies by growing of large displacements and redistributions of inner forces.

It is useful to denote that failure analysis shows that practically always the process of structural failure is avalanche-like, representing a sequence of failures of the members the is composed of, in which case "failure" means both, partial damage and complete failure. In the overwhelming majority of cases, however, in individual failures do not bad to a total breakdown; in a structure, provided it is redundant, stress redistribution takes place and the structure keeps performing its functions, though, perhaps, not to the full capacity.

This is favorable from the practice point of view; the situation can be accounted for by bearing capacity reserves that the structures posses. At present these margins are envisaged in the design, as based on experience and intuition. For achievement of an expedient reliability level the structure should be designed to bridge over a loss of a supporting member so that the area of damage is limited and localized [9].

It is but natural to use the word "survivability" applicably of the structural system to preserve an ability to carry out the main functions in the period of accidental perturbation and do not permit the progressive collapse or the cascade development of failures. Survivability is quite an important and, applicably to unique and important structure, indispensable property, since reliable performance of structures is only possible if an appropriate level of survivability is ensured.

There arises at once the question of this property's quantitative aspect. At present, conventional is a probabilistic approach to structural reliability evaluation; hence it is natural to employ it when obtaining numerical characteristics of survivability, too. Then, in compliance with the general methods, survivability level will be determined by a probability of some events characterizing the process of failure. It is logical to consider, how some critical state is attained in the process of successive failures of members. This can be the failure of some numbers of members, assigned in advance, and the formation of an instantaneous mechanism, or the failure of some isolated members, etc. Complying with this approach, a structure can be considered to possess

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[4] The term integrity can be used too.

survivability if the probability of the above event for damaged structure is not so high; as compared to its undamaged counterpart (other criteria can as well be used).

The index of survivability can be expressed in the following way

$$\eta = \frac{P_f}{P_f^{'}} \tag{1}$$

Where P_f -probability of failure of the designed system; $P_f^{'}$ –probability of failure of the same system when some members failed. Survivability factors η are in [0,1] interval. The more is its value, the larger is the reserve of survivability in structural system. The steel frame is considered in Fig.1.

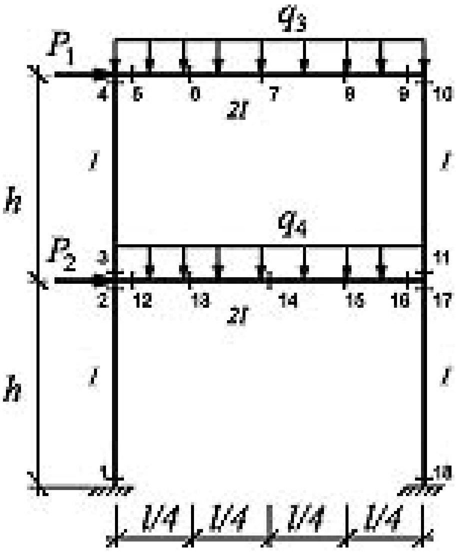

Fig.1 Two-story frame

In the longitudinal direction frame's span is 6m, h = 4m. All members of considered frame have I-sections with aria moments $W = 6.15\cdot10^{-5}m^3$ *(1st floor column);* $W = 8.28\cdot10^{-5}m^3$ *(2nd floor column);* $W = 1.270\cdot10^{-4}m^3$ *(1st floor girder);* $W = 1.098\cdot10^{-4}m^3$ *(2nd floor girder).*

Probabilistic analysis was performed taking into account random nature of applied loads and yield stress of frame's material, with given probability distributions. Table 1 contains parameters of these distributions. Calculations were made on the base of linear programming method (simplex method) with the application of the direct integration of distribution function [10,11]. Probability of failure is $P_f = 5.51\cdot10^{-5}$.

Table 1

Random value	Distribution	Mean value	Standard deviation s	Parameters of distribution	Design values
Wind load P_1, P_2	Gumbel	$0.144\,кН/м^2$	$0.037\,кН/м^2$	$u = 0.127\,кН/м^2$ $z = 0.029\,кН/м^2$	$0.2576\,кН/м^2$
Snow load q_3	Gumbel	$1.1418\,кН/м^2$	$0.4681\,кН/м^2$	$u = 0.931\,кН/м^2$ $z = 0.365\,кН/м^2$	$1.6\,кН/м^2$
Load due to use q_4	Gauss	$0.88\,кН/м^2$	$0.21\,кН/м^2$	–	$1.68\,кН/м^2$
				$\beta = 14.3$	

Random value	Distribution	Mean value	Standard deviation s	Parameters of distribution	Design values
Yield point σ_y	Weibul	305.25 *МПа*	25 *МПа*	$\alpha = 316.42$ *МПа* $x_0 = 0$	245 *МПа*

More probable is the partial mechanism of failure when plastic hinges appear in cross-sections 4, 7 and 9 (Fig.1). The values of the failure probabilities of considered frame are listed in Table 2 for different cases of cross-sections weakening.

Table 2

№ section s	Probability of failure P_f Lowering of aria moments W in different sections					
	5%	10%	25%	50%	75%	95%
1	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$7.53\cdot10^{-5}$	$8.42\cdot10^{-5}$
2	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$7.41\cdot10^{-5}$	$8.94\cdot10^{-5}$
3	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$
4	$5.83\cdot10^{-5}$	$5.96\cdot10^{-5}$	0.000101	0.000207	0.000389	0.000570
5	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$8.42\cdot10^{-5}$	0.000122	0.000309	0.000547
6	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	0.000107	0.000755	0.004562
7	$6.19\cdot10^{-5}$	$7.90\cdot10^{-5}$	0.000303	0.001246	0.006322	0.025580
8	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$8.34\cdot10^{-5}$	0.000734	0.004771
9	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	0.000137	0.000319	0.000593
10	$5.95\cdot10^{-5}$	$6.86\cdot10^{-5}$	0.000103	0.000207	0.000392	0.000564
11	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$
12	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	0.000112	0.000265
13	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	0.000224	0.000873
14	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	0.000890	0.001063	0.002327
15	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	0.000229	0.000871
16	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	0.000112	0.000259
17	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$7.30\cdot10^{-5}$	$8.27\cdot10^{-5}$
18	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$5.51\cdot10^{-5}$	$7.34\cdot10^{-5}$	$8.33\cdot10^{-5}$

From Table 2 follows that in the case of a failure of any cross-section, probability of failure for frame will not exceed the value $P_f^{'} = 0.02558$ (the failure of cross-section 7). The failure of cross-section 7 will not lead to the collapse of all structure but essentially decreases its survivability. Even the full failure of cross-sections 2 or 11 has no influence on probability of this frame. The failure of the cross-section 1, 2, 17 or 18 has also no essential influence at this probability. Survivability index of the considered frame with regard to the failure of cross-section 7 constitutes:

$$\eta = \frac{5.51\cdot10^{-5}}{0.02558} = 0.00215$$

If in the process of structure exploiting some actions will be ensuring, then the probability of the failure of the whole frame in case when one cross-section failed, can be decreased to the value $P_f^{'} = 0.004771$. Survivability index will be:

$$\eta = \frac{5.51 \cdot 10^{-5}}{0.004771} = 0.0115$$

At Fig. 2 graphs due to dependences between probability of failure and weakening of cross-sections 7, 8 and 3 are presented.

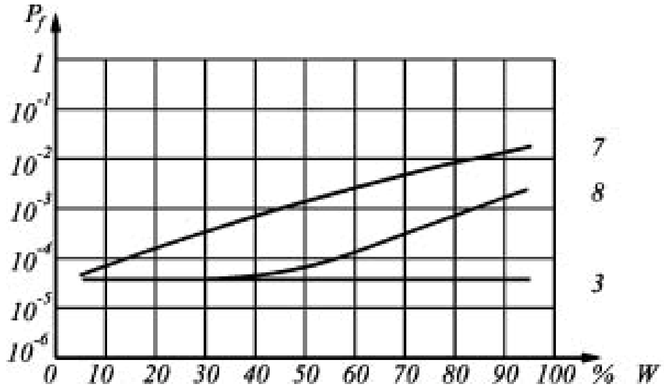

Fig. 2 Dependence between P_f and W

The process of developing and utilizing structures and structural members comprises numerous measures; considered herein, however, are only those ensuring a required reliability level. Different reliability levels are ensured through different cost of construction. For structures in hazardous areas an expedient reliability level should be specified. It should be determined the necessary safety guarantee of the structure and people. The failure criterion assumed in the design of buildings for ordinary performance conditions is mainly that of serviceability.

A reliability level for construction in hazardous areas should be that of failure –free performance. This should be an objective criterion determining the totality of codes, control services and other measures that would ensure an expedient reliability level.

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