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Measures for Predicting Accidents at Hydraulic Engineering Structures and their Prevention

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ABSTRACT. The paper deals with the urgency of research on accidents at hydraulic engineering structures. A brief description of some accidents is given and an approach to their prediction is proposed through the use of A.N. Kolmogorov's works devoted to defects. *© 2007 Bull. Georg. Natl. Acad. Sci.*

Key words: *accident, reliability, risk, defect, prediction.*

The vast natural and technospheric accidents happening in recent decades have justly troubled the world community. The population is especially shocked by the fact that these incidents were attended by hundreds and thousands of human casualties. Dozens of descriptions of the disasters have been published. Significantly enough, the hitherto unknown sites of accidents (Soneso, Flicksoro, Bhopal) have become known through disasters occurring there and are frequently mentioned as symbols of hazard.

The population of many countries, including that of Georgia, cannot help being concerned about the fact that, notwithstanding the effective measures taken, no reduction of the losses resulting from accidents and disasters is noticeable; on the contrary, these losses are appreciably growing.

Special note should be taken of the increase of losses resulting from floods and high waters throughout the world, including Georgia. At the same time, the question of potential accidents at hydraulic engineering structures has become acute. This is accounted for by the fact that the term of service of these facilities has reached a critical threshold, entering the phase of obsolescence. Their majority were built 40 to 50 years ago, i.e. they have exhausted their viability resource. Practice shows that, of other existing structures, accidents at water development works are most hazardous for the population and the environment owing to the vast scale of damage caused by them; suffice it to recall the horrific tragedy caused by the Vaiont dam in Italy.

The foregoing leads one to the conclusion that averting accidents at hydraulic engineering structures and mitigation of the losses (exceeding tens of millions of dollars, to say nothing of human casualties) inflicted by them demand more attention on the part of scientists and must be given priority among the questions studied by technical sciences.

Thus, study of accidents at hydraulic-engineering structures aimed at working out measures for averting such disasters or mitigating the damage inflicted by them should unconditionally be considered the most urgent and vital problem to be investigated as the first priority.

Among the novelties awaited by the population from science, development of effective measures of combating accidents at structures is doubtless accorded one of the first places among those bringing useful satisfaction. As the Japanese, who are advanced in many spheres, teach us, we must always feel satisfaction from our work done. If this is not the case we must do so as to create such a situation. There can be no doubt that measures for averting accidents will evoke great satisfaction among broad strata of the population. Determination of the probable frequency of accidents and of the time of their occurrence should be considered one of the first measures of combating them. Knowledge of this important characteristic enables timely and quality preparation for combating accidents. This will minimize the damage caused to the population and the environment.

There is no doubt that to date science stands heavily in the people's debt, for the population is under constant fear and threat of accidents, latter more often than not developing into catastrophes.

Notwithstanding the existing achievements in the study of this highly complex problem [2-10], many theoretical and practical tasks, which will shorten the long black list of disasters, stand in need of immediate in-depth study through wide and profound use of the latest achievements of different branches of science. Among the multiplicity of problems, whose solution is required from science by practice and safe economic development, study of the mechanism of the origin of accidents at structures, prediction of their frequency and working out measures – on the basis of these data – for averting them at hydraulic-engineering structures or for mitigating the damage inflicted should be considered a primary task.

In foreign specialist literature, to underline the magnitude of the damage caused by accidents at hydraulic-engineering structures, including great dams, the latter are referred to as hydrological bombs. Of course the simile is exaggerated, yet not a single year passes without the occurrence of an accident of the named structure in one or another "developed" country. That is why this question is given special attention at such forums as international forums on large dams and international congresses of the IAHR. The author is a direct witness of this who, until recently, was participant of these congresses and among their organizers. Storage reservoirs and their inseparable part - dams – are considered one of the most accident-prone facilities.

Numerous other structures occur in practice that may break down and inflict enormous losses to the environment and the economy. In recent times the probability of the occurrence of accidents has increased owing to the growth of the share of obsolescent structures. The substantial experience and knowledge, accumulated in the design and construction of dams, and progress in this direction should by no means blunt the attention of designers, builders, operatives and scientists to the safety of these major facilities. We should not be oblivious of the fact that many specialists believed atomic power stations to be absolutely safe. Yet, unfortunately, practice disproved this belief. However, it should be noted that today, too, atomic stations are highly reliable, so that starting their construction should not cause alarm.

The level of understanding of the reliability of safe functioning of hydraulic engineering structures has substantially grown, following the author's publications [2-10]. These publications encompass data on the prediction of the reliability and maintenance of hydraulic engineering structures of various purposes. However, his first study only mapped out the way of making a decision, and the necessity of expanding research for the development of methods of assessment of the risk of accident situations, without indication of the basic methods of the study of accidents, especially of measures towards predicting accidents and accident-prone situations and averting them. The results of research into the causes of accidents along these lines allow to predict a disaster with considerable approximation. For their part, these data facilitate a better understanding of the regularity of the functioning of designs and structures, directing the attention of operatives, scientists, designers and builders to improving the quality of design and construction; this will substantially ensure the prevention of accident-prone situations as well as accidents proper.

To achieve the goal set, it will be necessary to study this most complex problem, and primarily accidents at hydraulic engineering structures – analysis of measures for averting this phenomenon or mitigating the damage; this will call for the solution of a number of tasks, including: 1. Assessment of the pre-accident period; 2. Analysis of the process of accidents of structures; 3. Search for ways of predicting accidents; 4. Approximative prediction of accidents, using modern methods of the theory of random processes.

The principal steps to be taken towards averting accidents or mitigating the damage inflicted entail a number of theoretical, organizational and practical measures. This primarily requires the study (even approximative) of the frequency of the accidents or catastrophes at diverse-purpose facilities.

Judging from the literary sources available to the author, the available methods are not perfect either in this country of abroad, hence the urgent need for further studies, refinement of the existing results and development of a new approach.

Analysis of the accidents that have occurred will allow to develop designs that will be subject less to accident phenomena and their "vitality" will substantially increase.

Not only disintegration of the design should be considered an accident state of a structure but also the state in which normal exploitation of the facility is rendered difficult, when the design has cracks, major bends, the reinforcement is strongly corroded, or other similar defects are evident.

That the proposed method will allow consideration of the time factor in prediction should be considered a significant new approach. The existing traditional methods fail to take this parameter into account.

Although the chances of major accidents as well as catastrophes have diminished in recent years through the introduction of new perfect methods of calculation of construction and assembly work and exploitation, they, regrettably, still occur – and not infrequently. Therefore it is impermissible to neglect this problem. In other words, research in this sphere is extremely urgent.

More often than not accidents occur at hydraulic engineering facilities, inflicting appreciable damage to the country's economy, as well as to ecological stability. According to the material gathered by the International Committee on the Breakdown of Dams, of the 1150 cases of damage occurring in 35 countries of the world, the following were found to be damaged: concrete dams and their bases (21%); rock-fill dams with their bases (2-4%); earth-fill dams with their bases (36%); damage in the reservoir zone (3-4%); damage in the downstream wall (0-5%). Analysis of these and other data [2-9] points to the occurrence of accidents at earth-fill dams as well, built in 1900-1919; suffosional processes proved most hazardous for the stability of earth-fill dams. Observation carried out for 200 years in Britain, involving 2000 earth-fill dams, showed that here, too, suffusion processes take place, caused by aging. Thus, the causes responsible for accidents may be divided in the following way: suffusion: 55%; spillover: 14%; other factors: 31%.

An accident occurred in Georgia too, involving a small dam at Tsqneti, which, regrettably, claimed 7 human lives. The commission that studied its causes was headed by the present writer and it is extensively discussed in his monograph published in Russia.

To demonstrate the acuteness of the problem, here are a few examples of dam accidents widely talked about world-wide. To be sure, the accidents at hydraulic engineering structures did not have such resources as power supply accidents had. Thus, in 1979 a grave accident occurred at two units of the atomic power station on Three-Mile-Island, USA; in 1984 a major explosion occurred at a chemical plant at Bhopal, India; the crash of the "Challenger" multiple use spacecraft with seven cosmonauts on board; special mention should be made of the explosion at the Chernobyl Atomic Power Plant block IV in April 1986. Obviously, these and similar accidents cannot be overlooked. The above cases, occurring in different countries of the world, point out that the process is intensified owing to the aging of structures. The principal cause of accidents at hydro-electric stations is aging as well. If we exclude accidents in extreme situations as well as those that occur in the first years of exploitation, then a special risk occurs at the stage of reservoir filling.

The following phenomena have been found to take place at the aging of earth-fill dams: the overall and local strength diminishes; at aging the strength of various materials (earth, concrete, polymer films, etc.) weakens. In this case, biodamage is frequent (destructive impact of bacteria, chemical and mechanical degradations; fungi, rodents, mollusks become active). In the course of time various metal items suffer corrosion, while wooden parts rot.

During exploitation filtration and suffusion processes are noticeable in dams. Alterations in a dam may be determined by analysis of the physical characteristics of water, e.g. the presence of sediment, opacity, colour, smell, electrical conductivity. These data allow judgment of the damage of concrete, reinforced and metal constructions by chemical and mechanical suffusion, and of the presence of microorganisms.

Chemical analysis of water and its composition – acidity, content of iron ions, chlorine, sulphates, etc. – yields information on the presence of an excessive amount of chemical substances in the filtration and suffusion process. With the increase of the age of a dam, as a rule, negative phenomena intensify, in the tail race: the depth of local scour and washout of the structure increases; the length of scour increases in the tail race; as a result of the impact of waves the cyclic processes of the freezing and melting of water become more frequent.

The experience of combating accidents and catastrophes shows that economic losses may be reduced to a certain extent through scientifically-grounded prediction. This allows to adopt an adequate measure to prevent the rise of causes that provoke accidents. In this connection it should be noted that in the 1970s in European countries accidents showed a tendency to grow, and they became more frequent, with human casualties. An international commission was set up and a special measure was worked out, under the name of the "Seveso Directive". This Directive is obligatory for all countries of Europe, envisaging the submission of a Report on Safety by the organization that possesses an accident-hazardous facility. It is highly interesting that following the introduction of this measure, from 1983, the number of accidents dropped appreciably, e.g. in 1986 it fell from 400 to 150, and in 1988 to 50.

Precise prediction of accident situations is not feasible owing to the multiplicity of their causes. No universal expression can exist for its prediction; the more so, we cannot expect to obtain exact analytic expressions. This task is unresolved at the present stage of scientific development. We may search for an approximative analytic dependence to identify accidents of individual type or groups. It should be emphasized specially that all accidents are determined by one principle: "Fortuitous accidents do not exist". Thus, each accident has its causative factors, with the sources and causes of these factors. Leading among these causes are the errors made by engineers, designers and superintendents of work. The probability of accidents caused by these errors amounts to 90% [1]. Although these errors are indirectly taken into account in designing by increasing the reliability level, yet causes still remain that can provoke accidents.

Until recently, along with complexity and multifactorialness, the lack of study of the regularity determining the state of reliability of hydraulic engineering facilities and the difficulty in obtaining initial information may be given as the reason for the absence of a prognostic method for the assessment of a safe state.

The Nobel Prize winner, the American Robert Aumann considers simplification of the possibility of obtaining information needed for research to be one of the principal criteria of assessing the modern achievements of science. This is not surprising, as we happen to live in an age of information that has reached such a level that it is considered the fourth factor of production, while the other three factors in conditions of the market economy are: land, labour and capital.

Ensuring the reliable exploitation of facilities calls for regular identification of the weak parts, units and most critical points of a facility, from the viewpoint of its failure. Timely detection of expected damage is considered the principal condition of ensuring the reliability of facilities.

Recently, we have come to face the necessity of solving a number of fresh problems posed by the increase of the number of obsolescent structures. In the new economic conditions this calls for an improvement of the maintenance of these facilities; also taking special measures towards giving advance warning about an expected breakdown of structures of this category. To this end, it is necessary to determine the critical moment that precedes the accident at the facility. This in turn will allow timely prolongation of the term of exploitation through taking adequate measures; the extended term will correspond to the existing physical state of the facility. In order to select the index of degradation of properties at each stage of exploitation of the facility it is important to identify such a prognostic variable that fully reflects the physico-mechanical parameters of the current state of the facility.

The breakdown of a facility may be forecast through timely assessment of its state of reliability – by identifying the critical moment of its weakening and decline of its tolerance to the environment and variable loads. This information enables one to select a lightened regime of exploitation – to put it figuratively, "*to allow facilities to leave the scene honourably, following their fulfillment of all the conceptions reflected in their design*".

Operative assessment of the state of a facility permits to limit the term of its exploitation, when such a need arises; an extension of the term allows to select a suitable regime of exploitation (reducing the level of load, depending on the intensity of damage, and so on). Operative assessment of the state of reliability of hydraulic engineering facilities is especially important in determining the moment of breakdown of obsolescent and weakened facilities; to work out measures for full utilization of their resource potential, and, if need be, to write them off (to avert an accident).

In such an extremely complex situation, search for a general expression for predicting the rise of an accident situation, accident or catastrophe is as a rule inconceivably difficult – short of impossible. Prediction is feasible only in individual simple cases.

As shown by analysis, accidents of engineering structures constitute a genuinely random process. Hence it is natural to use modern means of the theory of random processes to investigate this question. To this end it is advisable to find an approach that will allow to predict the phenomenon on the basis of data on past incidents, using the experience of the exploitation of same-type facilities. This is in the first place feasible by the use of powerful and at the same time elegant methods, proposed by the well-known scientist A.A. Markov, predecessor of the outstanding 20th century mathematician A.N. Kolmogorov. As we shall see further, the task is solved broadly and profoundly enough on the basis of Kolmogorov's formulae [1,2-9].

Similarly to the solution of many applied problems, here too, the task may be reduced to a reasonable use of the arsenal of corresponding mathematical means. As at present many analytical methods of solution have been worked out mostly for Markov processes, the striving is but natural to adapt many problems to the apparatus of the theory of Markov processes. I have chosen precisely this path in working on this topic.

As demonstrated by an analysis of the experience, accidents often occur in the work of some design suddenly, without any malfunction having been noticed. It is mostly in this way that metal and wooden constructions lose their stability.

Analogously to solving problems set in other branches of engineering, a model is proposed in which use is made of approximative estimations of numerical parameters, and account will be taken only of the main prognostic variables of the system. In this situation it is acceptable and profitable to use mathematical models that are successfully employed in solving other analogous problems. Fruitful use of fundamental biological principles, physical and other regularities in different branches of engineering is common knowledge. The view set forth allows to presume that the way proposed below is not only formalized, which incorrectly describes the process in "mathematical language". However, I should like to note that employment of stochastic models in practice – based on a single parameter – can express only the average indices of a system. It can give us only an approximative estimation of the functioning of the design, taking into account the factors of environmental impact and load during the exploitation of facilities.

Of the various available techniques of reliability theory, the methods of Markov processes [7] should be considered the most effective, in particular, the use of the stochastic kinetic equation – widely used in physics in analyzing diffusional and other analogous processes.

Of course, in the study of a process it is advisable to take into consideration all the characteristics of the functioning of the system to be assessed. However, this is practically unfeasible. Hence, the identification of such a parameter should be considered one of the important stages in solving a problem, which is the principal prognostic variable among others and which will describe the functioning of the system under analysis with relative fullness. The results obtained will allow to assess the safety and permissible risk.

In working out measures for averting accidents it is logical and advisable to use systems analysis: - an approach widely used at present.

As noted above, gathering of observation data is an important stage of the study of an accident. But this is complex and labour-consuming, hence in the case of insufficiency of these data use may be made of the bootstrap method, techniques of Monte Carlo and expert assessments, as resorted to by the present writer in his other works [7].

It is expected that the recommendations worked out will enable a more objective determination of the length of exploitation of structures. The experience of exploitation of facilities shows that the terms set for the exploitation of many types are rather small, resulting in the premature stoppage of the facility, pointing to misused finances spent on their development, production and exploitation. An expression can be derived that will enable the assessment of the viability of a facility in conditions of exploitation. Account should be taken of the fact that, although some hydraulic-engineering structures still continue to function after the breakdown of some of their elements, their efficiency is low. It is said about such systems that they are reserved in excess, and the facility is of little viability. It will be recalled that the viability of a system is its property to perform its functions in the case of undesirable impact of outside forces on it, not envisaged under conditions of normal exploitation. Seismic and flood impacts are examples of such action.

Prediction of accidents by the proposed method will yield an answer related to the initial information (table of observations) used in the calculation. Thus, e.g., if sequences of accident situations are used, computations will yield the probable time of onset of an accident situation, as well as the level of risk of the occurrence of this phenomenon. At the use of observation data on accidents that have occurred, the prediction will yield the probability of accidents happening at a given time. The prognostic data obtained may be used in developing relatively perfect constructions and in raising the quality of structures. It should be noted that exact prediction of the hazard of accident situations and accidents is an extremely difficult – and often unfeasible – task. Therefore, not only an approximative expression should be considered acceptable that answers this import question but one that allows rough qualitative estimation of the frequency of these occurrences, and not qualitatively, in linguistic terms (‘will occur frequently’, ‘very often’, ‘seldom’, and so on).

Numerous observations of different facilities of various purposes give ground to assume that – under other equal conditions (obviously excluding cataclysms) – the onset of accidents depends to a considerable extent on defects. A defect of a facility implies a fault in the elements that may lead to a failure of the facility or lowers the level of its capacity for work. In many cases the presence even of small defects causes the breakdown of elements long before the onset of the fixed inter-repair time or the expiry of the resources of facilities, with grave consequences. In many elements, defects accumulate in the course of time, among which some are major defects of three-dimensional form: loose states, pores, various inclusions, cracks.

In view of the extreme importance of the description of defective states, they have been the subject of long and fairly in-depth investigation. Attention was given to the study of this problem by many outstanding mathematicians, including the great mathematician of the end of the 20th century A.I. Kolmogorov [1]. The enormous material losses caused, including human casualties, call for urgent and radical measures towards averting their occurrence. To this end, in the first place one must have an objective foresight of the impending danger. All grounds exist for the assumption that the world community – and not only individual advanced countries – will in the near future develop measures towards lowering the presence of defects in structures, thereby substantially reducing the hazard of accidents and preventing grave accidents in the technosphere. Observations of accidents demonstrate that they largely depend on defects in the facilities.

The thorough study of the characteristics of defective states, set forth in the foregoing, suggests its application in predicting the accident-proneness of various facilities. The first step in this direction is to begin with the use of the findings of the study of the presence of defects in facilities and of the factors causing them and directly related to accidents. Obviously, under other equal conditions, the more the number of defects in any randomly taken facility, the oftener it is subject to accidents. Observations and analysis show that the correlation between the number of defective items in a sample X and the number of defective items in the remaining – uncontrolled – batch X-x is positive – equals zero or is negative, if the dispersion number of the controlled item in batches is, respectively, higher, equals, or is lesser than the binomial dispersion.

$$\sigma_x^2 = NPq \cdot \quad (1)$$

In this connection, in predicting the process of the onset of accidents – by itself an exceptionally complex task – the use of rigorously derived mathematical expressions for the description of the presence of defects seems appropriate.

The formula given in [1], describing the covariation between the number of defective items in a sample and the number of defective items in the remaining batch serves as such an expression. Thus, we shall have: a mathematical expression for covariation between the number of accident-prone facilities in a sample and the number of accident-prone facilities in the remaining part of the group, obtained in [1].

$$E\{x(X-x)\} = \frac{n(N-n)}{N(N-1)}\left[\sigma_x^2 - Npq\right]. \quad (2)$$

Clearly enough, under positive covariation, the level of accident-proneness of the uncontrolled group $P_{N-n} = (X-x)/(N-n)$ will be close to the level of the accident- proneness of the sample $P_\pi = x/n$; under covariation values close to $\sigma_x\ \sigma_{X-x}$ - product of standard diviations of the numbers of accident-prone facilities in the sample and the uncontrolled part of a batch, with a probability close to unity, it may be asserted that, $P_n = P_{N-n} = P_N$. This fact constitutes the main principle of the classical theory of statistical acceptance inspection. As zero covariation P_n and P_{N-n} are independent random values and, therefore, random inspection is useless, for according to its results one cannot judge about the level of the presence of defects of the remaining part of the batch. Finally, under negative covariation two cases are possible, $P_n < P_N < P_{N-n}$ and $P_n < P_N < P_{N-n}$. These have the following probability meaning: the items in a batch are arranged with a definite regularity in such a way that the level of the number of defects in the remaining part of a batch is correspondingly less or more than that of the batch. In the limiting case, when $E\{x(X-x)\} = -\sigma_x\sigma_{X-x}$, any given level of the number of defects $P_\pi \ge P_N$ has its absolutely definite the number of defects $P_n \ge P_N$. The following designations are adopted in the formula: N, n - volumes of the batch and sample: X, x - numbers of defective items in a batch and sample; p - level of the number of defects, $q = 1 - p$; $g_N(X)$ - a priori distribution of the number of defective items in batches submitted for control; $N_n(x)$ - unconditional distribution of the number of defective items in the samples; $f_n(x/X)$ - conditional distribution of defective items in a batch (hypergeometric distribution); $\Phi_{N-n}(X - x/x)$ - a priori distribution of the number of defective items in the un controlled part of the batch at a given number of defective items in the sample; $j(x, X)$ - joint distribution of the number of defective items in the batches submitted to testing; $E\{x(X-x)\}$ - covariation between the numbers of defective items in the sample and control part.

Realization of the inexhaustible potentialities of branches of the theory of random processes and of reliability theory to forecast accidents and accident-prone situations on the basis of processing the observation data, in time, is one of the principal ideas in the foregoing works.

Detection of accidents through the presence of defects in the proposed method is effected by replacement of the presence of defects in formula (2) with accident rate. However, in the majority of practical cases the characteristics of the presence of defects are unknown, which inevitably causes difficulties in prediction. However, it is much simpler to determine these characteristics than to determine the accident rate directly.

Along with the above-said, in analyzing accidents the use of the so-called methods of leading indications of failures appear to be promising, which will undoubtedly facilitate timely implementation of the following measures connected with combating accidents: identification of weak points of constructions at exploitation, under group leading; assessment of the parameters of distribution of mean-time-to failure, allocating a specified life for concrete elements, typical of a group of facilities. In the case of group leading the group of facilities is identified that is characterized by a lead in operating time. At individual leading, several leader-indicators – models of the element under consideration – fall to each facility, having – under equivalent conditions of load – the same function of distribution of mean-time to failure and operating-time lead.

Conclusion

One of the principal tasks of the present paper is an attempt made once again to draw attention to the thorough and objective study of the causes of accidents, allowing an insight into the regularities and conditions of operation of constructional systems and their elements; to draw the attention of scientists to the solution of inadequately researched problems in the field of design and construction, as well as to flaws in design and construction, causing destruction, the removal of which should prevent accidents and raise the reliability of structures.

ჰიდროლოგია

ჰიდროსაინჟინრო ნაგებობების ავარიების პროგნოზირება და თავიდან აცილება

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ნაშრომში განხილულია ჰიდრონაგებობების ავარიების კვლევის აქტუალურობა. მოცემულია ზოგიერთი ავარიის მოკლე აღწერა და პროგნოზირებისადმი მიდგომა ა.ნ. კოლმოგოროვის ნაშრომების გამოყენებით, რომელიც დეფექტიანობას ეძღვნება.

REFERENCES

1. *K. Yu, A.N. Belyaev* (1960), Kolmogorov, Economic plans of acceptance inspection. IV All-Union Mathematical Congress. Leningrad. (Russian).
2. *Ts.E. Mirtskhoulava* (1975), Erozionnye i selevye processy i bor'ba s nimi, vip. 4, M., VNIIGiM, 1975, 48-62 (Russian).
3. *Ts.E. Mirtskhoulava* Avarii: uroki, prognoz, mery po bezopasnomu funktsionirovaniju objektov gidrotekhniki. Moscow. (Russian).
4. *Ts.E. Mirtskhoulava* (1993), Ecological disturbances (prediction of the risk of disturbances, measures for reducing the hazard). Tbilisi, 438 p. (Russian).
5. *Ts.E. Mirtskhoulava* (1998), Gidrotekhnicheskoe stroitel'stvo*,* 5:16-19 (Russian).
6. *Ts.E. Mirtskhoulava* (2003), Opasnosti i riski nekotorykh vodnykh i drugikh sistem. Vidy, analiz, otsenka. V 2-kh knigakh 503 p. (Russian).
7. *Ts.E. Mirtskhoulava* (1987), Reliability of Hydro-reclamation Installations. – Rotterdam: A.A. Balkema, 297 p.
8. *Ts.E. Mirtskhoulava* (2000), Mud floods and their prediction in the Caucasus and Central Asia. /*Floods*. Vol. II. Edited by D.J. Parker. – London, New York, p. 216-222.
9. Guidelines for Floods Loss Prevention and Management in Developing Countries. Aarhus Group Experts of Flood Prevention (S.K.Banerjee, I.Bogardi, A.Fahmy, H.Kikkawa, P.Maistr, Ts.E.Mirtskhoulava, S.Nesadurai, G.R.Phippen, L.S.Rahm, T.Tahara, J.W.Vam der Made), Natural Resources. /Water Series N5, United Nations, New York, 1976.
10. Construction Industry Research and Information Association (CIRIA) (1977) Rationalization of Safety and Serviceability Factors in Structural Codes, Report 63. CIRIA, London.

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