SIZE AND RETURN PERIODS OF EXTREME DISASTERS

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Abstract

Extreme disasters occur rarely and altogether occasionally, and therefore, the determination of maximum possible size or maximum expected size of natural and other disasters is important for the safety management and for the insurance domain, and considerable attention is paid to it. Systematic methodology development has been supported by professional papers since 70s of the last century or so. At present, the extreme value methods based on the great numbers of law, fuzzy sets etc. are used. The example shows the high differences in the extreme values existing in the application of old concepts and new methods. By use of the extreme value methods, it is also possible to calculate the return period of extreme disasters. The example showing return periods for different disaster sizes is given.

Key words

disasters, hazard, extreme impacts, extreme disaster size

Introduction

From of old long, the humans suffer from natural and other disasters (further only "disasters"). Far off it is also known that for each phenomenon (disaster) management or defence against it we must know its cause, size and return period. Therefore, the measurement of disaster size is important. Generally, we can measure the size or magnitude of disaster itself using an objective quantity (the energy or any other measure seems to be optimal) or we can determine its size by measuring or classifying its impacts. There are disasters, for which both accesses have been historically developed, e.g. earthquake, wind, industrial accidents.

The fundamental function of the state is to ensure the existence and sustainable development of human society (i.e. theoretically human system), which is not possible

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without ensuring the safe space for human society. It is necessary to define three basic terms for safety management tool that has been used to this aim. These terms represent integral terms, the definitions of which correspond to the English professional terminology and generalised meanings traditionally used in the Czech language. There are:

- protected interests (assets) of human system are components that are necessary for its safety and sustainable development,
- an impact is an adverse effect (influence) of phenomenon (disaster) at a given site and time of human system on protected interests,
- a disaster is each phenomenon in human system that has or can have impacts on protected interests of the human system, i.e. it threatens or can threaten from a given size or at given conditions the safety and sustainable development of human system.

The safe space, i.e. safe human system is a space in which the security is acceptable and in which sustainable development is guaranteed. With regard to the present knowledge, the safety must be mainly considered in integral sense and with regard to the protected (safeguard) interests that are:

- human lives, health and security,
- environment,
- property and welfare,
- technologies and infrastructures, mainly critical ones.

The extreme (beyond design/severe) disaster size plays a principal role in the human system safety, because the protective system creation, i.e. measures for averting or mitigating disasters and their impacts, depends on it.

Summarised knowledge on disasters

Disasters are divided into several groups according to the process types being in motion inside and outside the Earth like the Planet which causes them. Therefore, they originate at different sites and have different characteristics. With regard to present knowledge, their possible size depends on regional processes and their impact size on both, the regional and local conditions. Their causes and characteristics are generally incommensurable. From the protected interests' viewpoint, they have some common features, namely their ability to destroy, i.e. to cause harm and damages [1-3].

The number of disaster types increases; it is related to developed technologies and infrastructures. According to [4], we know that we must minimally take into account the following disasters:

- in and out of the Earth: natural disasters (earthquake, floods, drought, strong wind, volcanic activity, land slide, rock slide etc.); epiphytic; epizootic; land erosion; desertification; fundament liquefaction; ocean spreading etc.,
- in human body, behaviours and in human society divided to:
  - unintentional: illnesses; epidemic; involuntary human errors etc.,
  - intentional: robbery; killing; victimization; religious and other intolerance; criminal acts; terrorist attacks; local and other armed conflicts etc.,

- connected with human activities: incidents; near miss; accidents; infrastructure failures; technology failures; loss utilities etc.

- reactions of Planet or environment to human activities: man-made earthquakes; disruption of ozone level; greenhouse effect; fast climate variations; contaminations of air, water, soil and rock; desertification caused by human bad river regulation; drop of diversity of animal and vegetal variety; fast human population explosion; migration of great human groups; fast drawing off the renewable sources; erosion of soil and rock; land uniformity etc.

- connected with inside dependences in human system and its surrounding separated to:
  - natural: stress and movements of territorial floes; water circulation in environment; substance circulation in environment; human food chain; planet processes; interactions of solar and galactic processes;
  - human established: human society management; flows of raw materials and products; flows of energies; flows of information; flows of finances etc.

The listing shows that disasters are of different nature: physical, chemical, economic, biological, social and cyber, and, measures and activities for negotiation must therefore respect this fact.

The occurrence of disaster is accompanied by chains of undesirable phenomena (impacts, consequences) of external and internal character, primary and secondary, which affect negatively protected interests of human system with different intensity and at different time moments. The local vulnerability and pertinent faults in human behaviour or management on all levels play the substantial role.

To put the originated emergencies under the control, it is necessary to understand disaster impacts and to know all links and flows in human system that escalate or suppress disaster impacts. Interdependencies across the human system or across infrastructures that can under special conditions create undesirable couplings play a big role. Sources of such interdependencies are information networks, management tools, finance flows and electric energy networks etc. [3 and 4].

At present, there are technical standards and norms for technology vulnerability reduction, health standards for human population vulnerability reduction, environmental standards for environment vulnerability reduction and legal rules for human society vulnerability reduction. It is necessary to note that the standards for cyber infrastructure (IT) vulnerability reduction have not been qualified yet. The emergency plans contain rules for putting emergency situations under control [3].

From the viewpoint of human security, it is necessary to take into account that standards and norms ensure the human system safety only to a given disaster size. The disaster with the size greater than the given size is denoted as extreme / severe / beyond design disaster. It has extreme impacts and a lot of secondary impacts that are caused by links and flows going across the human system [3]. The Figure 1 shows that, owing to the IAEA and the NEA / OECD long-term effort, only nuclear technologies are protected from such disaster sizes.
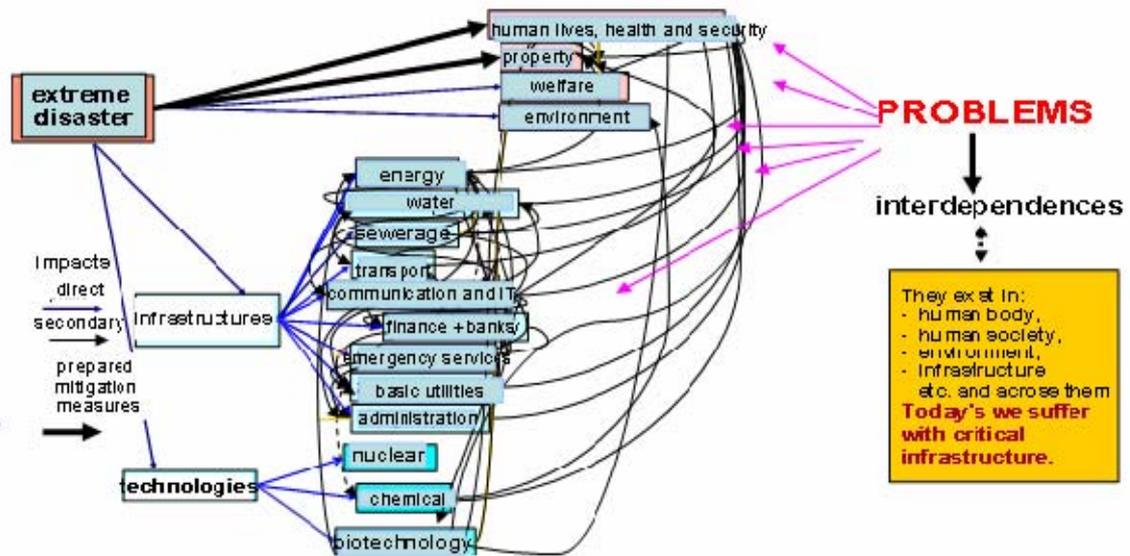
Fig. 1 *Extreme disaster impacts with denotation of impact categories classified according to preparedness of response measures*

The arrows in Figure 1 denote severe disaster impacts that lead to relevant detriments, harms, losses and damages. Bold black ones show relevant impacts, where countermeasures mitigating them are prepared. Dark blue ones show relevant impacts, where there are no the mitigation measures prepared in advance; they are solved ad hoc (welfare, environment, infrastructures and technologies). Thin black ones denote the impacts that have not been systemically solved yet (infrastructures vs. human lives and health, property, environment etc.). These interdependencies in human system escalate as a rule the disaster impacts on human lives, health and security, since they cause secondary impacts and elongate the emergency, i.e. they mean a great danger.

Pursuant to analyses of pieces of knowledge and examples in works [1-3, 6 and 18] it is clear that extreme disasters occur seldom and ate considerably random. In case of their occurrence, the common statistic laws applied to representative data files do not work. It is necessary therefore to take into account historical data [5-13], which are, from the objective reasons, incomplete, inhomogeneous (i.e. their accuracy depends on their size or on time of their occurrence), non-stationary and in addition heavy-laden by odd errors, the distribution function of which cannot usually be determined. In the case of historical data, data from observation, mostly non-instrumental and non-repeatable in sense of data obtained at physical experiments, are at disposal. With regard to it, to judge the dependencies and tendencies among those quantities, it is necessary to strictly distinguish formal mathematic-statistic accuracy of a given operation with data (numbers) and a real result reliability, which depends on the quality of input data set. We e.g. distinguish uncertainties and indeterminateness.

Development methodology for extreme disaster size determination

The analysis performed and quoted in papers [1-3] show that extreme disasters seldom occur. The task dealing with determination of maximum possible or maximum expected disaster [19-21] is of principal importance for both, the safety management and the insurance domain. Therefore, the attention has been paid to this domain for a long time. The methodology development in time progressed in accordance with the knowledge development roughly in this way [13and 19-21]:

- size of the maximum disaster in historical period,
- size of the maximum disaster in historical time + certain correction on the indeterminateness or on the reality that extreme disaster has not had to occur yet. The correction always depended on experience and knowledge of assessor,
- frequency occurrence vs. disaster size curve (mainly its intersection with disaster size axe). Challenges to this method mainly consisted in reality that results of such extreme assessments were physically impossible in some cases,
- methods for extreme value determination [14-17,19-21]. Applications of such method for extreme value determination for earthquakes and other disasters [17] for nuclear power plant site locations are in safety documentation of these power plants and a model example in [6], too.

Example

Development in the field of methodology led to the fact that, e.g. despite the earthquake in the Central Moravia ranging from 4.5° MSK-64 in 1980 up to 7° MSK-64, an industrial plant (industrial buildings and their equipment) has been built, though the intensity of site is 6.5° MSK-64 [8]. From the economic analysis regarding the earthquake it roughly follows that when increasing the resistance against earthquake by about one degree, the financial expenses roughly double.

Ground of methods for extreme values determination

The computation is started from the relationship between the cumulative frequency disaster occurrence and disaster size. In contradiction to common statistics, the summation starts at big disasters (see example of earthquake in [6]).

Starting relation of extreme value theory is the algorithm [17], which determines the probability of disaster occurrence with the I_o size, that is not smaller than disaster with the I_{oi} size in time t

$$R_t (I_o \geq I_{oi}) = 1 - \{T / [T + t \cdot P (I_o \geq I_{oi})]\}^{n+1},$$

where T is the time period of documented disaster occurrence (i.e. the observation time for disaster), n is the number of observed disasters and P is the function defined by the formula.

$$P (I_o \geq I_{oi}) = [\exp (- \beta I_{oi}) - \exp (- \beta I_{omax})] : [\exp (- \beta I_{omin}) - \exp (- \beta I_{omax})].$$

In both formulas, the I_{omin} denotes the smallest disaster size from the disaster catalogue i.e. it determines the database homogeneity limit, the I_{omax} is the maximum possible disaster size in a given area, $I_{omin} \leq I_{oi} \leq I_{omax}$. The β parameter $\beta = b \ln 10$, where b is the slope of the frequency graph $\log N_c = a - b\, I_{oi}$ and N_c is the cumulative occurrence frequency. In other words R_t $(I_o \geq I_{oi})$, it is probable that the disaster size Io does not exceed the I_{oi} value in time interval t and P $(I_o \geq I_{oi})$ is the probability, that the disaster size I_o exceeds the I_{oi} value [10]. The results are in Figures 2 and 3.

From the example in Fig. 2 (numerical values are in work [10]) it follows that when we take into account earthquake with intensity 8°MSK-64, so we get for the time interval $t = 50$ years the probability of non-exceedance 0.42704 and only for time interval t = 1000 years the probability is equal to 0.99998 = 1. For earthquake with intensity 9°MSK-64, for time interval t = 50 years we obtain the probability of non-exceedance 0.10355, for time interval t = 100 years the probability of non-exceedance 0.19635 and for time interval t = 1000 years the probability of non-exceedance 0.88661 and only for the time interval t = 10 000 years the probability of non-exceedance is equal to 0.91794, i.e. it is close to 1. The probability of non-exceedance of earthquake intensity 10.5°MSK-64 exceeds the value 0.05 only in time interval of 1000 years.
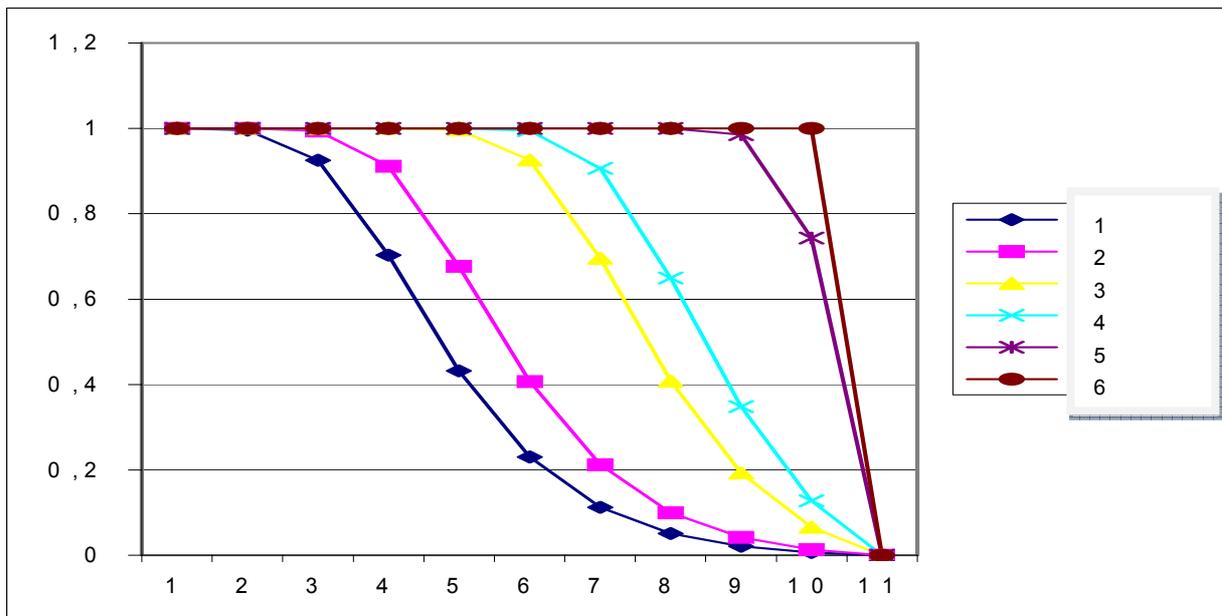
Fig. 2 *Probabilities of earthquake occurrence expressed by curves of non-exceedance R_t*
$(I_o \geq I_{oi})$ in dependence on time interval length for given site. P – the probability
of occurrence of earthquake with intensity I_o and R_t $(I_o \geq I_{oi})$ are probabilities,
which mean, that in the time interval t the value I_{oi} will not be exceeded [10];
time 1-50, 2-100, 3-200, 4-500, 5-1000, 6-10000 years

1.0
0.8
0.6
0.4
0.2
0

Probabilistic (median)

Probabilistic (median + σ)

Deterministic

P / I_0 6   7   8   9   10   11
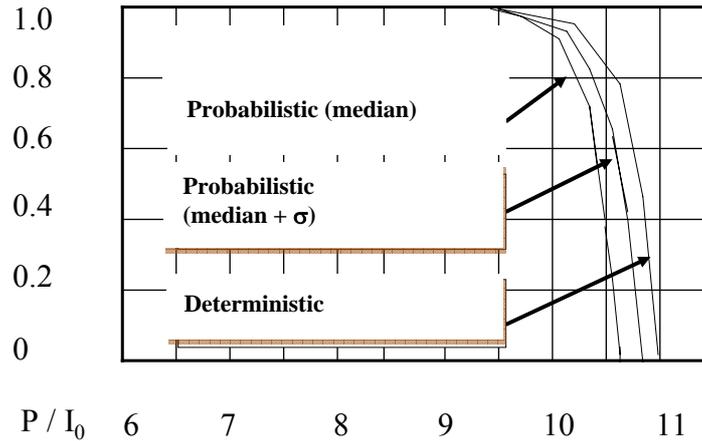
Fig. 3 Marginal probabilities and median of 81 variants for earthquake occurrence in form of curves of non-exceedance $R_t (I_o \geq I_{oi})$ of given earthquake size in time interval of 10 000 years in given southern Bohemia site [6, 10]

By help of extreme value theory, we can calculate the return period. It starts from the algorithm given in [17 and 19-21] and from the equation for probable error. Pursuant to it for a given disaster size Ioi the mean return period is τ_i . For each τ_i I = 1, 2, ….n it holds the equation R_τ = 0.633. It means that to one I_o there is one τ value that fulfils given equation. The mean return period for earthquake with intensity I_{oi} is τ_i and every value τ_i for I = 1, 2, ….n is defined by equation $R_{\tau i}$ = 0.633 and it is given in Table 1. The Table suggests that for I_{oi} = 9°MSK-64 in region of site under account approximately the mean return period is 460 years. It means that, in the followed site, the earthquake impacts corresponding to intensity 6°MSK-64 will occur once 460 years taking into account the attenuation of earthquake impacts with distance for given case. These impacts cannot damage buildings and equipment respecting the Czech technical norms and standards, because buildings in the CR are built so that they withstand such impacts, while the requirements for nuclear facilities are even much stricter [8 and10].

MEAN RETURN PERIODS τ_i FOR EARTHQUAKE
WITH INTENSITY I_{oi} IN SITE REGION [5]   Table 1

I_{oi} [°MSK-64]	τ [years]
6	4.20
6.5	9.17
7	19.30
7.5	41.38
8	90.08
8.5	199.76
9	459.33
9.5	1148.33
10	4568.37
10.5	7373.51

Conclusion

The analyses show that natural and other disasters will originate in the human system, because they are an inherent phenomenon of this system. The purpose of sapient human is to adapt to this situation and to create tools for its management, which in other words means to build complex safety contributing to sustainable development of the whole human system. Hazards from natural and other disasters cannot be eliminated, because they are inherent disaster properties, i.e. they constitute the potential of disaster to cause impacts on safeguard interests, harms, damages and losses on property and infrastructure. By reasonable safety management, it is possible to diminish the occurrence frequency of some disasters (e.g. accidents), or it is possible to prevent their undesirable impacts or at least mitigate them.

To ensure the safety and sustainable development, it is necessary to monitor and to evaluate disasters, i.e. to investigate the extreme disaster size, and systematically perform the measures to avert them, and to avert or mitigate their impacts.

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