Creative Construction Conference 2016

Mechanical Safety and Survivability of Buildings and Building Structures under Different Loading Types and Impacts

Vladimir Travush[1], Sergey Emelianov[2], Vitaly Kolchunov[2], Alexey Bulgakov[2]*

[1] GOROPROEKT, st. Academician Tupolev 15, build. 15, off. 5, 105005 Moscow, Russia
[2] Southwest State University, st. 50 let Oktyabrya. 94, 305040 Kursk, Russia

Abstract

Modern construction sites are characterized by rapid pace and complicated organization of work processes. One of the important problems of a construction site is the human safety. The paper contains a categorization of human hazards during construction activities and an analysis of main causes of accidents in buildings and at construction sites. Together with general definitions of safety the paper reviews some new research trends in the field of mechanical safety and structural survivability of buildings and structures under different loads and impacts, including regular and accidental types of loading. It is shown that up-dating of safety regulations should mean not only the clarification of new terminology adopted in building codes and regulations on structural safety, but also supplementation of the regulations with sufficiently justified and experimentally verified provisions that should regulate the safety of buildings and structures under design and beyond-design basis loads and actions.

Keywords: construction site, human safety, mechanical safety of buildings, structural survivability.

1. Introduction

Human beings exist in an environment that is potentially hazardous for their life activity. Yet, living environment itself is also endangered by a number of factors that can be ranged according to their global risk level. First, it is the position of Earth in the Universe, then, the different natural disasters like earthquakes, cyclones, avalanches, floods, hurricanes and, last but not least, military threats and the Earth's current condition formed due to technical activity of people. Many astronomic discoveries that were made during the last decade have also revealed new serious threats and risks for human existence.

The rate of human influence on the environment increased in the middle of the 19th century when industrial revolution started. By invading into nature and inventing new technologies people built up their artificial environment, or technosphere.

The philosophers of the past used to think that the development of science and technological progress would foster human dominance over nature. Population was expanding with urban residents increasing very quickly. It caused a growth of urban areas, including roads and disposal fields, which resulted in the degradation of nature and cut down natural habitat realm of many plants and animals.

That is why in the early 20th century new wave of thinkers critically reviewed the progress of technology that stopped being just a human tool and turned into an individual activity sphere that threatened natural environment and contributed to human extinction. In the second half of the 20th century the changes in the environment developed to such extend that they jeopardized the human beings either directly or indirectly and actually made their activity. A number of serious challenges emerged including radioactive waste disposal, climate changes resulting from atmosphere pollution and flooding of territories as a result of the construction of hydroelectric power them fall prey to plants. Now many biological interactions are replaced by the processes of physical and chemical

* Corresponding author. Tel.: +49-1577-581-7236
*E-mail address:*a.bulgakow@gmx.de

interaction, which have a negative impact on people and natural environment.   In fact we are talking about human safety under specific conditions. For biological systems safety quality is defined as survival rate [1].

2. Safety in living environment

Humanity exists in continuous interaction with its living environment in a constant exchange of substances, energy or information. Natural environment provides our planet with solar energy, flora and fauna. Technosphere provides artificially generated energy and various raw materials, supplies products and human resources, produces waste. Social environment is an integral system of material, economic, social, political and cultural conditions for existence, formation and activities of individuals and social groups [2, 3]. Depending on the size of the mentioned types of energies, substances and social conditions it is possible to trace down several typical interaction states in the system “human being – living environment”   (Fig.1):
comfortable state with best conditions for work and rest, preservation of human health and environment;
admissible state without negative impact on human health, but with a feeling of discomfort and decreased efficiency of human activity;
harmful state with negative impact on human health, which causes human diseases and environmental degradation;
hazardous state which causes disastrous effects in natural environment and results in lethal outcome.

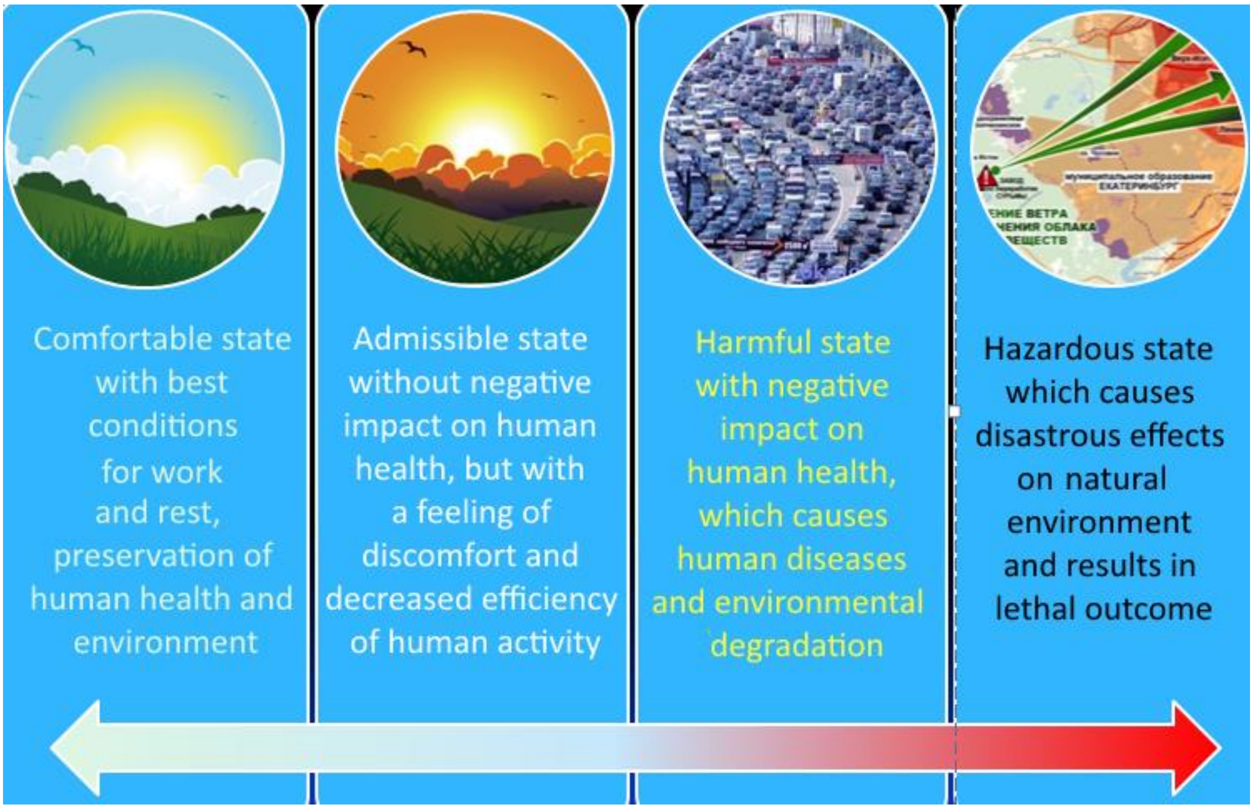


Figure 1. Levels of interaction with living environment

Two of the above mentioned states, harmful and hazardous ones, are inacceptable for human activity processes and natural environment preservation.

These two states are inseparably related to such notions as an emergency event (EE) and an emergency situation (ES).

Emergency event is a short-term incident that has a significant negative impact on people, natural and material resources. Emergency events include major accidents, catastrophes and natural disasters.

Emergency situation is characterized as conditions that have arisen as a consequence of an accident, a hazardous natural phenomenon or other acts on a certain territory or water area, and can endanger human life or health, cause material damage and deteriorate natural environment.

Urban habitat is characterized by significant amount of various modes of transport and intensive traffic, varied development, various industries, including potentially hazardous ones, and high concentration of utilities per unit area.

A city has some areas with elevated risk factors like concourse zones or locations in close vicinity to potentially hazardous facilities. In order to get protected against everyday natural risks people use dwellings, clothing, ventilation, heating and conditioning systems, and artificial lightening.

The list of negative factors is long. First of all it includes air polluted by industrial emissions, natural gas combustion products and automobile exhaust gases, discharges of incinerators and emissions of thermal or nuclear power plants. Then it includes contaminated waters, noise and vibration, electromagnetic fields, poor lightening, monotone activities and hard physical labor.

Location areas of main traffic arteries, radio or television transmitters, as well as the use of industrial or domestic appliances pose serious technogenic risks for people in case of their presence. Human errors are considered to be the main cause of about 80% of plane crashes; 60-80% of road accidents and over 60% of accidents at high-risk industrial facilities.

As life activity of people is potentially dangerous, the current world practice has turned down the idea of absolute safety in favor of risk concept [4,5,6]. Risk is the probability of a potentially dangerous event in a dangerous situation (Fig. 2).

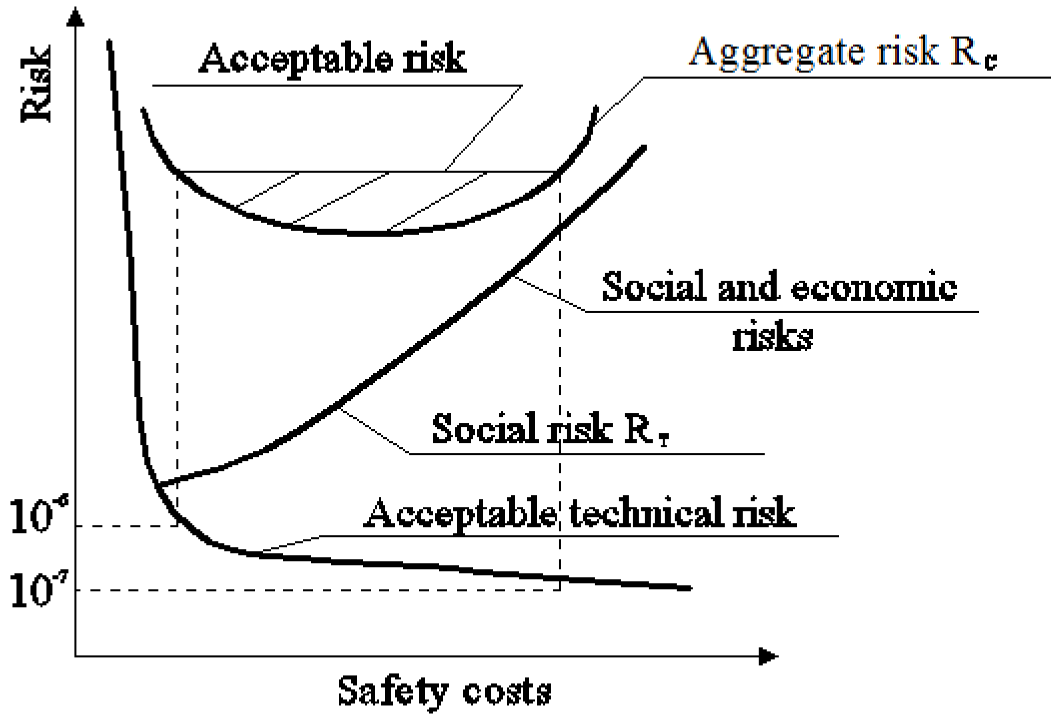


Figure 2. Acceptable risk concept

The analysis of human life activity shows that it is impossible to reach a zero risk level in any sphere. The quantitative assessment of the probability of a negative effect on humans is expressed as risk of harm or damage. When risk is acceptable the protection measures are able to ensure a certain preset safety rate, i.e. this is a compromise between safety level and possibilities to reach it. When investment into safety increases, new equipment and new production technologies are developed, hence technological risk is reduced, however, at the same time common wealth may go down, which will cause social and economic risks. Aggregate risk is minimal if investments into technical and social spheres are in due proportion. This factor should be considered when identifying a risk that the society should reckon with.

Objective need of an individual and the society in security and protection against hazards has almost reached its maximum. Death rate is high in many countries as a result of bad environment, significant injury rate, heavy alcohol drinking and diseases.

In Russia these factors are aggravated by high urbanization rate. It causes a growth of the disabled and consequently leads to serious challenges that have to be met in order to ensure safety and accessible environment for such social groups [7].

One of the most important strategic tasks of the Russian Government is to ensure safety of water supply and sewage systems [8]. In today's Russia the total yearly amount of water supply is over 18 bln m^3, however about

30 million people have no access to centralized water supply systems. At the same time there is a degrading trend in the state of central water supply sources and in sanitary and epidemiological condition of water supply lines. (Tables 1 and 2).

Table1 – Current condition of central water supply sources

Indicator	2011		2012		2013		Gain rate in per cent compared with 2011,%
	total, pieces.	share, %	total, pieces	share, %	total, pieces	share, %	
Sources that do not meet sanitary and epidemiological norms	16 583	16,2	16 103	15,8	16 020	15,8	-2,5

Table 2 – Water supply lines that fail to meet sanitary and epidemiological standards

Indicator	2011		2012		2013		Gain rate in per cent compared with 2011
	total, pieces	share %	total, pieces	share %	total, pieces	share %	
Water supply lines that do not meet sanitary and epidemiological noms due to the lack of	13 099	19,0	12 801	18,4	11 927	17,8	-6,2
- sanitary protection zones	7 445	56,8	7 315	57,1	6 350	53,2	-6,3
- water treatment facilities	4 832	36,9	4 600	35,9	4 518	33,9	-5,7
- water disinfection means	1 777	13,6	1 711	13,4	1 645	13,8	1,4

Treated sewage waters can still contain heavy metals, which can be explained by discharges of wastewater from industrial facilities.

Therefore the development of environmentally friendly water treatment systems together with reliable water supply and water drainage lines, which should meet up-to-date sanitary standards, is a top priority.

Air pollution with suspended particles, nitrogen dioxide, benzapyrene, benzene hydrocarbons is registered in 76 subjects of the Russian Federation. In 13 regions of the country the air pollution level is really high [9].

There are up to 100 bln tons of waste accumulated on dumps, waste grounds and in waste storages, among them about 1.5 bln tons is toxic waste [10]. Every year about 2 thousand hectares of lands, including agricultural areas, are allocated for solid waste storage purpose. Research Institute of Construction Physics of the Russian Academy of Architecture and Construction Sciences together with Central Research Institute of Ferrous Metallurgy have developed energy saving environmentally friendly technologies of processing bulky waste of metallurgical and power production industries. The waste is processed into composite astringents and aggregates that can be used in the production of light and heavy concretes. The research on this solution has been performed within the framework of the Federal Target Program “Housing”. Analytical data given in Table 3 shows that the share of processed bulky industrial waste in the production of cements is about 50% and in the production of dense and porous aggregates is about 20%.

Table 3 – The structure of bulky technogenic waste and its processing products that are recommended for use in the manufacture of light and heavy concretes (as of January 01, 2015). Source: Research Institute of Construction Physics

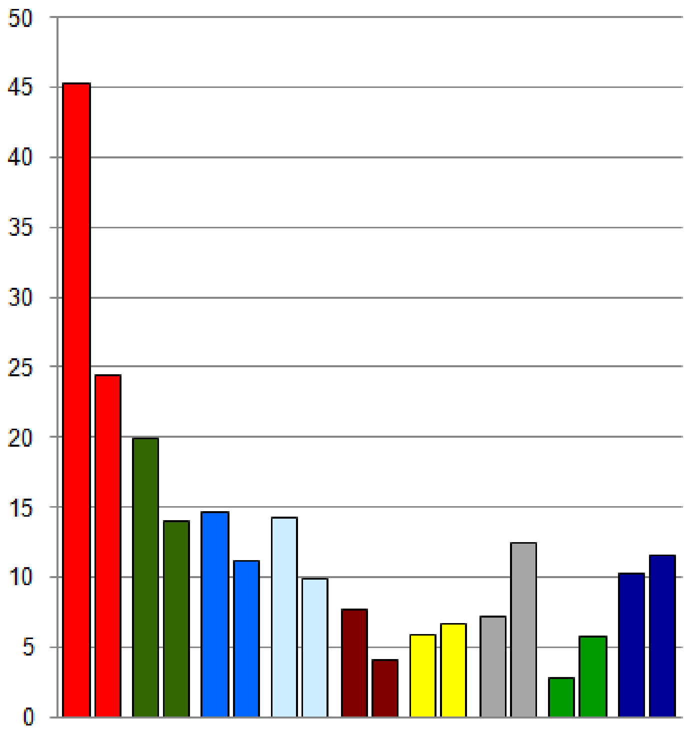
Types of technogenic waste	Waste production volume, mln t/year	Potential volume of processed materials, per year		
		Portland blast-furnace cement, composite astringents, mln	Dense aggregates for heavy concretes, mln m3	Porous aggregates for light concretes, mln m3
1	2	3	4	5
Ferrous and non-ferrous metallurgy				
1. Blast-furnace melts cast iron production waste	34,0	28,0	4,5	14,5
2. Granulated slags – copper and nickel production waste	12,5	–	11,3	–
3. Cast slags – nickel production waste	2,2	–	1,8	–
4. Bauxite sludge – aluminous production waste	2,5	4,2	–	1,2
Power production				
5. TPP slag and cinder	12,5	6,0	0,8	18,2
6. Coal enrichment waste	12,0	–	–	15,6
Total:	75,7	38,2	18,4	49,5

As for the causes of accidents on construction sites, as seen in Figures 3 and 4, more than a quarter of all accidents occur because of the poor quality of construction and installation work, a quarter of accidents occur due to poor operation of the facilities and about the same quantity of accidents occurs due to the poor quality of materials and structures. Poor quality of design work is the cause of a tenth of the accidents.

Economic crises contribute to the growth of accidents due to the reduction of so called secondary works like heat and waterproof insulation or anticorrosion coating works or due to interruptions in the construction works without proper mothballing.

The reliability concept is widely applied in the safety analysis of technical solutions. [11, 12]. Reliability can be described as an appropriate performance of a facility under specified conditions of operation, maintenance, storage and transportation. Reliability is an inherent feature of an object. It is revealed through the interaction of this object with other objects within a technical system and its relations to external environment. As reliability is a complex feature it has to be assessed on the basis of individual properties such as safety margin, durability, maintainability and integrity.

To assess the safety of a technical system, its reliability analysis should be supplemented by the review of possible consequences of its failure. It should be done in order to assess the possibility and extend of damage for people and equipment, i.e. it is necessary to assess the risk. Except general safety there is also mechanical safety, which is ensured load-carrying capacity of a structure. Effective technical regulations [13] introduce a new design condition – a design accident event which has a low probability of occurrence and a short-term period of action, but may be significant in terms of the consequences of reaching the limiting states that can develop thereof. In fact the new design condition concerns the survivability of structural elements in emergency situations [14, 15, 16].



№, color		Facility type	2013		2014	
			Number of emergences	Share, %	Number of emergences	Share, %
1	red	Residential buildings	177	45,3	59	24,4
2	green	Public buildings and concourse areas (institutions, schools, hospitals, sports facilities, stations, shopping centers, churches, etc.)	78	19,9	34	14,0
3	blue	Buildings under construction, renovation or maintenance	57	14,6	27	11,2
4	light blue	Other building structures (fences, railings, parkings, stacks, water towers)	56	14,3	24	9,9
5	dark red	Non-operating facilities (abandoned)	30	7,7	10	4,1
6	yellow	Industrial buildings	23	5,9	16	6,6
7	grey	Lifting mechanisms (cranes, elevators)	28	7,2	30	12,4
8	bright green	Bridges	11	2,8	14	5,8
9	dark blue	Grounds	40	10,2	28	11,6

Figure 3. Accidents at all types of facilities in 2013-2014

Type of facility	Zone of specific risk	Color	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Residential buildings	1		22	31	42	38	29	35	61	101	112	177	59
Public buildings and concourse areas	2		19	19	38	24	18	19	43	49	52	78	34
Objects under construction or renovation	3		12	15	20	27	22	21	36	26	37	57	27
Decommissioned facilities			6	7	13	15	11	8	23	25	30	30	10
Industrial buildings			12	13	15	9	10	10	28	24	34	23	16

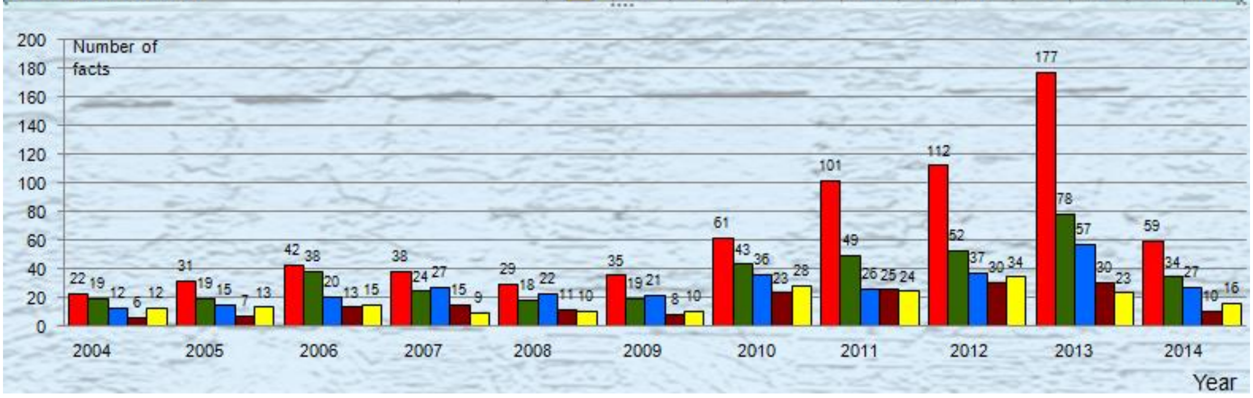


Figure 4. Building collapse accidents in 2004-2014

Progressive or avalanche-like structural failure is a chain reaction to a local disproportionate initial failure of a structural element, which results not only in a disproportionate collapse of the structure, but also in a disproportionate shortening life of operation and in damage. Such event can be initiated by one of numerous accident factors like accidental explosion, fire, design or construction error, or a terrorist act. Modern structures have a restricted load-carrying margin that is insufficient to withstand such accidental impacts. There is neither generally accepted scientific base nor design practice that can ensure a complete integrity of a structure in an emergency situation when design loads can be combined with accidental impacts. Obviously, methods and technologies should be developed to enhance resistive capacity of the existing buildings and their adaptability to progressive collapse. Modern effective calculation systems are able to determine the response of a structure to accidental dynamic loads. However these results have to be verified by large-scale experimental data. Of accident structural failures people have accumulated some knowledge about vulnerability of structural systems. The accumulated data can be used to build up a proven model of plastic work of buildings and structural elements under accidental impacts.

Probability and potential consequences of accidental impacts and progressive collapse should be clearly stated in the relevant standards and regulations and should become an integral part of the design process. Standards and regulations should basically define that the consideration of a progressive collapse event is an obligatory design requirement; it should be taken into account irrelevantly of the initiating event type, i.e. whether the initiator is an “accidental” or a “regular” loading.

The risk of a progressive collapse cannot be eliminated completely. Designers should be responsible for justifying the measures designed to minimize the risk of a progressive collapse. Design engineers should understand how complex this problem is and should consider different variants at the stage of conceptual project planning. Moreover the design engineer should inform the developers, architects, building owners and residents about possible consequences of emergences.

The safety of social and living environment largely depends on the safety of buildings and structures. In Russia the safety of environment has always been ensured by the system of national regulations that demand obligatory use of State Standards (GOSTs) and Construction norms and regulations (SNiPs). Recently there has been an attempt to make the use of standards optional. In 2003 the voluntary use of standards was fixed in Russian federal law on technical regulations. In the period when the use of SNiPs was obligatory there were no accidents, but those regulations were heavily criticized as “hindering the technological progress”. Russian Academy of Architecture and Construction Sciences together with numerous construction organizations put a lot of effort to prove the necessity of mandatory use of SNiPs. Finally, in 2009 the technical regulations on the safety of buildings and facilities were adopted in the status of the Russian Federation Federal Law No. 384-FZ. It includes Article 5.1 which concerns specific regulations for the safety of buildings and structures, outlines specific features of technical regulations in construction industry and fixes obligatory implementation of a certain group of construction norms and regulations.

Recently Russian Government has adopted a revised version of the List of standards and regulations that must be used in order to comply with the requirements of the federal law on technical regulations. The adopted list is not free from the mistakes that used to be in the former document, as it is also divided into two sections, with one part comprising mandatory regulatory documents and the other one containing optional regulations. Meanwhile the optional use is not regulated by any legal acts. Moreover, optional regulations and standards in Russia cannot be used as basis for expertise of design documentation or for building inspections, etc.

More detailed review of the List shows that, evidently, its authors' goal was rather not to register all necessary documents that contain safety requirements covering every aspect of the technical regulations on the safety of buildings and facilities, but to reduce the number of obligatory documents. As a result the new List contains 76 documents, which is by 15 items less than was in the previous list. Only two GOSTs were included into the List. Yet, even the main standard GOST 54257 "Reliability of building structures and foundations" was seriously revised: its two sections (Section 3.1 "Reliability of building structures" and Section 3.2 "Durability of building structures and foundations") were excluded from the list of obligatory documents and transferred into optional use. GOST standards that regulate the methods of building materials testing were included neither into the obligatory nor into optional sections. However, for designers, building inspectors and building engineers, testing regulations predetermine a similar understanding of mechanical and other properties of building materials. Such properties should be clearly specified and should not differ depending on a test lab. All rules of conducting construction operations have been left outside the List, though they logically should have been included into the list of obligatory standards as they have direct influence on the safety of buildings and construction elements. Experts from the Russian Academy of Architecture and Construction Sciences think that the technical regulations on the safety of buildings and facilities should be supplemented with a special section explaining basic principles of optional use.

Risk factors in industry, urban environment and individual dwellings usually have a prolonged effect, so it is necessary to monitor living environment continuously. It can be achieved by means of monitoring systems that register all changes in the environment and are able to generate alarm signals in case of deteriorating conditions. There is also a need to make electronic categorization certificates for all industrial and social buildings; the most important construction objects, construction elements and parts of buildings should be regularly inspected visually with registration of their current condition.

Figure 5. State information strategy is to protect environment against ourselves

The basis of city management is safety built on knowledge which includes professionalism, information, the development of proposals to eliminate the factors hindering the development [3]. In this regard, the state information strategy should include the following tasks: to regularly inform the public about toxic releases into the environment, to inform workers about the negative factors of production and their impact on health, to inform about the methods and means of protection against hazards. Protective measures to prevent or limit the identified hazardous conditions should include the introduction of special instructions for personnel (Figure 5).

3. Conclusions

For many centuries people have been developing technologies to protect themselves against natural hazards. As a result they have created technological risk factors related to production processes and everyday use of engineering means and technologies. In a modern city all challenges are lying in between two extremes: destruction of nature and degradation of the human being.

Today, when human activity has become global, an inadequate assessment of its consequences can cause disasters. In this situation urban future forecasts have become even more important. If in the past a forecast could be made on the basis of analogies and approximations, today we need extensive scientific research data and computer modeling.

Investigation of human life, cognition and activity is always related to uncertainty: people usually know much less than they would like to know. However uncertainty plays a very important role, as it prepares us for taking unexpected decisions.

Uncertainty can be surmounted by making hypothesis, or by creating images, which is a more frequent case. That is why many discoverers are artists, architects or poets.

People believe that their progress cannot be stopped by some barriers. Does it mean that human capabilities are unlimited, or does it mean that the humankind has not yet realized that people have reached cognition limits and no further development is possible? People are never satisfied by nature, especially considering that it is limited to their habitat. If in nature the properties of matter are set by nature itself, in human civilization people use natural resources to get some useful properties that have never existed in nature. These new properties sometimes produce unplanned effects that may run into an uncontrolled process of interaction with nature and even may conflict with natural properties or with the properties of a human being.

Safe living environment does not just mean the absence of any hazard or risk of loss of life or assets, first of all it means the feeling of being safe, secured and protected and that there is no danger. To reach this goal is the objective, challenge and main meaning of profession of a builder.

References

[1] Rachkov V.P., Novichkova G.A., Fedina E.N. «Chelovek v sovremennom tehnizirovannom obschestve: problema bezopasnosti i razvitiya», 1995.

[2] Ilichev V.A. i dr. Printsipyi preobrazovaniya goroda v biosferosovmestimyiy i razvivayuschiy cheloveka / Nauchnaya monografiya/ V.A.Ilichev, S.G. Emelyanov, V.I. Kolchunov, V.A. Gordon, N.V. Bakaeva. – M., Izdatelstvo ASV, 2015. -184 s

[3] Ilichev V.A. Preobrazovanie gorodov v biosferosovmestimyie i razvivayuschie cheloveka: kurs lektsiy [Tekst] / V.A. Ilichev, S.G. Emelyanov. – M.: Izd-vo Yugo-Zapadnogo gosudarstvennogo universiteta, 2013. – 99 s.

[4] Snizhenie riskov v stroitelstve pri chrezvyichaynyih situatsiyah prirodnogo i tehnogennogo haraktera/ Bulgakov S.N., Tamrazyan A.G., Rahman I.A., Stepanov A.Yu. Pod obsch. red. Tamrazyana A.G. – M.: MAKS Press, 2004. – 304 s.

[5] Maslennikov A.M. Riski vozniknoveniya prirodnyih i tehnogennyih katastrof: ucheb. posobie/ A.M. Maslennikov; SPbGASU. – SPb., 2008.-165 s.

[6] Tamrazyan A.G. Osnovnyie printsipyi otsenki riska pri proektirovanii zdaniy i sooruzheniy / A.G. Tamrazyan // Vestnik Moskovskogo gosudarstvennogo stroitelnogo universiteta. 2011. #2.- S.21-27

[7] Kolchunov, V.I. Metodika rascheta pokazatelya dostupnosti obschestvennyih zdaniy i sooruzheniy malomobilnyim gruppam naseleniya [Tekst] / Kolchunov V.I., Skobeleva E.A., Bruma E.V. // Stroitelstvo i rekonstruktsiya. 2013. #4. – S. 60-68.

[8] Pupyirev E.I. Sistemyi zhizneobespecheniya gorodov [Tekst] / E.I. Pupyirev M.: Izdatelstvo Nauka, 2006.

[9] Azarov V.N. Ekologiya. Uchebnoe posobie. [Tekst] / V.N. Azarov. –M.: Izd-vo Feniks, 2009. – 348 s

[10] Investment Consulting & Market Research. INVENTICA. MARKET RESEARCH. Tverdyie byitovyie othodyi v RF. Issledovanie ryinka upravleniya TBO v Rossii. Ob'emyi ryinka, regionalnaya struktura, klyuchevyie igroki. - M., Izdatelstvo OOO «Inventika» , 2010. – 143 s.

[11] Bolotin V.V. Metodyi teorii veroyatnostey i teorii nadezhnosti v raschetah sooruzheniy [Tekst] / V.V. Bolotin. –M.: Stroyizdat, 1982. – 351s.

[12] Rzhanitsyin A.R. Teoriya rascheta stroitelnyih konstruktsiy na nadezhnost [Tekst] / A.R. Rzhanitsyin. – M.: Stroyizdat, 1986. – 242 s.

[13] Federalnyiy zakon ot 30.12.2009 #384-FZ (red. ot 02.07.2013) «Tehnicheskiy reglament o bezopasnosti zdaniy i sooruzheniy» [Tekst].

[14] Travush V.I., Kolchunov V.I., Klyueva N.V. Nekotoryie napravleniya razvitiya teorii zhivuchesti konstruktivnyih sistem zdaniy i sooruzheniy // Promyishlennoe i grazhdanskoe stroitelstvo. 2015 (3), S. 4-9.

[15] Tamrazyan A.G. Raschet vnetsentrenno szhatyih zhelezobetonnyih elementov pri dinamicheskom nagruzhenii v usloviyah ognevyih vozdeystviy // Promyishlennoe i grazhdanskoe stroitelstvo. 2015 (3). S. 29-35

[16] Klyueva N.V., Androsova N.B. K postroeniyu kriteriev zhivuchesti korrozionno-povrezhdaemyih zhelezobetonnyih konstruktivnyih sistem // Stroitelnaya mehanika i raschet sooruzheniy. 2009 (1). S.29-34.

[17] GOST R 54257-2010. Nadezhnost stroitelnyih konstruktsiy i osnovaniy. Osnovnyie polozheniya i trebovaniya. – M.: Standartinform, 2011. – 18 s.