Maintenance of comprehensive safety of tunnel-type road interchanges

Alexander Ginzburg¹, Sergey Kachanov² and Sergey Kozminikh³

¹ Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia
² Federal State Budget Establishment All-Russian R&D Institute for Civil Defense and Emergencies, 121352, 7 Davydkovskaya street Moscow, Russia
³ University of Finance at Government of the Russian Federation, 125993, 49, Leningradsky Ave, Moscow, Russia

E-mail: ginav@mgsu.ru

Abstract. Numerous people, dead and injured as a result of road accidents at the tunnel-type interchanges proves that the measures, taken for prevention of emergency situations in tunnels are insufficient. At the same time, various monitoring systems are installed at such facilities, being not connected among themselves. So, they cannot reduce, but can even increase the consequences severity in case of emergency situation because of the inconsistency of joint operation of the automated control systems for safety and life support at the road interchanges of tunnel type. The analysis of possible types of threats for the road interchanges of tunnel type allows to conclude, that some adequate measures for ensuring their safety can be taken only with the use of automated systems of remote monitoring of the facilities condition, modern communication systems, organization of the proper training of specialists for complex safety of facilities as well as advanced trainings of designers in this sphere. The main causes of emergency situations at the road tunnel-type interchanges are considered to achieve this goal. The causes of insufficient efficiency of the existing technologies and technical means of ensuring complex safety of tunnels are also analyzed. The technology of complex safety of the road tunnel-type interchanges is developed and approved on the basis of the carried-out analysis and with the use of methods of systems analysis and the theory of experiment. Experimental studies were carried with the use of the theory of experiment and the use of certified measuring instruments. It was proved scientifically and confirmed experimentally, that the offered technology of complex safety of the road interchanges of tunnel type allows to reduce risk of emergency situations and people's death in tunnels by more than 50%.

1. Introduction
Nowadays numerous road interchanges are built for the increase in speed of traffic and reduction of the distance among cities, localities and various objects [1]. At the same time, the tunnels that are being designed and built have the increasing extent and they are intended for simultaneous transmission of a great quantity of cars. All that increases the risk of emergency situations at such facilities with thousands of dead and injured people as well as with significant material and social damage [2]. The destruction of tunnels can also lead to the violation of the city functioning because of the delay of delivery of goods, which are necessary for production and life support in the city. Nowadays technogenic threats, even in spite of the compensating means of their localization, are...
aggravated through the impact of natural disasters considerably [3]. Hurricanes, tsunami, earthquakes, other cataclysms, being the threats of natural character, lead to possible destruction of the tunnel-type road interchanges [4].

The carried-out analysis of data on the emergency situations at the tunnel-type road interchanges proved that the existing level of their safety not fully meets the modern requirements [5], [6]. The decrease in safety of tunnels is also promoted by the fact that they often function with the excess of the admissible limit of their handling capacity. For example, there pass more than 7000 cars an hour in the Lefortovo tunnel in Moscow, while they have to pass up to 3000 cars an hour according to the project.

It is possible to carry out the analysis of design and operation of the technical equipment and safety systems of tunnel traffic intersections, which was carried out by Department of maintenance of the Moscow transport tunnels equipment, and proved that misunderstanding of the importance of the unified system of management of the engineering procedures by the customer and general designer leads to the heap of various equipment in control offices. That results in the complexity of orientation at emergency and loss of management as an example of low safety in tunnels [7], [8], [9].

The management system is designed after the facility is built and technical systems are installed. That sometimes results in the impossibility of their integration [10], and in case of the equipment failure in only one of hundreds of chambers of the traffic intersection that leads to loss of control of the engineering systems of the entire transport interchange [11].

The control system in a tunnel is not connected with fire extinguishing systems and the gas analysis systems that already led to some serious consequences [12].

According to this analysis the Moscow transport tunnel equipment operation Department concluded that an integrated approach to safety of road tunnel-type interchanges.

It is possible to note the following accidents among the most serious consequences of emergency situations at the road tunnel-type interchanges: 39 people died and 10 people got severe injuries as a result of the fire within 53 hours in a tunnel Mont Blanc on March 24, 1999; in 2012 there was a collapse of the tunnel connecting Tokyo to Nagoyy, when a lot of people and cars suffered as a result; a lot of people died and suffered and dozens of cars burned down in the Alpine tunnel of Saint-Gotar between Switzerland and Italy as a result of the fire on December 7, 2017 [13], [14], [15].

Thus, creation of any technology of ensuring comprehensive safety of road tunnel-type interchanges is a relevant task.

Scientifically based approaches to the creation of comprehensive safety of unique, technically difficult and crucial facilities (further objects of the increased risk) to which road tunnel-type interchanges belong, have begun to develop relatively recently.

Some research was executed in the field of ensuring comprehensive safety of facilities of the increased risk. We should note Batyrev V.V., Volkov A.A., Volkov O.S., Topolsky N.G., Popov A.P., Bodie J., Zinka W., Wawryn K., C.M. Pietersen, M. Morris, G.A. Clay, V.C. Marshall, B.J.M. Alle, N.A. Roberts, A. Wolski, B.J. Paaske, L. Nesheim, O. Thomassen, L. Tronstad and other Russian and foreign scientists.

However, despite a great volume of domestic and foreign research in the considered area many matters concerning this research remain not covered. The analysis of earlier works proved the need of improvement of methods of increase in the safety of facilities of the increased risk [16], [17], [18].

2. Methods
The development of scientific and methodical bases of ensuring comprehensive safety is an initial, but extremely necessary stage in the field, as well as in any system matters. For this reason, the Ministry of emergency situations of Russia together with the National Research Moscow State University of Civil Engineering (NIU MGSU) carries out an active work on further increase in safety of facilities of the increased risk. Some regulating and methodical documents aimed at the development and implementation of technologies of prevention and emergency response at the facilities of the increased risk is developed and introduced for this purpose, including some works with the participation of the authors. Among the main Russian documents in the field It is possible to note: Federal law "Technical Regulation on Fire Safety Requirements", adopted on July 22, 2008 No. 123-FZ; Federal law "Technical regulation on buildings and constructions safety" adopted on 30.12.2009 N 384-FZ;
The standard GOST P 22.1.12 - 2005 "Safety in emergency. The structured monitoring system and control of the engineering systems of buildings and constructions. General requirements".

The carried out analysis of the technical equipment, used during design and construction of road interchanges of tunnel type, proved that the following main devices and systems are their part: automatic fire alarm; automatic fire fighting; all-exchange tunnel and emergency ventilation, antismoke protection; control of the gas environment; power supply, working light in the tunnel; redundant power supply; control of emergency exits; managements of traffic; fire water supply; water disposals (electrical heating of water-removing trays); safety alarm system; notifications and evacuations; control of access; video of observation and security television [19], [20], [21], [22].

Various, not connected information, which is output to many screens comes to control office of a road interchange from all the above-mentioned systems. It can be seen in Figure 1, which presents the appearance of control office of the 3rd transport ring of Moscow. It does not allow dispatching service to estimate safety status of a controlled facility quickly and in a comprehensively and, to reduce risk of emergency situation at the facility.

The structured monitoring systems and managements of engineering systems (SMIS) are being implemented in order to provide comprehensive representation and automated analysis of information about the threat or fact of emergency situations at high-risk facilities. It is expedient to implement such systems at all the road tunnel-type interchanges, which are planned and being under construction [23], [24], [25].

Figure 1. Control office of the road interchange of the 3rd transport ring in Moscow.

3. Results
Introduction of such systems at the road tunnel-type interchanges will allow to provide comprehensive information analysis about the threat or the fact of emergency situations and thus:

- to increase the efficiency and quality of forecasting and prevention of emergency situations;
- to transfer information on threat or the fact of emergency situations to the duty-dispatching services of the controlled facility and the operational duty services of the city in the formalized type and quickly;
- to start the warning system of the population and the specialists who are responsible for security of the facility about the occurred emergency situation in due time;
- offer automated algorithms for the prevention and elimination of emergency situations of various types, which have been worked out in advance and agreed upon by the relevant services, to the duty service of the facility;
- to make the automated accounting of emergencies.
The complex of problems has to be solved for the purpose of implementation of requirements to the comprehensive safety of road tunnel-type interchanges during creation and maintenance of Monitoring and control systems for engineering systems (MCSES) at this facility. This complex includes:

- determination of threats of technogenic and natural character at the facility;
- determination of the tasks solved by MCSES for different types of threats;
- integration of MCSES into the general complex of the engineering systems ensuring safety and activity of the facility;
- development of algorithms of interaction of all the engineering systems of the facility and its own operation algorithm of MCSES for working with these systems during an emergency situation;
- determination of an order of the system design and coordination of the project;
- determination of an order of carrying out installation and commissioning;
- determination of an order of carrying out complex tests of MCSES and the whole complex of engineering systems of the facility;
- determination of a method the system operation;
- implementation of the organizational actions connected with training, creating and operating of MCSES;
- the organization of work of the monitoring bodies, which carry out control over introduction and operation of MCSES;
- organization of communication of the object with the unified duty-and-dispatching service of the city (UDDS);
- development and the approval of regulations of interaction of the facility services and operational service of UDDS in case of emergency situations at the facility.

The solution of these tasks will allow to provide the required level of the facility safety and to minimize the expenses on the localization of emergency situations for all the designed systems.

4. Discussion

Potentially dangerous points and processes of the facility, the impact on which can change the functioning of the protection system and the security state of the whole facility, should be identified within the analysis of the protected facility features. The following features should be taken into account:

- the location of the facility and the level of crime in the area of its location;
- space-planning solutions for the facility;
- organizational structure, size of staff, operating modes of the facility;
- technological processes and their impact on the state of safety;
- vital centers of the facility (communications and life support at the facility);
- features of the facility operation that affect the safety mode;
- existing security organization at the facility.

The comprehensive analysis of "the expected threats" is to be carried out at the stage of development of the concept of the facility protection, including:

- definition of types (features, characteristics) of threats (including the threats of acts of terrorism, technogenic character and emergency situations);
- definition of the reasons and conditions, leading to emergence of threats and decrease in safety level at the facilities;
- detection of the directions and degrees of the threats danger, definition of ways of penetration to the facility and/or ways of the threats realization.

The analysis of quality of the offered security system at this stage has to be made on the basis of expert evaluations at various options of realization of "the expected threats".

It is expedient to hold the following complex of organizational-and-technical events for creation of MCSES at road interchanges of tunnel type and their information interface to the city's operational duty services:
• determination and coordination of structure of the city duty-and-dispatching services involved in the elimination of various types of emergencies, as well as the order of their interaction and information exchange with UDDS by the city administration;
• clarification of the city grouping of forces and means of constant readiness, definition and coordination of the main emergency response measures, which implementation should be organized by the UDDS in case of emergency at the facilities;
• development of the procedure for information support of UDDS in case of an emergency at the facilities;
• improvement of existing communication and warning systems in relation to the tasks and needs of UDDS in terms of prevention or elimination of emergency consequences;
• integration of UDDS automation tools with MCSES.

The main stages of creation of MCSES at the road tunnel-type interchanges and their information interface to UDDS of the city are the following:
• organizational stage, when organizational issues of creation of MCSES and their information interface to UDDS of the city are resolved;
• the technical stage, when program-and-technical means of MCSES are developed and introduced and their information interface to UDDS of the city is carried out.

The following documents are developed and approved during the organizational stage for the creation of MCSES and their information interface to UDDS of the city:
• regulations on MCSES and their information interface to UDDS of the city;
• instructions on the exchange of information among the duty-and-dispatching services of the facilities, UDDS and duty-and-dispatching services of the city;
• additions and changes to the existing instructions of duty-and-dispatching services.

UDDS have to solve the following main tasks regarding the problems of safety at the road tunnel-type interchanges:
• receiving information on emergency situation or current information from MCSES;
• the analysis and assessment of reliability of the arrived information, finishing it to services on duty and dispatching which competence includes response to the accepted message;
• processing and the analysis of data on emergency situation, determination of its scale and specification of structure of the services on duty and dispatching attracted to reaction;
• operational management of forces and means of constant readiness, setting and bringing to them tasks for localization and elimination of emergency consequences, acceptance of necessary emergency measures and decisions (within the limits, established by higher authorities);
• synthesis, assessment and control of data on the situation, taken measures for elimination of the emergency situation, specification and adjustment (according to the situation) the versions of decisions on emergency elimination, which were developed in advance and agreed with city services;
• constant informing of the duty-and-dispatching services, involved in the elimination of emergency and subordinated forces of constant readiness about the situation, taken and recommended measures;
• submission of reports for higher bodies of management according to their subordination about the threat emergence, developed situation, possible versions of decisions and actions for the emergency elimination (on the basis of earlier prepared and agreed plans).

The following information has to come to UDDS from MCSES: on the increase in the level of threshold limit value of chemical and dangerous substances (excesses of acceptable level of gas contamination in tunnels); on the fire at the facility; on any deviations from standard parameters of the technological processes capable to lead to emergency situations; on violations in electricity supply at the facility; on unauthorized penetration into service premises and other controlled zones of the facility; on flooding of chambers, drainage systems and technological pit; on violations in the heating system, hot and cold water supply caused by the engineering equipment failure; on change of the
condition of integrity of technical structures of the facility (structural elements regarding their deformation and destruction).

The following requirements are expedient to be observed during creation of MCSES of road tunnel-type interchanges:

- to create MCSES in the form of modular structure;
- control and management of security systems and life support of the facility has to be carried out in the automated mode;
- MCSES has to be created in the form of "an open system" in which it will be possible to connect entered in addition processing equipment and subsystems of safety of the facility;
- the opportunity of expeditious replacement and modernization of separate functional modules without violation of integrity and operability of the system in general.

It is expedient to develop and introduce the algorithms, allowing to provide timely prevention of emergency situations, which can arise on the traffic intersection, in the automated mode in advance in order reduce the probability of emergency situations at the road tunnel-type interchanges.

For an example, the algorithm of liquidation of the fire at the road tunnel-type interchanges can consist of the following stages:

1) Detection of emergency situation;
2) Authentication of information on emergency situation;
3) Refining of the place and scale of emergency situation;
4) Notification and collecting of forces and the funds raised to liquidation of emergency situation;
5) Carrying out necessary rescue and other urgent works;
6) Performance of works on mitigation of the emergency situation consequences for input of a facility in the normal mode of operation.

The sequence of these stages in the algorithm is rather conditional, since some actions can be carried out in parallel.

According to the preliminary expert estimates, death of people and material damage from emergency situations at the controlled facilities will be reduced not less than by 60% as the result of creation of MCSES at the road tunnel-type interchanges due to reduction of the quantity of the resulting emergency situations not less than for 50% and rapid, scientifically based response to the arisen emergency situation.

Design data are confirmed by the results of accident-free operation of some facilities of the increased risk at which MCSES are introduced. The Lefortovo tunnel in Moscow, Megasport sports palace in Moscow; the district thermal station Chertanovo in Moscow, the office building with an underground parking in St. Petersburg; the complex of buildings and structures of the sea passenger terminal in St. Petersburg; an industrial complex "KUIBYSHEVAZOT" Joint Stock Company, etc. should be noted among such facilities.

5. Conclusions

Summing up the aforesaid, for the increase in the safety of road tunnel-type interchanges it is expedient:

1) To equip all the road tunnel-type interchanges with the structured systems of monitoring and engineering systems managements with ensuring automatic transmission of data on the state of controlled facilities and parameters of emergency situation in the established form in the duty service of the facility and the unified duty and dispatching service of the city.

2) To develop the legislative documents of federal level allowing to stimulate the enterprises, introducing modern automated systems of monitoring for prevention of emergencies, financially. Such stimulation includes significant reduction of insurance premiums for the facility, preferential taxation at costs of the enterprise for the creation and maintenance of monitoring systems, etc.

3) To organize training of necessary specialists in the modern automated technologies of monitoring and prevention of emergencies.
References

[1] Kozminykh S.I. Methodological foundations of ensuring integrated security of an object, company, entrepreneurial activity. Monograph. M.: Moscow University of the Ministry of Internal Affairs of Russia, 2005. - 432 pp.

[2] Ginzburg A., Ryzhkova A., Accounting “pure” risks in early stage of investment in construction projects with energy efficient technologies in use, Trans Tech Publications, Switzerland, Applied Mechanics and Materials Vols. 672-674 (2014) 2221.

[3] Batyrev V.V., Volkov O.S., Kachanov S.A. Technologies for creating structured monitoring and control systems for engineering systems of buildings and structures. // Monograph of LLC Alfa-Porte Novosibirsk 2011.

[4] Ginzburg A., Kachanov S., Methodology for building automated systems for monitoring engineering (load-bearing) structures, and natural hazards to ensure comprehensive safety of buildings and constructions, Research India Publications, International Journal of Applied Engineering Research, Volume 11, Number 3 (2016) 1660.

[5] Ginzburg A., Kachanov S., Technology for Enhancing Safety of Buildings and Constructions, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 20 (2015), Research India Publications (2015) 40869-40872.

[6] Ginzburg A., Ryzhkova A., Information system of risks analysis and management for construction projects with energy-efficient technologies in use, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 21 (2015), Research India Publications (2015) 41828-41830.

[7] Ginzburg A., Kachanov S., Nigmatov G. Risk monitoring for the city in geological hazards conditions / 5th International Scientific Conference on Integration, Partnership and Innovation in Construction Science and Education, IPICSE 2016; Moscow State University of Civil Engineering: MATEC Web of Conferences, Volume 86, 04066 (2016).

[8] Ginzburg A., Khripushin A., Risk Management in oil refinery construction projects, Applied Mechanics and Materials Vols. 411-414 (2013), Trans Tech Publications, Switzerland, (2013) 2313-2316.

[9] Volkov A., Intelligence of buildings: formula, Promyshlennoe I grazhdanskoe stroitelstvo [Industrial and Civil Engineering], 3 (2012) 54.

[10] Ginzburg A., Kuzina O., Ryzhkova A. Unified resources marking system as a way to develop artificial intelligence in construction / IOP Conf. Series: Materials Science and Engineering 365 (2018) 062021 doi:10.1088/1757-899X/365/2/062021.

[11] Volkov A., General information models of intelligent building control systems: basic concepts, determination and the reasoning, Applied Mechanics and Materials Vols. 838-841 (2014) 2973.

[12] A prototype expert system for fault diagnosis in electronic device / Wawryn K., Zinka W. // Eur. Conf. Circuit Theory and Des., Brighton, 5-8 Sept., 1989.: ECCDT’89. London, 1989. - P. 677 - 680.

[13] Bodie J. Automated Satellite Carrier Monitoring Systems. MTTS 85, London, 1985, P. 128 - 132.

[14] Neural networks and fuzzy logic, tools of promise for controls / Mc Cusker Tom // Contr. Eng. 1990. - 37, № 6. - P. 84 - 85.

[15] Ginzburg A., Ryzhkova A. Assessment of construction project “pure” risks / Materials Science Forum. Materials and Technologies in Construction and Architecture Vol. 931 (2018), Trans Tech Publications, Switzerland, 2018, -pp. 1245-1248. doi: https://doi.org/10.4028/www.scientific.net/MSF.931.1245.

[16] Ginzburg A., Ryzhkova A., The most likely pure risk construction projects with energy efficient technologies in use, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 21 (2015), Research India Publications (2015) 42410-42411.

[17] Ginzburg A.V. LE IM: Living Environment Information Modelling / International Scientific Conference Environmental Science for Construction Industry, ESCI 2018; Ho Chi Minh City; Viet Nam: MATEC Web of Conferences, Volume 193, 05030 (2018).

[18] Volkov A.,Chulkov V., Kazaryan R., Gazaryan R., Cycle reorganization as model of dynamics
change and development norm in every living and artificial beings, *Applied Mechanics and Materials* Vols. 584-586 (2014) 2685.

[19] Kozhevnikov M.M., Kozhevnikova S.T., Ginzburg A.V., Gladkikh V.A. Improving the efficiency of the bridges construction organization on the basis of information modeling / *Materials Science Forum. Materials and Technologies in Construction and Architecture* Vol. 931 (2018), *Trans Tech Publications, Switzerland*, 2018, -pp. 1261-1266. doi: https://doi.org/10.4028/www.scientific.net/MSF.931.1261.

[20] Volkov A., Sedov A., Chelyshkov P., Usage of building information modelling for evaluation of energy efficiency, *Applied Mechanics and Materials* Vols. 409-410 (2013) 630.

[21] Ginzburg A. Sustainable Building Life Cycle Design / 15th International Conference on Topical Problems of Architecture, Civil Engineering, Energy Efficiency and Ecology, *TPACCE-2016; Tyumen State University of Architecture and Civil Engineering: MATEC Web of Conferences*, Volume 73, 02018 (2016).

[22] Garyaeva V., Garyaev N., Integrated assessment of the technical condition of the housing projects on the basis of computer technology, *Computing in Civil and Building Engineering Proceedings International Conference* (2014) 1336.

[23] Ginzburg A., Kozhevnikova S., Afanas'ev A., Stepanov V. Organization of concrete works on the bases of the information system of tracking / *Proceedings of the 19th International Scientific Conference “Energy Management of Municipal Transportation Facilities and Transport EMMFT 2017”*. Khabarovsk, Russia 10–13 April 2017. *Advances in Intelligent Systems and Computing*, vol 692. *Springer, Cham*. https://doi.org/10.1007/978-3-319-70987-1_126.

[24] Kozhevnikov M.M., Ginzburg A.V., Kozhevnikova S.T. Creation of the information system based on the integrated evaluation of a construction object at various life cycle stages // *International Scientific Conference on Modelling and Methods of Structural Analysis 2019, MMSA 2019; Moscow; Russian Federation; 13-15 November 2019. Journal of Physics: Conference Series*. Volume 1425, Issue 1 (012117), 2020.

[25] Ginzburg A.V., Shilov L.A., Shilova L.A. The methodology of storing the information model of building structures at various stages of the life cycle // *International Scientific Conference on Modelling and Methods of Structural Analysis 2019, MMSA 2019; Moscow; Russian Federation; 13-15 November 2019. Journal of Physics: Conference Series*. Volume 1425, Issue 1 (012156), 2020.