Description of the information service for high-precision monitoring of the composite engineering structures’ displacements and deformations to ensure the forecasting technological emergencies problems’ solution

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Abstract. The article discusses the issues of information support for the safety of composite engineering structures (CES), such as railway and automobile bridges, dams, high-rise buildings, objects of operation at space centers, etc. The most effective approach to creating systems for monitoring the CES safe state is the integrated use of data from the ground and space high-precision monitoring tools for the static and dynamic displacements and deformations of the CES design elements. The information service developed by the specialists of JSC “Russian Space Systems” relates to the field of monitoring composite engineering structures, namely for operational monitoring of the complex structural elements’ and unique engineering structures’ state. The services are provided by a measuring complex, which can be included as traditional for this area precision meters of physical quantities and meters that work with the support of global navigation satellite systems. The service identifies the dangerous state of a composite engineering structure, based on an analysis of the dynamics of changes in the CES parameters and scenarios of the dangerous state of a composite engineering structure. The ultimate goals of creating such information services is to provide the data necessary for assessing the mechanical safety of engineering structures, departments and individual enterprises involved in organizing the execution of functions to support the life CES cycles.

1. Introduction
Unplanned sudden destruction of composite engineering structures (CES) are the emergency situations (ES) and, as a rule, lead to man-made disasters with human casualties and great material damage. According to the Ministry of the Russian Federation for Civil Defense, Emergencies and Disaster Relief, in 2016, 2017, by the nature and type of sources of the emergency situations, the collapse of buildings and CES for various purposes took the third position in the number of cases after car accidents and aircraft accidents [1].

To assess the condition of buildings and CES, it is necessary to monitor their condition based on the monitoring informative parameters characterizing their stress-strain state. Federal law [2] defines the need to create the automated systems for monitoring the stress-strain state of the buildings and structures. Monitoring of the actual technical condition of engineering structures during monitoring, it is necessary to build an optimal maintenance and repair strategy, to ensure the timely adoption of measures to eliminate the emerging negative factors. The traditionally used geodetic methods for observing the stress-strain state of the CES do not provide the necessary speed of measurements, their processing and
the provision of monitoring and forecasting results to the customers. The development of information services that use the complex data from the ground-based and space-based surveillance equipment should ensure the prompt communication of information to the relevant organizations and services involved in the prevention of anthropogenic emergencies and the population and territory protection.

2. The current state of the problem
A large number of domestic and foreign works [3, 4, 5, 6, 7] are devoted to the construction of software and hardware systems that have functions for assessing the mechanical safety of building structures.

The system of high-precision monitoring of displacements and deformations developed at JSC “Russian Space Systems” using global navigation satellite system (GNSS) technology provides continuous monitoring of displacements and vibrations on the structural elements of bridges, dams, towers and other engineering structures, and allows monitoring the state of the information system with high accuracy and with small time costs, working in any weather conditions [8].

The most effective approach to creating the CES monitoring systems is the integrated use of monitoring data from the ground-based and space-based surveillance equipment.

Similar systems are already being created in the world. For example, the GeoSHM project (Earth observation project for monitoring the structural integrity of bridges using GNSS) is a project funded by the Integrated Application Development (IAP) program of the European Space Agency (ESA) [9]. The ESA IAP program in close collaboration with consumers is dedicated to the development, implementation and pilot operation of the integrated applications. The goal is to add an innovative component to existing services, combining various resources (such as telecommunications, Earth observation, navigation and manned space flight technologies) and integrating them with existing ground services.

The GeoSHM project started in August 2013 and was completed in March 2015. Using the integrated use of GNSS technology and remote sensing, GeoSHM proposed a tool for assessing the operating conditions of the bridge in a timely and reliable manner. Environmental data, such as wind load (speed, wind direction, etc.), were prepared to analyze the response from loads on the bridge structures. The system consisted of four GNSS receivers and two anemometers and was installed on the Forth Road Bridge in Scotland. At the stages of implementation and operation (field-performance) of the monitoring system, accurate estimates of 3D displacements (shifts) of the bridge were performed in real time under various conditions of the external load. The system also used important information on the geotectonic movement of the Earth to assess the potential hazards caused by groundwater and activities, geotectonic hazards and industrial activities.

This development came close to creating a comprehensive solution for the provision of a bridge monitoring information service, but the implementation of the project did not solve the problem of introducing and integrating the classical measuring circuit (measuring vibration, stress and temperature of metal structures) with the data on offsets from the GNSS equipment.

Krasnoyarsk Bridge is the first bridge in Russia equipped with a satellite monitoring system based on the global navigation system (GLONASS). The system makes it possible to control the structural elements of the bridge under adverse environmental conditions such as strong gusts of wind, which can cause high loads in the components of the structure, bringing them closer to the extreme design conditions. Special sensors detect any microcrack in the structure. Information on the “health status” of the bridge flows into a single monitoring center. The generalized data arrives at the regional computer. The system operates around the clock with automatic processing, archiving, display and storage of data. However, the chosen approach when creating the system does not provide an access to the information of all interested consumers, being limited only to the bridge operation service.

The existing solutions in the field of monitoring the state of the composite engineering structures are limited by the use of off-the-shelf hardware and software of the foreign (transnational) developers. As such, there are no accessible operated services providing customers with comprehensive information on the state of technically composite engineering structures.
3. Service Description
The information service developed by the specialists of JSC “Russian Space Systems” relates to the field of monitoring composite engineering structures, namely for operational monitoring of the state of structural elements of composite and unique engineering structures, such as bridges, dams, long-span and high-rise buildings, etc.

Information services for high-precision monitoring of displacements and deformations of composite engineering structures, based on the use of a user interface that provides control of the composite engineering structure’s state according to the data of a programmable device associated with many devices for monitoring the parameters of a composite engineering structure and the environmental factors that identify the dangerous state of this composite engineering structure, based on the analysis of its parameters, are known from the patents for inventions: [10, 11, 12]. A high-precision monitoring information service, in which using the user interfaces of a single control center and a safety control center provide status monitoring of a composite engineering structure, such as artificial structures of high-speed highways, was proposed in [12]. Such user interfaces receive data from a data processing and analysis the server connected through a monitoring data analysis unit and a sensor diagnostics unit with a plurality of control devices for the parameters of a composite engineering structure and environmental factors that identify the dangerous state of this composite engineering structure based on the analysis of its parameters.

In turn, the service being developed is a further improvement of the systems proposed in the analogues and will allow for prompt and reliable forecasting of the occurrence and development of the composite engineering structure’s dangerous state with a description of the type and probability of a threat when publicly accessing the monitoring data.

The information service for high-precision monitoring of displacements and deformations of a composite engineering structure includes a user interface that provides the status monitoring of a composite engineering structure according to the server, associated with many devices for monitoring the parameters of a composite engineering structure and environmental factors that identify the dangerous state of this composite engineering structure based on its parameters’ analysis. The user interface is a thematic portal located on the Internet, which provides the status monitoring of a composite engineering structure and is stored on a web server associated with many devices for monitoring the parameters of a composite engineering structure and environmental factors. This web server identifies the dangerous state of a composite engineering structure based on an analysis of the changes’ dynamics in the parameters of a composite engineering structure and the dangerous state scenarios of a composite engineering structure.

The work of the information service (system) is as follows (Figure 1).

![Figure 1. Block diagram of the service](image-url)
The thematic portal (website), located on the Internet, provides control over the state of a composite engineering structure using a graphical user interface. A means of organizing and storing this thematic portal is a web server connected to many devices for monitoring the parameters of a composite engineering structure (for example, GLONASS / GPS navigation measuring modules) and the environmental factors (meteorological data, etc.). The measurement results are converted in the web server into intermediate structures with the raw data using the OPC (Open Platform Communications) standard software interface. Intermediate structures are recorded in the data warehouse, from where they are transferred upon request for analysis and mathematical processing. The processed data is recorded in the knowledge base for the subsequent selection of parameter values according to the specified criteria.

To identify a dangerous condition by software, the following operations are performed sequentially: collection of initial data on the structure; collection and primary processing of the monitoring data; scenario formation of the structure; construction of a dangerous situation scenarios (Figure 2).

**Figure 2.** The procedure for the emergency situations probabilistic forecast formation using the service.
At the stage of collecting the initial data, an object card containing a mathematical model of the structure is formed, in which the structural locations subject to maximum loads and deformations are determined in advance, the limiting values of stresses, vertical and horizontal deflections and the displacements of the structural elements are calculated, the values of the structural elements’ resonant frequencies, etc. are calculated. Also, the facility card contains a list and classification of the external factors with an assessment of the risks of their occurrence, as well as an assessment of the structural elements’ current state.

At the stage of collecting and primary processing the monitoring data, the information and environmental parameters collected by the monitoring devices are analyzed relative to the calculated threshold values and recorded in the knowledge base. The situation development trend is analyzed, that is, the dynamics (speed) of the change in the readings for each measured parameter and the excess of the specified threshold values. A dangerous situation, starting with an increase in the values of the measured parameter modulo relative to the previous measurement by more than 10% with a short-term excess of thresholds and then a forecast for exceeding the thresholds without returning to the acceptable values’ zone, is diagnosed.

At the stage of generating scenarios of the structure state, the dependencies of recorded events with monitoring parameters and external factors are built. Based on the interrelated events in relation to the timeline, the registered events are arranged in chains. Each chain gets its own assessment of the occurrence and repetition probability and is tied to the dangerous situations’ matrix.

At the stage of constructing the scenarios of a hazardous situation, based on the accumulated chains of events and the initial assessment of the risks of a hazardous situation, appropriate scenarios are formed. Each scenario is a chain of events that may occur in the future. After constructing the chains of events that reflect the development of situations over time, the possible scenarios for the further development of these situations are determined, that is, the principle of historical analogy is the basis for the scenarios’ formation. The base of reference situations is prepared in advance based on past observations or is developed in the training mode. Scenarios of the occurrence of a dangerous situation are ranked by the severity of the consequences and the probability of elements failure of a composite engineering structure.

As a result, the web server identifies the dangerous state of a composite engineering structure based on an analysis of the changes dynamics in the parameters of a composite engineering structure and the scenarios of the composite engineering structure’s dangerous state.

Based on the foregoing, the information service for high-precision monitoring of displacements and deformations of a composite engineering structure includes: a user interface that provides the status monitoring of a composite engineering structure according to the server data associated with a variety of devices controlling the parameters of a composite engineering structure and environmental factors that identify the dangerous state of this composite engineering structure based on its parameters’ analysis.

A distinctive feature of this service is that the user interface is a thematic portal located on the Internet, which provides monitoring of the status of a composite engineering structure and is stored on a web server associated with many monitoring devices for CES and environmental factors, and the web server identifies the dangerous state of a composite engineering structure, based on the changes dynamics analysis in its parameters and scenarios of a dangerous state in a complex engineering structure.

4. Summary
The existing systems for monitoring the engineering structures’ state, without using GNSS GLONASS / GPS data, in most cases do not provide the prompt information for the users and do not provide the consumers with the information about the displacements and deformations (and condition) of engineering structures as a service.
The available information on the implementation of such solutions within the boundaries of the individual corporate information systems makes it possible to conclude that such systems operate in a closed environment.

In the proposed service of high-precision monitoring of displacements and deformations in the composite engineering structures, it is planned to use the new technological solutions in terms of the developed software and hardware, algorithms for collecting and processing (analysis) of monitoring measurement information, as well as bringing the results of the engineering structures’ state forecasting to the users. The sources of measurement information will be the specialized measurement modules that share the data from GNSS GLONASS / GPS with the data from the built-in inertial sensors. The collection and processing (analysis) of the measurement information will be fully automated. Processing of the measurement information will be carried out according to innovative algorithms that allow realizing the analytical data processing and forecasting in real time using the modern computer technology. In general, an information service will be created, implemented by a complex of hardware and software that provide a complete life cycle of information from the collection of measurement data to the provision of information resources to the consumer.

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