On studying the R&D support and the bridge structure monitoring

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Abstract. This article discusses the scientific and technical support of the engineering survey and design of unique buildings and structures at the time of construction. The R&D support aims at developing and implementing some new research approaches to collecting most accurate and reliable data that would both the prediction of the reliable future of the structure to be built and also save on construction costs. As an example, the authors offer a highways bridge at the town of Kamensk-Shakhtinsk on the M-4 "Don" federal highway. Bending moments at the design stage were determined by simulation using the SPIKA software, which enables, in a short time, to obtain the factual data on the structure, thus avoiding some outdated methods of inspecting building objects, thus facilitating the operations and shortening the time of diagnostics.

Introduction
In the last years, due to the wide-scale construction of unique projects, the importance of the R&D support of engineering survey, design, and erection has been growing. In contrast to the traditional technical supervision, aimed at monitoring the field-and lab operations of the surveyors, the RDSM also aims at the development and introduction of some new methods of research focusing on retrieving some factual data that would facilitate the predicting of the reliable future of the structure to be constructed and also saving on construction costs.

Materials and Methods
This problem has been studied and published well enough [1, 2]. Many sources touch, this way or other, upon the questions of analyzing and evaluating the RDSM in construction. The concept's ideology and contents are reflected in a number of research results, e.g. in the article "Monitoring the Changes in the Stress-strain Behavior of Building Structures Basing on the FEM Analysis of Spatial-coordinate Models" By A.B. Korguin and I.I. Ranov, and also in " The Monitoring of Building Projects and Structures" by A.B, Petrov and A. I. Yere meyev where they discuss the issue of implementing some front-edge software complexes in evaluating the state of structures.

Technical inspection is a process that spans checking, testing, analyzing, and evaluating the structures of buildings and constructions. The key target of the technical inspection of the structures of buildings and constructions is to determine their current technical state, discover the level of physical wear, specify the functional performance of structures, forecast their future behavior.

Preliminary inspection includes the following:
- general visual inspection of the building or structure;
- collecting general data of the building or structure (time of construction, expected service life);
- determining the technological features of production in case of production facilities from the angle of their impact on the structures;
- determining the factual parameters of the microclimate or production environment, temperature-moisture state of the premises, presence of aggressive technological emissions harmful to the building structures; data on corrosion preventive measures [3, 4];
- hydrogeological conditions of the ground and the general characteristics of the foundation supporting subsoils;
- reading survey archives [5,6,7];
- reading records relating to any surveys of the production environment and the state of the building structures of the project.

The stage of preliminary visual inspection is for determining, from the angle of on external characteristics, the categories of the technical state of structures depending on available defects and damages.

As an example, let us discuss the highway bridge at the town of Kamensk-Shakhtinsk on the M-4 "Don" federal highway. The total length of the bridge equals 380.84 m. The pavement width is 8.1 m. On both sides of the pavement there are pedestrian sidewalks resting on blocks on the right and laid along the in-situ concrete cantilever on the left. The bridge is designed for two one-way concurrent lines of automobile traffic, bound for the city of Rostov-on-Don. The sub-bridge space is spanned with the system of five frame-beam suspension bays. The suspension bay structures are of simple non-continuous supported T-beams with diaphragms as per the standard design of the "Souizdorproekt" company, edition 122-61, 22.16 m long. The frame consists of a support and a few rigidly fixed to it 32.85m long cantilevers, constructed as assembled prestressed concrete girders of different height (from 1.9 to 10. 0 m). For calculations, the sizes of the elements and reinforcement were accepted according to available design documents.

The loading capacity for A11 and NK-80 loads was calculated in accordance with the SNIP (construction rules and regulations) 2.05.03-84* "Bridges and Pipes" and SP 35.13330.2011.

According to our inspection, the load-bearing elements of the framework bear no serious defects that would decrease their load-bearing capacity. The designed impacts due to constant loads were determined based on the condition of the equal distribution among the beams of the proper weight of the beam elements, weights of sidewalks, pavement of the bridge road bed, (levelling layer, moisture barrier, protective layeaer, and bitumen concrete layer) and concentrated along the longitudinal direction of the application of the weight of safety and crash railings, cornices etc, by using the Midas Civil 2018 software complex for implementing the finite elements method.

The structural design contains beam and slab elements of general type with the cross-sectional geometric and rigidity characteristics in compliance with existing real structures (Figure 1).

![Figure 1. Structural Design of Framework](image-url)
bearing capacity of general-purpose highway bridge structures in operation. General.", we have accepted the following values of the safety factor $y_f$ of the load:

$y_f = 1.1 \ (0.9)$ - of the structure's dead weight;

$y_f = 1.2 \ (0.95)$ - of the weight of the layers of the bridge pavement coating (isolation and levelling layers) plus weight of the driveway coating.

While calculating, we have determined the forces of constant and dynamic loads. The specific moments of bending and longitudinal forces in the load-carrying elements of the framework are presented in Figure 2.

![Figure 2. Bending Moment Diagram of The Girder Load-Bearing Elements](image1)

We have also calculated the finite longitudinal compressing force for the lower girder of the console section of the bridge:

$N_{\text{finite}} = 158 \ \text{kp/cm}^2 \times 80 \ \text{cm} \times 100 \ \text{cm} = 1264 \ \text{tf}$

The calculations show that the critical components of the strain-and-deformation state of the framework are the bending moments in the mid-cross sections of the main beams. The evaluation of the load-carrying ability was made using the followind dependence

$M_p < M_{\text{ult}},$

where $M_p$ is an extreme rated bending moment in the mid-cross section of the framework due to service loads;

$M_{\text{ult}}$ is a finite moment accepted by the cross-section.

Defining the rated bending moments was made using the SPIKA software that employs the method of spatial calculations of the framework of bridges developed at the Central Institute of Scientific Research in Construction. This method is a discrete-continual variant of the finite element method. The software constructs and loads surfaces under stress and enables a choice of a spectrum of most unfavorable temporary loads and rated combinations of constant and temporary ones.

The results of calculations were the latitudinal diagrams of extreme forces and movements in particular framework sections. The suspended framework consists of 6 main beams made according to the typical design 122-62. The effective span is 22.16m. Spatial calculations using the SPIKA software resulted in the spatial diagrams of extreme bending moments in the middle of the span of the main beams of the suspended framework as shown in Figure 4.

![Figure 3. Diagram Of Longitudinal Forces in The Girder Load-Bearing Elements](image2)
The right column here lists the forces from the effective loads applied when performing a strength test. In the left column are shown the forces of standard loads applied when testing the second extreme state.

![Diagram of Bending moments M (tfm) at Span Middle](image)

**Figure 4.** Extreme Bending Moments in the Mid-Cross Section of the Suspended Bridge Framework

**Results**

The impact of the longitudinal profile on traffic conditions manifests itself in the vertical acceleration of vehicles and, as a result, in additional loads on the load-carrying structures. The state of the structure is also affected by the angles of break on the piers: the loads caused by uneven movement are accepted by the driveway deck slab and load-carrying units. Moreover, higher angles of break result in higher dynamic factor at unchanged traffic speed or the lower permissible (safe) speed, at which the value of overloads remains intact. No extreme angles of break over the piers have been discovered.

Over the service period, the bridge structure has been substantially damaged, which has affected its lifespan [8, 9]. The survey has helped to acknowledge that the development of destructive processes in the bridge units continues (as compared to the results of the 2015 diagnostics) [10, 11]. The expansion grooves have been almost ruined. Due to the ruined moisture barrier of the expansion grooves the parts of the beams adjacent to the piers, support beams of the consoles, and bearing blocks are being ruined as well. The moisture barrier structure of the bridge driveway and the water drain system is in poor state which lets water drain on the lower elements of the framework and piers. The aggressive
impact of the water leakage from the driveway on the lower structure results in corrosion of the reinforcement and crack formation with typical efflorescence and rust stains at drain points on the elements of the framework and piers. We have also detected some damages of the concrete, the exposed and corroded reinforcement of the framework and piers, and at the seams of insitu beams.

During the 2010 repairs, a layer of shotcrete was laid on all of the surfaces of the framework elements and piers. Probably, before shotcreating the reinforcement was cleaned of rust and processed with rust inhibitors. Cleaning the elements from weakly compressed concrete was poor. Corrosion of the reinforcement or under the shotcreated layer was not stopped and continued under the layer.

All of the inspected surfaces of the diagonal struts and other load-carrying elements of the pier consoles and suspended span structures showed corrosion cracks and partly peeling shotcrete. At tapping the concrete sounded substandardly. After removing the protective coating where were cracks and peelings; it was found that the reinforcement kept corroding and was even completely ruined in places. The concrete featured a laminating structure, which was not uniform. Most of the above defects were due to the absence of drainage and relevant maintenance of the bridge. The state of the load-carrying structures causes deep concern. The construction of the inspected load-carrying elements does not comply with the design.

The discovered defects of load-carrying elements (crushes, deformation, disintegration and breaks) may indirectly indicate that the available structures are incapable of handling the actual load-bearing reactions. A complete failure of the load-carrying elements is plausible. The survey results show that the current state of the bridge should be regarded as unsatisfactory.

The general assessment of the current technical state of the bridge is as follows: category of state - grade 2 (poorest), malfunctioning, limited performance. The state of safety of the bridge is unsatisfactory due to its deck being in non-conformity with the standard requirements and the wear of the deck structures (extension grooves, connections, traffic deck).

Summary

The diagnostics of the automobile bridge by using the software complex alone without employing some outdated methods of surveying construction projects, may enable in a short time to collect some data on its actual performance, thus facilitating the process of survey and decreasing the time of diagnostics.

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