Modular Prefabricated Building Load-Bearing Structures, Integrated observation of the condition, Diagnostics and Monitoring

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Abstract The article presents an integrated observation, diagnostics, and monitoring system for the condition of load-bearing structures of modular prefabricated buildings. A mobile diagnostic complex for monitoring has been developed, using non-destructive control methods and tools. The main advantages of the complex technology for monitoring construction structures have been identified: integration into a single complex technology - a combination of information modeling, finite element models and experimental data; Swift creation of a reporting SE model of building structures; Complex Technology is a platform for designing buildings and structures monitoring systems; The information modeling process involves the use of specialized software that allows the construction of three-dimensional dynamically changing information models. Information modeling technology is also very effective when monitoring the construction of buildings and structures. The advantages of using this technology are: high speed of model creation according to the results of working drawings or measurements on the object; The information model can include all information about the state of the of the model, starting

from the properties of the construction materials to the defects that appear during operation; An informational model is created once, and if necessary,
computational models can be created from this model for the analysis of various systems, as well as models for experimental investigation.

Keywords: Modular, Prefabricated, Building, Load-bearing Structure, Diagnostics, Monitoring.

1. Introduction

Structure of the monitoring system

The monitoring system should have a multi-level hierarchical structure:

Level 1. Structured information cable system;
Level 2. primary transformers;
Level3. Controllers of information collection;
Level 4. Input/output servers;
Level 5. Automated dispatch workstations.

The lower level of the monitoring system is formed by a structured information cable system through a connected connection. The power of the monitoring system elements of construction sites, as a rule, is carried out by linear cable systems.

[1] *Investigation* - This is a set of measures for the examination and evaluation of controlled

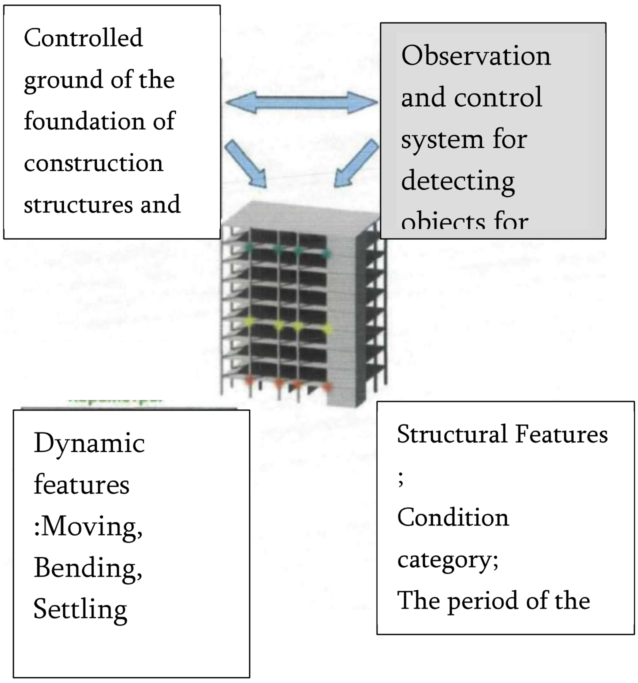


Fig. Structural Investigation and

parameters of actual importance, which characterize the operating condition, usability and labor ability of the objects to be investigated and to determine their suitability for further exploitation. Or the need to restore and strengthen them. The examination is of a periodic nature. Unlike examination, monitoring is stationary. 2] *Monitoring* is a system for detecting objects of observation and control, on which there have been significant changes in the tense-deformed state and for which it is necessary to investigate the technical condition. So, investigation and monitoring - These are two parallel mutually beneficial processes that ensure safe operation (Fig.1)

Monitoring, like surveying, offers the definition and evaluation of controllable parameters, which include:

1. Static Characteristics:
   - Properties of materials
   - Deformation
   - Displacement (lowering, bending, tilting, etc.)
2. Dynamic Features:
   - Frequency
   - deformation coefficient

The monitoring system should have an open architecture that should allow for further expansion, both in terms of the number of monitoring objects and the number of functions of the systems, as well as allow integration with other monitoring and management systems.

Monitoring Paradigm

Among the controlled parameters may be the load that we assign to the construction, thus causing the internal force to be exerted in the construction. Often, monitoring is used only to control the properties of the structure itself, and therefore the monitoring process is equated with the process of damage detection of structural damages, in which several levels are involved:

Level 1. Finding out the presence of damage in the construction

Level 2. Damage Localization

Level 3. Damage Hazard Assessment

Level 4. Safety forecast for post-construction operation

Here, damage refers to a change in the condition of the structure caused by a change in the properties of the material, which is caused by fatigue deformation, as well as due to the conception and development of micro and macro cracks.

The solution of monitoring tasks by a team of scientists from the laboratory Los Alamos (http://mstitute.lanl.gov/ei/, USA) at all levels is proposed to be considered in the context of the paradigm of static face recognition [3]. This paradigm implies that the monitoring process includes several parts:

1. Evaluation of the tasks of the monitoring system;
2. The process of measuring data;
3. Calculation of materials features;
4. Development of statistical models.

During the evaluation of monitoring tasks, a set of measurement parameters (statistical, dynamic) is determined in the weakest and potentially dangerous areas of the construction.

In the process of data measurements, the selection of transmitters, the determination of their number and the determination of their location, as well as the selection of secondary mark converters are involved.

A feature means a result, a direct or indirect measurement of any of the characteristics of an object. The sign has a sharp physical basis, for example, the frequency of its own oscillations, the shapes of the oscillations, the tensile force. Also, the signs can be heuristic, that is, they may not have a physical dimension, but at the same time give an acceptable result. In fact, signs are parameters of mathematical models that describe physical processes.

Static models are developed to determine the meaning of signs that belong to different states of structures. The processes for calculating signs and developing static models are based on several axioms. Two axioms are more important for this work (given as an indication of the level of monitoring):

Damage assessment requires a comparison of the two bitterness of the monitoring facility: basic (normal) and continuous (potentially hazardous);

Determination of the presence of damage (level 1) and location (level 2). Damage can be assessed relative to baseline (baseline) condition, injury hazard assessment (level 3) and prognosis (level 4)

We have developed a mobile diagnostic complex for monitoring, using unbreakable control methods and tools given below.

Based on the construction and operation methods of the modular buildings, we distinguish the following types of monitoring:

Dynamic-when the basis for expertise is the data collection on the modular building development. This is the easiest way and can be used to evaluate relatively basic structural elements. In this case, the monitoring objectives are primarily to warn of possible dangers, and to find out the causes is of a secondary nature, because the causes could be directly observed by the engineer.

Competitive- when the results of the identical examination of other building systems are chosen as the basis for examination. In this case, monitoring becomes an analogue of a multi-series exam plan. The study of two or more subsystems of a larger system is carried out in parallel, with the same equipment, at the same time, which provides the basis for making a conclusion about the magnitude of the effect. In addition, such an approach allows to evaluate the magnitude of the hazard, its criticality.

Monitoring during construction and operation allows timely detection of operational problems and structural defects , such as:

1.Bending of horizontal load-bearing structures as a result of the effects of permanent and temporary loads, with an accuracy of up to 0.01 mm;

2. Horizontal displacements in supporting constructions. with an accuracy of up to 0.025%;

3. Displacements in deformational joints, with parallel temperature measurement;

4. Determination of compressive and tensile stresses in the sections of the load-bearing constructions of frame type buildings;

5. Deviations from structural design of beam, diaphragms or supporting walls ;

6. Control of the geotechnical condition of the foundations by
ground water level measurement;

7. Determination of vertical and horizontal displacements of the ground;

8. Ground (lateral) pressure measurement on reinforced concrete structures;

To do listed above measurements are used various sensors(tensiometers, pressure sensors, acceleration sensors). All collected data must be processed by the software.

Methodology

We have developed a mobile diagnostic complex for monitoring, using non-destructive control methods and tools, which are given below.

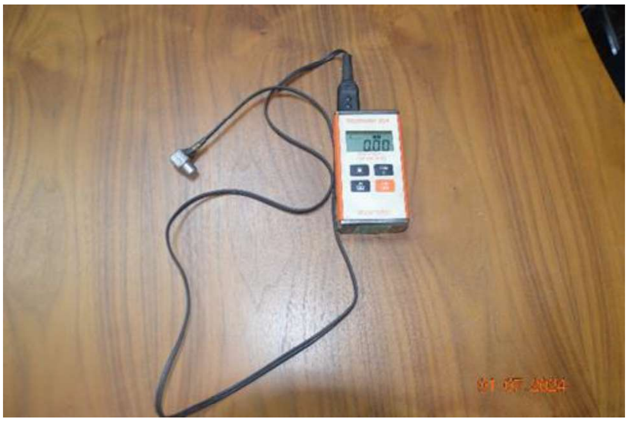
Non-Destructive Tools

Pic. Moister tester

Pic. Thermal camera

Paint thickness tester

Concrete crack thickness tester



Picture Concrete thickness and Rebar locatorPicture Rebar locator

Picture Weld ultrasonic testing equipmentPicture Weld testing penetrate spray

Picture Distance Measurer

Picture Drone with camera

Non-destructive testing (NDT) is directed to evaluate properties of the material, component or system without causing damage.

Evaluation is conducted in to four phases. The mobile diagnostic complex is used to evaluate modular buildings integrity, to determine the degree of hidden defects, to assess the stability and condition of foundations, collectors, underground utilities, including geo-technical and geophysical studies of the site.

First phase- Information model - this is a model that contains the geometry of the building, the spatial relationships between the construction elements, and contains the properties of the building components.

Second phase-Certified software is used to learn the finite element model of the object using information model data. Various computer reporting programs can be used for this purpose

Third phase- an experimental analysis is carried out using the data of natural measurements of the acceleration of the structure's oscillations. For experimental modal analysis, a software tool is used here as well.

Fourth phase -In the fourth phase, a comparison is made between the calculation data of the finite element model and the experiment (natural measurements) in order to identify (calibrate) the finite element parameters of the second phase model according to the experimental results of the third phase dynamic analysis.

The main advantages of the complex technology for monitoring are:

- Integration into a single complex technology - a combination of information modeling, finite element model and experimental data.
- Quick creation of the reporting model of the buildings structures.
- Complex technology is a platform for designing monitoring systems for buildings and structures.
- The modeling involves use of the software that allows to create a three-dimensional dynamically changing information models.
- High speed of model creation based on working drawings or on-site measurement results.

An information model is created once, and if necessary, reporting models can be generated from existing model for the analysis of different finite elements, as well as models for experimental modeling.

Let's consider an example of a modular building, where mobile diagnostic complex

could be used for monitoring the structural stability and seismic resistance of the building.

Modular building foundation is reinforced concrete (concrete class B -25). For structural modules are used prefabricated containers. It is a two-story building; second level modules are connected with metal staircase.

Non-destructive tools were used to determine construction materials (Picture 1,2,3,4,5,6,7,)

Foundation dimensions are 600x600x750 mm, concrete class B25, rebar 12mm

Metal Piles 140 mm
RHS 100x100x5
I and U metal profiles N16 and N10 Timber 80x160 mm

Picture RHS dimensions

Picture U profile measurement

Picture

Profile dimension measurement

Pic Timber dimensions measurement

Picture Observed deviation

PictureConcrete testing

Picture . Observed welding defect

Picture . Observed welding defect

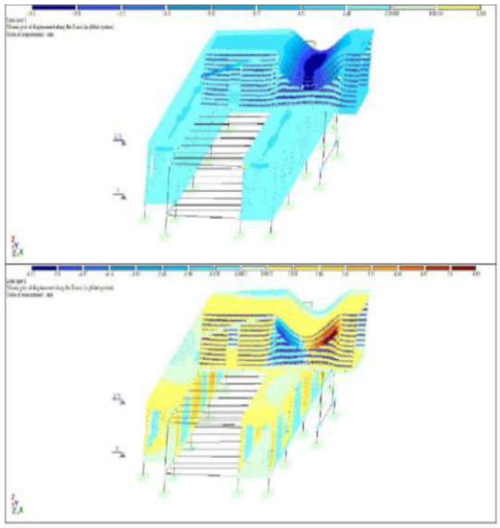
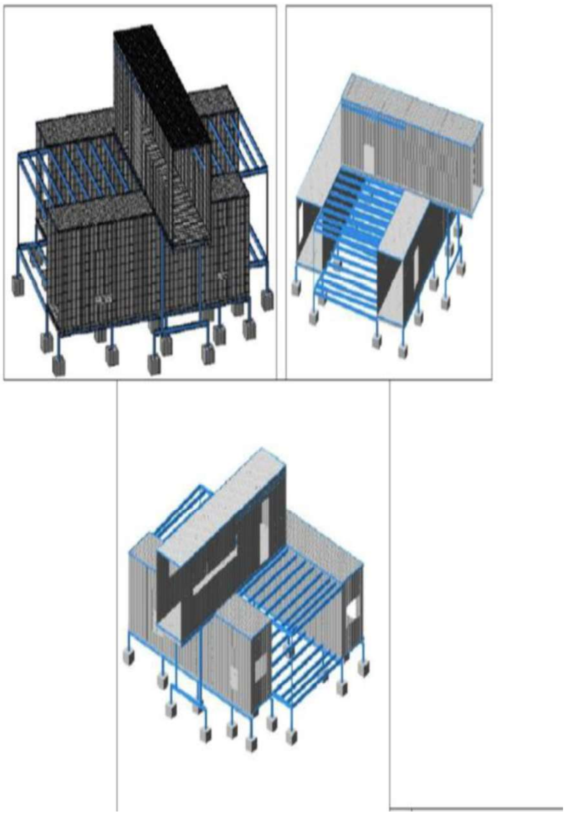


Figure. Screenshots of Structural load distribution Diagram

.Computational Model

According to the data obtained as a result of diagnostics and project documentation, a model of the building is constructed and spatial



calculation is carried out in "LIRA SAPR 2016 PRO" license N 1/5515. Georgian Construction Code and standard

All on site data measurements were incorporated in a spatial model calculation.

Structural incompliance was not found.

Welding quality was low, but it will not affect structural stability of the building

Although some data were taken from existing on site structural drawings.

Modular buildings digital model was created .

The structure of the mobile complex developed by us makes it possible to obtain objective numerical parameters in the operational monitoring mode, which are related to the total loads on the structure, as well as to determine the stability, seismic resistance and reliability of the modular building, including residual resources. Based on these data obtained, a passport of the technical condition of the building will be developed.

The mobile diagnostics complex includes: a software and technical complex for determining the frequencies of their own oscillations of buildings, structures, technological systems;

Tools for non -destructible control of the strength of structural elements;

Instruments for performing high-precision geodetic measurements;

Tools for conducting geophysical and geological surveys of the construction site;

The mobile diagnostic complex is used to test the strength of buildings, to determine the degree of hidden defects, to assess the sustainability and condition of foundations, collectors, underground and above-ground communications, technological and energy systems, to assess the condition of the fields. Including technological and geophysical surveys.

For the construction of new objects of modular buildings, the following work must be carried out:

Conducting engineering and geological surveys of the construction site, determining the geological structure of the site;

Assessment of the physical, mechanical and load-bearing properties of the soils of the construction site and adjacent territories, detection of hidden cavities;

Identification of a safe distance to the nearest building in terms of the impact of the new construction on the stability of already constructed buildings and structures and on the engineering safety.

Taking into account the identified features of the construction of quickly erected modular buildings during construction, we propose to carry out:

Detection of hidden defects of building structures;

Assessment of the quality of building materials and their compliance with state standards;

Determination of the reliability of the bearing capacity of structural elements;

Conducting high-precision geodetic measurements.

During the reconstruction of the construction of

quickly erected modular buildings in operation, it is advisable to perform:
Assessment of the physical-mechanical and bearing properties of the foundations and the soils of the adjacent areas;
Determination of the technical condition of the foundation;
Conducting high-precision measurements of the geometric parameters of the building and the construction site;
Determination of the bearing capacity of structural elements and the possibility of building additional floors;
Development of specific recommendations for strengthening the structures of buildings and structures;
Secondary examination of buildings and structures in order to verify the effectiveness of the reinforcement works carried out.

The existing methodology of examinations with the help of a mobile diagnostic complex during the construction of fast-moving modular buildings allows for the monitoring of buildings and structures. Based on the data obtained before the exposure to the hazard during the test and its comparison with the data obtained after the impact, a conclusion is made on the degree of damages, as well as the dynamics of the subsequent change in the technical condition of the building are predicted.
Collecting measurement data and analyzing them.

We offer complex monitoring technology, which systematically resolves the issues raised, includes the following stages:
The first stage is informational modeling. Informational model - This is a model that contains the geometry of the building, the spatial connections between the elements of the construction, as well as the properties of the components of the buildings and other information necessary for the future. The information model can be easily changed subsequently based on the results of visual and instrumental examinations or according to the results of the operation of the monitoring system. The second stage, using certified software, is to learn the finite element model of the object using information model data. For this purpose, various computer reporting complex programs can be used, for example, the program ANSYS, Lira sapr, Revi.

The third stage, an experimental analysis is carried out using data from natural measurements of the acceleration of structural oscillations. For experimental modal analysis, a software tool, such as "ARTeMIS Extractor", is also used here.

The fourth stage is to compare the reporting data of the finite element model and the experiment (natural measurements) in order to identify (calibrate) the SE parameters of the second stage model according to the experimental results of the dynamic analysis of the third stage.

The fifth stage, using a calibrated finite element model, is completed by calculating the tense deformed state of the structure and estimating the residual resource.

Conclusion

The main advantages of complex technology for monitoring building structures are:
Integration into a single complex technology (combination of information modeling, finite element modeling and experimental data); Rapid creation of a reporting SE model of building structures; Complex Technology is a platform for designing buildings and structures monitoring system; The information modeling process involves the use of specialized software that allows the construction of three-dimensional dynamically changing information models. Information modeling technology is also very effective when monitoring the construction of buildings and structures. The advantages of using this technology are: high

speed of model creation according to the results of drawings or measurements on the object; The information model can include all the information about the state of the structure of the object, starting from the properties of the construction materials to the defects that appear during operation; An informational model is created once, and if necessary, computational models can be created from this model for the analysis of various systems, as well as models for experimental investigation.

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