IRSTI 67.09.37

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Design a Building Information Modeling (BIM) project concept in combination with foundation monitoring on the example of the Abu Dhabi Plaza construction project

Abstract. With the advent of new technology in the monitoring of buildings and high-rise structures it has become possible to monitor damage and defects in existing structures and infrastructures. The need for timely detection of critical points of building structure defects through the use of sensors, as well as the lack of description tools for understanding, visualizing and documenting sensor output data increasingly encourages designers, builders and facility managers to use the capabilities of such a powerful system as the Building Information Modeling System (BIM). The primary goal of any construction project is safety for people, which can only be ensured by proper monitoring of building health, where the presentation and management of the received information about changes in the system and structure can be ensured by using BIM. The purpose of this paper is to describe the application of a distributed fiber optic strain gauge sensor system, and the possibility of integrating the data obtained from the sensors into the BIM system.

Keywords: building Information Modeling System, basement slab, high-rise buildings, fiber-optic sensors, civil engineering.

DOI: doi.org/10.32523/2616-7263-2022-138-1-23-33

Introduction

Over time, the condition of concrete structures and foundation slabs can deteriorate, which becomes a serious and ongoing problem for owners. Evaluation of the actual condition of deteriorated structures is important for timely identification of critical defect values and making decisions for appropriate repairs.

Due to the large number of aging infrastructures, structural health monitoring (SHM) has come to play an effective role in the operation and maintenance phase of the structural life-cycle management process.

SHM makes it easier to monitor and evaluate the properties of structures, which optimizes the cost of maintaining structures and improves their safety [1].

Structures have different reactions under different loads during their life cycle, which can be measured with SHM systems and sensors to obtain information about changed parameters and elements [2,3]. The main stages of condition monitoring are design observation and measurement, condition assessment, information management, planning and decision making, repair execution, and evaluation of repair and maintenance effectiveness [4,5].

Speed and accuracy are two key factors in assessing the condition of structures in sanitary monitoring, which will be enhanced by the use of BIM software. BIM has shown to have tremendous potential for use in the construction industry. BIM plays an important role in making SHM information accessible, practical, and understandable. It can improve the quality of stages of assessment and management of objects, in addition BIM includes tools, processes and technologies for documenting and sharing 3D digital models. This is especially important BIM is the traditional basis for describing information related to monitoring because it prepares a methodology for interdisciplinary metamodeling to qualify [6]. BIM workflows based on digital models make it easier to evaluate model changes in real time. Efficient data management is possible by linking elements of SHM systems, such as sensors, with external sources (e.g. sensor data stored in databases) for various aspects, such as monitoring the condition of building elements [6].

BIM processes are organized into different kinds of information from different areas depending on whether these processes are coordinated with the same software, called "closed BIM", or with cross-program applications, called "open BIM" [6]. The advantage of closed BIM processes is the consistency of models with the same file format, which is usually a specific file format of a particular software vendor. On-site closed BIM processes also have disadvantages, such as some limitations and limited flexibility due to these limitations. On the other hand, industry reference classes (IFCs) support platform-independent or open BIM processes. IFC is standardized according to ISO 16739-1:2018 [7] in its current version for the description and exchange of building information models.

With the help of IFC a standard for semantic models describing construction information at all stages of the life cycle of a building was created [6]. IFC follows an object-oriented approach in which construction information is treated as a set of objects, and each object has attributes to describe it. In addition, IFC provides a set of types, functions, and rules to obtain information appropriate to the domain of interest, such as structural engineering [6].

The modeling center of the Kazakh Scientific Research and Design Institute of Construction and Architecture (KazNIISA) developed the concept of information model of the basement of Abu Dhabi Plaza and integration of data coming from sensors. Information modeling in Kazakhstan in official documents received the abbreviation TIMSO (Technology of Information Modeling of Construction Projects), although the term BIM is also used as a synonym for this concept.

BIM can facilitate the lifecycle management and monitoring of structures throughout the various phases of design, material production, layout selection, and maintenance, such as recycling and maintenance such as recycling and reuse of materials.

In general, the effectiveness of using BIM in SHM and maintenance comes down to the following as: managing and controlling SHM data, better interpretation by connecting real-time data in BIM models, and preparing a confident database for various projects.

Modeling and analysis systems using BIMs

All properties of buildings, components, documentation and other parts of the structure are accessible via the BIM model. The BIM database is easily represented using the IFC standard to pass the exchange step [8]. This is a standard for interpreting data about a building or facility during construction or maintenance phases and is useful for categorizing data as a BIM model. IFC was developed so that different platforms can integrate construction information, i.e. interoperability enabling collaborative work. IFC allows the construction process to be standardized because it is an open exchange format and compatible with various applications [9]. Many researchers use BIM in SHM models to explain the benefits and limitations of existing standards.

We are faced with the task of determining the best format for saving SHM model data to a digital database through the BIM system, as this will help increase the efficiency of monitoring. In this case, it is necessary to determine what range of data obtained from the sensors will be integrated into the BIM system using the IFC standard as a tool for creating a three-dimensional digital model of the real foundation equipped with fiber optic sensors. Software that will transmit data from the recorder to the monitoring room in real time and will integrate this data with BIM requirements is the most important aspect of the project.

In order to improve the visual properties of the monitoring process, the researchers tried different software and visual programming environments. Connecting environmental sensor data to BIM via Dynamo, Arduino, and Revit APIs, integrating BIM with other tools such as building management tools to gain comprehensive control over project monitoring, and integrating BIM with a geographic information system (GIS) to better manage building information [10-12]. In addition, some maintenance strategies have been developed to manage massive data, visualization, quality and data storage.

Visualization quality and data storage processes serve as a model for other areas of research [13].

Researchers have explored various aspects of BIM approaches to improve the quality of building design and management by increasing the speed and reliability of big data modeling with BIM, such as modeling concrete structures and optimizing sensor placement [14-20].

Of great interest is the plan for future research on integrating 4D BIM models with on-site sensor monitoring to improve the health monitoring imaging and analysis process, in addition to accounting for duration, performance and hazards in real time [15,16]. Due to the fact that these upper-dimensional models improve the quality of designs in all phases of design, maintenance, and monitoring, researchers are enthusiastic about this area of research [17].

Most of the studies cited in various parts of this paper used real-time and dynamic monitoring; however, they were categorized under these sections according to the primary purpose of each study [9, 17]. After understanding the reliability of BIM to account for static loads, researchers can use dynamic monitoring to diagnose sensor data based on the latest situation and changes in structural properties [18]. This helps researchers better understand the workings of the structure, leading to confident decision-making. There are several works in the field of structural monitoring systems in an interactive three-dimensional environment [19]. Some researchers believe that the use of data-driven technologies presents problems such as the lack of BIM approaches, the discreteness of the AEC sector, and the lack of real-world practical examples; so they worked on the parametric use of BIM for structural monitoring with time-dependent sensor data and dynamic analysis in a high-quality three-dimensional environment [20].

In this paper, a foundation slab with an integrated fiber optic sensor was considered as an example to show that the model facilitates the interpretation of data using a dynamic BIM environment. The use of this model will be the result of research to monitor the health of the foundation slab and parking area of the Abu Dhabi Plaza project (Figure 1) in Nur-Sultan city and solve the various problems encountered during operation. The main objective of this work is to solve such a problem as the dependence of integrated data into the information model of the building on the received sensor data in terms of time.

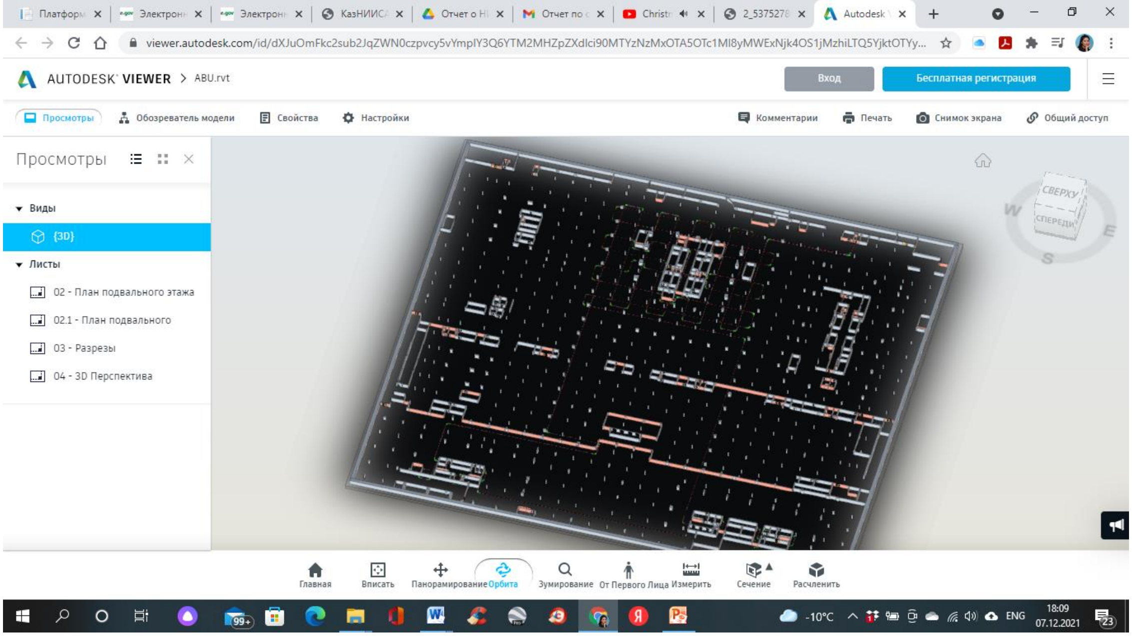

Figure 1. The foundation slab and parking area of the Abu Dhabi Plaza project

Some researchers propose to solve and remedy a similar problem in research using methods such as a combination of BIM and the Internet of Things, which would provide a dynamic data transfer and appropriate data format to show the feasibility of this method in improving safety and quality in the maintenance of structures [21-26].

As stated earlier, traditional researchers have used BIM primarily to design, monitor, and analyze new structures over their lifetime; however, the view of BIM has changed, and it has recently been used to enhance visualization to improve decision-making [27-29]. Many types of studies have encountered problems with sensor data extraction and lack of compatibility, which prevents the integration of BIM and SHM [27, 29].

Previously, some researchers have worked on using sensor output data in an IFC-based BIM model using embedded sensors; however, a number of researchers [29, 33] have conducted an online BIM modeling process to improve static BIM models from static to dynamic using real-time SHM data. Long-term monitoring of structures faced real problems in processing the large amounts of data that were added to the BIM model; however, this problem was solved by using sensor data and moving applications to dynamic mode [34]. Analysis of large amounts of data has also been facilitated by data compression techniques to deal with missing data [35].

Sensors and remote monitoring technologies

Collecting real-time information about facilities, buildings and other construction-related areas is an effective way to manage construction projects.

The integration of WSN and BIM technologies improves the accuracy of hazard monitoring and energy consumption, which are major issues in lifecycle management and human safety [36, 37]. These tools are mainly aimed at reducing the cost of building maintenance by improving the accuracy of decision making based on data collection and processing. The performance of sensing technologies depends on the main purpose of monitoring and maintenance and is widely accepted among researchers to navigate equipment and building safety by considering the advantages and disadvantages of each technology. Some important types are global positioning system, encoding sensors, laser, radio frequency identification devices, audio technologies, radio detection and range, magnetic sensors, vision cameras, and Ultra-Wide Band [38, 39].

In our project the monitoring tasks are solved by the distributed fiber optic strain sensing system (DFOSS). DFOSS has been used to measure deformation in civil engineering structures for more than ten years. It is currently used worldwide to monitor a wide range of structures, including tunnels, bridges, piles, dams, embankments and diaphragm walls.

DFOSS is based on backscattering of light as it is transmitted through an optical fiber. One component of backscattered light is produced by Brillouin scattering. At any point in the fiber, the frequency of the Brillouin scattered light depends on the strain and temperature at that point. Therefore, given the effect of temperature, it is possible to determine the strain at any point in the fiber by transmitting pulses of light along the fiber and analyzing the frequency of backscattered light [40].

Compared to the use of isolated strain gauges, DFOSS offers a new paradigm for strain measurement:

- DFOSS returns a continuous strain profile along a structural element. Strain gauges can only give discrete point readings and can miss important strain changes between gauges.
- Backscatter from the optical fiber is unaffected by electromagnetic interference.
- The core of the optical fibers is made of pure silicon dioxide, which is very stable and inert. Therefore, the fibers are not susceptible to corrosion, do not contaminate the local environment and have an estimated service life of decades.
- Optical fibers can operate over a much wider temperature range than most electronic devices.
- Optical fibers are small and unobtrusive, so they are easy to integrate into both new and existing

designs.

- A complete strain profile can be reconstructed for a fiber several kilometers long, potentially replacing tens of thousands of discrete sensors. The single-cable approach greatly simplifies installation.

- As a result of ongoing development of DFOSS readers, a DFOSS system installed now can take advantage of potential enhanced measurement capabilities in the future.

Most analyzers require the installation of an additional optical fiber for temperature measurement along with the strain-sensitive fiber to eliminate the effect of temperature on the Brillouin frequency shift.

The proposed DFOSS system (considered based on a study of the foundation slab and parking area of the Abu Dhabi Plaza project) consists of a grid of fiber optic cables attached to slab B4, connected to an analyzer located in a temperature and humidity-controlled room at B1 (see Figure 2 "General Plan of Cabling on Slab B4" and Figure 3 "Partial Plan of Cabling in the Block R Monitoring Area on Slab B4").

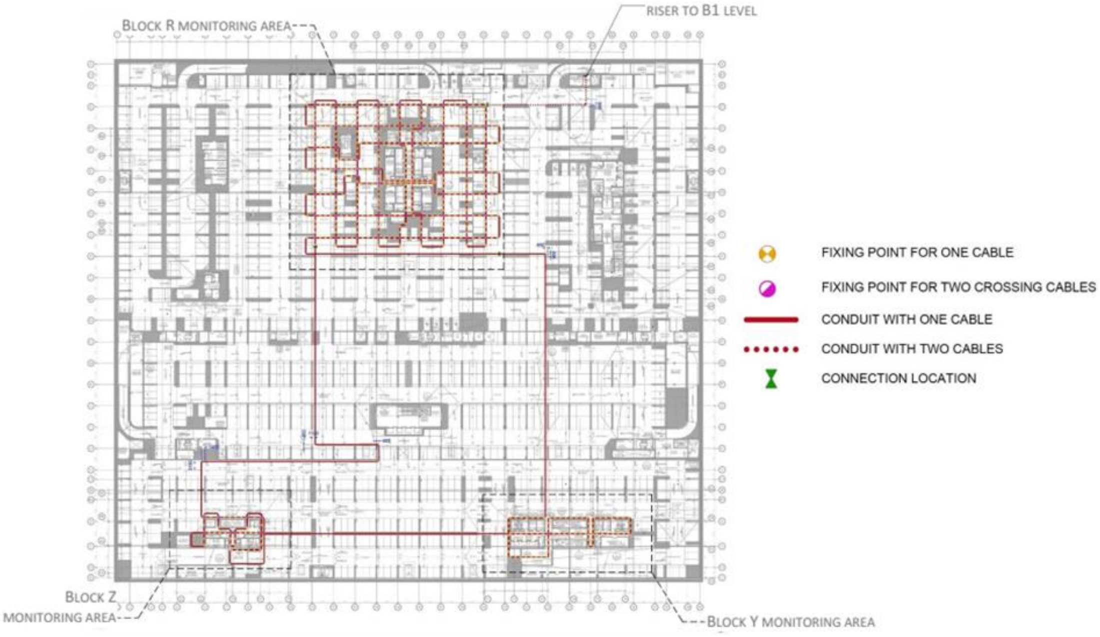

Figure 2. General plan of cable routing on B4 slab

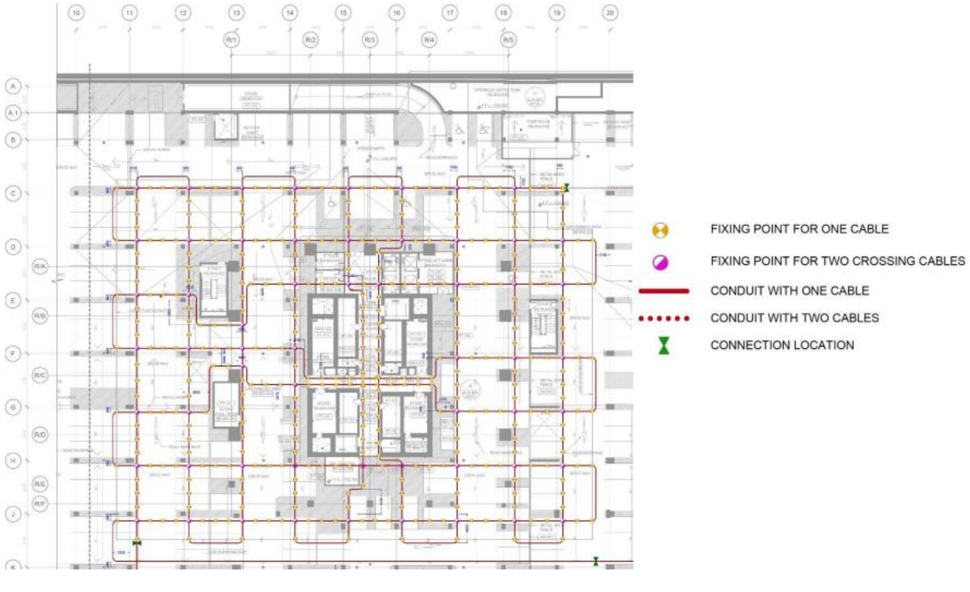

Figure 3. Part plan of cable routing in Block R monitoring area on B4 slab

In some areas, the base slab is thickened by pouring additional concrete above the level of the structural slab, and in some areas, steel mesh is poured into the thickened part to prevent surface cracking. To reduce the risk of laying cable on curvature greater than acceptable, keep the height of the cable in the thickened sections and instead adjust the depth of the channel to accommodate changes in the thickness of the slab (Figure 4).

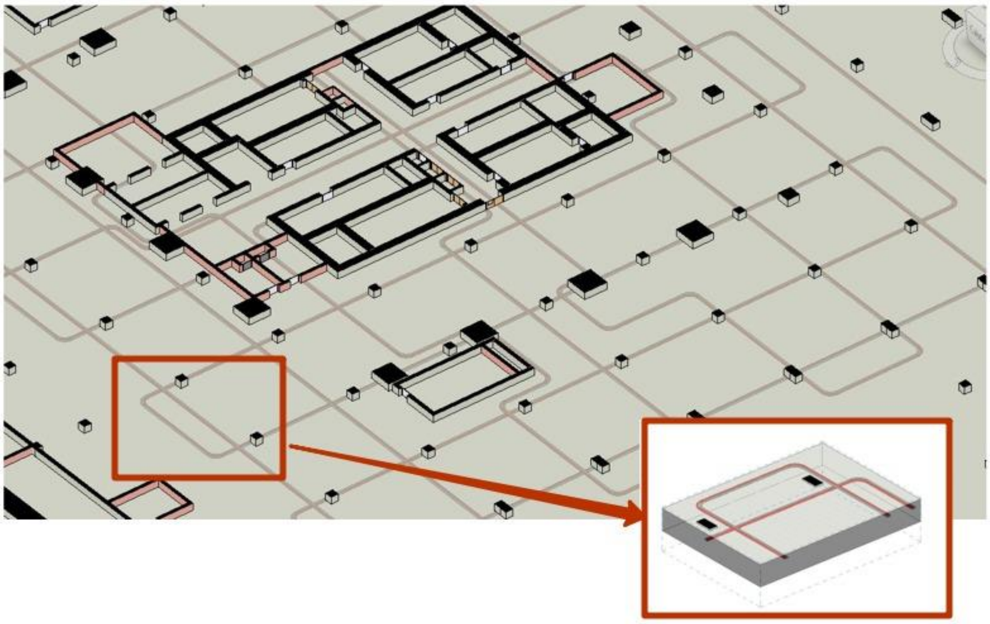

Figure 4. Cable installation in cover drain system

Creating the channel in the thickened sections will require cutting through any steel mesh that may be present, so additional time and tools should be provided for this task.

The attachment points in the controlled areas in the R, Y and Z units are shown at intervals of approximately two meters or more to create measured lengths. Of the 525 attachment points, 450 clamp one cable and the remaining 75 clamp two perpendicular cables. To clamp one or two cables, a fixture similar to the one shown in Fig. 5.

In most intersections, both cables are clamped, but in six specific intersections, namely four in the center of the R block core and two in the Y block monitoring area, the intersections are much closer than two meters. In these six locations, only one cable is clamped to avoid creating a calibration length of less than two meters.

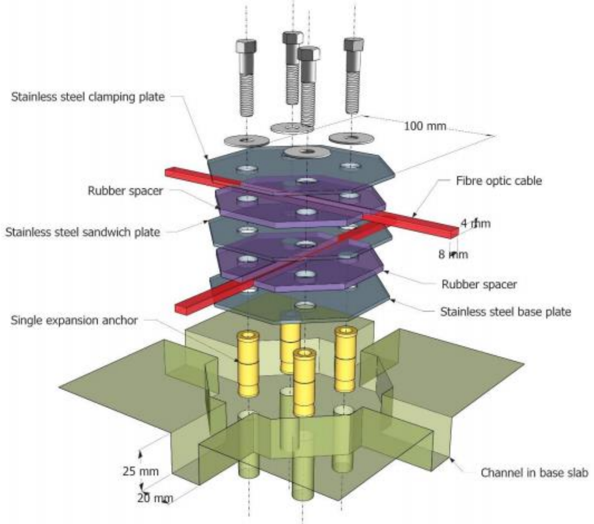

Figure 5. Conceptual design of cable fixing point (contractor to provide design)

The analyzer measures strain by transmitting pulses of light along the fiber and analyzing the frequency spectrum of the backscattered light. The optical budget of the analyzer can be increased by increasing the pulse duration, measured in nanoseconds, which reduces its attenuation. However, if the pulse duration is too long, the scattered light from the leading edge of the pulse begins to interfere with the scattered light from the trailing edge of the pulse, and the analyzer cannot distinguish one from the other. This imposes a limit on the minimum distance at which the strain value can be interpreted by the analyzer. This distance is called the spatial resolution and can be likened to the width of the averaging window for the sample point [41].

Spatial resolution up to 2 cm is achievable by some analyzers on the market, but because of the trade-off between optical budget and spatial resolution, this comes at the expense of the optical budget, which is only about 2 dB at this low spatial resolution. To achieve the required optical budget of 11 dB, the spatial resolution is typically at least 0.5 m.

Although the spatial resolution limits the minimum distance at which the strain value can be interpreted, the analyzer is still capable of taking multiple measurements at small intervals along the fiber. The smallest interval between two sampling points is called the sampling resolution and depends on the number of measurements taken by the analyzer. Cable lengths and connections as shown in Figure 6.

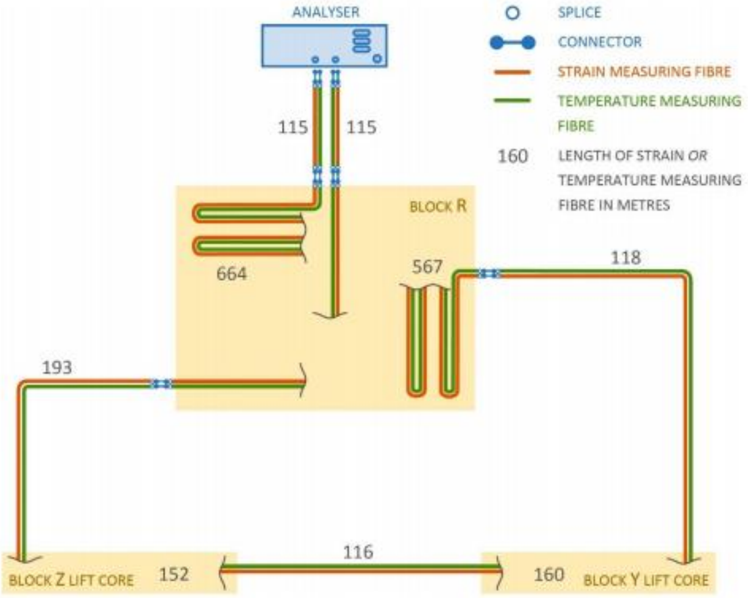

Figure 6. Schematic diagram of distributed fibre optic strain sensing system

Expansion caused by both retarded ettringite formation (DEF) and alkali-aggregate reaction (AAR) has the potential to lead to cracking in the slab. The fiber optic system must be designed to detect the formation and development of cracks and to withstand the highly localized deformations that are likely to develop in them. According to section 7.3.4 of Eurocode 2 (1), the crack width depends on the stress in the reinforcement. A numerical analysis has been performed to estimate the surface deformations and stresses in the upper part of the reinforcement caused by expansion under the action of DEF and AAR.

The numerical analysis was performed using PLAXIS 2D 2018.01. It should be recognized that the factors determining slab expansion are complex, and the computational effort required to accurately model all scenarios and interactions would not be feasible for design purposes.

The assumptions underlying the analysis have been carefully considered to provide an approximate estimate of stresses and strains, while limiting the computational effort to an acceptable level.

Conclusion

For the first time the authors considered the possibility of combining BIM technology with real data from automated monitoring of the foundation slab of the underground parking of Abu Dhabi Plaza Complex in the soil conditions of Nur-Sultan. Combining these technologies allows us to evaluate the results of geomonitoring in real time, which will ensure the safe operation of high-rise buildings with a developed underground part of the complex engineering and geological conditions of the new capital of the Republic of Kazakhstan.

Given the novelty of this field of research, there are many gaps in all existing studies, there is no single standard for all modeling procedures. Most researchers have considered the integration of BIM and monitoring with some assumptions. Extension of the IFC scheme, optimization of sensor data under a single system and management of large amounts of data are some of the main problems that still need to be investigated in the future.

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Нұр-Сұлтан қаласындағы Абу-Даби Плаза құрылыс жобасы мысалында іргетас мониторингімен үйлестіре отырып, Building Information Modeling (BIM) жобасының концепциясын жасау

Аңдатпа. Ғимараттар мен көпқабатты құрылыстарды бақылауда жаңа технологияның пайда болуымен қолданыстағы құрылымдар мен инфрақұрылымдардың зақымдануы мен ақауларын бақылау мүмкін болды. Датчиктерді қолдану арқылы ғимарат құрылымы ақауларының сыни нүктелерін уақтылы анықтау қажеттілігі, сондай-ақ сенсордың шығыс деректерін түсіну, визуализациялау және құжаттау үшін сипаттама құралдарының жоқтығы дизайнерлерді, құрылысшыларды және мекеме басшыларын Building Information Modeling System (BIM) сияқты қуатты жүйесі мұндай жүйелердің мүмкіндіктерін пайдалануға барған сайын ынталандырады. Кез келген құрылыс жобасының басты мақсаты адамдардың қауіпсіздігі болып табылады, оны тек ғимараттың денсаулығын дұрыс бақылау арқылы қамтамасыз етуге болады, мұнда жүйе мен құрылымдағы өзгерістер туралы алынған ақпаратты ұсыну және басқару BIM көмегімен қамтамасыз етілуі мүмкін. Мақаланың мақсаты таратылған талшықты-оптикалық тензометрлік сенсор жүйесін қолдануды және сенсорлардан алынған деректерді BIM жүйесіне біріктіру мүмкіндігін сипаттау болып табылады.

Түйін сөздер: ғимараттың ақпараттық модельдеу жүйесі, жертөле тақтасы, көпқабатты үйлер, талшықты-оптикалық сенсорлар, құрылыс инженериясы.

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Построение концепции проекта информационного моделирования зданий (BIM) в сочетании с мониторингом фундамента на примере строительного проекта Abu Dhabi Plaza

Аннотация. С появлением новых технологий в области мониторинга зданий и высотных сооружений стало возможным отслеживать повреждения и дефекты в существующих конструкциях и инфраструктурах. Необходимость своевременного обнаружения критических точек дефектов строительных конструкций с помощью датчиков, а также отсутствие инструментов описания для понимания, визуализации и документирования выходных данных датчиков все чаще побуждает проектировщиков, строителей и руководителей объектов использовать возможности такой мощной системы, как система информационного моделирования зданий (BIM). Основной целью любого строительного проекта является безопасность для людей, которая может быть обеспечена только путем надлежащего мониторинга состояния здания, где представление и управление полученной информацией об изменениях в системе и структуре может быть обеспечено с помощью BIM. Целью данной статьи является описание применения распределенной системы волоконно-оптических тензометрических датчиков, а также возможности интеграции данных, полученных с датчиков, в систему BIM.

Ключевые слова: система информационного моделирования зданий, подвальное перекрытие, высотные здания, волоконно-оптические датчики, гражданское строительство.

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