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Satbayev University

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НАЦИОНАЛЬНОЙ АКАДЕМИИ
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METHODS FOR REMOTE MONITORING OF BRIDGES UNDER THE INFLUENCE OF GROUNDWATER ON THEM

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Abstract. Today infrastructure cannot be imagined without roads and bridges. In the world, special attention is paid to their condition, which in turn is an extremely important factor in ensuring the safety of the civilian population and the entire infrastructure in general. One of the main reasons for the deterioration of the condition of bridges is that a huge number of them have stepped over the 50-year mark and no longer meet technical standards. The article presents the reasons for the weakening of the load-bearing structures of bridges, as well as the influence of groundwater or river water on these structures, which together can lead to multimillion-dollar costs or, even worse, to tragic consequences. Calculation methods were given to determine the settlements of structures, such as absolute or total settlement, average settlement, heel and horizontal displacement. Methods for organizing remote monitoring of the state of the position of the bearing structures of bridges are considered. One of the considered solutions is a bridge condition monitoring system using satellite systems, which can consist of several segments, such as the ground segment, consisting mainly of measurement sensors, the space segment responsible for the centralized collection of information from all sensors, and the ground segment responsible for processing the information received and alerting the relevant departments in case of emergency. Wireless sensor networks are considered as the second method of organizing monitoring, since today they are most used in various industries and have the prospect of further improvement.

Keywords: groundwater, deformation, bridges, remote monitoring, satellite systems, sensor networks

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КӨПІРЛЕРГЕ ЖЕР СУЛАРЫНЫҢ ӘСЕРІ КЕЗІНДЕ ҚАШЫҚТАН БАҚЫЛАУ ӘДІСТЕРІ

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Аңдатпа. Бүгінгі таңда инфрақұрылымды жолдар мен көпірлерсіз елестету мүмкін емес. Әлемде олардың жағдайына ерекше назар аударылады, бұл өз кезегінде бейбіт тұрғындардың және тұтастай алғанда бүкіл инфрақұрылымның қауіпсіздігін қамтамасыз етудің аса маңызды факторы болып табылады. Көпірлердің жай-күйінің нашарлауының басты себептерінің бірі — олардың көп бөлігінің 50 жылдық межеден асып, техникалық талаптарға сай келмеуі. Мақалада көпірлердің жүк көтергіш құрылымдарының әлсіреу себептері, сондай-ақ бұл құрылыстарға жер асты немесе өзен суларының әсер етуі, олар бірге миллиондаған долларлық шығындарға немесе одан да сорақысы қайғылы зардаптарға әкелуі мүмкін. Абсолютті немесе толық шөгу, орташа шөгу, өкшелі және көлденең жылжу сияқты құрылымдардың қоныстарын анықтау үшін есептеу әдістері берілді. Көпірлердің тірек конструкцияларының жай-күйін қашықтықтан бақылауды ұйымдастыру әдістері қарастырылған. Қарастырылған шешімдердің бірі жерсеріктік жүйелерді пайдаланатын көпір жағдайын бақылау жүйесі болып табылады, ол негізінен өлшеу сенсорларынан тұратын жер сегменті, барлық сенсорлардан ақпаратты орталықтандырылған жинауға жауапты ғарыш сегменті және алынған ақпаратты өңдеуге және төтенше жағдайда тиісті бөлімдерге хабарлауға жауапты жердегі сегмент. Сымсыз сенсорлық желілер мониторингті ұйымдастырудың екінші әдісі ретінде қарастырылады, өйткені бүгінгі күні олар әртүрлі салаларда кеңінен қолданылады және одан әрі жетілдіру перспективасына ие.

Түйін сөздер: жер асты сулары, деформация, көпірлер, қашықтықтан бақылау, спутниктік жүйелер, сенсорлық желілер

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МЕТОДЫ ДИСТАНЦИОННОГО МОНИТОРИНГА МОСТОВ ПРИ ВЛИЯНИИ НА НИХ ГРУНТОВЫХ ВОД

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Аннотация. Сегодня инфраструктуру невозможно представить без дорог и мостов. В мире особое внимание уделяется их состоянию, что в свою очередь является крайне важным фактором в обеспечении безопасности гражданского населения и всей инфраструктуры в целом. Одной из основных причин ухудшения состояния мостов является то, что огромное их количество перешагнули за 50-летний рубеж и уже не соответствует техническим нормам. В статье приведены причины ослабления несущих конструкций мостов, а также влияние грунтовых вод или речных вод на эти конструкции, что в совокупности могут принести к многомилионным затратам или что еще хуже — к трагическим последствиям. Были приведены методы расчета для определения осадков сооружений, такие как абсолютная или полная осадка, средняя осадка, крен и горизонтальное смещение. Рассмотрены методы организации дистанционного мониторинга за состоянием положения несущих конструкций мостов. Одной из рассмотренных решений является система мониторинга за состоянием мостов с использованием спутниковых систем, которая может состоять из нескольких сегментов, таких как наземный сегмент, состоящих в основном из датчиков измерения, космический сегмент, отвечающий за централизованный сбор информации со всех датчиков, и наземный сегмент, отвечающий за обработку полученной информации и оповещению соответствующих ведомств в случае чрезвычайных ситуациях. Вторым методом организации мониторинга рассмотрены беспроводные сенсорный сети, так как на сегодняшнее время они имеют наибольшее применение в различных отраслях и имеют перспективу к дальнейшему усовершенствованию.

Ключевые слова: грунтовая вода, деформация, мосты, дистанционный мониторинг, спутниковые системы, сенсорные сети

Introduction

Over the past decade, the number of bridge collapses has become more frequent in the world (most of them are road bridges) or emergency conditions have been registered. One of the main reasons is that a huge number of these bridges have stepped over the 50-year mark and no longer meet technical standards. Most of the structures have worked out their service life and their load-bearing structures have already weakened. In addition, many bridges were built using outdated technologies of the times, which are not designed for modern realities.

However, there is another reason and this is the influence of natural, namely climatic and geological factors, because it is no secret to anyone that climate change in recent decades has caused dozens, if not hundreds of destruction of various structures (buildings, bridges, etc.), for the restoration of which a huge a

m In some cases, it is impossible to avoid damage or destruction, for example in cases of large o earthquakes, avalanches or other natural disasters on a huge scale. However, there are cases when it is possible to avoid destruction or high costs for restoring damage if seasonal climatic features of the hydrogeological state of the area, such as groundwater, are taken into account during construction (Prudhomme et al., 2017: t 16).

Main part. Groundwater is the gravitational groundwater of the first permanent aquifer from the Earth's surface, located on a regional aquiclude (Figure 1).

f They mainly appear due to infiltration (i.e. seepage) in the form of precipitation from the earth's atmosphere into the waters of irrigation canals, reservoirs, lakes and rivers. In various regions of canals and rivers, groundwater will be filled with ascending waters of deeper horizons due to condensation of water vapor or with waters from artesian basins (Frappart et al., 2018).

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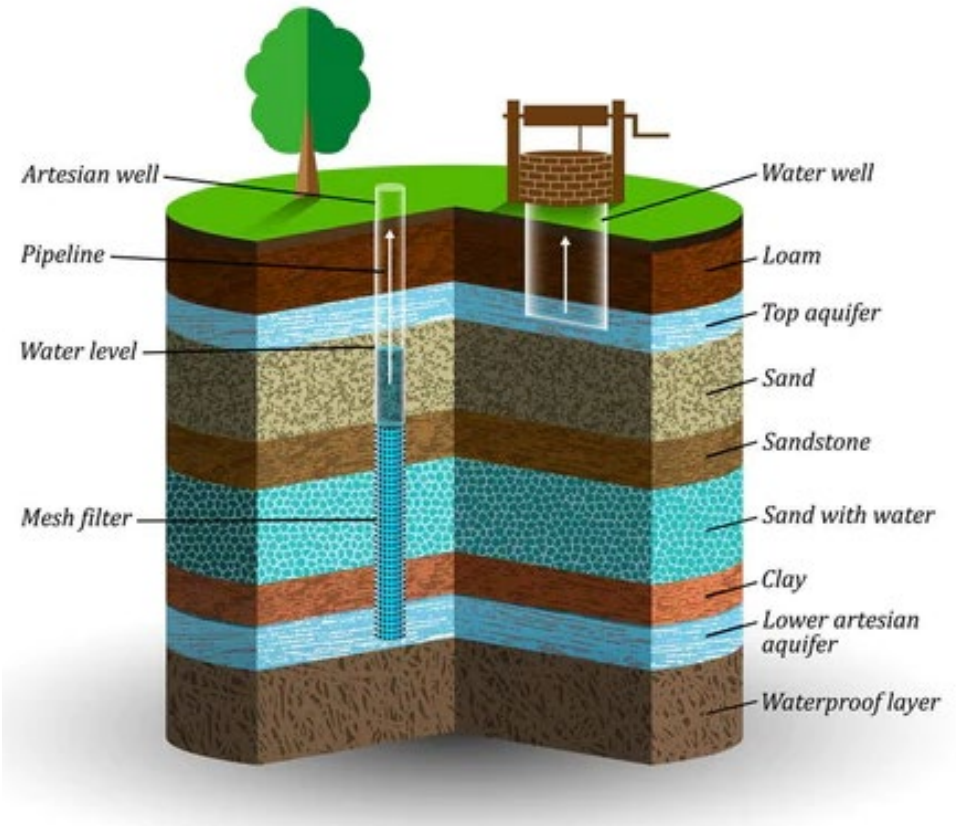

Figure 1 - Location of ground and artesian waters (Davronbekov et al., 2020).

e t With a high level of groundwater, flooding of the territory occurs, which causes a certain degree of difficulty in the construction and operation of buildings and structures, which can lead to deformations in a structures (Figure 2) and neglect of these problems can lead to deformations in the future.

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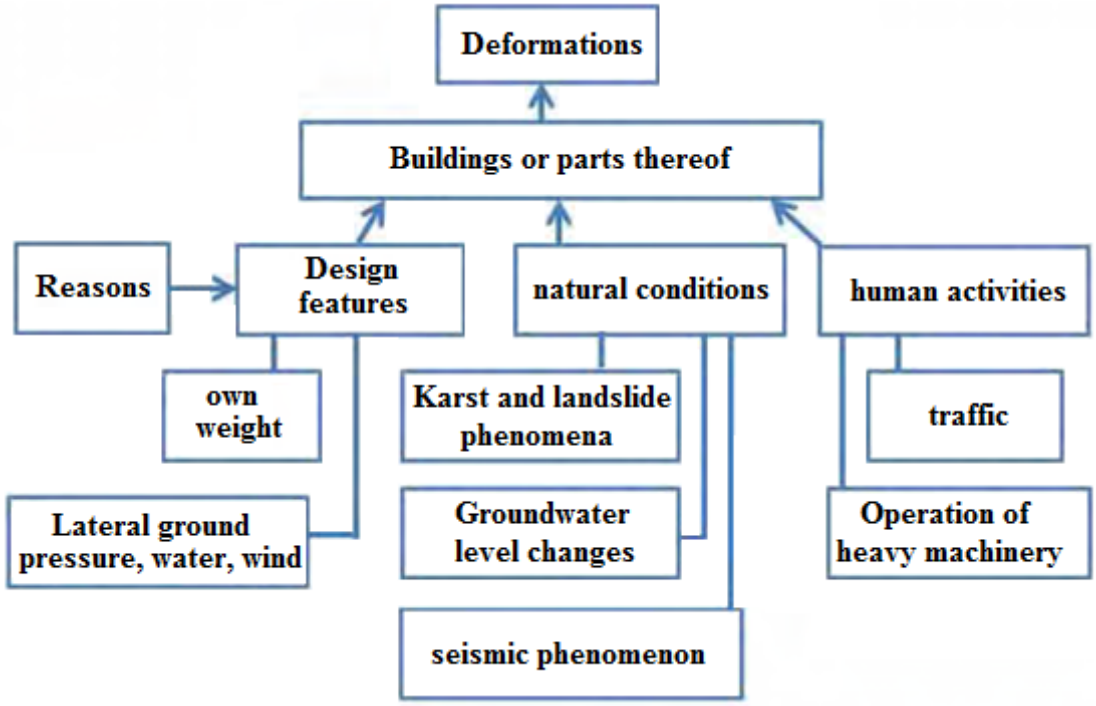

Figure 2 - Causes of structural deformations

In general case, the term deformation is understood as a change in the shape of the object of observation. In geodetic practice, it is customary to consider deformation as a change in the position of an object relative to some initial position. In most cases, the following types of deformations are determined:

- vertical movements (precipitation, subsidence, rises);
- horizontal movements (shifts);
- banks.

Draft - displacement of the structure in the vertical plane; subsidence - a fast-flowing settlement of a structure with a radical change in the structure of porous and loose soils; shear - displacement of the structure in the horizontal plane; roll - uneven draft of the structure. To determine the deformations, first fix the points in the characteristic places of the structure (Davronbekov et al., 2020 :4).

Calculation methods

for determining the settlement of structures:

The absolute or total draft S is the difference between the absolute heights (marks) of the initial and current cycle of observations, determined relative to the starting point:

$$S = H_{int} - H_{cur}, \quad (1)$$

The average draft S_{ave} of the entire structure or its individual parts is calculated as the arithmetic mean of the sum of the draft of all n of its points, i.e.

$$S_{ave} = \frac{\sum_1^n S}{n}, \quad (2)$$

Where, *S* – is the draft of individual grades; *n* - is the number of brands.

Simultaneously with the average draft, for the sake of completeness of the general characteristics, the largest S_{max} and the smallest S_{max} draft of the points of the structures are indicated.

The unevenness of the draft can be determined by the difference in draft Δs of any two points 1 and 2, i.e.

$$\Delta S_{1,2} = S_2 - S_1, \quad (3)$$

The roll or inclination of the structure is defined as the difference between the settlement of two points located on opposite edges of the structure, or its parts along a selected axis. The slope in the direction of the longitudinal axis is called a blockage, and in the direction of the transverse axis – a skew.

The amount of roll related to the distance *l* between two points 1 and 2 is called the relative roll K, which is calculated by the formula:

$$K = \frac{S_2 - S_1}{l}, \quad (4)$$

The horizontal displacement q of a single point of the structure is characterized by the difference of its coordinates $x_{current}$, $y_{current}$ and $x_{initial}$, $y_{initial}$, obtained in the current and initial cycles of observations.

The position of the coordinate axes, as a rule, coincides with the main axes of the structure. Displacements are calculated in the general case by the formulas:

$$q_x = x_{cur} - x_{int};\ q_y = y_{cur} - y_{int}, \quad (5)$$

Similarly, you can calculate the offsets between the previous and subsequent cycles of observations. Horizontal displacements are also determined along one of the coordinate axes.

Ground waters, at a certain concentration, form an aggressive environment, since they are weak solutions of various chemicals, in relation to the materials of structures (Figure 3).

Figure 3 - Impact of rivers and groundwater on bridge supports

All over the world - bridges are the most important part of the entire infrastructure of the country, and special attention is paid to their construction, as well as monitoring their condition, the systems for organizing the construction and operation of bridges, overpasses and other artificial structures, overpasses and other artificial structures, and the development of transport infrastructure are being improved and improve the efficiency of their operation. But, despite all these efforts, today the condition of the bridges requires special attention.

The analysis of literary sources showed that it is necessary to make the necessary decision as soon as possible to improve the existing methods for diagnosing the condition of bridges (Tidriri et al., 2016: 23).

Figure 4 - An example of a collapsed bridge

Determining the technical condition of reinforced concrete structures is a complex and urgent task. This is due to the presence of uncontrolled factors and parameters that affect the joint work of concrete and reinforcement and their physical and mechanical characteristics. Most of the parameters are estimated from indirect data, since the removal of fragments of reinforcement and concrete leads to a decrease in the bearing capacity of the structure (Stepanov et al., 2012: 5).

The main means of increasing the efficiency of the use of systems for operational monitoring of objects is to ensure timely and maximally automated receipt of comprehensive information on the dynamics of the development of potentially hazardous processes through an integrated approach to the use of traditional measurement methods (stress-strain state of structural elements) (Alimdzhanov et al., 2021: 6).

One of the solutions is to create a unified monitoring system using wireless technologies. Consider some options for these systems.

First. System for monitoring the condition of road bridges using satellite systems. This monitoring system consists of a set of equipment (Figure 5.), which can be conditionally divided into three segments:

1. Ground segment of measuring devices. It, in turn, also consists of several parts:

– Measuring devices and sensors. Their main task is to directly measure the condition of bridges. In terms of functionality, they can measure various parameters, such as deformation of the reinforcement of load-bearing supports, pressure in the soil under the supports, displacement sensors between spans or joints, and you can also add humidity and temperature sensors.

– Transmission part. Responsible for transmitting data to the satellite system. Here you can use two methods of transmission, directly from the sensors themselves, by installing transmitting devices on them, or create a centralized data transmission node (transmitting segment) to collect data from all sensors at the facility and send it to the satellites with one signal. The first method can be used if the number of sensors on the object is small or one and the sensor measures only one parameter, and the second method is more efficient to use when many measuring devices are installed on the object and they perform different measurements.

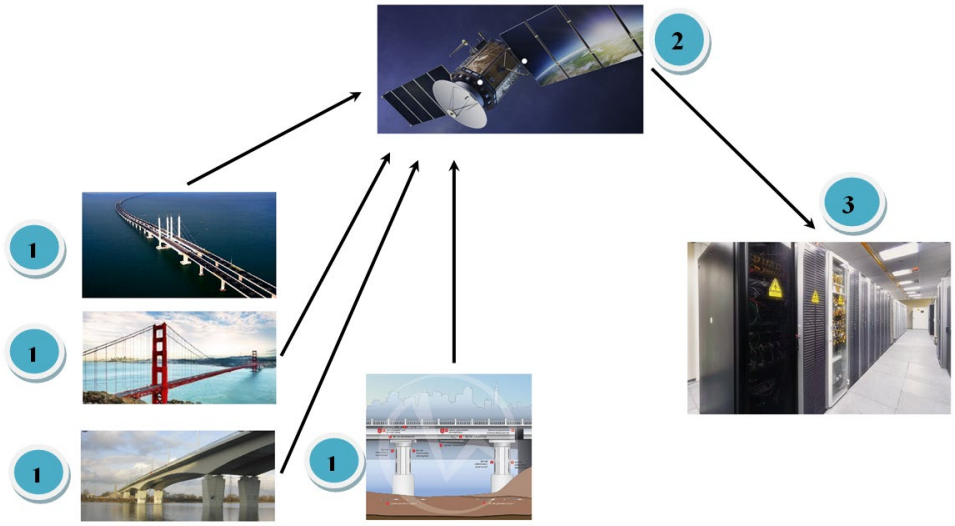

Figure 5 - Monitoring system for the state of road bridges using satellite communication systems. 1 - Ground segment of measuring devices, 2 - Space segment, 3 - Ground segment of remote monitoring of the state of road bridges.

2. Space segment, responsible for receiving data from measuring devices or from a centralized data transmission node and transmitting this data to the ground segment of remote monitoring of the state of road bridges.

3. Ground segment of remote monitoring of the state of road bridges, consisting of a software and hardware complex for processing information transmitted from all measuring devices.

This monitoring method allows real-time tracking of changes in the parameters of the state of road bridges and timely warning of changes, which in turn will help to quickly respond in case of emergency due to changes in the permissible parameters of the structure and take the necessary measures to ensure the safety of the civilian population or timely repair of this facility (Alimdzhanov et al., 2022).

Second. Wireless sensor networks (WSN), consisting of sensors, elements and radio communication nodes for the purpose of observing, monitoring and responding to a specific process.

Wireless sensor networks (Figure 6) consist of nodes, which in turn also consist of various sensors, microcontrollers and radio transmitters. These devices have various applications and can be used in any field (Kogelman et al., 2020).

The data from the sensors received at the main station are analyzed and processed. The main characteristics of WSNs are: energy cost management, node failure capability, node mobility, node heterogeneity, scalability for large-scale deployment, ability to withstand harsh environmental conditions, and ease of use. These features provide a wide range of applications for sensor networks (Mike et al., 2019).

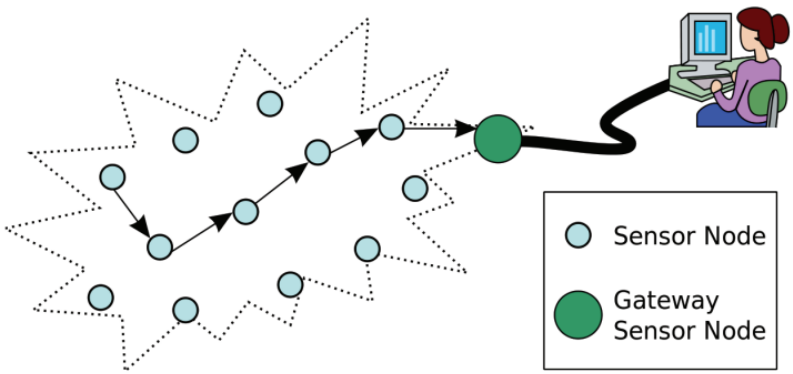

Figure 6 - Architecture of a simple wireless sensor network

To date, WSN nodes provide a long operating time - several years (up to 10 years). However, when planning a network for a long period, it is impossible to be absolutely sure that its structure will not change in the future. The main reason for the loss of functionality is the loss of network connectivity (Sedalishchev et

al., 2012: 3). Network connectivity characterizes the possibility of delivering data from the source node to the recipient. Therefore, it is necessary to develop WSN models that allow estimating the connectivity of the network (or the potential for its provision) (Buzyukov et al., 2017: 8).

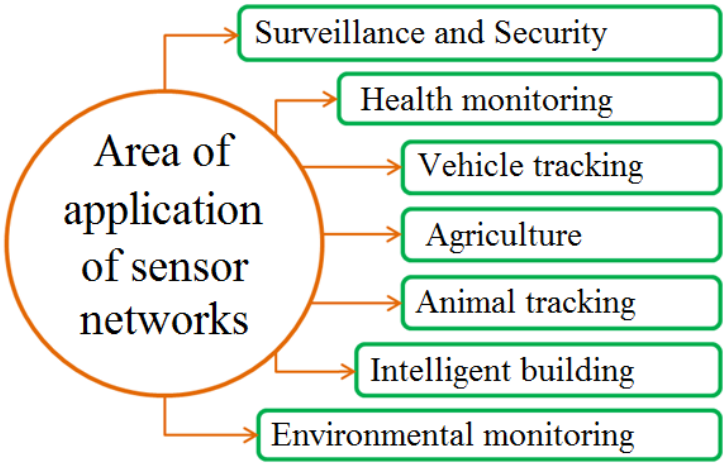

Figure 7 - Fields of application of WSN

The main areas of application of the WSN can be classified as shown in Figure 7, and the goals of the WSN are given in table 1.

Table 1 - Scope and tasks of sensors in WSN

Application area	A task
Environmental monitoring	Environmental Monitoring and Disaster Warning
Security and surveillance	Perimeter control and intruder detection, as well as tracking various unfixed vehicles.
smart building	Ensuring the safety of civilian facilities using energy-saving elements.
Health Monitoring	Monitoring the physical condition of the observed in real time and warning of possible health risks.
Vehicle Tracking	Monitoring traffic on busy roads, identifying and monitoring parking spaces, monitoring the location of vehicles.
Animal Tracking	Optimized monitoring of animal rearing conditions. Health and location monitoring.
Agriculture	Monitoring the cultivation of crops by providing a suitable environment by observing parameters such as pressure and temperature.

Analysis of literary sources shows (Davronbekov et al., 2021). that wireless sensor networks as a whole are an important technology for the twenty-first century. Recent developments in engineering, communications, and networking have led to new designs for sensors, information technology, and wireless systems.

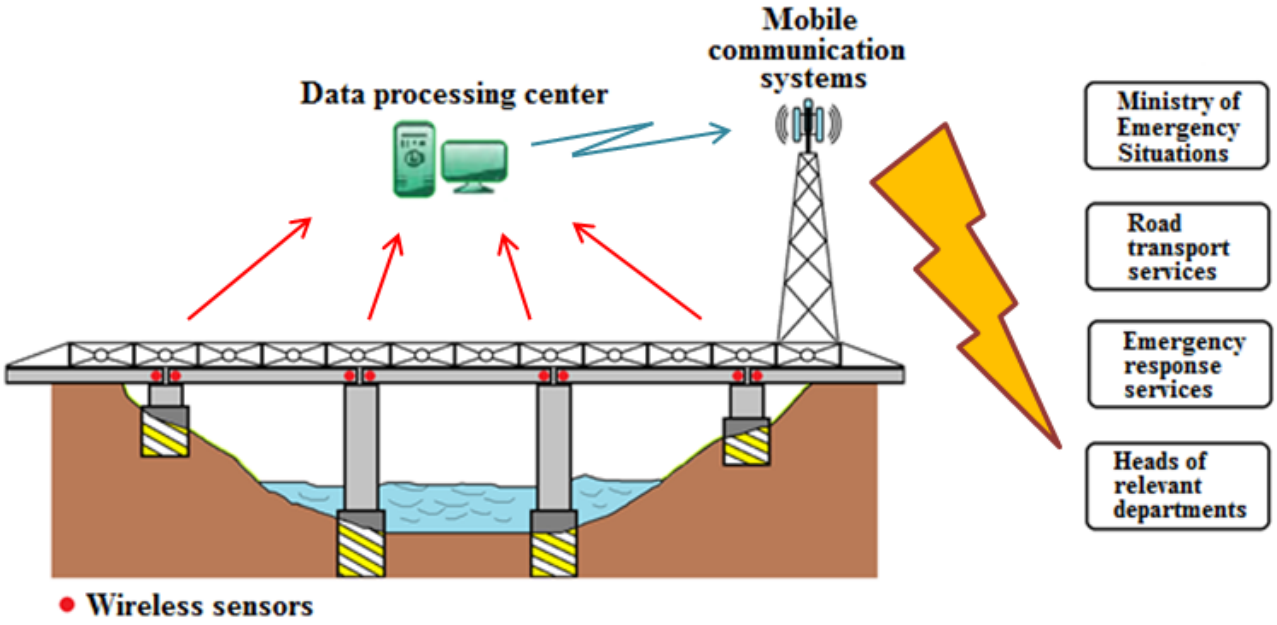

Figure 8 - Using WSN to organize remote monitoring of bridges

The principle of organizing a wireless bridge monitoring system using sensor networks is as follows:

Sensors are installed on certain sections of the bridge. The data received from the sensors is transmitted to the data processing center, where a specially developed program will check the received data for changes from the initial parameters, which in the case of monitoring the bridge is a displacement between the plates that are located on the load-bearing beams of the structure and transmit any changes to the relevant services, authorities or directly to the heads of departments responsible for the operation and maintenance of these facilities (Khizirova et al., 2021: 4).

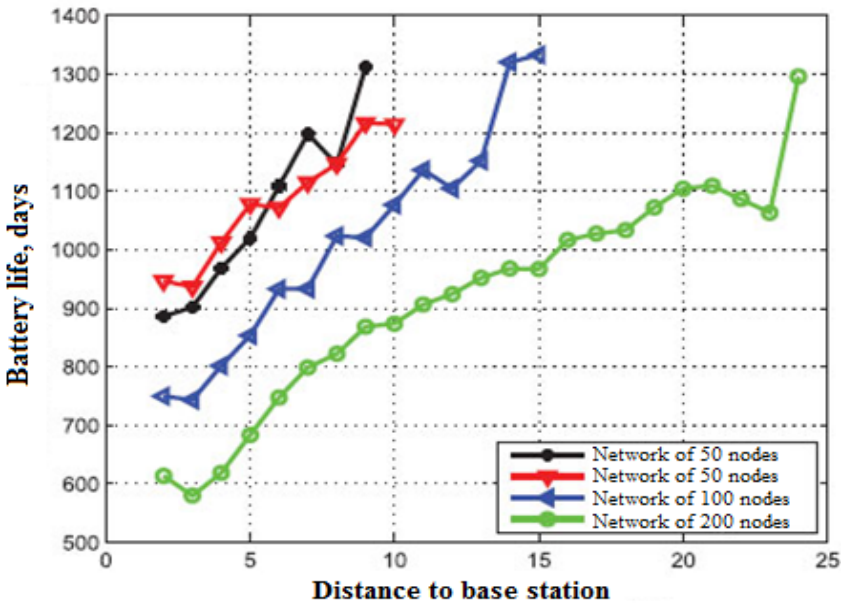

Figure 9 - Graph of energy efficiency of WSN nodes with increasing distance to the base station (Baskakov et al., 2010: 4)

Such advanced sensors can be used as a bridge between the physical world and the digital world. Sensors are used in many devices, industries, machines and environments to help avoid infrastructure failures, accidents, conservation of natural resources, wildlife conservation, productivity, safety, etc.

Another major advantage of wireless networks is the energy-efficient elements of the system. They can provide long-term operation due to the service life of the power supply, which, depending on the distance, can reach several years of operation (Figure 9) without replacing power supplies.

To ensure the safety of the civilian population, the following are proposed:

– it is necessary first of all to consider the existing methods for diagnosing and monitoring the state of objects in an emergency or pre-emergency state.

– it is necessary to create a single center for monitoring the state of road facilities using modern measuring devices, as well as use wireless or satellite technologies to detect accidents in a timely manner to prevent emergencies with subsequent deaths among the population or damage to them or state property, which will lead to multiple costs.

Conclusion

1. In conclusion, we can say that, despite the existing norms for the construction of various structures and laws to improve the construction system of road bridges, overpasses and other artificial structures, today thousands of bridges are in emergency or unusable condition due to the influence of natural, including groundwater or river water, as well as non-compliance with these rules and regulations during their construction or operation.

2. The proposed systems for monitoring the state of road bridges using satellite communication systems or wireless sensor networks will provide timely information on the state of structures and help detect deformations in the observed objects.

3. The use of wireless sensor networks will enable the location of measuring sensors in hard-to-reach places, where it is difficult or expensive to pull ordinary wired solutions. They also allow rapid and rapid deployment and maintenance of wireless monitoring systems;

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