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FLOOD EMBANKMENTS MONITORING SYSTEM IN ON-LINE MODE

The chapter presents a short description of flood embankments assessing and presents the concept of a solution for the continuous monitoring of flood embankments with the use of currently available ICT technologies. The architecture and description of the designed system and the benefits of its implementation are presented. The concept of the flood embankments monitoring system, presented in this chapter, was developed by the research teams of IHP Frankfurt (Oder) and the University of Zielona Góra as part of the INTERREG project.

MONITOROWANIE WAŁÓW PRZECIWPOWODZIOWYCH W TRYBIE ON-LINE

W rozdziale przedstawiono krótką charakterystykę sposobu oceny wałów przeciwpowodziowych i zaprezentowano koncepcję rozwiązania systemu ciągłego monitorowania wałów przeciwpowodziowych z zastosowaniem współcześnie dostępnych technologii teleinformatycznych. Przedstawiono architekturę i opis projektowanego systemu oraz korzyści wynikające z jego wdrożenia. Prezentowana w rozdziale koncepcja systemu monitorowania wałów przeciwpowodziowych opracowana została przez zespoły badawcze IHP Frankfurt n/Odrą i Uniwersytetu Zielonogórskiego w ramach projektu INTERREG.

1. INTRODUCTION

Flood embankments are an important element of the flood protection infrastructure. Catastrophic floods that have occurred in Poland and Europe in recent years (1997 and 2010) have caused significant damage to the economy and infrastructure of individual countries. This situation made it necessary to develop national and international flood protection programs. This problem was also raised by the European Union in two documents, the 2000 Water Framework Directive and the 2007 Flood Directive. In the assessment of flood risk, resulting among others from the condition of flood embankments and for the needs of crisis management during floods, continuous monitoring systems for flood embankments can play an important role. Damage to a flood embankment usually results in very large economic and social losses. One of the basic threats to the safety of the embankment is the development of filtration and erosion processes both in its body and in the subsoil. The existing methods of monitoring and assessing the condition of flood embankments are not sufficient to ensure the safety of these objects. They are based primarily on local inspection and the performance of geotechnical surveys in distant sections. The assessment of filtration and erosion processes, especially in their initial stage of development, and the assessment of their dynamics using classical methods is usually difficult [1,2,7,8,13]. The solution is to implement a system for monitoring the state of flood embankments in real time. The desirable features of a modern flood embankment monitoring system include: real-time monitoring of filtration and erosion processes, possibly early and precise detection of the destructive process, the possibility of assessing the dynamics of the destructive process, the possibility of developing an automatic alarm system informing about the occurrence of a destructive process, an unmanned installation. The chapter presents the concept of building a modern system of continuous monitoring of the embankments of the Odra River at the level of Słubice / Frankfurt with the use of ICT technology. Fig. 1 shows the location of the sensor part of the designed system in a graphic form.

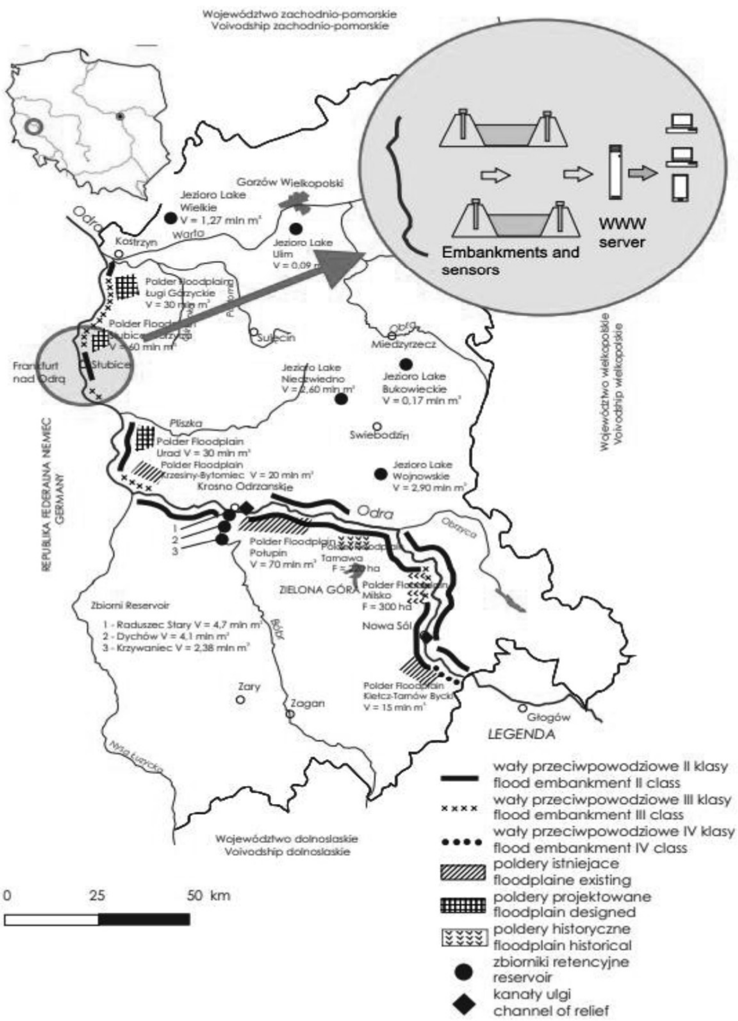

Fig. 1. Location of the flood embankment monitoring system
Rys. 1. Lokalizacja systemu monitoringu wału przeciwpowodziowego

2. ASSESSMENT OF THE FLOOD EMBANKMENTS CONDITION

Large floods on the Odra River occurred many times. The Odra River regularly, twice a year, rises from its banks, in spring when snow melts, and in summer in June and July after heavy summer rains. This situation forced the managers of the areas adjacent to the Odra River to build flood embankments. The construction of flood embankments in the Middle Odra River began in prehistoric times. The largest works related to the construction of embankments were carried out in the 18th century and at the beginning of the 20th century. Fig. 2 shows historical floods in the basin of the Middle Odra in the section from Głogów to Kostrzyn, which took place in the 19th, 20th and begin 21st centuries. [6]

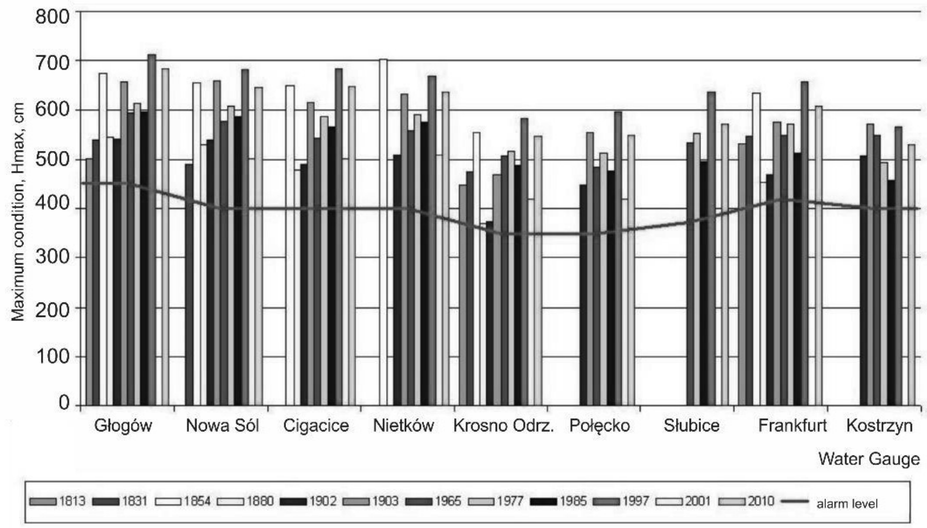

Fig. 2. Historical floods in the Middle Odra Basin [6]
Rys. 2. Historyczne powodzie w środkowym dorzeczu Odry [6]

The current practice of assessing the technical condition of flood embankments is based on annual inspections and periodic inspections of the technical condition usually performed every five years [4,5,10].

These controls are carried out on the basis of:

- analysis of archival materials,
- analysis of available aerial or satellite images,
- local vision of the site, including, among others, the correctness of the location of research points due to the availability of the site, the course of power lines, pipelines and other infrastructure elements, etc.,
- specialized field and laboratory tests, the scope of which is determined individually for a given section of the flood embankment,
- the results of settlement, stability and filtration calculations.

Documentation, which is the result of the inspection includes, among others, the assessment of the technical condition of the flood embankment with the identification of threats and conclusions resulting from the inspection. On the basis of the inspection results and formulated conclusions, flood embankments are assigned to the following categories of technical condition and safety [4,10]:

0 - no assessment due to lack of data,
1 - security emergency,
2 - a condition that may endanger safety,
3 - good technical condition, not threatening safety.

The assessment of the technical condition and safety of the embankment includes the following elements of the flood embankment:

- flood embankment body,
- the ground directly under the embankment and in the area adjacent to the embankment within 50 m from the embankment's foot, both from the upstream and downstream sides, with particular emphasis on those areas where filtration phenomena occur,
- structures accompanying the embankment, such as: pumping stations, culverts, locks, drainage, drainage devices, drainage water drains, embankment ditches, embankment crossings, flood and access roads to the embankments, control and measurement devices and other elements related to the protection line created by embankment,
- outside the embankment, in the inter-embankment and protected area.

Due to the fact that modernization works are being carried out on the section of the flood protection embankment selected for monitoring, the assessment of the technical condition of the modernized flood embankment, containing various sealing elements, will require a different approach than in the case of embankments with a traditional, purely ground structure.

The system of continuous monitoring of flood embankments developed under the project is not intended to replace the conducted inspections and control of the technical condition of the embankment. The scope of continuous measurements performed at test points will cover only selected geotechnical parameters of the embankments and will be a guide for the conducted inspections, which may have an impact on their rationalization. Periodically performed inspections are insufficient to reliably assess the condition of the flood embankments, which directly affects the size of the losses caused by floods due to damage or breakage of the embankment. Proper assessment of the state of flood embankments should be carried out on the basis of data obtained from measuring sensors on a regular basis, which would be collected and processed by the designed system. This approach allows for constant comparison of results, and especially for the analysis of their trends over a longer time horizon.

The automation of the real-time data collection process proposed by the system consists in the use of sensor measuring nodes, grouped into a wireless sensor network. Due to the assumed long-term maintenance-free operation, the sensor measuring nodes installed in the flood embankment body or in its neighbourhood will operate in the measurement or standby modes. The measurement information will be provided at discrete instants. Physical quantities such as soil temperature, soil moisture, pore water pressure, and water table level will be measured. Based on the measured values, other indirect features of the measured flood embankment will be determined. The information from the measuring sensors will be collected in a database located at the UZ Computer Center and IHP Farankfurt (Oder) and will be used by the developed application software. Data from measurement sensors (current and historical data for a selected period) and the results of their processing will be made available to authorized end users via a web browser.

3. SENSORS FOR MONITORING OF FLOOD EMBANKMENTS

In order to determine the condition of flood embankments, and in particular to locate places where filtration and erosion processes develop, the monitoring systems for flood embankments use soil temperature, soil moisture, pore water pressure, soil pressure sensors, piezometers and inclinometers. The system will be complemented by local weather stations that will measure: rainfall, air humidity, air temperature and atmospheric pressure.

The sensors are installed both in the body of the flood embankment and in its surroundings. Temperature sensors measure temperature, which allows to determine gradients of temperature changes that depend on changes in thermal conductivity within the measured embankment. The resistance sensors [3,9] are the dominant type of sensors used for temperature measurements and recommended for flood protection monitoring systems. It should also be noted that there is a growing interest in temperature sensors based on optical fiber. Depending on the type of the embankment body, these sensors are recommended to be used on the upstream side of the embankment or behind the screen. Their temperature measurement accuracy should be about is 0.1 °C. The measurement methods used and the resolution achieved allow for a very precise indication of places where dangerous filtration and erosion processes take place. These solutions are expensive and are currently used only in sensitive places [9].

In the assessment of filtration processes, it is important to know the dynamics of changes in the groundwater level in relation to the water level in the river. For this purpose, open piezometers with hydrostatic level sensors are installed [2,11]. Pore pressure sensors are one of the most important sensors from these used in flood protection monitoring systems. They make it possible to locate and evaluate the development of the embankment destruction process. Pore pressure sensors also allow the measurement of the groundwater level. Angular deflection sensors used in inclinometers are used to measure displacements in the shaft body.

Based on the evaluation of the functioning of the flood embankment monitoring systems built up so far, the most effective methods of locating and developing filtration and erosion processes are fiber-optic thermomonitoring and the measurement of pore pressure changes [9]. In Poland, a team of AGH scientists from Krakow built an experimental embankment in Czernichów and a system for its continuous monitoring for research purposes. The above-mentioned measuring sensors were used in it and during the conducted research. The usefulness of data obtained from them for the assessment of the state of the flood embankment [2] was demonstrated.

From the geotechnical point of view, the measurements of the position of the water table and the water pore pressure are the most important parameters for assessing the stability of flood embankments. These parameters can be measured in open piezometers (the water table) or closed piezometers (the water table and the water pore pressure). Open-type piezometers are usually tubular steel or plastic piezometers, similar in structure to a drilled tubular well. Open piezometers are equipped with filtering tips ensuring the flow of water to the piezometer. The groundwater is then in direct contact with the atmosphere and the measurements consist in direct measurements of the ordinate of the water table by means of optical-acoustic meters, hydrological whistles (hydrological whistle) or measurements of piezometric pressure using hydrostatic pressure sensors. The advantages of this solution are: the ability to monitor water from various piezometric levels, ease of installation, low cost and the ability to precisely assess the position of the groundwater table by direct measurement.

Even the most accurate measurements of the water table carried out in the piezometric well, taking into account the period needed for the stabilization of the water table in a short period of time, will not allow for an accurate estimation of the amplitude of changes in the position of the water table in a short time period, which is associated with the hydrodynamic time delay. The hydrodynamic time delay corresponds to the time it takes for water to enter or exit the piezometric well until the pressure equilibrium (water table height) is achieved. It depends on the type and dimensions of the piezometer as well as the filtration coefficient (permeability) of the surrounding soil. Open piezometers have a much longer hydrodynamic delay time than closed piezometers. For many practical applications, a 90% equilibrium reaction is considered sufficient. The Penman equation [8] is used to estimate the response time of open piezometers. In the case of using open piezometers, the measurement results should take into account the atmospheric pressure (Fig. 5).

Closed-type piezometers are usually piezometers without a casing, driven into or placed directly in a borehole or trench. The principle of their operation is based on the measurement of the pore pressure in the soil, on the basis of which the position of the groundwater table can be assessed. In closed piezometers with sensors for measuring water pressure, response times are practically instantaneous. Figure 3 shows the distribution of measurement nodes in the designed flood protection monitoring system.

Based on the analysis of the results of current and historical measurement data, it will be possible to determine the location of places where the development of filtration and erosion processes takes place and to determine the approximate direction and amount of water filtration in the soil pores. The obtained information will allow to assess the state of flood protection and selected elements of the environment in the Słubice region.

Measurements will be carried out in measurement profiles, while the interpretation of the obtained data will be related to a given profile or measurement node. A measurement node should be understood as one or more measurement profiles with a diameter of 10 cm, in which the measurement sensors for soil temperature, soil moisture, pore water pressure and the level of the groundwater table will be placed, installed at precisely defined depths. Each of the measurement profiles will be equipped with a local controller (IoT Hub) to read data from sensors installed in a given profile. The local controller shall be equipped with a wireless bi-directional communication channel.

Due to the ongoing modernization of the flood embankments, including reinforcement of the existing flood embankments of the Odra River in the section from km 582.5 to km 588.0 the project implementers envisage two stages of research: in stage I, the measurement profiles will be installed outside the embankment, in the inter-embankment and in the embankment, while in stage II - directly in the embankment, on the upstream side - in the inter-embankment, in the body of the embankment and on the upstream side - the cave. The map of the distribution of measurement profiles on the flood embankment, in the vicinity of the town of Słubice, in the first and second stage of the project deployment is presented in Fig. 3.

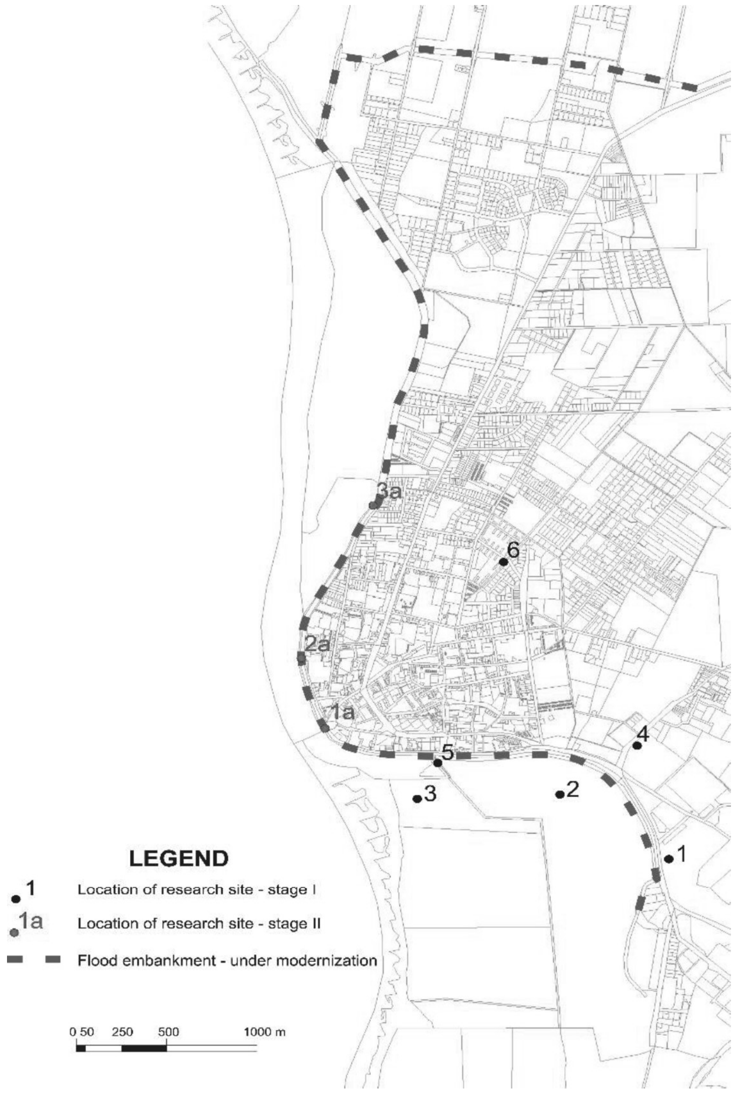

Fig. 3. Location of measuring nodes on the flood embankment
Rys. 3. Lokalizacja węzłów pomiarowych na wale przeciwpowodziowym

4. LOGICAL STRUCTURE OF THE MONITORING SYSTEM

The logical structure of the designed system for continuous monitoring of flood embankments is shown in Fig. 4. The data source in the designed system will be measuring sensors located in the embankment and at selected points in the area adjacent to it.

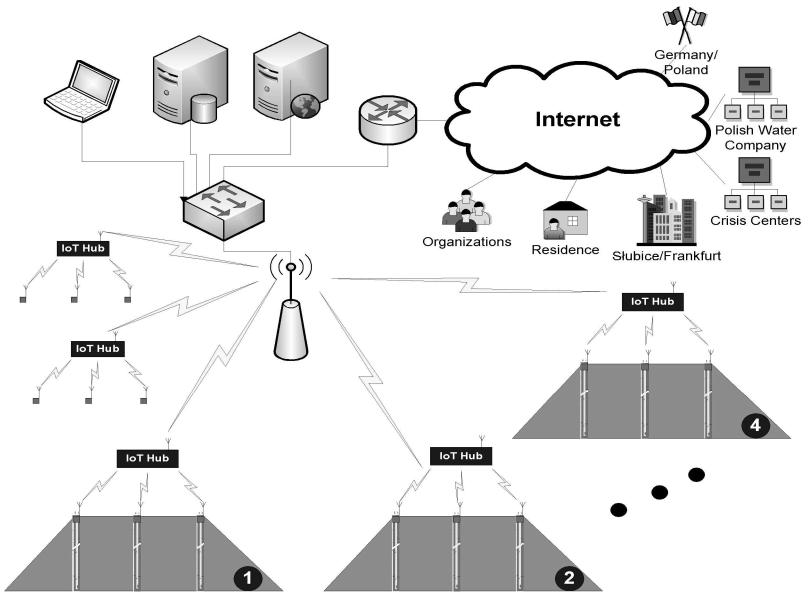

Fig. 4. Logical block diagram of the flood embankment monitoring system
Rys. 4. Schemat blokowy systemu monitoringu wału przeciwpowodziowego

The evolution of the Internet has led to a situation in which simple devices are connected on a mass scale to the hierarchical structure of the public Internet created by Internet operators and routing devices. These devices are logically addressable with public IPv6 addresses. They function in our surroundings, environment or industry, creating the edge of the Internet of Things (IoT). In the IoT architecture, data from these simple devices are sent to the existing hierarchical structure of the Internet via IoT hubs or IoT gateways to the cloud, where they are collected, processed and analysed. IoT hubs and IoT gateways are new devices that perform the function of aggregating data from simple nodes, most often via wireless communication links and sending data to the cloud. For the purposes of this communication, new lightweight application layer communication protocols such as MQTT, CoAP, AMQP, XMPP and the tunnelling protocol of the 6LoWPAN network layer have been developed to compress IPv.6 address fields. However, the key device in the IoT architecture is the IoT gateway, which in addition to the functions of data aggregation, IoT device management, the implementation of functions related to data security and operational security, performs the functions of edge analytics (Edge Analytics). Analytics at the edge of the network will be crucial especially for large IoT domains [7,12,13]. In the case presented in this chapter, due to the small number of measurement nodes, IoT Hub was envisaged as a device aggregating data and entering the Internet.

An exemplary logical structure of a measurement node in a flood embankment cross-section is shown in Fig. 5. The measurement node consists of a group of measurement sensors (humidity, temperature and pore pressure sensors) mounted in strictly defined places and at strictly defined depths in the flood embankment body. Adopting the convention of a measuring node with one IoT Hub, which includes measurement profiles located in the body of the flood protection embankment or in its vicinity, is a solution that allows to reduce the demand for electricity to power devices.

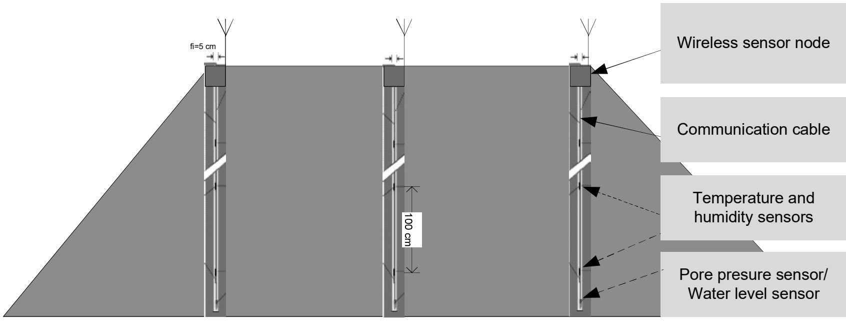

Fig. 5. Measurement nodes in flood embankment
Rys. 5. Węzły pomiarowe w wale przeciwpowodziowym

Due to the fact that communication with a distant central node will be performed only by IoT Hub, and local controllers supporting measurement profiles will communicate with the IoT Hub that will be in their vicinity, the power of transmitters required for wireless communication will be small. This solution of the system architecture also allows for a simple implementation of security measures for measurement profiles installed in the field against their damage or devastation. Low Power WPAN standards such as Bluetooth Low Energy, ZigBee or Thread can be used for local wireless communication between local controllers installed in the upper part of the measurement profiles and the IoT Hub. However, for communication between IoT Hub and the data centre, Low Power WWAN standards such as LoRa, Sigfox, Weightless, NB-IoT or IoT profile in 5G cellular network can be used.

In each of the measurement profiles, sensors for soil temperature, soil moisture, pore water pressure will be installed, with a distance between them, e.g. 1 m vertically and a pore pressure sensor at the end of measuring profile. Measurement information from sensors placed in the measurement profile will be read by the local controller, which is a node of the wireless sensor network. From the wireless network node, the measurement data will be sent wirelessly to the IoT Hub aggregation node, and then - also wirelessly - to the measurement server, where it will be saved to the measurement database. It is assumed that both the local drivers and the aggregation node will be unattended devices. The measurement data will be processed by the application software, and the results of the software operation will be made available to authorized users (users with accounts in system) in text and graphic form. From the user's point of view, the web browser will be the primary interface for accessing of the measuring data processing results of the flood embankments monitoring system.

Sample results from the experimental, real measurement node with three measurement profiles (manual measurement), obtained in the period from September 2019 to September 2020 in the flood embankment in Milsko (446 km of the Odra River) are shown in Fig. 6.

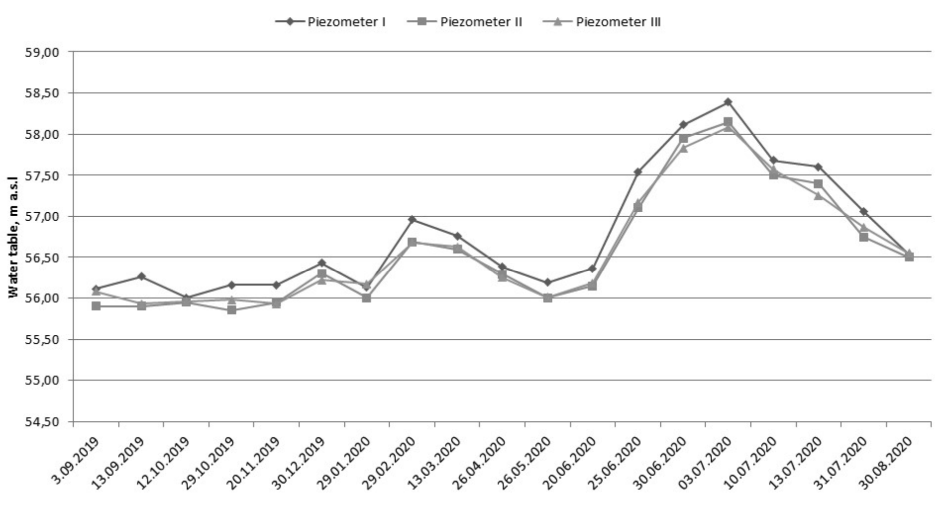

Fig. 6. Water table level measurements with an open piezometer
Rys. 6. Pomiary poziomu lustra wody za pomocą otwartego piezometru

5. REQUIREMENTS FOR DATA PROCESSING IN CLOUD

Measurement data from sensors through the data acquisition system will be sent to the database server (Fig. 7). The database requirements are as follows:

- defining a cloud-based database tool,
- defining the database structure,
- defining tables for storing current and historical data,
- authentication and authorization when accessing data,
- specification of the hierarchy of authorizations in access to data,
- authorization management,
- management of measurement nodes,
- information security management:
    - ensuring confidentiality,
    - ensuring integrity,
    - providing authentication,
- creating automatic backups,
- estimating the size of the database and estimating the dynamics of its growth.

Apart from the database, an important element of the IT part of the system are applications that use the database and algorithms for their processing in order to make the processing results available to end users. Application development requirements and tasks should be as follows:

- choosing an IT environment,
- managing access to the application:
    - for account management,
    - for password management,
    - for authorization management,
- software for the algorithm for processing measurement data contained in the measurement database,
- preparation of statements and reports,
- development of a user interface for various end users,
- development of a system security management module, development of a measurement node management module.

6. FUNCTIONAL STRUCTURE OF THE FLOOD EMBANKMENT MONITORING SYSTEM

The description presented in the chapter refers to the functional structure of the flood embankment monitoring system presented in Figure 7. This figure shows the logical structure of the designed system, in which the measurement layer is distinguished, which is formed by measurement sensors placed in individual measurement profiles. Measurement profiles are grouped into measurement nodes (IoT node), usually covering several measurement profiles. Each of the measurement profiles will be equipped with a local controller to read data from sensors installed in a given profile. The local controller shall be equipped with a wireless bi-directional communication channel. Measurement data from sensors will be aggregated in measurement nodes and then sent wirelessly to IoT Gateway nodes. IoT Gateway aggregates measurement information and can pre-process it, but its main task is to deliver it to the central database via the Cloud Gateway module. The basic values measured in the designed system of permanent monitoring of flood embankments and adjacent areas will be: soil temperature, soil moisture, pore water pressure and the level of the groundwater table.

In the central database, the measurement data will be stored in the time domain. The frequency of data acquisition will be determined arbitrarily by authorized users or in a manner dependent on the dynamics of changes in the measured quantities in accordance with the programmed algorithm. The frequency of reading data from measurement sensors should be programmed and dependent on the flood situation. The following operating modes of the monitoring system will be defined: normal, research, alarm, test and service, and an algorithm for the frequency of reading will be developed for each of the defined modes. The reading frequency is an important parameter of the system operation, both due to the measurement data in a given flood situation and the impact on the battery life of the measuring node and the local controller communication module. In order to estimate the electrical parameters of the power battery, at the design stage, analyses of the energy demand of individual devices for the appropriate operating mode should be performed.

For the purposes of the monitoring system, the collected data will be processed in accordance with the developed algorithms and applied mathematical models.

In addition to the measurement data from sensors, the same communication path will send information managing the operation of individual devices operating at individual levels of the designed system (configuration, parameterization, servicing, etc.). This means the necessity to enter user profiles and assign them appropriate permissions. Both the user groups and the rights assigned to them will constitute one of the elements related to the administration of the developed system. Verification of the monitoring system users will take place in a classic way, i.e. when logging into the system, the user will be required to enter a username and password.

One of the design decisions to be made at the stage of designing the monitoring system is to define the method of identification of devices and users installed in the system. This decision will be made at the next stages of preparing the final specification of the system. Adopting the device identification method will affect the names of individual fields in the database.

In order to enable access to source and processed data, it is planned to develop a web user interface in the designed system. Thanks to it, system users will be able to access data from the level of a web browser after meeting the system requirements defined for specific user groups.

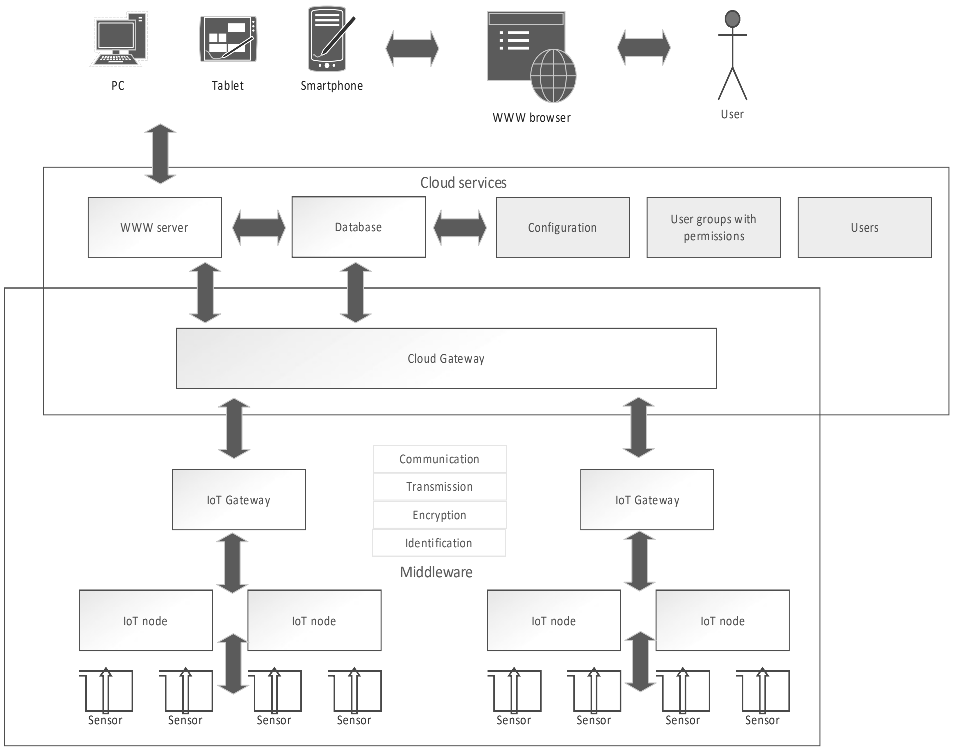

Fig. 7. Logical structure of the designed system
Rys. 7. Struktura logiczna projektowanego systemu

7. STRUCTURE AND MANAGEMENT OF THE DATABASE

An important element of the IT part of the flood embankment monitoring system is the database and applications cooperating with it [12]. For the purposes of the system design, the structure of the database is proposed as shown in Fig. 8. The database will contain a set of tables connected by relations that enable defining a list of system users with their authorizations, the structure of system nodes with the properties of measurement nodes and collecting measurement data from sensors installed in nodes . Based on the measurement data collected in the database, it will be possible to query the database for specific data on selected nodes in a specified period of time. The data can be aggregated into a form that allows determining the value of average, minimum, maximum, and counting the available values. The results provided by the inquiries can be used to prepare reports and data summaries. It is assumed that typical functions of the SQL language will be used.

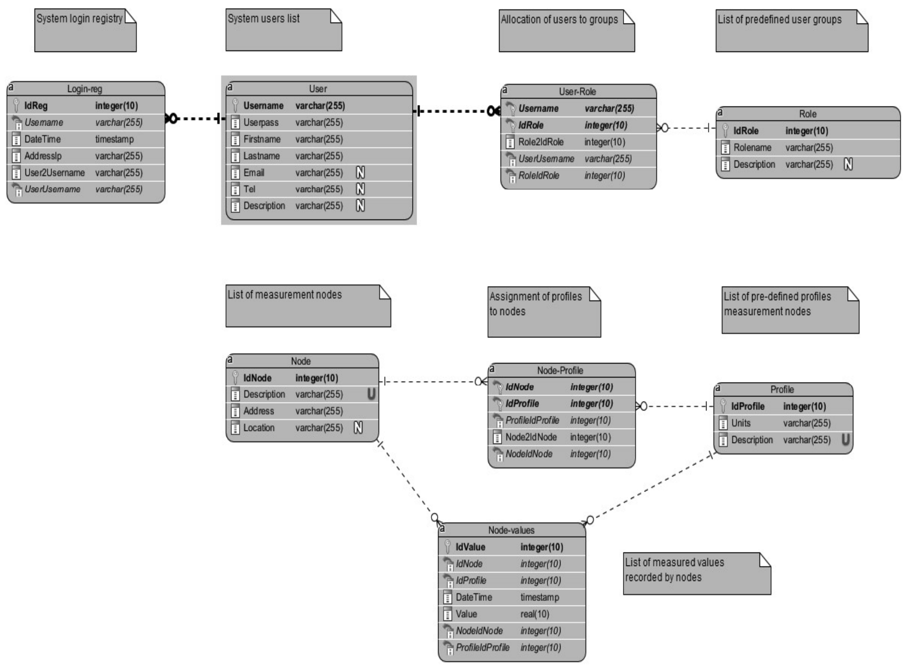

Fig. 8. Data base structure of the embankment monitoring system
Rys. 8. Struktura bazy danych systemu monitoringu wału

The presented structure is preliminary, the tables contain only basic fields for storing information. The structure of tables and relationships will be clarified and may change. Both at the user level and at the level of user profile

management and security, it is an important part of the monitoring system. The user interface will be available as a web portal. Access to the detailed pages will be possible after logging in for authorized users.
The basic information available to users through the browser interface should be included:

- graphical representation of the logical structure of the monitoring system,
- map of the distribution of measurement profiles along with their logical identifiers and information on geolocation, types of sensors and installation metrics,
- graphical representation of the logical structure of the measurement node and measurement profiles making up the measurement node. A measurement node can create one or several measurement profiles,
- graphical (chart) or tabular presentation of the results of current and historical measurements (week, month, year) and the results of data processing available in the database. Access to live and processed data will depend on the user profile,
- node management (logical addressing, reset, configuration, security level, authentication method, creating a node metric, reading the battery status) - for the ADMIN user profile.

8. SUMMARY

The chapter presents a synthetic description of the method of the currently performed flood embankment assessment and presents the concept of building a system for continuous monitoring of the flood embankments and adjacent areas in the area of Słubice / Frankfurt on the Oder.

The architecture of the monitoring system was presented and the basic requirements for the designed system were outlined. Based on the analysis of data obtained from measurement nodes and using the developed model of their processing, it will be possible to initially estimate the state of flood protection and indicate the places of flood risks in the city of Słubice. The assessments obtained from the system of continuous monitoring of flood embankments may be an indication for a more detailed identification of flood hazards on a given section of the embankment with the use of geophysical methods.

Analysis based on archival and current data will allow for a detailed correlation of filtration and erosion processes and other environmental processes that take place in the monitored area. The information obtained will allow to indicate effective solutions in terms of improving the condition of the environment, including the effectiveness of flood protection measures.

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