Application of geophysical monitoring system and GIH 01 tool at the river basin scale as a part of integrated water resources management in the Czech Republic

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Abstract

The Geophysical Monitoring System (GMS) has been designed as a new instrument for maintenance of and checks on safety of flood control dikes in the Czech Republic. Having used the new tool to define hot spots of an existing embankment system, detailed investigation, maintenance and renewal efforts can be concentrated in a cost-effective way on the critical parts of the embankments. Based on the analysis of geophysical measurements carried out on the dikes and based on the discussion with the dike owners/caretakers representatives it can be stated that for maintenance and check of the dikes there are 3 basic types of tasks that can be effectively covered using geophysical methods. The first task includes a survey of long embankment sections (Quick Testing Measure), the second refers to detailed investigation of problem sections and the third one aims at providing basic data for classification and a geomechanical description of the dikes material. The GMS comes with special software – GIH 01. This GIH01 tool is a light version of software for geophysical inspection of the dams and it is being developed and tested within research projects financed by the Ministry of Industry and Trade of the Czech Republic: "Research and development of the modular system GIH 01 for applications for Integrated Water Resources Management in the catchment scale and floods prevention". Thanks to the GMS control method and GIH 01 data evaluation and visualization it is possible to design the optimal process of dike reconstruction and protection within the entire river basin areas.

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1 Introduction

Sustainable development of river basin is an important keyword for all planning and decision-making authorities, organizations and persons working at the river basin management scale. Sustainable practice is one of the main topics for our actual decision-makers to keep the natural environment in a good status for the next generations. Decisive process in the sphere of protection of a river basin against floods represents an extensive and complex problem, which puts great demands on responsible organizations and persons.

Conception of control of river dikes and related decision-making lead from partial solutions to holistic systems, which allow, during the research, to respect majority of significant factors in sufficiently wide area in adequate detail. Nevertheless, these systems simultaneously bring problems connected with expensive acquiring of necessary data and with computing support during their processing. In Europe, the solution of problems of water management and especially the protection against floods must necessarily get to a qualitatively higher level. The Geophysical Monitoring System (GMS) accompanied by the GIH 01 tool may significantly contribute to achievement of the desired improvements. At the same time, it will support effective utilization of decision-making systems in the area of specific dikes management at the river basin scale as a part of the Integrated Water Resources Management (IWRM).

2 General description of the problem

2.1 Monitoring of the dikes

Monitoring of flooding dikes conditions is nowadays often performed only visually. This visual monitoring is considerably dependent on precise knowledge of history of the followed terrain section of a dike and experience of the field worker, but it still represents just a rough estimation of the actual condition without any possibility to verify the conclusions. Moreover, the visual monitoring makes it possible to find only a failure, which is evident on the surface of the monitored section (e.g. fall through of the dam crown, etc.) the reconstruction of which is very expensive. For determination of the actual status, it is possible to advantageously utilize geophysical methods, mainly geophysical electromagnetic methods in connection with modern devices and corresponding analytical and interpretation software, which will enable to acquire information on the conditions of the dike section of substantially higher quality. An important characteristic of geophysical survey methods is the fact that they provide information on failures and status of the dikes much more accurately and, above all, earlier than they can be revealed visually on the surface.

2.2 Geophysical methods

Geophysics, as a branch of science, utilizes knowledge of physics, astronomy, geology and applied mathematics. It studies naturally or artificially generated physical fields of Earth. Applied geophysics is an applied science, studying naturally or artificially generated fields to help clarify geological conditions in the Earth crust. Because the Earth crust is nonhomogeneous, its particularities are reflected also in the observed geophysical fields. Its principle consists in differentiation between the contrast properties and surrounding environment. Therefore, different geophysical response is directly dependent on extent of different properties of environment. Likewise, important is also dependence on depth of deposition of these nonhomogeneities, what closely relates to the action radius of used geophysical methods.

Applied geophysics is conventionally divided into the methodical groups according to character of the field, which is monitored. These methods are: gravimetric, magnetometric, geothermal, geoelectric, radiometry and methods of nuclear physics, seismic and geo-acoustic methods.

During the survey for engineering-geological or geotechnical purposes, it is necessary to select appropriate complex of these methods and related methodology of the field works. Likewise, it is necessary to know relationship between measured physical properties of rocks and parameters, which have to be finally received or indirectly determined. During application of geophysical methods, it is necessary to keep the principle of complexity (selection of appropriate methods), work in stages and economic efficiency (Boukalova and Beneš [1]).

All geophysical measurements require always a qualified interpretation of measured data, for which it is necessary to consider a series of factors. The specific software tool GIH 01 is an analytical module of ***Geophysical inspection of dikes***, which will provide maximum support for correct interpretation of measured data to a qualified operator and which will be complemented by database of all measurements. This tool enables analysis not only of a single application, but also with repeated measurements conducted in various periods and it gives a maximum support for time analysis of the measured data and their interpretation to the user. At the same time, GIH 01 facilitates connection of the measured and interpreted data with map documentation and thus an easy orientation in the results not only for a qualified operator but even for field workers with lower qualification. This software is divided into two basic sections – analytical and visual. Analytical section involves analytical and filtration functions essential for the operator’s work in the complex process of interpretation and decision-making. Visual section displays processed data using external map server, which is chosen individually according to concrete needs of the respective researcher or stakeholder (Boukalova and Beneš [2]).

3 Geophysical Monitoring System (GMS)

GMS is established on quick testing measurements and application of GEM2 apparatus for rapid measurement using the dipole electromagnetic profiling method. GEM-2 is broadband digital multi-frequency electromagnetic device with the frequency range from 330 Hz to 47970 Hz. It enables simultaneous measurement using up to 15 frequencies (3 to 5 recommended). Unlike other commonly used tools, which use one frequency only (the transmitter broadcasts mono chromatic harmonic signal) and which are tuned for exact combination of working frequency linked with the distance of transmitting and receiving coil, this device is based on revolutionary conception of using frequency synthesis of the transmitted signal (which enables mutual superposition of selected number of frequencies) and separation (deconvolution) of individual sections of measured signal. The technical solution of the device is made possible by modern component base (analogue and digital components, micro-miniaturisation). The core part of the GMS is a database of repeated geophysical measurements, which were and will be carried out within a river-basin.

The GMS system is composed of 3 basic building blocks:

Quick testing measurement – fast and cheap measurement for basic evaluation of dike condition and homogeneity in the whole river-basin. This method is also the core of repeated (monitoring) measurements. We suggest DEMP using multi-frequency tool (for example GEM-2) as suitable method for this purpose.

Diagnostic measurement – detailed measurement of eroded (non-homogeneous) sections aimed at finding hidden defects of the dikes. The method is based on the application of a set of geo-electric methods, especially multi-probe resistivity method MEM or resistivity tomography complemented by another independent method selected accordingly to the type of the expected possible defect.

Assessment of geotechnical condition – geophysical measurements to monitor geomechanical condition of eroded dike sections. Seismic methods and micro-gravimeter are usually used for the analysis of geomechanical characteristics of the dikes. The GMS system asset lies in the possibility of objective evaluation of dikes homogeneity and condition. Geophysical methods represent suitable supplement for current methods of monitoring (visual check, aerial and satellite image analysis).

The GMS consists in a wide application of dipole electromagnetic profiling (DEMP) method for quick testing measurements (QTM) and repeated monitoring measurements (RMM) which serves for quick description of dike condition and its monitoring.

The measured parameters include conductivity of soils and rocks, their magnetic susceptibility and level of noise at an industrial frequency of 50 Hz. Based on these parameters, the homogeneity of materials used (dike structure) can be assessed and the materials can be described (gravelly – sandy – clayey materials). Relative permeability can be assessed and underground distribution systems (cables, piping, collectors) in the dike body detected. The measurement proceeds at a foot-pace, measurement positions are automatically recorded using

GPS system. The measurement proceeds simultaneously at several operating frequencies corresponding to several depth levels of the investigated medium. Penetration depth ranges between first meters and tens of meters according to frequency applied and resistivity of the medium. The basic output of a single QTM measurement is the dike division into so-called quasihomogeneous blocks. These are sections showing similar dike structure and similar materials used. This is important information needed to design exploratory boreholes and test pits, for example, before dike reconstruction.

The repeated, monitoring measurement using DEMP method (RMM) brings a new type of geophysical information. This means that we can delimitate in time unstable dike segments showing anomalous changes in electric properties of dike materials. This "instability" occurs most frequently at places of repeated seepage through dike or its underlying layers. In the event of dike saturation with water (during flood event), the pores and cracks are filled with water and a relative decline of resistivity (in comparison with undisturbed dike segments) occurs. On the other hand, when dike is dried up, the given segment may show a relative rise of resistivity due to an increase of material porosity which is caused by the occurrence of cracks and by repeated sediments washing out. In analyzing the RMM measurement, two basic rules have to be respected:

- It is necessary to differentiate "standard/normal" variations of soil resistivity originating due to differing moisture contents of dike material and underlying layers in repeated measurements. Moisture contents fluctuate due to precipitation and river water level changes. Such variations of resistivity commonly reach tens to hundreds of per cent.
- Repeated measurements should be performed under contrasting conditions preferably in dry period when dike is dried up (basic measurement) and in flood condition when dike is flooded (control measurement).

We suppress the effect of "standard/normal" resistivity variations mathematically through calculation of a so-called relative residual resistivity anomaly (with respect to expected length of anomalous segments).

$$\mathbf{R_{res} = 100 * (R_{meas} - R_{reg}) / R_{meas} \ [\%]}$$

R_{res} - relative residual resistivity anomaly
R_{meas} - resistivity measured by the apparatus GEM2
R_{reg} - regional trend of R_{meas} (this is calculated using the polymeric regression)

4 GIH 01 tool

The software tool is designed for operations with data measured by GEM or any other instrument for electromagnetic profiling of terrain. The solution of the project does not arise as a single task (one software block) in the frame of the analysis of possible requirements put upon the software and with respect to its future development, but the solution is divided into several smaller, mutually independent blocks. This solution is advantageous mainly with respect to future modifications. It consists of the following sections:

- **Loader:** block of data administration
- **Analyzer:** block of primary interpretation
- **Viewer:** block of results visualization
- **Export:** block for transfer of data into database

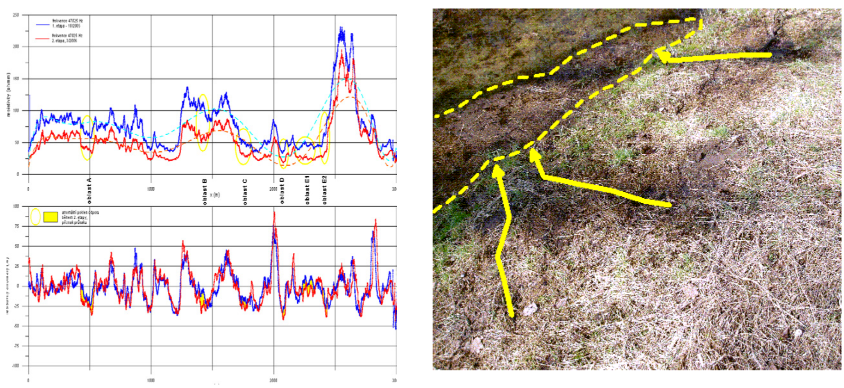

Figure 1: An example of repeated RRM measurement results interpretation.

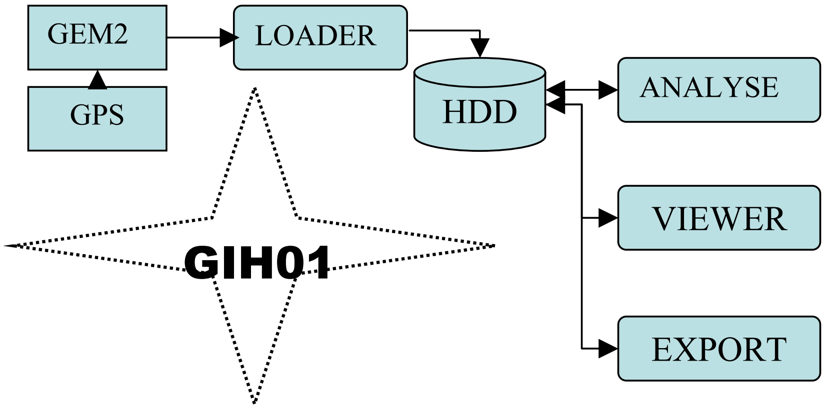

Figure 2: GIH 01 software packet – "Geophysical Inspection of Embankments".

The software tool takes care of import of data files created by the apparatus GEM and of their complementation with documentary photographs and notes created by user. The read data are interconnected by means of GPS coordinates and S-JTSK coordinates (Krovak coordinate system) with the position in the map. In the first stage the data are interpreted automatically using digital filtration. The results are presented to a qualified operator in a graphically friendly form. The operator will interactively mark special sections according to the character of measured signals and he will specify a special method of interpretation for them. Software will perform corresponding conversion, which will be included into the final processing after being confirmed by the operator. The resulting data are connected to the database and a map server. Illustration of the results is projected directly into a standard map or an orthogonal map. It is possible to view the results remotely by means of a network (Internet).

4.1 Block of data administration – *Loader*

Loader is a software block, which collects data from field measurements and documentation. It completes these data into complete data units, which cohere mutually directly. On the contrary, it distributes the measured data according to the boundaries of measured objects into independent units.

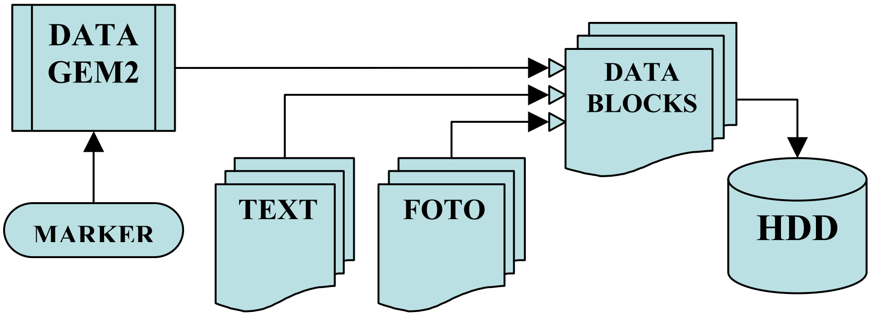

Figure 3: The principle of the loader block

There is a series of mutually connected monitored objects in the field. A dam divided into several independent parts that are mutually connected together only from the view of their position, but which are evaluated separately, may serve as an example. The task is to measure the required data on all monitored objects as quickly and reliably as possible with little requirements upon its attendance and preparation of measurement in the field. The measured data are subsequently processed in office. Field measurement actually means passing the defined route at the speed of free walking with the GEM2 instrument recording the data. The instrument records geophysical properties, GPS coordinates and marks and notes entered by the operator. When passing the terrain, it is possible to measure simultaneously several connected objects, which are recorded together in the instrument but which should be then separated for subsequent interpretation.

It is necessary to follow some limiting rules when operating the instrument. The main rule is that minimum of two field operators should always measure simultaneously. One operator operates with the device GEM2, second operator collects documentation photos and notes. A very important limiting factor is the fact that the electro-magnetical method (GEM2 apparatus) is very sensitive to presence of “parasitic” metal objects in the vicinity of the instrument. Therefore the operator cannot wear a camera for documentation or an electronic recorder for putting on text notes. All these activities should be performed by the second member of the measuring group. The second operator must not stand in the close vicinity of the operator of the GEM2 instrument.

Loader will accomplish the following functions:

- Analyze the data taken from the GEM2 measuring instrument and conversion of the data format into CSV tables.
- Division of continuous data record into individual sections, which describe separate objects or their selected parts.
- Analyze files of description notes, which were made by the operator directly during field measurement.
- Analyze files of photographs documenting significant points and objects that are regularly monitored or which can influence the measured data. Documentation of these objects is necessary for correct interpretation of the data.
- Conversion of GPS coordinates into S-JTSK "Krovak" coordinates applying a conversion program.

4.2 Block of primary interrelation – *Analyzer*

Analyzer is the most important part of the whole interpretation software. It serves for interactive processing of measured data, filtration, calculations and interpretation of the results. Great part of interpretation conclusions cannot be accurately mathematically generalized and described and for this reason this software will never be able to give fully automatic interpretation. Interpretation of measured data contains a series of independent activities. These activities are divided into fully automatic, automatic with operator's correction, manual division, marking and manual or semi-automatic validation.

4.3 Block of results visualization – *Viewer*

The block for visualization of the measurement is fully independent. It is assigned entirely to different range of users than the previous blocks. The users of the viewer block are persons without any special knowledge of geophysics. Considered persons come from local administration bodies, which will have the possibility to monitor the condition of flood-protection dikes at any time or will have all information of critical places at disposal when necessary. The viewer works with interpreted data and it displays selected variables in a map document for external users.

The viewer will only enable to make the selected information accessible via the Internet. Since the users will be persons usually out of the sphere of the managers and owners of the dams, it is necessary to provide them with the access to the data without any special requirement for buying, downloading and installing special visualization software. For this reason, the viewer is designed so as to intermediate the access to selected results of interpretation to the users by means of a standard Internet viewer via any type of Internet connection.

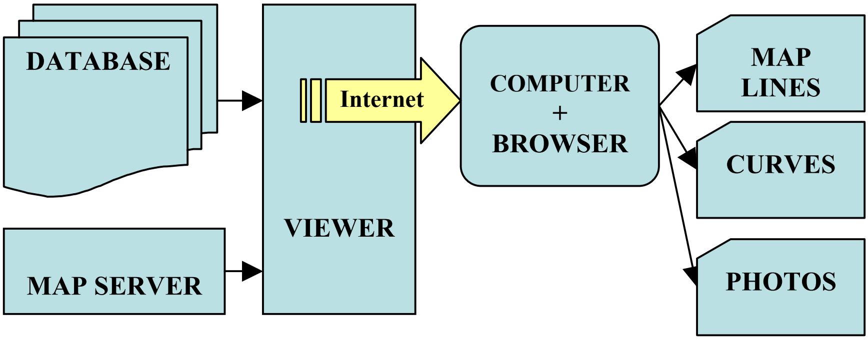

Figure 4: The block diagram of a viewer.

Interpreted, classified and properly interpreted data will be located on a server of the owner of measured objects. Some owners operate even their own map server connected in the frame of their database system. The viewer application will run independently on the owner of the objects and the owner will have access both to the map server and to the database of measurements. From the side of the users, the viewer will be accessible as a common webpage. It means that external users do not need to apply any special software and they can use any Internet browser. Also administration and access rule limitation is very simple. Users will be able to easily find a specific part of a dike or of another object of interest using the map layer, which will be also displayed in the interface.

Users are allowed to display any measured parameter. Values of different parameters are coded in different colors. Even the documented external effects and objects, which are connected with the recorded data, e.g. building objects, photo-documentation of the repairs, etc. are to be displayable. The user has the possibility to view even this documentation in detailed view of the map. Simultaneous display of several measured parameters in the location of the last repair of a dike, etc. may serve as an example.

4.4 Block of the transfer of data into the database – *Export*

The block of external links is the most demanding component of the GIH 01 tool. It must serve for correct insertion and download of the data at various stages of completion, but it must also prevent any unintentional damage of the data from the side of the operator. Unfortunately, the database systems and tools of the owners of measured objects are very heterogeneous. The administrators of large river basins (“large administrators”) have their own extensive databases and therefore they require transfer of measured data directly into their structure. The size of the created data files is relatively small in comparison with their other data. These companies often use their own visualization tools operated only in the frame of the company’s network. Naturally, they also require these tools to be applicable even for access to and operation with the results of the geophysical measurements.

Small companies, owners of fishponds etc. ("small administrators") usually do not have any databases for their own specific needs. The amount of measured data, installation of independent databases and other equipment represents a significant load for them. It is very complicated to propose a universal tool for all types of owners. For this reason we proceeded to a multi-stage solution, which is different for small owners and administrators of large basins.

Figure 5: Field testing in Odra River Basin – QTM using GEM apparatus.

5 Practical results

At present, GMS system is being introduced in 3 of 5 river basin areas in the Czech Republic. Since 2004 (starting year of GMS system introduction), approx. 200 km of flood control dikes in the Morava River Basin Area, approx. 80 km of dikes in the Odra River Basin Area and approx. 10 km of dikes in the Labe River Basin Area have been measured. These are mostly the major risk-posing segments, which regulate watercourses in the vicinity of bigger towns. The database has been growing; at present it includes approx. 15% of the total length of dikes in the Czech Republic. The newly applied electromagnetic GEM measuring instrument provides data usable for high quality assessment of actual status of the terrain sections if interpreted by a qualified person and involving suitable analytic tools. Additionally, regular control of selected sections (e.g. once in a year) and analysis of individual measurements in time will make it possible to predict behavior of the selected terrain section (dike) and to propose the terms and extent of repairs and maintenance appropriately.

The GMS and GEM2 tool were validated and tested during the integrated project FLOODsite of 6-th Framework Programme in dikes of the Odra river-basin (Boukalova and Beneš [3]).

The GMS asset lies in the possibility of objective evaluation of dike homogeneity and condition. Geophysical methods are suitable supplement for current methods of checks (visual check, aerial and satellite pictures analysis). In the year 2009, the GMS technology was successfully implemented on the river basins in Czech Republic, where is helping to policy makers and technical staff in their day-to-day monitoring and maintenance of the state of the dikes. The GMS system success is largely based on narrow co-operation between geophysics specialists and dikes caretakers. They have large quantity of information which can help in making the geophysical measurements interpretation much more precise. Without mutual trust and communication the GMS database program has no meaning.

6 Conclusions

There is an urgent need for better disaster prevention and risk mitigation support actions at the catchment scale. In order to achieve sustainable management of water resources, in particular at river basin level, it is of prime importance for decision-makers (Directors of River Basin Organizations and Administrations, Basin Committee members, representatives of Local Authorities and associations of users) to have an easy access to comprehensive, representative and reliable information at all relevant levels. Geophysical survey of linear flooding dikes and generally earth-fill structures by means of electromagnetic methods is very modern, mobile and cost-effective method for detection of failures and regular monitoring of geomechanical conditions of such structures.

GMS with potential application of the GIH 01 system is unique in the whole Europe. Until now, no other competitive prototype exists abroad. The designed GIH 01 system brings for a number of different potential users the possibility to utilize a comprehensive informational support of the GMS adapted generally to the sphere of water economics and it will make it possible to solve the problems of prevention of floods and to predict weak areas in linear water construction bodies (dikes), including the results of modelling, simulation and complex analyses, which will significantly improve the quality of decision-making (comparison of scenarios, alternatives of solution, suggestions of infrastructure changes and repairs of embankments, etc.). After necessary adaptation, the module system will provide utilization of numerical modelling tools even in hydrological and hydrogeological applications at the River Basin scale supporting common activities of the managers of water construction works and local water administration bodies.

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