A decision support system for emergency flood embankment stability

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Abstract

This article presents a concept of decision support system for emergency flood embankment stability. The proposed methodology is based on the analysis of data from both a flood embankment measurement network and generated through numerical modeling. Decisions about the risk of embankment failure are made based on this analysis. The authors present both the general concept of the system as well as a preliminary detailed description of the system components.

Keywords: automatic data analysis, decision-making system, time series analysis

1 Introduction

Protection against flooding in built-up areas is especially important due to the increasing number of floods in urban areas and the increasing scale of economic and social consequences caused by floods. Flood threat monitoring systems have been the subject of research in the framework of two European projects: UrbanFlood and Ijkdijk [1, 3, 5, 7, 8]. These projects developed experimental flood embankments with mounted sensor networks, which measure pore pressure, temperature and inclination [7]. These three parameters make it possible to assess the stability of flood embankments. The same necessity has been also recognized in Poland and in response to these needs the strategic project, implemented by an academic-industrial consortium and funded by the National Centre of Research and Development within the Applied Research Programme that has been launched. In order to create an automatic system to assess the state of flood embankment in Poland the Computer System for Monitoring River Levees (ISMOP) project was established [9, 6]. The main purpose of the project is to enable the development of a complex system that can help the authorities protect civilians against flooding by providing current information about the dynamics and intensity of processes within flood embankments. An experimental flood embankment (a full-size flood embankment at Czernichów near Krakow) will be built as a part of the ISMOP project. This project is particularly important because it will provide future monitoring network in the critical areas of the flood disaster. The constructed embankment is built in the test area, nonetheless in the case of success of the project,
these solution will be implemented across the country. The installed measurement network involves more than 50 points sensors and two optical fiber sensors stretched along the embankment. The point sensors are distributed at different heights, so that the measurements can be carried out in cross sections. Time step in measurements may be changed during the experiment from 1 to 60 minutes. The idea is to examine the variability of the temperature as well as the pore pressure values on the embankment stability and capture the changes of parameters in the moment of embankment failure. A cross-section of the experimental flood embankment with the arrangement of sensors is shown in Fig. 1.

2 An outline of the system for the analysis of flood data

Evaluation of experimental flood embankments condition will be based on the analysis of data retrieved from sensors located inside the flood embankment (Fig. 1), and measurements performed on and around its surface. The analysis will also involve the use of data retrieved from numerical modelling, which depicts possible changes in flood embankment behavior due to various internal parameters and variable external conditions. The proposed workflow divides data processing algorithms into modules (Fig. 2). Data measured with the use of real sensors will be converted and interpreted automatically with methods suitable for the analysis of multivariate time series. Synthetic data is processed and interpreted in model based modules, which use method of comparison and evaluation of model scenarios of flood embankment behavior. Information about the current condition of the flood embankment (and the short-term forecast) is obtained in the decision support module.

2.1 A data-driven module for anomaly detection

This data-driven module is used for detecting anomalies in a given time-frame of measurements from the sensors placed in the experimental flood embankment. The anomaly is defined as a deviation from of the standard system behaviour [4]. Input data to the anomaly detection module are time series of constant length. For each sensor we have a time series of 100 observations (25h window length) of two parameters: temperature and pore pressure, with information of sensor type and sensor position. The output data contain an anomaly report. The report contains information about the possibility of anomaly occurrence in time series for every sensor, with graphical presentation of results. In ISMOP project the preprocessed data were analyzed in the anomaly detection module based on algorithm: validated data were stored in a database; incorrect or missing data were replaced; data transformation was performed, including standardization necessary for the proper performance of the Fourier transform; the decomposition of the time series into a few systematic components was performed, it is particularly useful for data from temperature sensors placed in the subsurface of the embankment, for which there is a periodicity associated with daily and seasonal cyclicity; a fast Fourier transform (FFT)
was performed on the $n$ observations of time series and a periodogram was analyzed to detect changes in amplitude for a particular harmonic; non-stationarity in a time series could also be detected by a time-varying periodogram used for the analysis, thereby indicating the occurrence of harmful changes in the structure of the embankment; detection of non-stationarity in the periodogram is achieved by analysis of changes in the high frequency range (rapidly rising and falling spectral density values). The value was calculated according to the determination of the model residuals, which is the difference between time series and the constructed model. If the calculated value of the coefficient of determination is higher than 0.5, the residuals of the model are normally distributed, and the variance of the residuals is constant in time than in the analyzed time window, there is no anomaly. There is an anomaly if any of the above conditions are not fulfilled in the analyzed time window. Information about the presence or absence of anomalies for a given time frame is measured by sensors in an experimental embankment and forwarded to the decision-making system to be compared with synthetic data.

2.2 Application of model-driven method to determine the synthetic scenarios of embankment behavior

The second module of the system is used to identify synthetic models of embankment behavior and to reproduce the behavior of embankments at failure risk, by defining a set of models describing changes in the dynamic state of the embankment. There are two types of input data for model driven module: time series from real data from sensors and time series from corresponding for sensors nodes. In the first iteration of comparison of real data with simulated data we got time series of 100 samples. In each iteration time series length increases, until the similarity measure exceeds the threshold. Output data contain information to which scenario time series from sensor are the most similar with information, about the scenario result. Also some graphical representation of results. This stage of dynamic modeling involves preparation of many simulation scenarios. A scenario is referred to as one type of flood wave transition (freshet-stabilization of the water level (plateau)-falling water level). Each simulation relates to sensor values for three cross-sections of the embankment. Embankment stability is analyzed with the use of parameters (computed density, pore pressure, water saturation, plastic deformation rate, temperature, horizontal stress, vertical stress, shear stress, displacement and vertical and horizontal flow) calculated during the simulation. The aim of the authors was also to read simulated parameters at the moment of embankment rupture. In this way the rules defining the moment of disaster were generated. The detailed description of the method is available at preview research and publications [9, 6, 2, 7]. These rules were then used in the decision-

Figure 2: A model of proposed solution for a system construction for the analysis of flood data
making system. Simulations are created using 2D FLAC Itasca software v7.0.

2.3 A description of a decision making module for the analysis of flood risk

The authors assume that the decision-making system is the final module in the proposed system for the analysis of flood embankment conditions (Fig. 2). It is based on the following assumptions: the rule based system will contain information obtained from human experts and the knowledge based systems will contain information obtained from self-study and automatic exploration of input knowledge. Input data comes initially from the real data anomaly detection module as well as numerical models of the behavior of flood embankments. It will be fed with a set of scenarios from a model-driven method. The dynamic numerical models of the flood embankment (with simultaneous determination of failure risk), and also the use of data analysis in the time window (anomaly detection module) will be compared in order to find the similarity between the behavior of the embankment’s state. In this way, the method can determine a set of models that match the measurements \(RISKN\). Secondly, this interpretative system is supported by historical data, i.e. information about previously conducted experiments (according to the assumptions of the ISMOP project). This data are the basis of analogies between the current condition of an embankment (and previous scenarios, thereby driving the systems conclusions of its behavior during defining various experimental configurations of boundary conditions during the experiment, \(RISKN\) and knowledge from historical data (temporary called \(HD\)) – it evaluates a new state \(RISKN + HD\). The next data source is the weather forecasts of e.g. The National Institute of Meteorology and Water Management (IMGW). The role of the IMGW is to provide weather forecasts so the system can define any possible dangers, which may affect the stability of a flood embankment, resulting from e.g. increased precipitation, which may affect the humidity of a flood embankment. It will be supplied by the forward inference with the manual rules \((ER depends on precise statements about general rules of flood embankment maintenance (e.g. a sudden increase of pore pressure may cause instability) from, for example, geotechnical experts e.g.:

\[
\text{IF embnk\_dislocation} = \text{high AND weather\_forecast} = \text{heavy\_rainfall} \text{ THEN flood\_emergency};
\]

The results \((RISKN + HD + ER)\) will provide last information on the possible embankment’s state. The final number of states will depend on the number of expert rules, which are not yet fully defined, due to the preliminary phase of the project. The idea of a self-training system assumes that further rules are obtained during the systems lifetime (knowledge is obtained all the time and used immediately). This involves automatic evaluation of recognized anomalies in accordance with available models of flood embankment behavior. Based on the above, the system, in Author’s opinion, will be able to calculate possible behavior scenarios of the embankment.

3 Conclusions

The system presented and described above is still under development and testing. Because of the very interesting results of Projects Ijkdijk and UrbanFlood, the idea of the proposed ISMOP system is also based on application of combination data driven methods and model driven methods [1, 3, 5, 8]. Some components of the proposed system currently work using knowledge taken from experiments performed on various hydro engineering objects [3, 1], or using the results of numerical modelling. The numerical models used for the simulation of dynamical
processes, the adequacy of the assumed geomechanical parameters, as well as the correctness of
the mathematical model of dynamical processes inside the simulated embankments are currently
being tested. The essential novelty of the proposed method of embankment analysis is the
application of the results of numerical simulations, which are calculated in advance and stored
in a special database. The result of each numerical simulation is a real time rendering of the
real processes of water infiltration, temperature change and stability loss of the earthen dam.
Appropriate simulations can be identified in a database much quicker than individual numerical
modelling can be evaluated, therefore making real time identification possible. The database
containing the results of simulations of possible models allows allowing creating rules, on which
the decision support system relies on. It is also important that the applied rules are verified using
data and results from past and future experiments performed on experimental embankments.

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