Proceedings of the 19th IAHR-APD Congress 2014, Hanoi, Vietnam

ISBN 978-604-82-1383-1

USING THE THERMAL MONITORING METHOD TO DETECT SEEPAGE AND LEAKAGE OF EARTH DYKES AND DAMS IN ORDER TO IMPROVE THE SAFETY OF FLOOD CONTROL FACILITIES IN VIETNAM

LUONG MINH CHINH [(1)], KRZYSZTOF RADZICKI [(2)]

[(1)] *Department of Transport and Communication, Faculty of Civil Engineering, Thuy Loi University, Hoa Phong E&C JSC., Hanoi, Vietnam, e-mail: chinhlm@wru.edu.vn*

[(2)] *Institute of Engineering and Water Management, Faculty of Environmental Engineering, Cracow University of Technology, Cracow, Poland, e-mail: radzicki@hotmail.fr*

ABSTRACT

Vietnam is a country with about 10 thousand small and large reservoirs, in which nearly 500 reservoirs have a large dam (ICOLD). Most dams built in Vietnam in the early stages were earth and rock dams, while concrete dams were built and developed only in 15 recent years in new hydropower projects. Currently about 1200 earth dams are degraded, and their upgrading and improvement are required (MARD). The phenomenon of erosion and seepage inside the dam itself is one of the main factors affecting the structure and safety of the earth dykes and dams.

At present, the thermal monitoring method is one of the key methods for monitoring these processes.

The applications of distributed temperature sensors and the recent development of methods and modeling for analyzing and calculating the coupled heat and water transfer phenomena make it possible to detect and analyze the change and development of seepage and erosion inside the dykes and dams. The thermal monitoring method has improved the quality of observations for detecting and monitoring the seepage and leaks in the earth dams and dykes. The efficient and accurate application of this method can help Vietnam to minimize the probability of a disaster occurring in irrigation and hydropower facilities. At the same time, it can minimize the loss of life and property due to floods and natural disasters causing dyke breaks and landslides. It can also minimize the cost of operation, repair and maintenance of the structures.

Keywords: Thermal monitoring, dam and dyke safety, flood control, internal erosion, seepage, leakage.

1. OVERVIEW

Vietnam is a country with a dense river system. Residential areas, cities and agricultural areas are developed along the riverside and generally affected by the factors of flood and inundation risk. The dyke system along river branches consists of flood control measures which were used by our ancestors long ago to protect the riverside population and river deltas from the risk of flooding. After its development over many years the current dyke system in the country is a system of large-scale projects with approximately 13,200 km of dykes, including about 10,600 km of river dykes and 2,600 km of sea dykes. The main river dyke system with over 2,500 km varies from Class III to the special Class, while the remaining part is under Class III and uncategorised. It includes:

The dyke system in North and North Central Vietnam: 5,620 km long, to protect thoroughly from floods, ensuring safety for the North Delta and North Central Vietnam.

The dyke system of river estuaries in Middle Central and South Central Vietnam: 904 km long.

The river dyke system, including embankments in the Mekong Delta: 4,075 km long.

Most of the existing dyke and flood protection systems in our country have been designed and built based on the experience accumulated from many generations and the safety standards applied in these systems reflected the actual situation of a few decades ago. Given the weather patterns and the natural disasters which increase due to the effects of global warming and climate change, and the meteorological and hydrological condtions in basins which greatly differ from those at the design time, it is necessary to evaluate the safety of the existing dyke system in Vietnam.

The purpose of this article is to introduce and provide a thermal monitoring method, which is new in Vietnam, for monitoring seepage and leaks inside dykes, dams, irrigation and hydropower facilities. It also emphasises the potential of this method compared with other classical methods for monitoring dykes and dams, as well as its ability to significantly enhance the safety of dykes, dams and irrigation facilities in Vietnam to minimise the loss of life and property caused by floods.

The climatic and geographical conditions of Vietnam are the reason for a very high frequency of flood and disasters every year. Moreover, the global climate change in recent years also increased this frequency. According to the Central Committee for Flood and Storm Control (CCFSC),: "In the past 5 years (2008-2012), the loss of property caused by natural disasters is estimated at nearly 74,000 billion VND (3.5 billion US dollars), i.e. higher by 19,300 billion VND (equivalent to 1 billion USD) than 5 years ago. The rate of the loss of property to GDP in the 2008-2012 period was 1.48% of GDP / year, in which the proportion of the lowest year (2011) was 0.94% of GDP, while that of the highest year (2009) wa 2.47% of GDP.". Particularly in 2013, Vietnam was affected by 15 hurricanes with very intensive and complicated impacts, especially rain and floods after storms which caused heavy losses of life and property in many provinces and cities. According to the statistics of the CCFSC, the total estimated loss caused by natural disasters in 2013 was 30 trillion VND, twice as high as in 2012, in which Quang Binh lost about 12.4 trillion VND, accounting for 41.6% of the country total loss.

In the past few years, the floods were caused by the degradation of dykes and dams, leading to their break and collapse to cause a serious loss of life and property in Vietnam, worth billions of dollars every year. This significant damage affected the pace of development speed in the regions which suffered from the floods. Floods disrupted agricultural production, changing the farming practices. In the Mekong Delta, along with an expansion of the cultivated area of agricultural land, it led to the dense construction of dykes with very large total investment.

In order to ensure the safety of the dyke system and ensure comfortable working conditions for people, it is necessary to take practical and effective measures and technology solutions to minimize the loss of life and property, but most of all, the early detection of phenomena which potentially may cause floods, along with effective investment, is one of the very important issues of water resources management.

The phenomena occurring inside dams, such as seepage, leakage or erosion, are the main factors affecting the safety of these structures. The erosion inside a dam is particularly serious, especially the piping process, which can create continuous holes through the dam and shortly lead to the collapse of the structure. An effective monitoring of the erosion process, primarily including the early detection and assement of its development rate, is of key significance for ensuring the safety of dams and dykes (Fry, 2012; ICOLD, 2013).

In recent years in our country, there were many serious cases of broken, collapsing dykes, especially the flood prevention dykes. They included:

On October 19, 2010, the Ru Tri dyke of the Ngan Sau River, ensuring flood protection for nearly 20 thousand people in four communes of Duc Tho district, was broken. The flood waters swept away nearly 1 km of a rail track, causing severe flooding. The broken section was more than 30 m long. Running down, the upstream flood waters from the Ngan Sau River made the broken dyke area very dangerous (Fig. 1).

Figure 1. RU TRI flood prevention dykes broken in Ha Tinh province.

On October 13, 2011, the dyke on the north bank of the canal route in the Vinh Chau Commune was broken over 40 m. Water flooded as a waterfall into the fields in two commune

s of Vinh Chau and Vinh Te (Chau Doc Town) causing serious damage to people and property. Particularly in An Giang, 12 people were swept away, including 9 children, 22 houses were completely destroyed, more than 17,750 households were flooded, 4,248 ha of rice were submerged, about 700 fish ponds were overflowed and hundreds of kilometers of roads were submerged. Over 1,300 students could not go to school. And in Dong Thap 17 people were swept away (14 children). The total losses amounted to 854 billion VND (42 million USD).

Figure 2. The Army helps the people reinforce the dyke broken in An Giang Province.

When, on September 12, 2012, the Cau Chay dyke in Thanh Hoa broke due to erosion inside it, thousands of people lost contact with the outside world and many places were flooded to the ceiling. Just within a few hours more than 1,500 households with thousands of hectares of rice and crops were inundated. According to the local statistics, 8 people were killed, 100 houses collapsed, more than 2,400 households were inundated by water, nearly 20,000 hectares of rice crops were flooded and more than 900 fish ponds were overflowed.

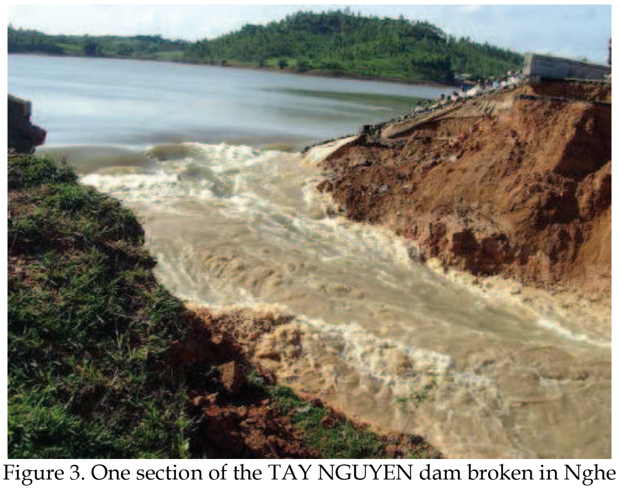


Figure 3. One section of the TAY NGUYEN dam broken in Nghe An and its impact on the surrounding areas.

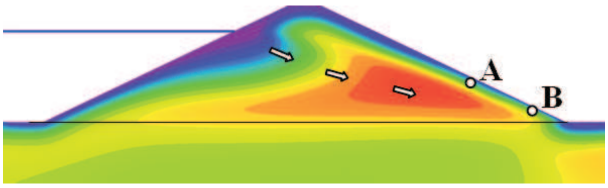
On September 11, 2012, the breach of the Tay Nguyen storage dam in Quynh Thang (Quynh Luu District, Nghe An), with capacity of 1.2 million m3 had a serious impact on the adjacent residential area. The broken section was about 20 meters long. The breach of the dyke was attributed to the presence of a termite nest inside the dam which led to a hollow dam (Fig. 3).

In the next part of the article we will introduce the thermal monitoring method. This method is very effective in detecting and monitoring the development of seepage, leakage and erosion processes inside earth dams and dykes.

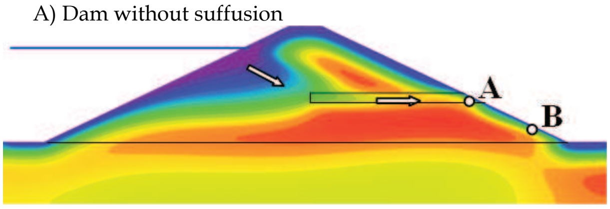
The thermal monitoring method quantatively changed the monitoring of the seepage and erosion processes in hydraulic structures and the ground underneath them. A correct application of this method minimises the probabillity of a breach and collapse of a hydraulic structure and makes it possible to prevent them. At the same time, by allowing for a reliable assessment of the state of hydraulic structures, it enables institutions and entities managing hydraulic structures to rationalise and optimise their repairs.

2. FUNDAMENTAL KNOWLEDGE OF THERMAL MONITORING

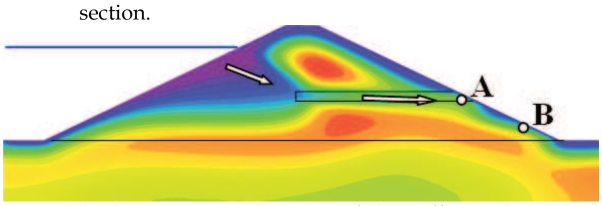
Thermal methods for analysis of water flow in the ground are based on the relations between heat and fluid transport processes which are coupled processes. A change in the moisture content of the ground, in particular, the emergence of water seepage and changes in its velocity, significantly disturb the heat distribution in the body of the structure and the underlying ground. In consequence, the measurement of body temperatures and their analysis enable the identification of leakage and the monitoring of seepage processes. Since the erosion proces affects the seepage vector field, it also directly influences the temperature field of the ground medium. Each of the erosion process types causes a characteristic disturbance of the hydro-thermal field (Radzicki and Bonelli, 2010 and 2012). In consequence, the thermal monitoring method allows for the detection and analysis of both seepage and erosion processes.



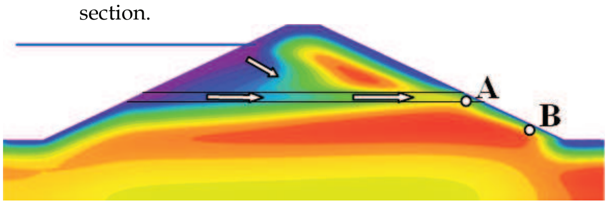
A) Dam without suffusion



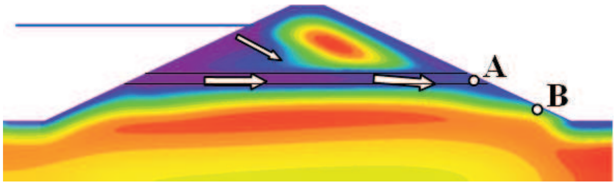
B) The hydraulic conductivity of the suffusion layer K=1e-4 ms-1. The suffusion layer developed to half the cross-section.



C) The hydraulic conductivity of the suffusion layer K=1e-3 ms-1. The suffusion layer developed to half the cross-section.



D) The hydraulic conductivity of the suffusion layer K=1e-4 ms-1. The suffusion layer extends all over the cross-section length.



E) The hydraulic conductivity of the suffusion layer K=1e-3 ms-1. The suffusion layer extends all over the cross-section length.

Figure 4. Temperature fields of a dam cross-section registered at the same time instant for different lengths of the suffusion layer and for different values of suffusion layer hydraulic conductivity (Radzicki and Bonelli, 2012).

The methods for thermal detection of leaks have been applied in hydro-engineering for more than 20 years (Johansson, 1991). Due to the very substantial development of these methods over the last few years, in terms of both the measurement systems and the models and methods for the analysis of the measurement results, at present these methods are regarded as the most effective ones for the detection of leaks and internal erosion; particularly in its early development stage. These methods allow for the analysis of the dynamics of the seepage and erosion processes. In many cases, the analysis of temperature measurements can also determine the values of the seepage velocity. (Radzicki 2009; Radzicki, 2014; Fry, 2012) (Figure 5).

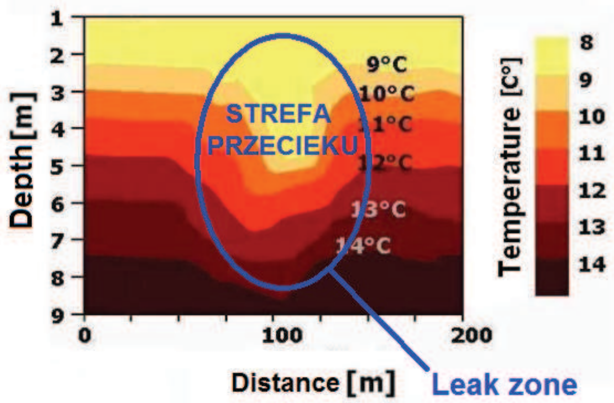


Figure 5. Example of abnormal temperature field in the cross section of earth dam due to leakage.

Professor Fry, President of the European Working Group (EWG) on Internal Erosion of the International Commission on Large Dams (ICOLD), in the publication of ICOLD's congress in Japan (Fry, 2012), stated that: "*Temperature measurement in dam body is the best detection of leaks at small and medium depths*" and "*For the largest consequences of failure, it is prudent to use a preventive maintenance based on fiber optic system of detection*".

One of the basic reasons for the success of the thermal monitoring method was the use of linear temperature measurements, continuously over the length of the structure. It Introduced a qualitative change in the process of monitoring seepage and erosion in relation to local monitoring, conducted only in selected points or cross-sections of the damming structure.

One of the technologies applied in thermal monitoring is the fiber optic temperature measurement technology. A laser signal is transmitted through the fiber optic. As the light crosses the fiber optic core, photons are dispersed on its molecules. Some of the photons return to the point where the impulse was transmitted, as the so-called photon backscattering (Figure 6).

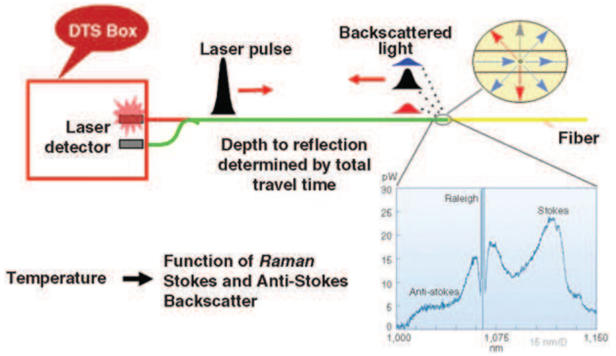


Figure 6. Fiber Optics-Based Distributed - Temperature Sensing System.

The spectral analysis of backscattering and its comparison with the spectrum of the light fed into the fiber optic enable, inter alia, the determination of the temperature of the fiber optic at the point where the backscattering emerged (Vogel, 2001). The existing instrumentation allows for the determination of the exact temperature with 1-meter space resolution, while enabling temperature measurements by fiber optic sensors over several dozen kilometres. The fiber optic sensors applied for a hydraulic structure have high mechanical and shock resistance, and a waterproofing shield. These advantages ensure easy installation in the structure with high durability and stability over decades.

Another technology, which provides an alternative to fiber optic sensor technology, is the Multi Sensor Cables technology. It uses a cable which integrates within it multiple individual sensors cords and the signal transmission wire. The sensors in this cable must be distributed throughout the length of the cable over a certain distance. The distance between sensors must be so selected as to ensure "quasi" continuous measurements which match fiber optic sensors as regards their spatial resolution. The biggest advantage of this technology is that it can be applied to short section of dams and dikes, as well as that the cost of this technology is several times lower than that of the fiber optic sensor technology. MCableS© multi- sensor cable from NeoStrain is a typical example of this technology. Multi-sensor cable technology also can be installed to monitor the temperature of the water inside the piezometric tubes. With their compact size, the multi sensor cables do not impede the regular monitoring of piezometric tubes to verify the accuracy of the automatic measurements.

After discovering the location of seepage and leakage in the body of dykes and dams with linear temperature measurements along the structure, we can also install in this location a piezometric tube to monitor the heat spectrum in the vertical direction.The combination of automated measurements throughout the length of the dam, along with measurements at piezometer tubes in the chosen sections of the dam, makes it possible to carefully analyse seepage and leakage all along the dam.

Another basic factor ensuring the effectiveness of the thermal monitoring method was the development over the recent years of a number of methods and statistical as well as statistical and physical advanced models enabling the readout of information of seepage and erosion proceses "encoded" in temperature measurements. Radzicki (2011 and 2014) introduced the thermal monitoring method in detail, together with the characteristics of each model. More detailed information on this issue can be found in Radzicki and Bonelli (2010), Radzicki (2011) and Beck et al. (2010).

3. PROPOSED SOLUTIONS FOR THE MANAGAMENT AND MONITORING OF DYKES AND DAMS

There are many factors that affect the scope and choice of methods for the management and monitoring of dykes and dams. We will name a few of them: particularly the type, design solutions and scale of the structure, the foundation conditions, the economic significance, the threat posed in case of a collapse and the present status of the structure. The obligations ensuing from the law of a given country are particularly important, as it is exactly they that set out the required minimum scope of the application of these methods. The current legislation is especially important, because it sets out the minimum requirement to be achieved. The detailed analysis of this sector is beyond the scope of this article. Below we will present proposals for supervision and monitoring measures for two basic types of hydraulic structures, i.e. dams and dykes, in relation to the application of thermal monitoring methods. . It must be emphasised that in order to effectively implement this technology in Vietnam we need to have more extensive research and implement pilot projects to accumulate experiences and apply it appropriately and effectively in the Vietnamese conditions.

3.1 Flood control dykes

Most of the flood control dyke system in Vietnam was built a long time ago, but has not been properly maintained. In addition, the structure and construction process of these facilities do not satisfy the current technical standards. Therefore, the possibility of increasing erosion and leaks inside the dyke itself is very high. Another risk is the one posed by the nest cave of a rat, snake or termite or even a decayed root inside the dyke itself. When there is flood, the risk of erosion and leaks in the dyke body is also very high. In addition, as the above phenomenon will accumulate from year to year without being detected, the probability of erosion and leaks within a short time is very high, resulting in a broken dyke at a certain point.

At present, the system of dykes in Vietnam is managed by carrying out field inspections after each flood, simultaneously with the classical method involving drilling or geotechnical methods in doubtful locations. However, for these locations which may have leaks, inspections at some points only are not effective. It should be emphasized that the geotechnical method must be applied at these points, but before that we have to determine exactly the weakened point by other methods, especially in areas that may have erosion and leakage during the flood.

In turn, certain geophysical methods enable the implementation of non-intrusive, direct investigations of the body of a dyke and/or the underlying ground, depending on the method, by one research team in the course of one working day, even along several kilometers of the dyke. With dyke lengths reaching tens and hundreds of kilometers, this is a very important feature. However, at present the interpretation of the results of geophysical investigations on flood protection dykes is ambiguous and often imprecise.

Based on the above facts, we find that the application of the linear thermal monitoring method enables the early detection of seepage and leakage along the length of the dyke, combined with automatic alarm system to ensure an early warning of the development of destructive phenomena inside the dyke in order to improve the quality and safety of the facilities. It is especially important to be able to ensure an early warning of destructive phenomena inside the dyke at the time of the flood. This ability allows for a quick response and the launch of effective methods to ensure the safety of dykes in the course of floods and storms and to minimize the effects of natural disasters. Additionally, it can help the management unit in planning human resources, financial and equipment in an optimal way (Figure 7).

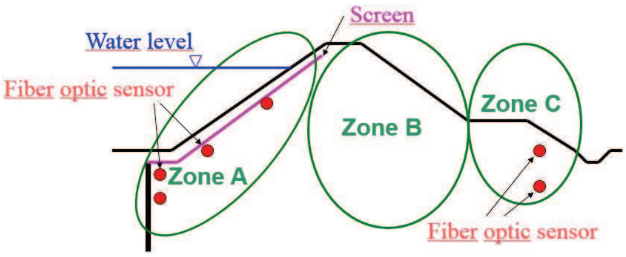


Figure 7. Example of location of fiber optic sensors for flood control dike.

The application of the thermal monitoring method requires an appropriate financial plan as well as a professional management and organization system for the number of dykes in Vietnam is huge. First of all, we need to pay attention to dykes protecting important areas, especially densely populated areas, and dykes which have deteriorated due to the leakage or erosion and need to be upgraded.

Due to the thermal monitoring method with accurate and continuous monitoring capabilities throughout the dyke length, the inspection and assessment of dyke status after the flood waters have receded are much more effective and easier. If the thermal monitoring system is installed for a large number of dykes, then the management units will have a comprehensive and extensive overview of the state of the dykes under their management. This can help the management units plan the maintenance, repair and upgrade of the dykes to a reasonable and economic extent and to plan the effective allocation of human and financial resources.

3.2 Dams

With the complicated geographical conditions in Vietnam, which is an ideal location for the damming facilities, there are over 7,000 dams which are important in the energy and agriculture sectors in Vietnam. For earth dams, particularly for those that have a permanently high water level, the application of the monitoring methods and especially the thermal monitoring method has a wider scope than for the flood prevention dykes. A variety of methods were, for example, introduced in detail along with their advantages and disadvantages in the article by Fry (2012). It is particularly valuable, since it presents in a synthetic manner an initial, as it were, concise summary of the long-term work of the EWG on Internal Erosion of ICOLD, the members of which are persons representing universities and companies which carry out important research and development work on the methods for monitoring seepage and erosion processes.

In most of the dams in Vietnam with 50m height, a monitoring system using the classical measurement technology has been installed to measure punctually piezometers water levels, water pressures, deformations and other quantities. A few of these are automatic monitoring systems. Depending on the demand, detailed geotechnical and geophysical measurements are made. The information which they produce is more often than not valuable, but they have limitations which were already presented above in the section on dykes. At the same time, at a significant number of dams there are no measurement systems at all or no observations are carried out on them (2013, Pham Tien Van).

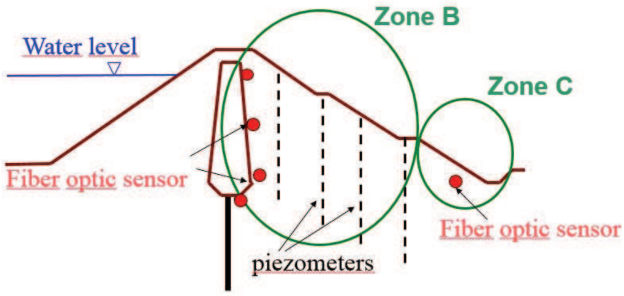


Figure 8. Example of location of fiber optic sensors for dam with a core

The irrigation and hydropower dams are very important structures. Once an incident occurs, it can lead to significant damage. In the field of safety of dams, the thermal monitoring method is particularly important to minimize the damage which has occurred. Given the large size of the dykes and dams, the collection of precise information about the extent and status of the development of the destructive phenomenon is very important, affecting the optimization of the financial plan for repairing, upgrading and maintenance of dykes and dams.

It can be added that in the case of scarce resources for the installation of a linear thermal monitoring system across a dam, one of the basic methods for substantially expanding the range of information from point measurements is the temperature measurement using the aforementioned "multi sensor cable" technology in existing or added piezometers. Such measurements enable, for example, the determination of the height at which the leakage zone lies in the dam.

4. CONCLUSION

Vietnam is a country with a dense river system. Residential areas, cities and agricultural areas are developed along the riverside and generally affected by the factors of flood and inundation risk. There are large dyke systems along river branches, consisting of flood control measures which were used by our ancestors long ago to protect the riverside population and river deltas from the risk of flooding. Simultaneously, in Vietnam there are some thousand dams which are very important for irrigation and hydropower.

The phenomena occurring inside dams and dykes, such as seepage, leakage or erosion are the main factors affecting the safety of these structures.

The thermal monitoring method to detect and analysis the leakage has been applied for dam monitoring for more than 20 years. In recent years this method rapidly developed in the world, in both the field of monitoring instrumentation and computational models, and so did the methods for analyzing the results of monitoring. One of the basic activities which led to the success of the thermal monitoring method was the use of linear temperature measurements, continuously over the length of the site, including fiber optic cables or integrated multi sensor cables. It introduced a qualitative change in the process of monitoring seepage and erosion in relation to local monitoring, conducted only on selected sites and cross-sections. The next step towards the success of the thermal monitoring method was the development over the recent years of a number of methods and statistical as well as statistical and physical advanced models enabling the readout of information on seepage and erosion processes unfolding in the bodies of dams and dykes and in the underlying ground, and "encoded" in temperature measurements.

When the thermal monitoring system is installed for a large number of dykes, the management units will have a comprehensive and extensive overview of the state of the dykes under their management. This can help the management units plan the maintenance, repair and upgrade of the dykes in a reasonable and economical manner and to plan the effective allocation of human and financial resources.

To effectively implement this technology in Vietnam we need to have more extensive research and implement pilot projects to accumulate experiences and apply it appropriately and effectively in the Vietnamese conditions.

ACKNOWLEDGMENTS

We sincerely thank NeoStrain Company Ltd, for supporting and providing equipments, machines to help us implement our research to complete this article.

REFERENCES

Fry J.J. (2012). How to Prevent Embankments from Internal Erosion Failure? *International symposium on dams for a changing world, 5 czerwca, Kyoto, Japonia, p. 64. 2013. ICOLD, Internal erosion of existing dams, levees and dikes, and their foundations, Bulletin no. 164, Volume 1: Internal erosion processes and engineering assessment*, 151.

Beck Y.L., Cunat P., Guidoux C., Artieres O., Mars J., Fry J.J. (2010). Thermal monitoring of embankment dams by fiber optics. *Proc. 8th ICOLD European Club Dam Symposium*. Innsbruck, Austria, September 22-23, pp.461- 465, 2010

Johansson S. (1991). Localization and quantification of water leakage in ageing embankment dams by regular temperature measurements, *17eme Congrès des Grands Barrages*, Vienna, Q.65-R.54, pp.991-1005

Pham Van Tien, (2013). "Situation of dams safety and dams safety management in Vietnam". *National Scientific Conference - Construction of irrigation, hydropower in Vietnam - Problems facing*.

Radzicki K. (2009). Analyse retard des mesures de températures dans les digues avec application à la détection de fuites. *PhD report, AgroParisTech (Paris),* France, p. 176

Radzicki K. (2011). Zastosowanie termomonitoringu do detekcji przecieków oraz erozji wewnętrznej w ziemnych budowlach piętrzących. *XIV Międzynarodowa konferencja technicznej kontroli zapór. Bezpieczeństwo zapór - nowe wyzwania*, 13 - 16 Juin 2011, Zamek Książ – Wałbrzych, Poland, 230-239.

Radzicki K. (2014). Phương pháp quan trắc nhiệt (thermalmonitoring) – một phương pháp hữu hiệu trong quan trắc hiện tượng rò rỉ và xói mòn trong lòng đê và đập đất. *Conference Modern monitoring solutions of dams and dikes*. 18 February 2014, Hanoi, Vietnam. 25-32.

Radzicki K. Bonelli S. (2010). Thermical seepage monitoring in the earth dams with Impulse Response Function Analysis model. *8h ICOLD European Club Symposium*, 22-25 September, pp. 649-654, Innsbruck, Austria.

Radzicki K., Bonelli S. (2011). Monitoring of the suffusion process development using thermal analysis performed with IRFTA model. *6th ICSE*, 27 - 31 August, Paris, France, 593-600.

Vogel L. B., Cassens C., Graupner A., Trostel A. (2001). Leakage detection systems by using distributed fiber optical temperature measurements. *Proc. SPIE Smart Structures and Materials 2001*, vol. 4328, pp. 23–34.

Copyrights