Estimating Seepage in Embankment Dams based on Temperature Measurement: A Review Paper

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***Abstract*—Temperature measurements have been employed to estimate seepage through embankment dams for a long time, the effectiveness of the method was proved by many researches as well as practical applications, especially for the results published in the last ten years. Although a number of related papers were published and each of them carried a short review, it is difficult to find out a synthetic and systematic literature for the problem. This present work studies synthetic and systematic the problem in order to provide useful information for readers who want to practice or continuously develop the problem. Three main works of the problem including basic theory, temperature measurement technologies, and seepage estimation approaches are carefully summarized. Besides, criticisms of objectives are also presented.**

Keywords*— Seepage Evaluation; Temperature Observation; Numerical Modeling; Leakage Detection;

I. INTRODUCTION

Dam constructions are known as the most effective way to control and exploit the water resource, by this way, it contributed a lot for human developing. However reality witnessed that during operation process there are many dams were damaged or broken, this usually causes huge loss of lives and destructions of properties and environment, some examples relating consequence of dam failures could be found in [1]. Various statistics of dam failures uniformly indicated that failure of embankment dams occupied majority in total, furthermore, among the reasons causing embankment dam failure seepage/erosion accounted for significant proportion. Examples of dam failure statistics are [2-4]. Most dam failures relating to seepage problems either caused by lacking of monitoring system or had monitoring system but it was out of order [5]. All the aforementioned problems obviously indicated that seepage observation for embankment dam is a crucial task which promotes efficiency and safety of project during operations process.

Among various methods, seepage evaluating from temperature data has been expressing as a feasible method which could give real time information of seepage condition. Right from the1934 Van Orstrand indicated that heat transportation by water movement could cause variation of temperature gradients within the earth [6]. Next, in 1953 temperature of seepage flow, playing the role of nature tracer, was applied to localize leakage in embankment dam, this method had been demonstrated to be a good approach to detect and monitor in situ [7]. Nowadays, with advancement of monitoring technology and improvement of evaluating method, many approaches were proposed to analyze seepage condition within the dam.

The method development are commonly considers in two aspects, one is analytic method and the other is temperature monitoring technologies. For the former, seepage evaluation from temperature data can be divided into two categories based on the length of time monitoring. Short-term observations are usually applied to detect leakage regions, while long-term surveillances can be used to estimate seepage velocity. The later one, temperature monitoring technologies are classified by the types of equipment or measuring methods.

Although a number of related papers were published and each of them carried a short review, it is difficult to find out a synthetic and systematic literature for the problem. This paper aims to present a synthetic and systematic review of thermal and heat transfer in soil media. In which three main goals comprising basic theory, temperature measurement techniques, and analytic methods are documented. Moreover, the advantages and disadvantages of each method are also discussed and appraised, thus it can be a useful information for future works.

II. BACKGROUND

A. Governing equation

It is apparent that when seepage goes through an embankment dam it exchanges temperature carried by itself with adjacent soil medium. Conversely, varying of temperature affects dynamic viscosity and density of water, thus it changes seepage velocity. The mutual dependency is mathematically expressed by conservative principals.

Fully coupled thermo-hydraulic-mechanical models for unsaturated deformable soil were introduced by a number of scholars, in which every aspect of the problem denoted through conservative principals were considered by theories, for examples [8-11]. However, it is difficult to employ these models in practical problems of such field, because many factors needed to be specified in circumstance of lack of experimental data. Even these factors can be determined, it will take a very high cost and long time. Moreover, the reality also proved that in range of temperature and seepage variation inside an embankment dam some hypotheses as presented below will not trigger a significant difference in final result.

1. Fluid is incompressible substance; 2. Water movement in soil is laminar flow; 3. There is no temperature difference between soil and water at local points; 4. Effects of air and water vapor in thermal processes are neglected; 5. Soil deformation is ignored;

Many mathematical models were introduced based on above hypotheses, some representative work are [5, 12-16]. Flowing DHI-Wasy (2009) heat and water transport in variable saturated soil can be denoted as Eq.1, Eq.2.

$$\begin{aligned}&[s^f\varepsilon\rho^f c^f+(1-\varepsilon)\rho^s c^s]\frac{\partial T}{\partial t}+\rho^f c^f q\nabla T\\&-\nabla[(s^f\varepsilon\lambda^f I+(1-\varepsilon)\lambda^s I+\varepsilon\rho^f c^f D_m)\nabla T]\\&+\varepsilon\rho^f c^f\overline{Q}_\rho(T-T_o)-\varepsilon\rho^f\overline{Q}_T^f+(1-\varepsilon)\rho^s\overline{Q}_T^s\\&=0\end{aligned}\tag{1}$$

$$q=-K_r(s^f)Kf_\mu\left(\nabla h+\frac{\rho^f-\rho_o^f}{\rho_o^f}e\right)\tag{2}$$

And constitutive relationships

$$h=\frac{\rho^f}{\rho_o g}+z=\Psi+z\tag{3}$$

$$K=\frac{k\rho_o^f g}{\mu_o^f}\tag{4}$$

$$f_\mu=\frac{\mu_o^f}{\mu^f(T)}\tag{5}$$

Where: s^f- Saturation (dimensionless); ε- Porosity (dimensionless); ρ^f, ρ^s- density of fluid and soil, [ML^{-3}]; c^f, c^s- specific heat capacity of fluid and soil, [$L^2T^{-2}K^{-1}$]; T- Temperature, [K]; t- Time, [T]; q- Darcy flux vector, [LT^{-1}]; $\lambda^f \lambda^s$- Thermal conductivity of fluid and soil, respectively, [$MLT^{-3}K^{-1}$]; I- Unit vector; D_m- Tensor of mechanical dispersion, [L^2T^{-2}]; $\overline{Q}_\rho$ - Average fluid mass sink/source, [T^{-1}]; $\overline{Q}_T^f, \overline{Q}_T^s$- Average heat sink/source of fluid and soil, [$ML^{-1}T^{-3}$]; h- Hydraulic head, [L]; K Tensor of hydraulic conductivity, [LT^{-1}]; k- Intrinsic permeability, [m^2]; μ_o^f, μ^f -Reference dynamic viscosity and dynamic viscosity of fluid, [$ML^{-1}T^{-1}$]; ρ_o^f - Reference fluid density [ML^{-3}]; e- Gravitational unit vector; g- Gravitational acceleration [LT^{-2}]. K_r- Relative hydraulic conductivity, (dimensionless). $0 < K_r \leq 1, K_r = 1\ when\ s^f = 1$, and operator ∇ stand for $\left(\frac{\partial}{\partial x}+\frac{\partial}{\partial y}+\frac{\partial}{\partial z}\right)$.

K_r, and s^f are usually specified by empirical relationship relating to pressure head. Some popular models using to estimate these parameters such as Genuchten-Mualem model, Brooks-Corey model, and Havekamp model [16, 17]. Genuchten-Mualem model stated $K_r\ and\ s^f$ as:

$$s_e^f=\begin{cases}\dfrac{1}{[1+|A\Psi^n|]^m} & \text{for } \Psi<0\\ 1 & \text{for } \Psi\geq 0\end{cases}\tag{6}$$

$$K_r=\left(s_e^f\right)^{1/2}\left[1-\left(1-\left(s_e^f\right)^{1/m}\right)^m\right]^2\tag{7}$$

And the effective saturation

$$s_e^f=\frac{s^f-s_r^f}{s_s^f-s_r^f}=\frac{\theta^f-\theta_r^f}{\theta_s^f-\theta_r^f}\tag{8}$$

Where: s_s^f, s_r^f: Maximum and residual saturation of fluid, dimensionless; $\theta^f, \theta_s^f, \theta_r^f$: Volumetric moisture content, saturated volumetric moisture content and residual volumetric moisture content, respectively.

To determine temperature, seepage velocity and hydraulic head from nonlinear Eq.1 and Eq.2 a set of thermal-hydraulic parameters need to be complemented. These parameters can be specified by either experiment methods or analytical methods. Next paragraphs will present how to determine some important thermal and hydraulic parameters of soil using to simulate the problem.

B. Estimation of some soil parameter

To analyze concurrent of heat and mass transportation through an embankment dam a set of thermal-hydraulic parameter need to be supplied. By attempting numerical modelling with different values of these parameter authors found out that in typical condition of embankment dam just some of these parameters had significant effect on computed processes of the problem. They are comprising Hydraulic conductivity, effective porosity, thermal conductivity, and volumetric heat capacity [18]. Therefore, next paragraphs is concentrated to explain these factors.

Hydraulic conductivity

Hydraulic conductivity is one of the most important property used for groundwater modeling, it highly depend on porosity, and texture as well as grain-size of soil. Methods to specify hydraulic conductivity are drawn as in fig.1.

The laboratory methods, cheap and fast means, are used for core soil samples, but the small sample area can lead to high possibility of a large random error. Supposing acceptable simplification of groundwater flow, Small-scale field methods relatively give fast and cheap estimation for hydraulic conductivity. Besides, Large-scale field methods assure the representative K-value, however, they are expensive and time-consuming. On the other hand, correlation methods is easy, fast and cheap ways to evaluate K-value. Nevertheless, the same with laboratory method, it can result in random errors. Correlation methods should be applied in case that other methods of monitoring the hydraulic conductivity is difficult or unavailable for example in deep soil layer [19].

Some empirical models for hydraulic conductivity approximation were stated by Hazen, Kozeny-Carman, Breyer, Slitcher, Terzaghi, USBS can be found in [19-21]. Among these expression, the equation presented in Lopez's paper seem to be the most general equation.

$$K = \beta \frac{g}{\upsilon} \xi(n) d_{10}^2 \quad (9)$$

Where: β- the coefficient depending on the shape of the grain; υ- kinematic viscosity of water; d_{10}- effective grain diameter.

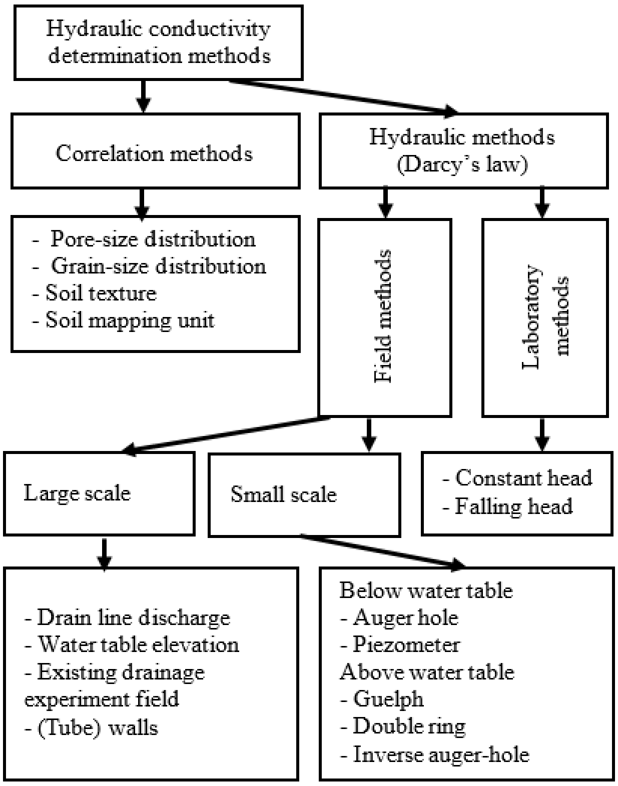

Fig.1. Methods for the Hydraulic Conductivity Determination [22].

Effective porosity

In saturated condition voids of porous media are discriminated by two portions, the first one is unconnected voids or dead-end pores where there is no water movement through, the other is called effective porosity in this portion the pores are interconnected and permit water goes through. The effective porosity is usually affected by practical size, shape, and packing arrangement. This factor need to be considered in case of flow analyses such as tracer migration. Effective porosity either can be preliminarily determined by relationship between median grain size and total porosity, specific yield, specific retention proposed by Davis and Dewiest or specified by experiment containing laboratory and field methods, the detail could be found in [23]. On the other work, a comparison of effective porosity estimated from textual data, moisture retention, and published values with field calibrated value indicated that the difference were approximate 50-90%. Thus, the best estimation for this factor is laboratory or field tracer test [24].

Thermal conductivity

Thermal conductivity of soil conforms to Fourier' law, it is defined as the amount of heat passing in unit time through a unit cross sectional area of the soil under a unit temperature gradient. Generally, Fourier equation in three-dimension is formulated as:

$$q_x = -\lambda \nabla T \quad (10)$$

Where: q_x- Heat flux, [MT^{-3}]; λ- Thermal conductivity tensor [MLT^{-3}K^{-1}];

There are several ways to measure thermal conductivity of soil, and basically, it is distinguished by steady and transient method. In steady method, one dimensional heat flow is applied to a specimen, then input power and temperature difference between cross sections are recorded. Thereafter thermal conductivity is calculated by Fourier's law. Whereas, by transient method, heat is propagated through specimen, at the same time temperature change over the time is logged. The transient temperature data is utilized to determine thermal conductivity [25]. Some methods applied to specify soil thermal conductivity can be itemized as cylindrical configuration, in situ sphere method, guarded-hot-plate test, heat flow meter test, guarded comparative longitudinal heat flow technique, rhometer apparatus, rapid k method (for steady-state), and the proper method, periodic temperature wave, thermal shock method, as well as thermal needed method (for transient-state), more detail see [26-28].

Experiment methods are expensive and time-consuming, it is reasons that many empirical models are offered. These empirical expressions were generated based on reasoning that thermal conductivity depends on soil texture, moisture content, temperature, porosity, and saturation. A vast number of illustrations for the problem is found in [26, 27, 29-31]. Among them, perhaps Series model, Parallel model, and Maxwell model combining with effective medium theory are the most frequent application. The general equation represents for three-aforementioned models can be written as in Eq.11 [32, 33].

$$\lambda_{eff} = \lambda^s \left(\frac{a\lambda^s + \lambda^f - a(\lambda^s - \lambda^f)n}{a\lambda^s + \lambda^f + (\lambda^s - \lambda^f)n} \right) \quad (11)$$

Where: λ_{eff}- Effective thermal conductivity, [MLT^{-3}K^{-1}], a- Empirical structure-related factor, [dimensionless], λ^s, λ^f - Thermal conductivity soil and fluid, [MLT^{-3}K^{-1}], n- Porosity, [dimensionless].

It is easy to recognize that if a equals 0 the Eq.11 superimposes on the series model, and if a gets the value of 2 the Eq.11 becomes Maxwell model, and when a goes to ∞ the Eq.11 denotes Parallel model.

Volumetric heat capacity

Soil volumetric heat capacity stands for stored internal energy ability of a given soil volume while undergoing a given temperature change. Together with thermal conductivity, it plays a very important role when analyzing coupled heat-water transfer in soil medium. This parameter is affected by soil components, soil water content, and soil density [34]. Calorimeter is known as the widespread approach for volumetric heat capacity test. Procedure of the method can be consulted by [34-37]. Besides, Probe methods also are a worthy choice for heat capacity specification. References for probe method were expressed in [38-41].

In a deferent way, volumetric heat capacity also could be estimated from empirical equation, some of them expressed in [26, 37, 40]. Basically, it was expressed through soil components (solid, water, and gas phases):

$$C_V = (1-n)C_V^s + nsC_V^f + n(1-s)C_V^g \qquad (12)$$

With C_V- Bulk volumetric heat capacity, [$ML^{-1}T^{-2}K^{-1}$]; C_V^s, C_V^f, C_V^g- Volumetric heat capacity of solid phase, fluid phase, and gas phase, [$ML^{-1}T^{-2}K^{-1}$]; n- porosity, [dimensionless], s- Saturation [dimensionless].

The values of thermal and hydraulic parameters of soil now are available in many documents, Interested readers can find the needed information in some documents as [42-45] and [30, 37, 46, 47] for soil hydraulic and soil thermal properties, respectively

III. TEMPERATURE MEASUREMENT

In this method, temperature is a crucial parameter for analyzing the process of coupled thermal-seepage transfer in embankment dam. This parameter can be acquired by point measurements or distributed measurements with possibility of passive or active approaches.

Active method is implemented by using temperature measurement and heating (or cooling) systems together, temperature is recorded in parallel with process of heating. Temperature before heating and at peak of heating of measured points are compared to take out leakage zones. This method can reduce time observation and is suitable for measurement in short distance (shorter than 2 km). When distance of measurement longer than 2 km a high electric power device (around 3 to 15 W/m) is needed, and is not always cost effective in term of monitoring [48, 49]. The active method could be applied in standpipes by inserting heat source into standpipe and measuring temperature in such standpipe or/and others located surrounding the standpipe. Because of the limitation in amount of existing standpipes so the installation of new standpipes is often needed, in this case the employment of Dornstädter's method is good selection. Dornstädter (1996) proposed a method that ramming array of small diameter metallic tubes into soil, temperature was recorded along the tubes when temperature of tubes were equal with surrounding temperature. This method was cost-effective for embankment dam with height around from 20 to 30 m [5, 49]. According to author's experience the application of heat source in a standpipe could give an answer for seepage condition of a 6 m dam segment (in direction of dam axis). This approach could be flexibly implemented in a dam according to both of time and space. On the other way, also an electrical wire (heat source) can be embedded with fiber optic sensor, this providers a long distance ability of seepage exploration. However, in perpendicular plane the influence of heat source is usually negligible, thus the seepage condition only could be assessed at the position of fiber optic sensor and electrical wire. To get full of seepage condition of a dam a grid of temperature sensor combined with electrical wire is required. The disposition of fiber optic sensors and line heat source is easy for a new dam or a dam with considerable upgrading, they can be set up without a significant obstruct for construction process. Whereas, an existing dam without a considerable rehabilitation is typically considered to use this method in nearby downstream dam toe.

In contrast, Passive method observes changing of internal temperature affected by nature external thermal loads (air temperature, water temperature, geothermal). When heat transfer through the dam, thermal signal is modified, and the intensity of thermal changes specially denote the information of seepage and erosion [48, 50]. The temperature measurement can also be realize in standpipes or along fiber optic sensor but the seepage can only be evaluated at position of observation sensors. Moreover, because of the slow seepage velocity hence a long time observation is required to observe temperature variation.

Positioning temperature sensors in a dam varies according to dam structures, in particular case, it needs to be analyzed to point out proper positions. However, Temperature sensors are primarily disposed nearly or directly in zones designed to capture and direct a leakage. Popular zones for sensor situation as sketched in figure 2.

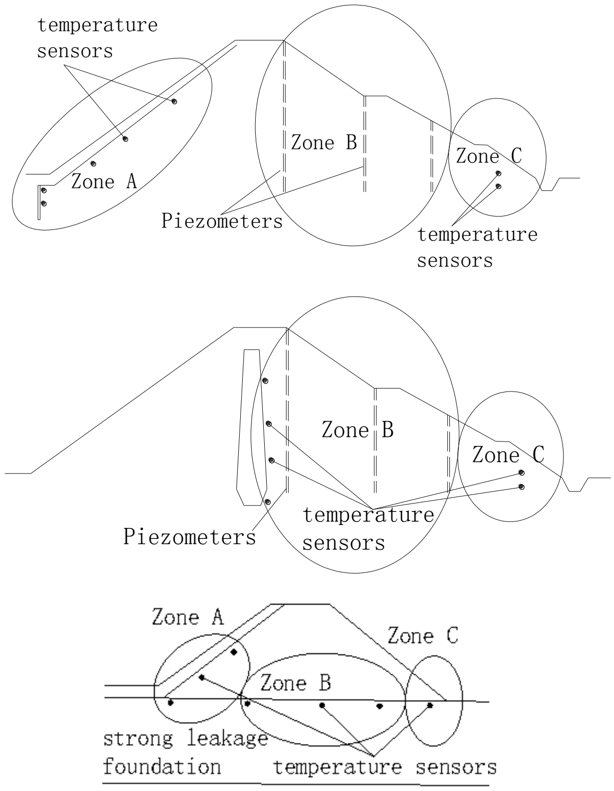

Fig 2. Typical locations of Sensors [48, 50].

In zone A, Temperature sensors are buried behind the upstream impervious membrane to observe seepage goes through the membrane into the dam. Temperature sensors are set up in construction process, but sometimes it was installed during period of repaired works. For zone B, Temperature sensors are possibly placed during construction process or considerable upgrading. Temperature sensors are usually located in downstream of anti-seepage element, especially in filter and drains. In other way, Temperature sensors can also be sited along existing piezometers. The last division, zone C, is the most cost-effective part to install temperature sensors for an existing dam. In this section, temperature sensor can be installed without considerable works [48, 50].

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IV. SEEPAGE EVALUATION FROM TEMPERATURE DATA

Concurrent flow of heat and fluid through soil media has been studying for more than 40 years. Some pioneers in this field can be mentioned as in [12, 51-56]. Despite these researches were not developed far enough to serve as orthodox method for leakage detection in embankment dam, they contributed as the basic foundation for post-studies.

Recently with support of advanced technology in temperature measurement as well as the development of analytic approaches, a number of models using temperature data to estimate seepage has been introduced. Several typical model were selected to revise as follows:

A. Dissimilarity approach

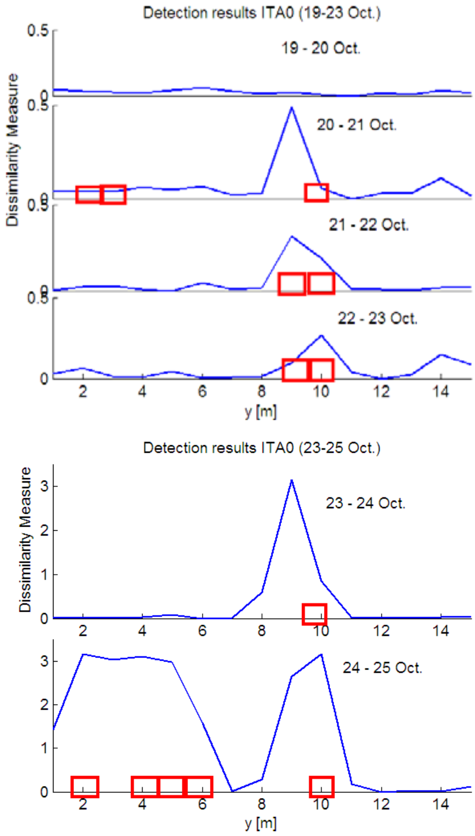

Fig 3. Illustration of Dissimilarity approach. Red rectangles represent for leakage observation through visual inspection [48].

Analyzing daily temperature to localize leakage regime, dissimilarity approach was introduced by Beck et al., in 2010. Fiber optic were used to record temperature along its length. Without the presence of anomalous seepage the achieved signal is almost the same as presented in the first day of surveillance, however, the dissimilarity signal occurred with the development of abnormal seepage which was pointed out by visual inspection. Furthermore, the increment of abnormal magnitude correlated with the evolution of seepage intensity, thus it provides to some extent the information of seepage degree. However, from the revision we had some consideration that: in the original experiment five fiber cables were disposed a long model's foundation but the result presented in original paper was not indicated which one was in accordance with the presented result. The comparison of the signals obtained from different cables was not realized, it would reveal the way of piping. And how earlier dissimilarity signal recorded before the abnormal seepage was recognized by visual was not compared but this should be a strong point to assess the efficiency of the method in the ability of early detection suffusion region. Anyhow, the contribution of the method cannot be denied, it would be integrated with other components to sever as automatic early warning system for embankment dam.

B. Source separation technique

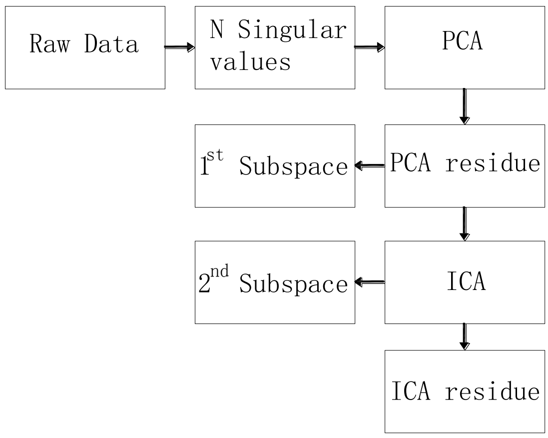

Fig. 4. Scheme of source separation technic.

Temperature variation in a dam is not only driven by seepage but also be affected by air temperature, precipitation, drains (structures), geothermal, etc. Each factor is represented by a separate and independent source signal, therefore, recorded data set is specified as a mixture of these source [57] . By the reasoning above, Khan et al., (2008) presented source separation method based on two algorithms, principal component analysis (PCA) and independent component analysis (ICA), more information of PCA and ICA can be found in [58]. Source separation technique is expressed as in figure 4.

Firstly, raw date is treated to get space encompassing N singular values, then m singular values which have no relation with considered parameters are chosen from the N singular values by PCA to create the first signal subspace. Next ICA subtracts n de-correlated singular values from PCA residue to create second subspace. Finally, ICA residual is determined and this part contains the unique information related to leakages. This method was applied to analyze long-term observation as well as short-time monitoring, however, Results from Khan et al., (2008) indicated that it is better to use the approach for short-time analyses (around 14 days). The method is useful for leakage localization, but it is not accessible to determine seepage parameters.

C. Impulse response function thermal analysis model (IRFTA)

IRFTA model was developed based on Green's function connecting input signal (Thermal load) and output signal (recorded temperature) by impulse response function. In other work it could be said that impulse response function reflects the information of the porous zone. The application of the approach was presented in [15, 48, 59], where impulse response function was approximately specified by exponential decay in form of two parameters (α, η). α (dimensionless),

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characterizes the damping, and η stands for diffusion time – The time-lag between the one set of the loading and response. The role of these parameters obeyed harmonic analysis, if the input is Sin(ωt) then the output will be αSin(ω(t-η)). The analyses of α, η in respect of water and air temperature could give not only the solution for abnormal seepage detection but also can somewhat estimate the intensity of seepage. The application of this approach avoids the determination of soil thermal-hydraulic parameters which is usually difficult and time consuming to specify thus it can promote the seepage evaluation process. Nevertheless, a weak point of this approach is the application of a hypothesis that the heat equation was behaved in the linear manner, it means that porous medium properties and seepage velocity are constant. In fact, seepage velocity and porous properties are altered by seepage gradient what is determined by varied hydraulic load, also when abnormal seepage occurs it will develop according to time instead of stable at a value, this apparently change the seepage velocity and porous properties as well. This describes that why the method would not reproduce the data from fiber optic measured in regions closing with leakage zone. Besides, two months observation requirement is not always attractive.

D. Signal processing method

Using artificial intelligence components including pre-processed data and one-side classifier, signal processing method is a good tool to explore seepage regimes from temperature data. Pre-processed data constitutes short time Fourier transforms or the maximum overlap discrete wavelet transform, which is utilized to generate input set for one-side classifier (neural clound). One-side classifier is a combination of an advanced K-means clustering algorithm and an extended radial basis functions network approach, is utilized to investigate abnormal phenomena. The method provides robust identification of anomalies for both spatial-temporal data set. In addition, the method is flexible, thus it can be easily integrated into any decision support system. For details of the approach see [4, 60].

E. Lag-time and amplitude methods

Johansson and Dahlin (1996) offered simple methods, Lag-time and amplitude, which computed seepage velocity based on velocity of temperature wave from upstream to measured points. The method requires long-term temperature monitoring, six months and a year temperature measurement for lag-time and amplitude methods correspondingly. Although there are some limitations, for example neglect of conduction process and/or effect of air temperature in thermal process, it is still good tools for preliminary seepage analysis of saturated suffusion layers.

F. Numerical simulation method

As stated in basic theory section, mathematical expression of heat and mass transfer in embankment dam are very complex, thus it is unreal to manually solve the problem. Reality shows that numerical method is a unique tools with capacities of solving complex differential equation-system for complicated geometries. When apply this approach, differential equations are firstly transformed into approximate algebraic equations which can be written in form of matrix. Then computer program are applied to handle these matrix. Basically, the procedure of numerical model can be depicted as seen in figure 5.

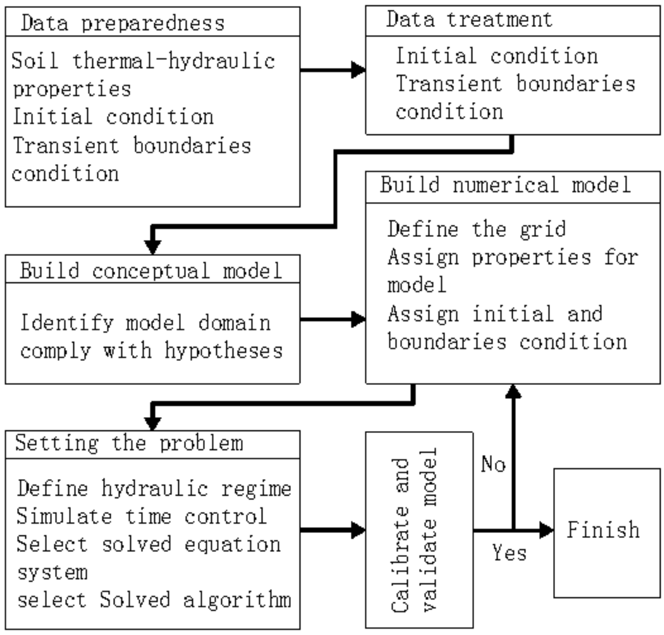

Fig. 5. Basic Steps for Numerical Simulation of Coupled Thermal-Fluid Transport in Soil Media

Previous researches, for example [5, 14, 61-63], implemented their models with various array of thermal-hydraulic parameters to compute temperature and seepage, then the expected temperatures from numerical solutions were compared with temperature measurements to find out the closest result. From which seepage velocity were determined. However, these applications revealed some main limitations as: 1. Numerical simulation in case of passive method requires a long-term temperature measurement (monthly, yearly), and the using of weekly or monthly average temperature for the problem analysis somewhat did not reflect the actual process. 2. Applications purely compares expected temperature from modeling and temperature observation without any analysis about other factors affecting to thermal process. 3. A sinusoidal variation in near surface temperature was widely assigned for boundary condition contacting with air, but actually, heat transfer processes in soil surface is complex and it should be expressed by energy conservative equation.

Recently, numerical simulations and laboratory experiments have been implemented with addition of heat injection, this gave a promised solution for seepage evaluation from temperature observation. By this way, not only observed time requirement is reduced, but also the effects of boundaries temperature such as air temperature, water/reservoir temperature, and geothermal were proved to be negligible. The document relating to this method could be found in [18, 64-66]. However, the experiment presented in the documents is laboratory scale and the material is not the same with real situation. Moreover, the leakage in field is very complex in regarding to its developed process, ways of movement, intensity, etc., therefore, field scale investigation need to be carried out to confirm the accuracy and the feasibility of the method.

V. CONCLUSION

By reviewing literatures, this work can confidently affirms that temperature measurement is good parameter for seepage evaluation in embankment dam, thus it is key parameter for dam safety management.

Temperature sensors are generally disposed nearly or directly in zones designed to capture and direct a leakage. In new dam, they can be set up without any significant obstruction for construction process whereas for old dam, temperature sensors would be situated in existing structure (standpipe) or new installation in the event of repaired works. When fiber optic sensor is considered for an existing dam, downstream toe was highlighted as the most effective position.

Short-term temperature analyses are good approaches for leakage localizing, and their results delivered helpful information for dam safety early warning system. By applying proper approach it would not only explore a very small leakage process but also can specify intensity of seepage inside the dam. Consequently, it improves dam safety and minimizes the cost in case of repaired works. Nevertheless, a model for quantitative seepage evaluation need to be developed for the method.

Seepage velocity can be evaluated from temperature measurement. Passive method developed for long time expresses as reliable approach for seepage assessment, however, it requires long time observation. While active method, introduced recently, provides a rapid solution for seepage estimation, nevertheless, the field experiment need to be implement to assess the efficiency of the method.

This paper supply synthetic and systematic information about basic theory, numerical models as well as temperature measurement technique of thermal-heat behavior in embankment dam, so that it provides useful information for readers who want to practice or continue to develop the problem.

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