Reliability analysis of earth fills using stochastic finite element methods

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Abstract

This paper considers the uncertainties in geotechnical parameters of earth fill structures, specifically their spatial variability. The use of random field theory will be introduced, in conjunction with the stochastic finite element method, to describe and model the uncertainty in geotechnical properties of compacted soil masses. The paper focuses on the importance of the use of conditional random fields that take into account supplementary data acquired during the construction phase of earth fills. This approach helps decision making during construction by providing continually updated evaluation of the safety of the structure as building proceeds.

1. Introduction

Homogeneous earth fill designs and constructions still face many problems and difficulties. In order to assess some of the main factors influencing the reliability of these fills, specifically the influence of the spatial variability of the mechanical properties within the mass, stochastic modelling could provide a robust tool for their design (Mrabet 1999, Mrabet & Bouayed 2000).

The design of earth fill structures and their construction is based on using materials associated with properties that have a significant degree of uncertainty due to their inherent heterogeneity. These properties can be represented by means of random variables or random fields. Random field theory can be used to better represent these uncertainties and provide a basis for probabilistic modelling.

An increasing amount of research has been undertaken on the possibility of applying probabilistic methods to earthworks design (Mrabet & Giles 2002). Each appears to offer promising systematic way of treating uncertainty and has probabilistic approach can quantitatively framework for reliability within the design. also be used to relate uncertainty in

2. Stochastic finite element method

The finite element method (FEM) is now commonly used to, for example, predict stresses, displacements and pore pressures in a variety of geotechnical structures and earth works, particularly within slopes and embankments. A long experience of using this method has shown that uncertainty affects both the results of these analyses as well as the parameter input in the calculations.

The finite element method, as widely described by Zienkiewicz (1973), consists of evaluating the mechanical behaviour of elements in which the domain is discretized into individual elements (triangular or trapezoidal, for example). Then, caution has to be exercised in assembling these elements in order to satisfy equilibrium equations and compatibility of the calculated displacements.

Uncertainty associated with the properties of the construction materials will also exist and can be estimated using the stochastic finite element method (SFEM). This method is a generalization of the conventional finite element method used in conjunction with probabilistic concepts in order to take into account the randomness of the material properties.

Recently (Bouayed 1997), the stochastic finite element method has undergone several important developments and improvements. It has been successfully developed and applied to earth structures subjected mainly to static loading. However, its presen form, the SFEM algorithm is very difficult to apply the reliability analysis of dynamic loading in the time domain.

3. Random field models

Early probabilistic approaches have considered the uncertainty of natural and compacted material properties as random variables. However, the spatial dependenc within the medium should be considered, particularly in strongly compacted soil (Mrabet 1997, 1999, Mrabet & Bouayed 2000).

To take into account spatial dependency it is possible to model he variability of soil properties with a spatial stochastic process also known as random field (Vanmarcke 1983). Values taken by a given property at any point of the domain are then considered as a sample function of such a field, defined classically by the following parameters: *Expected Value*, *Variance*, *Auto-covariance* or *Auto-correlation function* and the *Probability Distribution Function*.

Extensive instrumentation and measurement programs performed on earth dams (Fry & Rossa 1988) such as Mirgenbach and Vieux-Pre dams (France) have led to the conclusion that for such structures significant spatial correlation exists. The influence distance at which auto-covariance becomes negligible is sensitive to the construction procedure as well as the material nature, but is practically identical for properties. A pronounced anisotropy (i.e. due to compaction) of the auto-covariance exists with a vertical distance of influence of the order of meters and horizontal distance of influence of the order of tens of meters.

Many studies (Cherubini 1997, Mrabet 1999) have stressed the effect of existing auto-correlation on the results of probabilistic models of slope analysis. Ignoring auto-correlation is conservative and considerably more than desired and the analysis that considers typical auto-correlation distances results in reduction of probability of failure (Mrabet 1999). The probability of failure may be considerably reduced if the auto-correlation function is taken into account. Cherubini (1997) stresses that the integration of the fluctuation scale (i.e. auto-correlation distance) in probabilistic models in a geotechnical context generates failure probabilities consistent with frequencies of failure observed in practice.

4. Conditional random fields and Bayesian updating

The updating procedure based on conditional random fields was developed to incorporate the results of control tests in reliability analysis as soon as they are available in order to take decisions based on an actualized evaluation of the reliability of the structure. The ability to use Bayesian method to update probabilities of event occurrence, based on new information, is one of the most powerful tools available and operate in many circumstances, not just the field of geomechanics.

If the uncertainties and risks have been quantified before construction begins, then updated information obtained during construction can be used to devise risk estimates and to guide decisions made during construction process. The reliability analysis can be performed using conditional random fields to incorporate the results of control tests in reliability analysis as soon as they are available in order to take decisions based on an actualized evaluation of the reliability of the structure.

5. Case study: Embankment Dam

The Abid Dam was selected as a case study for performing analyses described previously to predict displacements in the dam and to perform the reliability analysis related to the spatial variability of the materials properties within the dam.

The Abid Dam is an embankment dam with a central plastic impervious layer located on the Abid River, in the northern part of Tunisia. It has a crest length of about 550 m and crest width of

about 8 m. The total volume of the embankment is about 650,000 m^3. A maximal cross-section of the dam is shown in Figure 1.

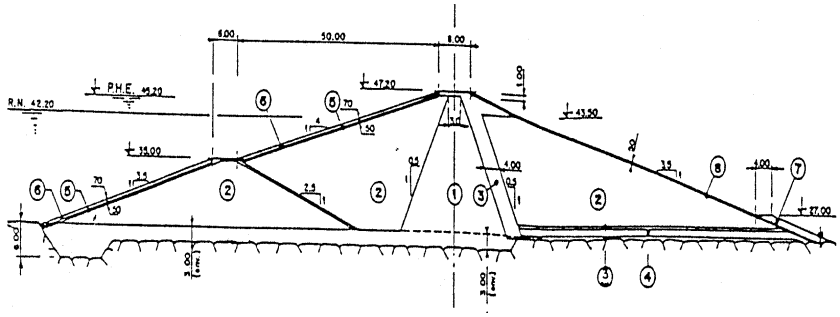

Figure 1: Maximal cross-section of the Abid Dam. 1: Plastic clay soils; 2: Clay soils; 3: Drain; 4: Filter; 5: Transition material; 6: Rip-rap; 7: Rockfill protection; 8: Downstream slope protection.

Initially, the analysis was performed using simple random field. Secondly, conditional random field and conditional simulation were undertaken to assess the uncertainty related to the spatial variability of the material properties within the dam based on quality control data results obtained during construction. The coefficients of variation of vertical displacements within the dam are presented in the annex (Figures 2a, 2b, 2c).

These results show that uncertainty affected vertical displacements for points situated at the base and the rest of the dam. Conversely, the largest uncertainty in these displacements occurred far from the boundaries, mainly close to the cofferdam and downstream slopes.

The conditional random field technique gives a lower coefficient of variation of vertical displacements than the simple random field method. This can explain the reduction in uncertainty when using the additional data.

Conditional simulation gives higher coefficients of variation for vertical displacements within the dam than both simple and conditional random field methods.

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Annex:

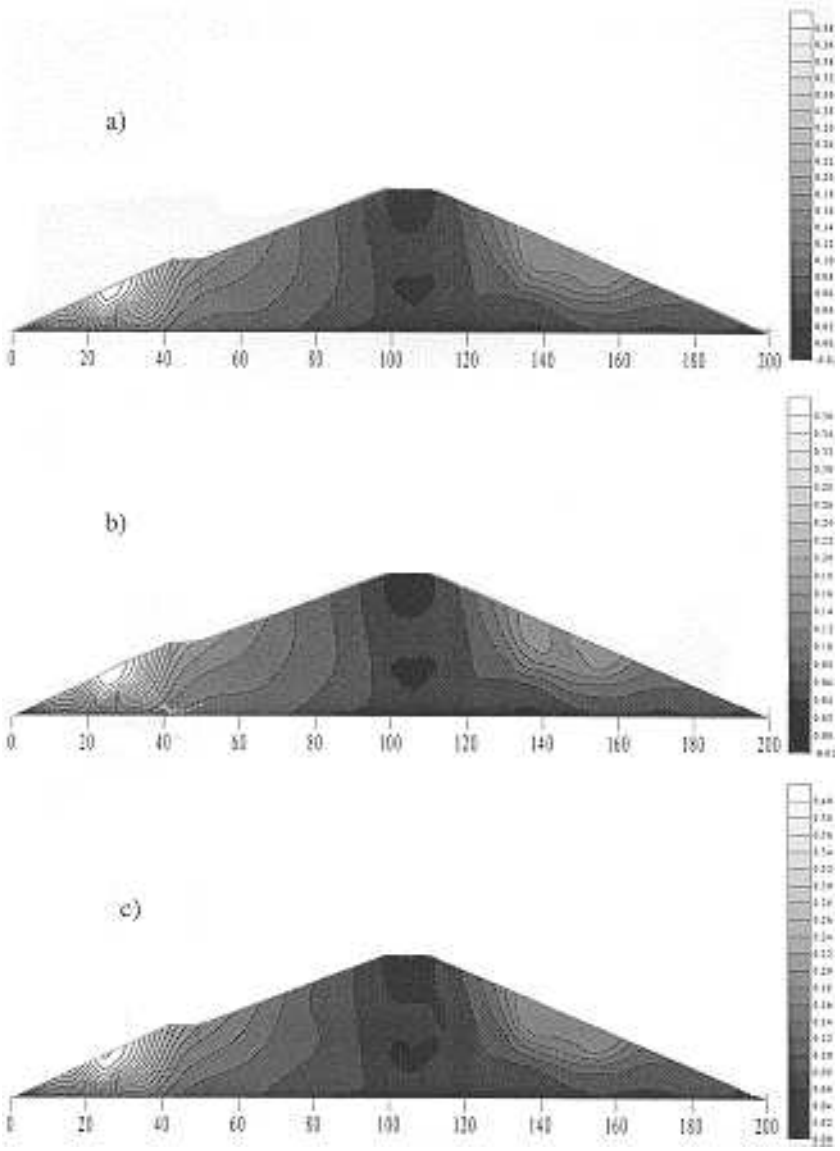

Figura 3: Coefficient of variation of vertical displacements: a) simple random field, b) conditional random field, c) conditional simulation