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Research Paper

Numerical analysis of hydro-thermal behaviour of Rouen embankment under climate effect

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ABSTRACT

When modelling the variations of soil volumetric water content and temperature in earth constructions, it is essential to adopt a fully coupled hydro-thermal model and to well determine the boundary conditions by considering soil-atmosphere interaction. In this study, a numerical approach combing coupled hydro-thermal model and soil-atmosphere interaction model is developed and applied to investigate the hydro-thermal behaviour of a field embankment constructed at Rouen. The related meteorological variables were recorded hourly from more than one year. Comparisons between the measurements and the simulation results show the relevance of the proposed numerical approach and its further application in longer term.

1. Introduction

During drought periods, evaporation can cause significant reduction of soil water content or growth of soil suction, leading to ground settlement or soil cracking. Basically, the evaporation rate is totally governed by the interaction between soil and atmosphere. When the evaporation rate is determined by considering the climatic conditions and the soil-atmosphere interaction, the evolution of soil suction and soil water content can be evaluated, helping the assessment of the impact of climatic changes on the earth constructions and buildings.

Generally, climate effect on soil greatly depends on energy and mass transfers at soil-atmosphere interface. Energy balance involves net radiation, sensible heat, latent heat, and soil heat at soil and atmosphere interface [1,2]. Soil heat is estimated through consideration of soil-atmosphere interaction and used as the surface heat flux boundary condition. For bare soil, mass balance consists of rainfall, runoff, actual evaporation and infiltration. Rainfalls are normally recorded at weather station and runoff can be measured at soil surface using specific devices, such as flumes [3], UBe-Tube [4]. The actual evaporation at soil surface has been studied widely [5–7]. Normally, with known rainfall, runoff and actual evaporation on soil surface, infiltration can be calculated and applied as surface water flux boundary condition.

It is worth noting that both heat and water flux boundary conditions are influenced by the real-time soil surface situation in terms of temperature and volumetric water content. Indeed, heat and water transfer in soil are coupled and have been studied widely through various hydro-thermal or T-H-M coupled soil models [2,8–13]. In order to study the soil moisture content variations in non-isothermal conditions, different hydro-thermal coupled soil models have been proposed [2,8–11]. The T-H-M coupled soil models were also proposed to study the deformability of soils under the combined thermo-hydro-mechanical effects [12,13]. Good predictions of soil temperature and volumetric water content/suction variations can be obtained by these models. Even though the influence of soil-atmosphere interaction on hydro-thermal soil performance in these models was investigated, to the authors' knowledge, no numerical investigation in two-dimensions has been conducted to study the climate effect on the behaviour of earth constructions, even though most geotechnical constructions need, by their natural geometry, two- or three-dimensional analyses. This was done by An et al. [14] through proposing a new numerical approach and by application of this approach to the case of an embankment. However, owing to the limited data, only a period of 20 days was considered to study the coupled hydro-thermal behaviour of soil with more attention paid to the influence depths of climate on soil temperature and volumetric water content. In this study, the soil-atmosphere interaction is further investigated using this numerical approach through a treated soil embankment built in Rouen, France. In the period from 27/10/2011 to 17/11/2012, complete meteorological data, soil

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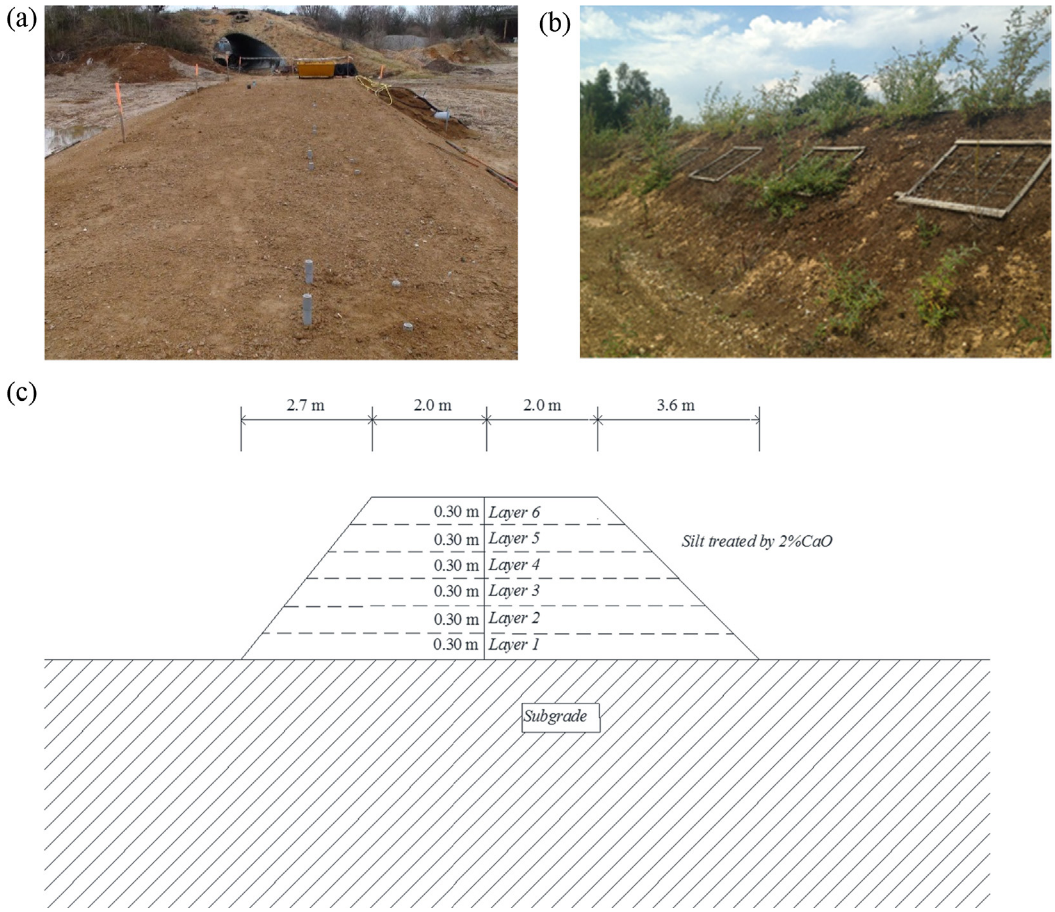

Fig. 1. Field view of Rouen experimental embankment: (a) embankment surface situation in Oct. 2011; (b) the slope situation of embankment in Jul. 2015; (c) field embankment cross section.

temperature and soil volumetric water content at different positions were recorded, enabling the evaluation of climate effect on treated soil embankment for more than one year. Note that the soil-atmosphere interaction is strongly dependent on the boundary conditions at the soil-atmosphere interface. Even though the global numerical approach adopted is the same as that in An et al. [14], the boundary condition considered in this study is quite different from the one described in An et al. [14]. Moreover, the suggestions of the collection of meteorological data are also proposed in this study for future research on soil-atmosphere interaction. Note also that as no significant settlement was observed, a fully coupled hydro-thermal soil model was used to analyse the embankment behaviour.

2. Field embankment monitoring

The field embankment was constructed at Rouen region in the west of France, characterized by a continental climate influenced by ocean. The soil used for the embankment construction is a silt treated by 2% CaO. For the untreated silt, its plastic limit w_p is 23%, liquid limit w_l is 37%, plasticity index *IP* is 14, and methylene blue value *VBS* is 2.38. In Fig. 1a and b, the surface and slope situations of the embankment are shown respectively. The embankment is 21 m long, 1.8 m high, with different slopes 1: 2 (right) and 2: 3 (left) (Vertical: Horizontal) for the two sides as shown in Fig. 1c. During the construction, the height of each layer was controlled by a laser line level and each layer was compacted by a compactor.

As no field meteorological information of this embankment is available, the information of hourly solar radiation provided by ECTOT-LES-BAONS station of METEO FRANCE (30 km away from the embankment) is used. Wind speed recorded at the same station is adopted. Other hourly meteorological data come from a nearby site meteorological station (20 m away from the embankment) with some short periods of data missing. The records of wind speed at this station are not reliable due to some technique problems. The solar radiation, rainfall, wind speed, air temperature, air relative humidity and dew temperature information are presented respectively in Fig. 2a–f. Seasonal variations can be clearly observed in relative humidity, air temperature, dew temperature and solar radiation.

Fig. 3 presents the studied section of Rouen embankment, indicating the presence of excess soil on the designed slope surface (dashed line). The soil temperature and volumetric water content were recorded by PT100 and TDR sensors, respectively (Fig. 3). These sensors were installed at different layers during the construction as follows:

(1) 1C0 to 4C0 were set up on the interface between subsoil and the first soil layer.
(2) 1C2 to 3C2 were set up on the second layer.
(3) 1C4 to 3C4 were set up on the fourth layer.
(4) 1C5 and 2C5 were set up at the interface between the top layer and the layer below.

The sensors used for the temperature measurement (PT100) and volumetric water content measurement (TDR) are presented in Fig. 4. In the monitoring period, the soil temperature was measured every two hours and the soil volumetric water content was recorded every six hours. More information about the embankment construction can be found in Charles and Froumentin [15].