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Deformation behavior of clay cap barriers of hazardous waste containment systems: Full-scale and centrifuge tests

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ABSTRACT

The objective of this paper is to study the deformation behavior of a clay cap barrier of waste containment system for storing hazardous waste. The risk of bending of a clay barrier in case of differential settlements within underlying waste is focused in the present study. Field bending "bursting tests" were performed in France on clay barriers of 0.7 m thickness at different water contents. An attempt has been made to determine limiting distortion level at which cracks are initiated. The cap clay barrier configuration tested through field bursting tests was simulated at 12.5 g in a geo-centrifuge on model cap clay barriers of 56 mm thickness subjected to bursting mode of failure. Digital image analysis technique was used to ascertain initiation and propagation of cracking at the onset of differential settlements. Further influence of discrete and randomly distributed polypropylene tape fibers in restraining cracking tendency of the clay barrier was evaluated through a centrifuge model test. With an increase in the molding water content and the presence of randomly distributed fibers, an increase in limiting distortion level was observed. Use of 0.5% of fiber dosage and 90 mm long discrete fibers was found to restrain propagation of cracking of a clay barrier subjected to differential movements. Analysis and interpretation of field bursting tests was found to be in good agreement with physically observed centrifuge model test results.

1. Introduction

Clay barrier forms one of the key elements of cap barrier of low-level radioactive waste disposal (Daniel, 1983; USEPA, 1989). It is very important to retain physical, mechanical and hydraulic characteristics of the cap barriers during the operation and monitoring stages of waste disposal systems. Low-level radioactive wastes in France are generally stored in blocks (or containers) of variable shapes, and spaces between these are filled with buffer materials (Camp et al., 2005a). Due to this type of storage and prevalence of voids, settlements within the waste cells are likely to occur. The deformation of the cover system may occur due to the collapse of the cavities within the waste or between waste packages or toppling of waste containers (Camp et al., 2005a; Viswanadham and Rajesh, 2009) The deformation of the cover system may lead to the cracking of the clay barrier, which in turn drastically increases the permeability of the clay barrier (Cheng et al., 1994). Several authors have studied the behavior of fine-grained soil subjected to bending. Leonards and Narain (1963) and Ajaz and Parry (1975) performed four point bending tests on clay beams to study the influence of molding water content and of compaction energy on the behavior of the clay. Indraratna and Lasek (1996) studied the influence of reinforcement on the behavior of a clay beam submitted to a four point bending test.

A limitation of scaled-down physical models under normal gravity conditions is that stress levels in models are much smaller than in full-scale structures, thus leading to different soil properties and loading conditions (Schofield, 1980). In a centrifuge, identical stress-strain behavior of the soil in the model and the prototype can be achieved through centrifuge model tests by subjecting $1/N$th scale model to N times the earth's gravitational acceleration (where $N =$ scale factor or acceleration level or gravity level). By adopting a suitable acceleration level the unit weight of the soil being tested can be increased by the same proportion by which the model dimensions have been reduced, and thus stresses at corresponding points in the model and prototype become identical (Viswanadham and Jessberger, 2005). In view of this, a majority of the researchers adopted the centrifuge modeling technique to study the response of clay barriers to artificially induced continuous differential

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settlements (Jessberger and Stone, 1991; Scherbeck and Jessberger, 1993; Craig and Gallagher, 1997; Viswanadham and Mahesh, 2002; Viswanadham and Jessberger, 2005; Viswanadham and Muthukumaran, 2007; Viswanadham and Rajesh, 2009; Viswanadham et al., 2009).

Viswanadham and Mahesh (2002) have evaluated the deformation behavior of clay barriers in a small geotechnical centrifuge. Viswanadham and Jessberger (2005) and Viswanadham and Muthukumaran (2007) have brought out the significance of reinforcement effect on the performance of clay barrier subjected to differential settlements. The above-cited studies have revealed that the risk of cracking of a clay barrier was found to depend upon the molding water content of the clay barrier material and the compaction energy provided to the clay barrier during its construction. Further, inclusion of reinforcement can reduce the danger of clay barrier cracking.

In order to evaluate the influence of molding water content and randomly distributed fibers on the integrity of clay barriers subjected to differential settlements, field bursting and centrifuge model tests were carried-out. In the framework of the present research programme, field bending "bursting tests" were performed in France on clay barriers of 0.7 m thickness. The cap clay barrier configuration tested through field bursting tests was simulated at 12.5 g on model cap clay barriers of 56 mm thickness subjected to bursting mode of failure. The influence of molding water content, presence of geotextile layer and randomly distributed fibers on the integrity of clay barrier was studied through field and centrifuge model tests. Further, an attempt has been made to compare observed results of centrifuge model test results with field bursting tests.

2. Background of the site

Since 2003, the French radioactive waste agency ANDRA is responsible for storing very low-level radioactive waste at a site, located in the Aube, France. This kind of disposal facility requires a lot of precautionary measures. The radioactive waste containment is ensured by the confinement of the storage cells by a cap cover including an impervious barrier made of compacted clay, a reinforcement geotextile layer and a geomembrane (Camp et al., 2005a). Fig. 1 depicts a schematic cross-section of the cap cover. In cap cover systems, clay barrier thickness ranging from 0.6 m to 0.8 m (1 m in France) is generally adopted. Due to this configuration of the cover system, there is a risk of damage to the geomembrane during the compaction phase of the overlying clay layer. Hence, compaction energy has to be relatively low to reduce the danger of damaging the geomembrane layer.

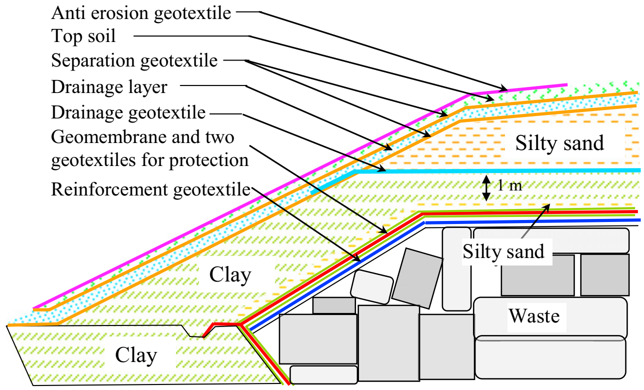

Fig. 1. Structure of the cover of the storage cells 25.

Fig. 2 depicts the schematic cross-section for extreme conditions of the support showing bursting mode of deformation of clay barrier of cap cover system along with its components. Quantification of settlement areas within the cap covers is difficult. At a particular location, degree of the differential settlements can be referred to either in terms of curvature radii or by the distortion level a/l, which is defined as settlement a, over a horizontal distance l (considering only half of the differentially settled waste, see Fig. 3). Use of the distortion level for characterizing differential settlement was adopted earlier by LaGatta et al. (1997).

3. Field bursting tests

3.1. Field test procedure

The influence of differential settlements on the cap cover can be modeled by subjecting a clay layer to bending stresses (Jessberger and Stone, 1991; Viswanadham and Mahesh, 2002). In the framework of the present paper only bursting tests which induce the most critical situation with regard to the risk of cracking are presented (Fig. 3a). The stretched zone in this test is located along the top surface of the clay barrier, which is consequently not confined. In the present study, effects due to the presence of drainage layer and cover soil above the clay barrier was ignored. These tests can be considered as inverted bending tests. They do not represent the actual situation in the case of differential settlements but these tests give an opportunity to observe cracking initiation along the most-stretched surface of the clay barrier (i.e. at the center along the top surface of the clay barrier). In the next series of field tests, settlement tests, as shown in Fig. 3b are planned.

For executing field bursting tests, a rigid pit made out of reinforced concrete (breadth: 2 m) was built, and an articulated steel plate (2 m × 2 m) placed over the pit. A system of four vertical hydraulic jacks fitted in the pit allows the plate to induce a vertical movement of the central plate. These jacks are synchronized in such a way that they impose identical movement at all four corners. Performance of the jacks was monitored with the help of displacement transducers and load cells. Fig. 4 shows the details of the field bursting set-up along with hinged plate arrangement. For all the tests, a 200 mm thick moist-tamped silty sand layer was placed. The purpose of this layer is to prevent stress non-uniformities to the clay layer and also to facilitate uniform compaction of the clay layer. A maximum vertical movement of 250 mm along the central line, as shown in Fig. 3a, is possible with a rate of 4 mm/min. When the horizontal distance from the center of the clay barrier is zero, the value of vertical movement is defined as a central movement a and it is referred herein as the maximum central movement a_{max}, if the induced central movement equals to

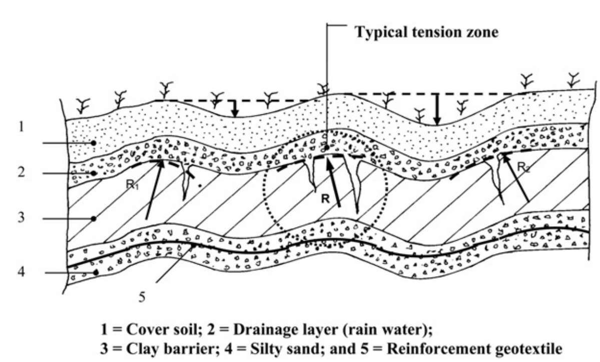

Fig. 2. Schematic cross-section showing for extreme conditions of the support bursting mode of failure of clay barrier of cover system.