An experimental procedure to study the impact of animal burrows on existing levee structures

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Abstract: Animal burrows have been reported to cause extensive damage to existing levees and other earthen structures in different parts of the world. In this study a centrifuge model that has been designed to investigate the impact of animal burrows on the performance of an existing earthen structure is described. The proposed methodology simulates animal burrows in an earthen structure by introducing cylindrical-shaped openings inside a pre-designed model. A homogenous levee with 1:1 side slopes and a horizontal toe drain was chosen for this preliminary investigation. The steps taken to construct the model and the effect of the adopted burrow simulation technique on the model performance are discussed. Crest settlement was measured before and after the burrow introduction and during the increase in water level to failure. Conclusions regarding the adequacy of the adopted technique are made.

Keywords: Earthen structures; Animal burrows; Physical modeling; Pore pressure; Levee failure.

1 INTRODUCTION

Adverse wildlife activities and their damage to earthen structures are observed worldwide. Animal burrows have been known to negatively impact the hydraulic performance and structural integrity of levees and earth dams. The yearly cost of failed earthen structures and other infrastructures due to animal burrows worldwide is estimated to exceed billions of dollars (Bayoumi and Meguid, 2011). A significant amount of the literature that is available in the area of wildlife focuses on the ecological and environmental impact of animal activities and habitat. However, studies related to the synthesis of failure mechanisms of earth structures due to wildlife activities appear to be relatively limited. This study is intended to make a step forward in that regard.

Levee breaches are generally caused by several individual or combined conditions including excessive forces from the retained water, weakness in levee prism or foundation, and seismic activities. Extensive research has been done to investigate the mechanisms that lead to levee breach and failure including erosion (e.g. Chen et al., 2011), overtopping (Wang and Kahawita, 2003), in addition to backanalysis of previously failed levees (e.g. Steedman and Sharp, 2011).

The objective of this paper is to introduce the experimental program which is currently being undertaken to investigate the impact of animal burrows on the stability of earthen structures. Emphasis is placed on the physical model and the methodology used to create a stable burrow system in levee body during a centrifuge flight. Details of the failure mechanisms and analysis of the measured pore pressure are beyond the scope of this paper.

2 THE EXPERIMENTAL PROGRAM

The experimental program involves the design of a two-dimensional levee model that is large enough to allow for the introduction of a uniformly distributed burrow system within a levee prism and foundation and at the same time reaches failure under water pressure at a predefined g-level. The height of the levee should also be chosen to allow for the burrows to be placed at different depths in order to examine the role of burrow location on the changes in the hydraulic properties of the levee and the factor of safety against slope failure. For that purpose, a series of numerical analyses was performed with various levee geometries, side slopes and water levels and the geometry that satisfied the above conditions (for the given soil properties) were chosen and used throughout this experimental study.

Centrifuge tests reported in this research were conducted at the C-CORE centrifuge center in Saint John’s, Newfoundland, Canada. The C-CORE centre has a 5.5 m beam centrifuge with g-level of up to 200g. The payload capacity is 2200 kg at 100g (see Figure 1).

Figure 1. The C-CORE beam centrifuge

2.1 Levee model

2.1.1 General configurations

The chosen levee model is 21.4 cm in height and crest width of 11.4 cm with 1:1 side slopes and an L-shaped toe drain. Based on the internal (cross-sectional) dimensions of the plane strain box (90cm ×30cm), the scaled down levee prototype with the foregoing dimensions was subjected to centrifugal acceleration of 35g. The plane strain box is equipped with a transparent face to allow for monitoring the deformation of the levee. As shown in Figure 2, the levee model is contained inside the rigid box with two main drains on both downstream and upstream sides. The drains are separated from the levees model using retaining plates.

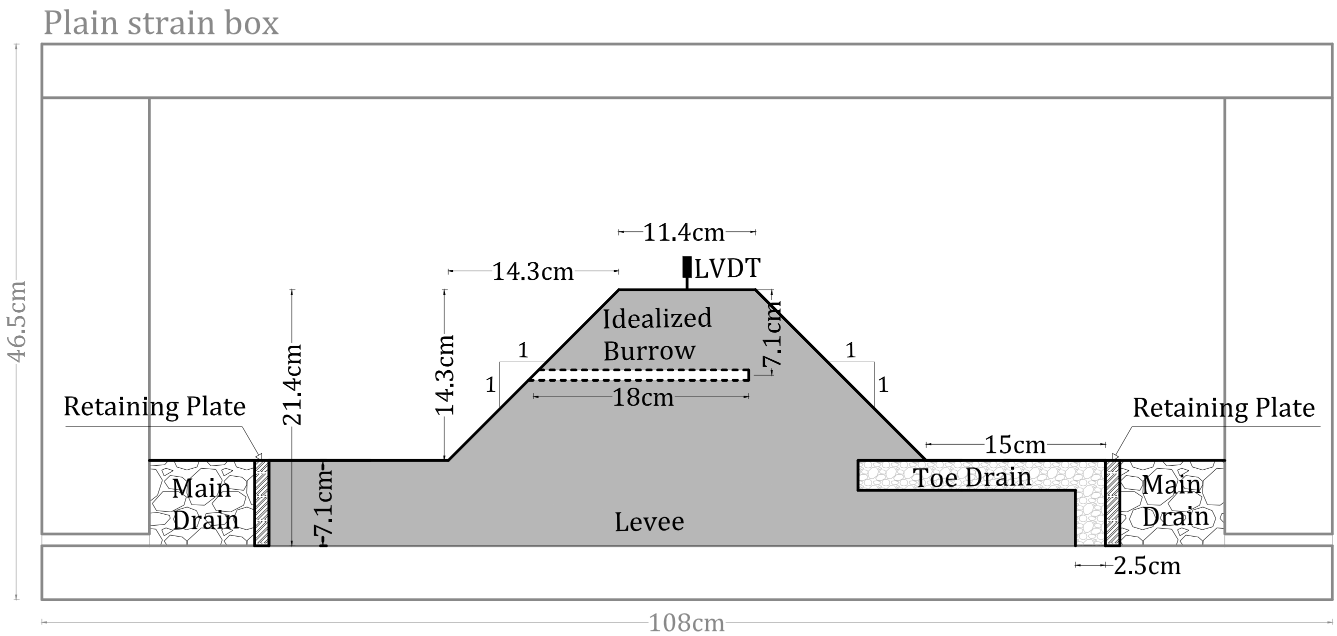

Figure 2. Model configuration

Natural Kasama soil from Japan was used to build the homogenous levee structure. Kamasa soil has been used successfully in similar centrifuge studies to investigate the effect of rainfall on the stability of earth structures (Hori et al. 2007). It also mimics the favourable soil condition for burrowing animals. The available physical and mechanical properties of Kasama soil are summarized in Table 1. The material is classified as Elastic Sandy Silt (MH) with plasticity index of about 26%. The soil gradation curve is presented in Figure 3.

Table 1. Soil properties

Grain Sizes	Gravel 3.9%	Sand 37%	Silt 38%	Clay 21.1%		
	Particle density 2.61 g/cm^3	Liquid limit 65.2 %	Plastic limit 39 %	Maximum dry density 1.21 g/cm^3	Uniformity coefficient 79.82	Coefficient of curvature 1.62
Compacted Kasama Soil	Moisture content 36%		Friction angle 30^o	Cohesion 15 kN/m^2	Hydraulic conductivity 3.8 x 10^{-3} cm/s	

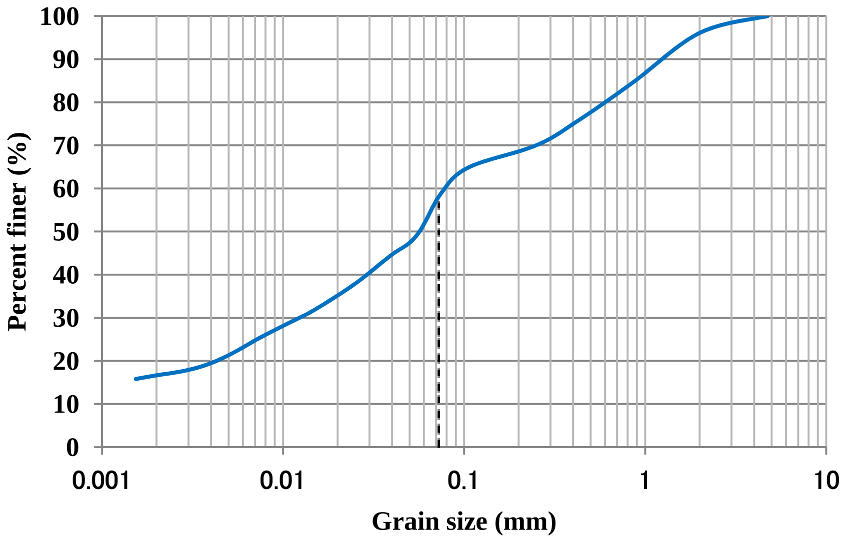

Figure 3. Gradation curve of Kasama soil

2.1.2 Model construction

The model was constructed using the compaction and excavation technique. This method involves two main steps: (1) placing and compacting the soil in layers within the entire box up to a target height, and (2) removal of the soil by excavation in order to shape the levee cross section (Figure 4). The target levee cross section was identified using reference lines that are made on the box walls before placing the soil. The levee is divided into 9 horizontal identical layers of approximately 2.5 cm thick (except the first layer which was 2.14 cm thick). In each layer the soil is poured uniformly and compacted by a vibratory compactor to reach the desired thickness. The moisture content of the compacted soil was approximately 36% and the hydraulic conductivity was estimated to be 3.8 x 10^{-3} cm/s. The toe drain material was placed inside the space bound by vertical and horizontal spacers that are used as mold in the first three layers. After finishing the first two layers, granular material for the vertical part of the toe drain was placed and compacted. The horizontal part of the toe drain was placed after the 3rd layer is completed. Pore pressure transducers (PPT) are installed at selected locations to monitor the pore pressure changes during the centrifuge flight. A key point in installing the PPT was to ensure that the wires are long enough to allow for the settlement of the levee during the test, otherwise they may cause local tension and possibly model failure. After the placement of each layer, the surface is scratched to create a rough interface between consecutive layers.

The excavation process started following the completion of the last (9th) layer. Core samples were taken form the upstream and downstream soil to verify the compaction level and the water content before the excavation. The soil removal process stared form the upstream side (Line AB in Figure 4) and continued towards the upstream slope. Similar procedure was followed for the downstream side. Excavation was performed slow enough to minimize disturbance of the levee model. Reference line BCDEFG representing the upper surface of the levee model was continuously monitored. At the end of the excavation the complete soil volume ABCDEFGH above the model was removed. In order to monitor the deformation of the levee, three G7 cameras were placed outside the box and reference points at selected locations were monitored using the cameras. The top surface of the levee was also meshed using white color and tracked using a webcam.

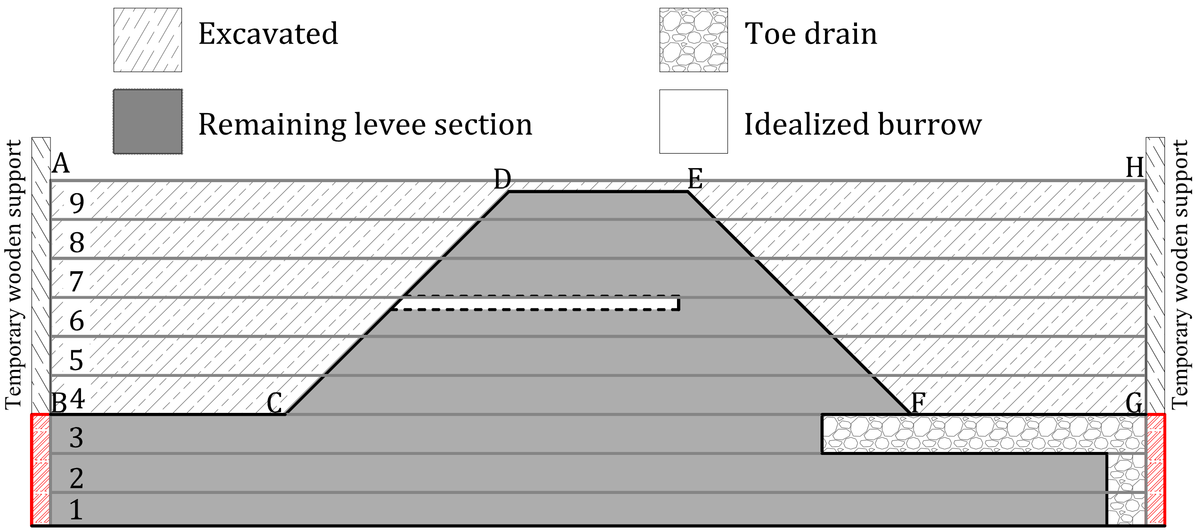

Figure 4. Model construction zones

2.2 Burrow simulation

The real animal burrows in levees may differ in length, diameter and orientation. In this study, burrows were idealized using cylindrical shaped openings of the same length, diameter and elevation with respect to the levee height. This was achieved using 6 cylindrical steel rods of the same dimensions spaced at 50 mm apart. The length of the burrows was chosen to be 70% of the levee width at the investigated height. (e.g. 18 cm at mid height of levee prism). It is worth noting that the burrow set included 5 full sections and one half section right next to the transparent. The half section allows for the tracking of the seepage and burrow deformations during the test. These burrows need to be stable following the rod removal and during the centrifuge spin-up to the maximum g-level.

The steel rods were pre-installed at the burrow locations during model construction and were removed during centrifuge flight by means of a specially designed pullout system. Rods were connected to a rectangular steel beam as shown in Figure 5a. Depending on the burrow elevation, the rod set was buried in pre-excavated grooves (Figure 5.b). The grooves were made accurately to fit the rod dimensions to avoid overcutting and maintain a constant burrow size throughout the test. Rods are marked at several intervals to facilitate tracking of the buried length using the webcam and the G7 camera. To minimize the friction along the rod-soil interface, the outer surface of each rod was smoothed and polished before installation.

Since the burrow openings need to be introduced during the centrifuge flight after reaching the preselected maximum g-level (35g); electrically controlled pullout system was designed to allow for the removal of the pre-installed rod set form the model. The system consisted of a linear actuator, pulling cable running over a fixed pulley, in addition to vertical and horizontal support plates as illustrated in Figure 6.a. Once the target g-level was reached and the stability condition was ensured, the pulling system was triggered and the cable was pulled leading to smooth sliding of the connection beam on the support plate until the rods were completely removed form the model. In order to account for the model settlement during spin-up, a small gap (about 3 mm) was left between the beam and the support plate. Figure 6.b shows a plan view of the rod set installed within the model at the target elevation.

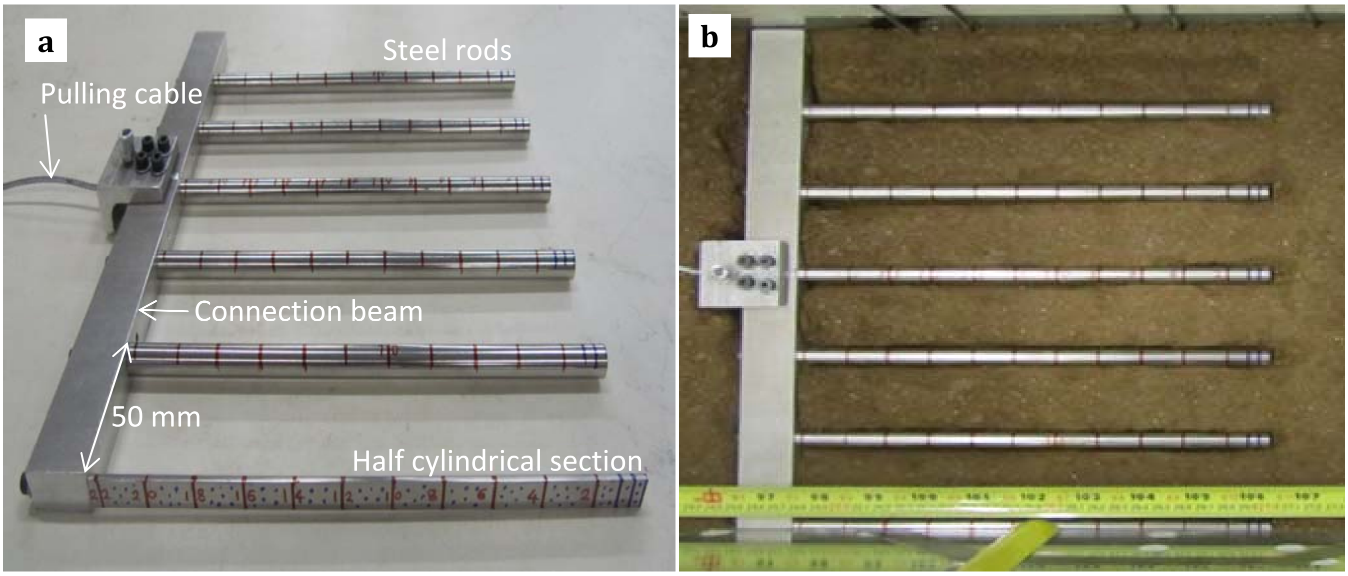

Figure 5. a) The prepared rod set, b) The rods set inside the model

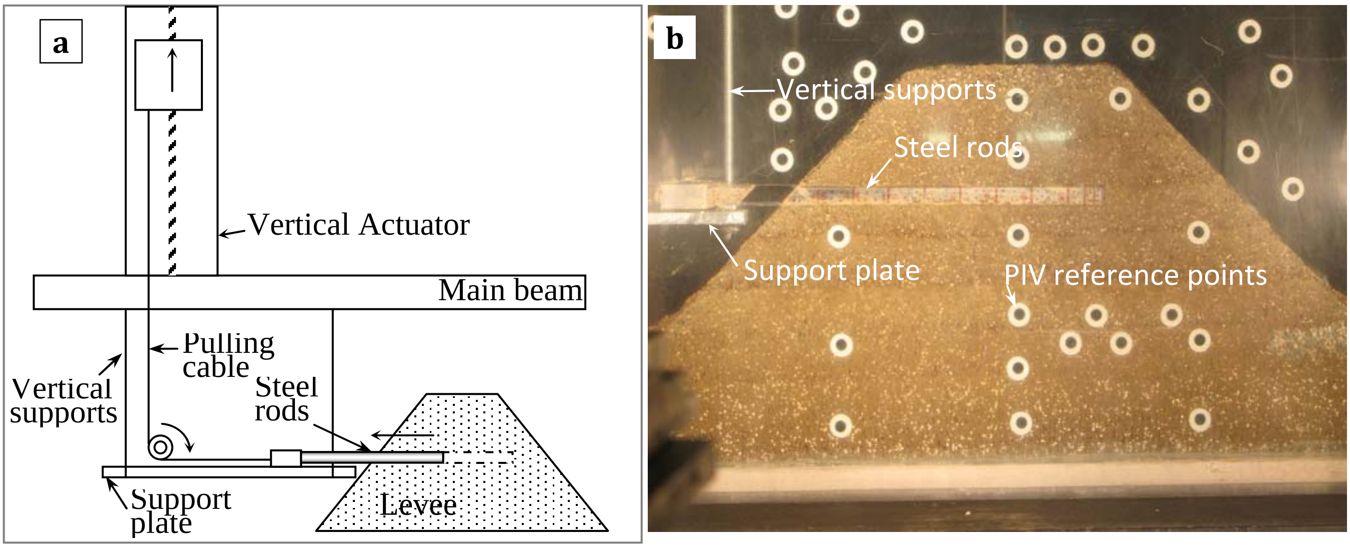

Figure 6. a) Rods pullout system, b) Final model cross section with installed rods

3 PROCEDURE AND RESULTS

Centrifuge spinning started by spinning up the model to 10g. The performance of the model and the installed instruments were checked to ensure that all transducers and cameras are functioning properly. In the next step the spin up was continued to reach the target g-level (35g) which was kept constant throughout the test. The rod set pulling procedure started after reaching the maximum g-level at a rate of 0.33 mm/sec. Figure 7 shows the successive images that have been captured by the G7 camera facing the levee cross section. The stability of the created burrows during and after the rod removal process was monitored through the transparent wall of the box.

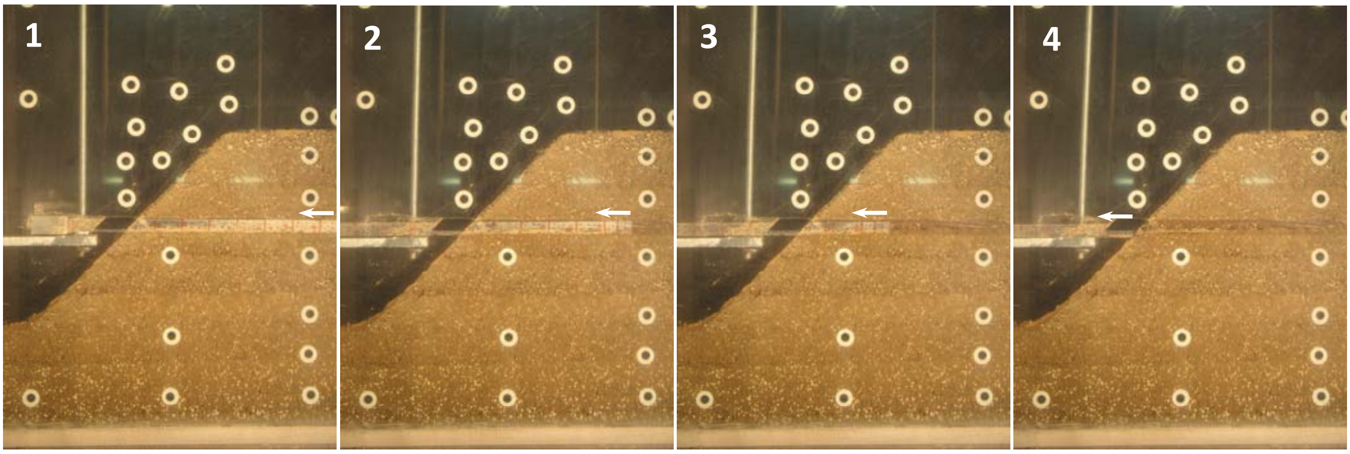

Figure 7. Rods pulling out procedure

Figure 8.a shows the monitored edge burrow next to the transparent wall and the two reference lines (white lines) at the burrow walls. The final burrows after the complete removal of the rod set is shown in Figure 8.b. The figure also shows that the burrows are generally stable with little soil adhering to the surface of the rod set, which indicate minimum disturbance of the excavated burrows.

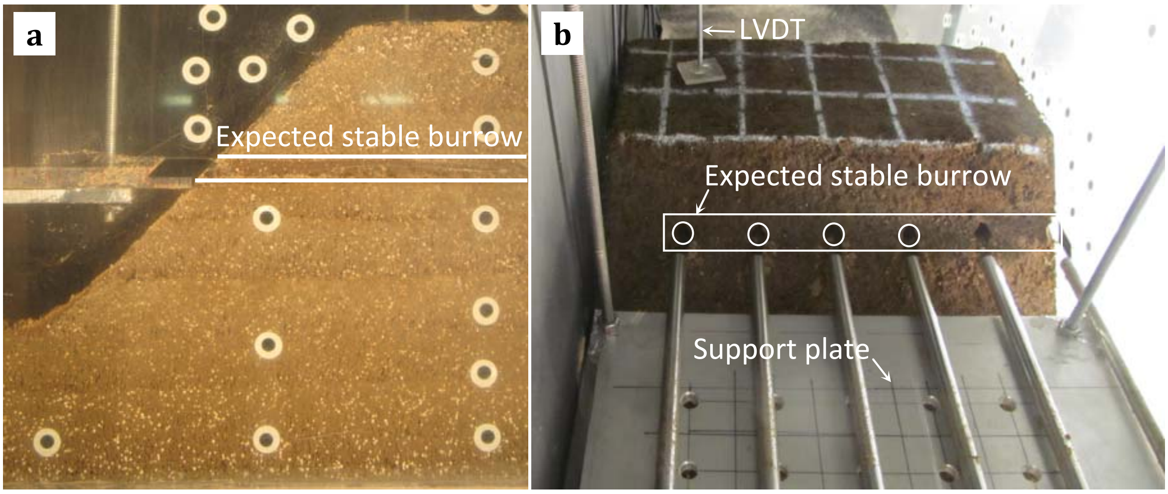

Figure 8. Monitored burrows after the rod set removal

To measure the settlement of the levee crest during flight, LVDT was placed near the solid wall of the box as illustrated in Figure 8.b. The measured crest settlement during the test versus normalized time ($T/T_{Failure}$) is presented in Figure 9. Particular emphasis is placed on the vertical levee movement before and after the rod set removal to ensure that burrows are stable before the water level is increased (part AD in Figure 9). It is evident that no significant settlement was recorded during the rods removal (part BC). Continuous monitoring of the settlement indicated that burrows were stable up to the stage where the upstream water level was increased. Post test CAT scans were performed on the model. Images showed that burrow walls have experienced minimal disturbance. The tests have been repeated for two different burrow elevations and the results indicated similar burrow behavior.

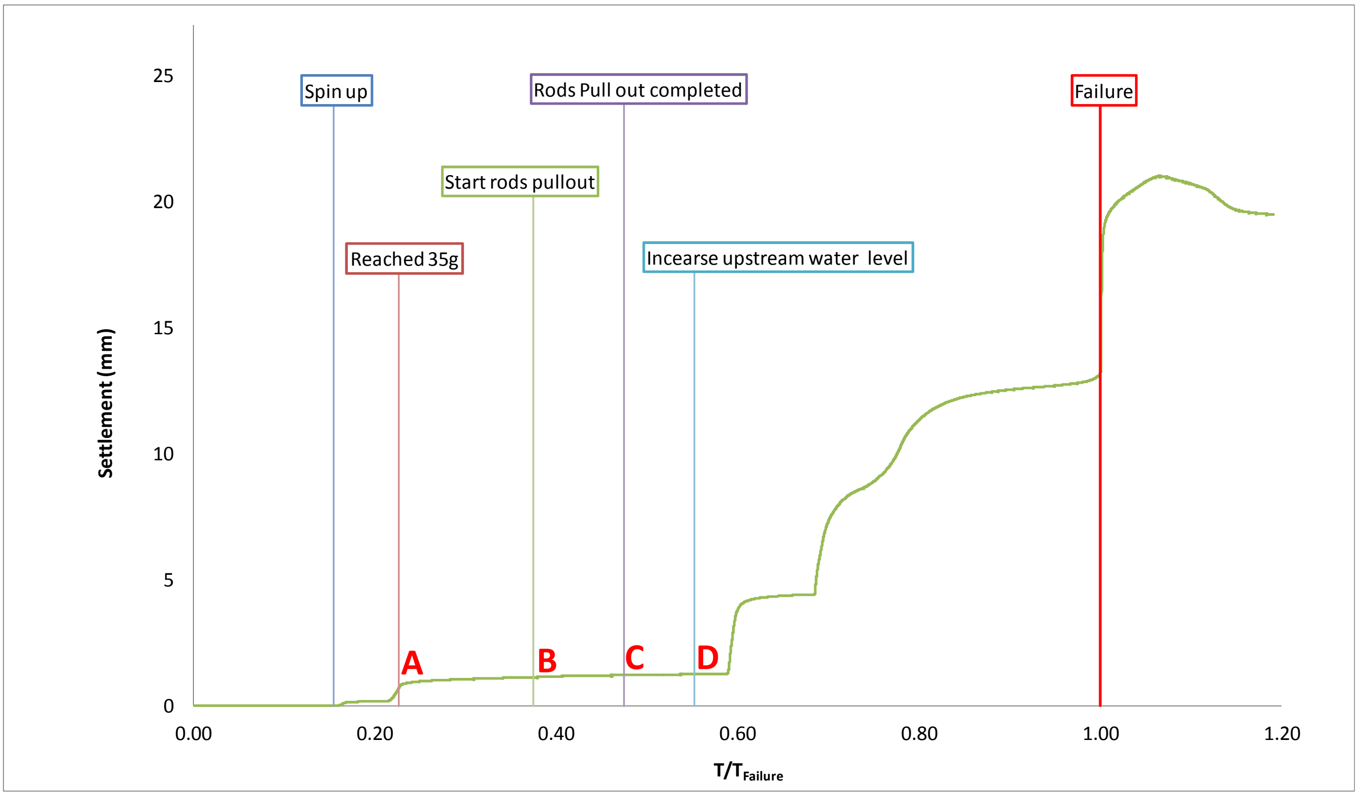

Figure 9. Levee crest settlement during centrifuge flight

4 CONCLUSION

This paper presented the general description of the experimental work that is being conducted to investigate the impact of excavated burrows on the stability of existing levee structures. The specifically designed pull out system and the associated rod set are described. The monitored levee settlement confirmed that the proposed modeling procedure can adequately simulate the introduction of an idealized burrow system in the levee with minimum disturbance. Test results indicated that, for the investigated soil material and burrow geometry, the surface settlement of the levee did not experience significant changes during the centrifuge spin up and following the removal of the pre-installed rods until the water level was raised. This confirmed that the proposed technique used to simulate the burrows in the conducted tests is successful. Further investigation is needed to evaluate the levee response to burrows excavated using other in flight excavation methods.

5 ACKNOWLEDGEMENT

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