Investigation of the influence of animal burrowing on the failure of the levee of San Matteo along the Secchia river

Maria Luisa Taccari¹,²,a and Raymond van der Meij²

¹Delft University of Technology, Civil Engineering, 2628 CD Delft, Netherlands
²Deltares, 2629 HD Delft, Netherlands

Abstract. Animal burrowing can greatly influence the water pressures in a flood protection embankment and thereby be a cause of breaching of flood defences. However, little guidance and literature is available on this subject. This paper investigates the contribution of badgers, porcupines and foxes to the failure of the levee of San Matteo (Modena, Italy) on 19th January 2014. The proposed method evaluates their influence on the water pressures in the embankment during rainfall and a high water tide. The influence of the burrowing is assessed through a transient FEM flow analysis. Starting from the documented entrances situated in the vadose zone, different scenarios for the internal distribution of tunnels and chambers are proposed. The most likely representative network for the loss of stability of the dike is assessed.

1 Introduction

On the 19th January 2014, around 6am, a high water level in the river Secchia created a breach along a dike in San Matteo (Modena, Italy). The water volume flowing out of the breach flooded the surrounding countryside and the villages of Bastiglia and Bomporto. Around a thousand of people had to be evacuated and one man died during the relief operations.

Figure 1. Breach on the right side of Secchia river. (R. Ferrari, Protezione Civile di Modena, 19-01-2014)

During the months after the failure, a scientific committee composed of six members of five Italian universities investigated the causes leading to the event. In July 2014, the Investigative Evaluation Report “Relazione tecnico-scientifica sulle cause del collasso dell’argine del fiume Secchia avvenuto il giorno 19 gennaio 2014 presso la frazione San Matteo” (Technical-scientific rapport about the causes leading to the collapse of the levee of Secchia river, which took place on 19th January 2014) was published [1]. The report presents hypotheses on failure mechanisms, indicating that internal erosion and macro-instability are possible causes of the breach. The presence of animal burrows could have contributed to the formation of these phenomena.

The current paper investigates the influence of animal burrowing on the pore water pressures to predict the failure mechanism for the Secchia river. When the outside water level increases, the phreatic line changes in shape and with a rate depending on the properties of the soil body. The heterogeneity introduced by the animal burrows influences this trend and the pore pressure distribution. The groundwater flow inside the dike body gives an indication of possible failure mechanisms, which can be derived for several scenarios of animal burrows. Finally, the paper concludes over the likely holes distribution and failure mechanism leading to the breach.

2 Initial and boundary conditions

2.1 Soil properties and stratigraphy

In order to define the stratigraphy and soil properties, field and laboratory tests were performed in three sections near to the location of the breach. Core samples have also been taken in these three locations and laboratory tests have been performed [1].

The dike body, defined as Unit A and whose top is placed at 37.66 MAMSL (Figure 2), consists of silt with...
sand and sandy silt. Underneath the levee body, Unit B consists of sandy silt, locally with clay, and it is formed with sub-horizontal layers; it extends from 31.55 MAMSL till 25.16 MAMSL. Finally Unit C is mostly composed by clay and, locally, sand and silt. The phreatic level is placed at 29 MAMSL and the river is situated on the left side.

![Figure 2. Profile of the dike.](image)

The soil is classified according to the USDA classification system. The results of the classification proofs are made public available [1] and used in the current study. The parameters for the strength and deformability of the soil have been obtained through interpretation of the laboratory tests and the field tests (Table 1) [1].

<table>
<thead>
<tr>
<th>Unit</th>
<th>A- Dike Body</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type</td>
<td>Silty Sand</td>
<td>Silty Sand</td>
<td>Clay</td>
</tr>
<tr>
<td>γsat (kN/m3)</td>
<td>21.7</td>
<td>18.8</td>
<td>18.9</td>
</tr>
<tr>
<td>γunat (kN/m3)</td>
<td>19.5</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>E' (kPa)</td>
<td>78.5E3</td>
<td>48.7E3</td>
<td>54.2E3</td>
</tr>
<tr>
<td>m (-)</td>
<td>0.2-0.3</td>
<td>0.2-0.3</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>c (kPa)</td>
<td>7</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>φ' (°)</td>
<td>32</td>
<td>28.8</td>
<td>-</td>
</tr>
<tr>
<td>su (kN/m²)</td>
<td>-</td>
<td>-</td>
<td>55</td>
</tr>
<tr>
<td>kν (m/day)</td>
<td>1</td>
<td>0.162</td>
<td>10E-3</td>
</tr>
<tr>
<td>kν (m/day)</td>
<td>1</td>
<td>0.162</td>
<td>10E-4</td>
</tr>
<tr>
<td>c (-)</td>
<td>0.8</td>
<td>0.8</td>
<td>1</td>
</tr>
</tbody>
</table>

The curves are constructed with the model of Van Genuchten-Mualem and the used parameters are summarized in Table 2.

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a (cm⁻¹)</td>
<td>0.0154</td>
</tr>
<tr>
<td>n (-)</td>
<td>1.4938</td>
</tr>
<tr>
<td>m (-)</td>
<td>0.3306</td>
</tr>
<tr>
<td>Θν (-)</td>
<td>0.0785</td>
</tr>
<tr>
<td>Θν (-)</td>
<td>0.4037</td>
</tr>
<tr>
<td>Kν (cm h⁻¹)</td>
<td>0.6771</td>
</tr>
</tbody>
</table>

2.2 Hydraulic boundary conditions

During the night of the breach, the values of river water levels and rainfall leading to the failure were not exceptional, compared to other events during the previous year. Few months before the breach (05/04/14, [2]) the water level had a peak just 30cm below the maximum water level at 6:00 at the moment of the breach, while, during the whole year 2014, higher values for rainfall were also recorded.
2.2.1 Rainfall

The rain was light during all the day before the failure until 8pm on 18/01/2014, when its intensity increased presenting a peak of heavy rain during the night of the 19th January. Around 2am the intensity decreased and moderate rain was present at 6am when the failure took place [1].

2.2.2 Changing water level

The model in the Investigative Evaluation Report with simulation time between 15-01-2014 and 27-01-2014 presents a minimum water level of 29 MAMSL on 17th January 2014. The water level rose during the afternoon of the 17th January 2014 until reaching its peak after the moment of the breach. At 6.00am on 19/01/2014, when failure took place, the water level in the river was equal to 36 MAMSL, that is 1.50meter below the levee crest (Figure 4). There was no significant wave run-up, therefore failure due to overtopping can be excluded.

Figure 4. Water level in the river between 17-01-2014 at 18:00 and 20-01-2014 at 0:00 in the section of the breach [1]

The breach occurred when the water in the river was not at its maximum level yet and the peak that came after didn’t cause other breaches along the levee. This observation confirms the hypothesis of a localized weak spot along the dike where failure occurred.

3 Animal burrows

3.1 The environment

The levee of San Matteo offers an ideal environment for the diffusion of badgers, porcupines and foxes. Even if little grass is present along the slopes, the vegetation at the inner side of the dike and the isolation of the levee from human presence attract the animals. Few houses are present next to the embankment and the road is around 100 meters far from it.

The height of the levee is around 7-8 meters, ensuring dry places where to build setts, which are usually not reached by the water level in the river. The soil consisting on silty sand is also an ideal soil where to dig on.

3.2 The entrances from the Italian report

The presence of four burrow entrances is indicated in the Investigative Evaluation Report, where their location is calculated from an aerial photo from 2012 [1]. Only one entrance is located along the outer slope (Figure 5) and the entrances are located almost at the top of the levee, since badgers, porcupines and foxes dig in dry places. Only in rare occasions, the water level in the river covers the entrance placed along the outer slope. During the night of the 19th January 2014, the water level was around 30cm below it.

Figure 5. Position of burrow entrances along the dike slopes

3.3 Likely geometry of burrows

Setts, which are the underground system excavated by badgers, usually have a mean number of entrances between 7 and 12. The width of the sett is often very large, from 50 to 150m [3].

The system of the levee of San Matteo under analysis has 4 entrances and the maximum distance between them is around 10 meters. Thus, it is reasonable to assume that the entrances belong to the same main sett: the three entrances along the inner slope are most likely linked to the one in the outer slope.

The burrows of badgers are tunnels with semi-circular (arched) or squashed elliptical form, wider than the high [4]. The tunnels have a typical height of 0.20 m and are 0.30-0.35 m wide [5]. The nesting chambers have squashed spherical shape with arched roof and their horizontal section is roughly circular [6]. The dimensions of the chamber can be wider if more badgers occupy it.

The geometry of the subsurface network under analysis is not a-priori known but good assumptions can be made based on the available observations. The tunnels, modelled as cylinders with diameter equal to 0.2m [5], start from the known entrances and go down for 1 meter with slope of 45°; they continue then horizontally until reaching the centre of the levee. There the tunnels are linked together forming a whole system.
3.4 Possible influence of burrows on water pressure

The phreatic line inside the dike body changes with the hydraulic boundary conditions depending on the properties of the soil body. In presence of animal burrows, the phreatic line can rise and thereby decrease the effective stress and strength and posing a risk to the stability of the dike.

![Figure 6. Alteration of phreatic line due to animal burrow [7].](image)

If the phreatic line exits above the inner toe of the dike and the seepage forces are high enough, the probability of seepage and micro-instability increases.

The presence of animal burrows can also facilitate “internal erosion as evolution of defects”, such as piping is defined when cracks and microfissures are present in the soil matrix [8]. As water flows into the cavities, the seepage forces act along the surface, eroding them and removing the subsurface soil.

![Figure 7. Internal erosion in presence of animal burrows [9].](image)

4 Possible failure mechanisms

4.1 Macro-Stability

4.1.1 Analyses

Groundwater flow analyses are performed with the software PLAXIS 2D, which is a finite element computer program used to perform deformation and stability analyses for several geotechnical applications. The program is chosen to investigate the case study in order to analyse the groundwater flow while implementing transient boundary conditions. Once the initial conditions are implemented, a first steady state calculation is performed with the water level in the river posed equal to its maximum value. Transient groundwater flow analyses are instead carried out for a simulation period of 18 days. Mohr-Coulomb model is used for the stability analysis during the phi/c reduction phase. The input parameters for the unsaturated soil described by the Van Genuchten-Mualem model and the other input values used for the analyses have been introduced in paragraph 2.1. In the Investigative Evaluation Report an initial negative pore water pressure distribution (suction) is assumed inside the dike body, which is based on data available in literature for similar levees during winter conditions: it presents a minimum value of -40 kPa in the centre of the dike body while the water pressure is equal to -10 kPa at the top of the levee [1]. Due to the unrealistic low value of permeability associated with the high suction at the top of the levee that the hydrostatic distribution of pore water pressures would give in the unsaturated zone, this assumption is accepted also for the current study.

First, the analysis is carried out without considering the presence of animal burrows (case a). The burrows are then implemented as soil tunnels with unique values of permeability and porosity in their all domain, according to the dual porosity and dual permeability model [10]. In order to simulate the void of the burrow and the ease of the water to flow into the cavity, high values of porosity and permeability are implemented. In particular, the porosity is equal to \( n = 0.999 \) and the permeability is assumed 100 times higher than the one of the surrounding soil. The analysis is carried out for a cross-section along the entrance at the outer slope (case b) and for one entrance at the inner slope (case c). Finally, the last scenario considers the case in which a more developed system was present when the breach occurred. As a matter of fact, the entrances described in the Investigative Evaluation Report are derived from data from 2012. The geometric configuration of the system is obtained considering the average growing rate of badger setts [6] and geometrical assumptions. The assumed sett present in 2014 consists on a system with one new entrance, placed along the outer slope at 35.7 MAMSL. It is connected to the burrows at the inner slope, thus forming a whole system (case d).

4.1.2 Results

In all the analysed cases, the phreatic line of the steady state solution crosses the levee body and it exits in a point placed 1.5 meter above the toe of the dike. The transient flow analysis presents lower pore water pressures that the steady state solution, while, at the inner side, the water level exits at the dike toe due to the influence of rain. The burrow situated at the outer slope below the maximum water level (case d), has the main influence to the pore pressures for both steady state and transient flow analyses (Figure 8).

![Figure 8. Pore pressure distribution at the end analysis, case d.](image)
The safety factors obtained with the φ-c reduction method are summarized in Table 3. If the animal burrows are not considered in the analysis (case a), the safety factor is equal to $SF=1.333$ for the steady state calculation and $SF=1.812$ for transient flow analysis. Steady state solution gives lower results than transient flow because of the higher pore water pressures and so the lower effective stresses. Then, the animal burrows are implemented in the analysis. The results of the 2d calculations for cross sections along the burrow entrances show that the burrows recorded in the Investigative Evaluation Report and located at the outer and inner slope have relatively small influence to the results (cases b and c). Instead, the burrow assumed in the scenario for 2014 and situated along the outer slope below maximum water level (case d), decreases the safety factor to 1.173 for steady state solution and to 1.412 for the transient flow: this burrow gives the biggest impact to the macro-stability of the inner slope.

### Table 3. Safety Factors for the analysis performed in Plaxis 2d

<table>
<thead>
<tr>
<th>Case</th>
<th>SF – 2D steady state</th>
<th>SF – 2D transient flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) No burrow</td>
<td>1.333</td>
<td>1.812</td>
</tr>
<tr>
<td>b) Burrow at the outer slope</td>
<td>1.258</td>
<td>1.733</td>
</tr>
<tr>
<td>c) Burrow at the inner slope</td>
<td>1.390</td>
<td>1.786</td>
</tr>
<tr>
<td>d) Burrow in 2014</td>
<td>1.173</td>
<td>1.412</td>
</tr>
</tbody>
</table>

The dike proves to be safe to macro-instability: the safety factor is largely above one for all the performed analyses (2d analysis, steady state and transient flow, with and without animal burrowing).

#### 4.2 Micro-Stability

If the phreatic line exits at a point above the toe of the inner slope and seepage flow develops, micro-instability can occur [11]. Failure starts at the exit of the phreatic line at the inner slope when the weight above and the forces created by the flow exceed the resisting shear resistance. Particles at the exit point are detached and carried away by the seepage flow and the process gradually retrocedes towards the upstream side of the levee.

In all the analysed cases, the phreatic level for the steady state solution exits in a point placed 1.5 meter above the toe of the dike. However, it is the transient flow solution which simulates the conditions when failure took place, rather than the steady state analysis. The solutions given by the transient calculations in all the analysed cases present the water level crossing the dike body, reaching the layer underneath the embankment and finally exiting at the inner toe of the dike (Figure 8). The intense rain locally hits the surface, increasing the pore water pressures and so raising the water table at the inner side. However, no real seepage point, which exercises seepage forces against the inner slope, is present and can cause micro-instability.

In conclusion, the water table at the end of the transient flow analysis never exits at the inner toe of the dike; it remains below it. No seepage point and forces against the inner slope are present, excluding so micro-instability as a possible failure mechanism for the levee of San Matteo.

#### 4.3 Internal erosion

The failure of the Truckee Canal Embankment (2008) due to a large network of animal burrowing was the incentive for performing Hole Erosion Test (HET) by the U.S. Department of the Interior (Denver, Colorado). Bezzazi et al. [12] have presented a simplified analytical model to the Hole Erosion Test which estimates the evolution of the inner tube radius as a function of time. This paper applies the approach derived by the Hole Erosion Test for the levees of San Matteo in the conditions that led to the breach. When the water level in the river covers the lower burrow entrance at the outer slope and the burrow is connected to the inner slope, a pressure difference develops between the outer and inner side. If then this pressure difference overcomes the critical shear stress, internal erosion starts and causes the hole to increase.

The scenario used for the analysis of internal erosion corresponds to the network which has been assumed to be present in 2014. A burrow entrance is placed at 35.70 MAMSL, under the maximum water level that led to the breach. This burrow is connected to the lower burrow placed at the inner slope through a central tunnel which longitudinaly crosses the levee. The total length L of the cavities connecting them is approximately 20 meters. The initial radius of the burrow $R(0)$ is equal to 0.2 meter, the soil density $\rho_d$ is obtained by the available data and the critical shear stress $\tau_s$, for which erosion starts, is set equal to 50 Pa, that is a value found in the literature for similar soil [8]. The soil of the levee is diggable and erodible as proved by the animal burrowing activity, but it also maintains some erosion resistance while standing after the same burrowing activity. As suggested in the literature for similar soils [13], the surface erosion coefficient $C_{er}$, which varies among several orders of magnitude and indicates the ease of the material to erode, assumed equal to 1.58E-04 s/m.

### Table 4. Input parameters for the analysis.

<table>
<thead>
<tr>
<th>R(0) (m)</th>
<th>L (m)</th>
<th>$\rho_d$ (kg/m$^3$)</th>
<th>$\tau_s$ (Pa)</th>
<th>$C_{er}$ (s m$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>20</td>
<td>1989</td>
<td>50</td>
<td>1.58E-04</td>
</tr>
</tbody>
</table>

The pressure loss is equal to 0 until the water level is below the entrance of the tunnel. At 0:00 on 19-01-2014 the water in the river is at the same level of the entrance of the burrow at the outer slope; the water level then increases and water enters into the cavity. At 0:00 on 19-01-2014, the water overcomes the entrance of the burrow
and erosion starts (Figure 9). The phenomenon develops in time: at 3:00 the radius is equal to 0.60m and it reaches dimension of 1 meter at 04:30.

![Figure 9. Development of Radius with Time due to Internal Erosion, using the approach derived by the Hole Erosion Test.](image)

5 Conclusion

The current paper has analysed the failure of the levee of San Matteo (Italy, 19th January 2014) previously investigated through the Investigative Evaluation Report (“Relazione tecnico-scientifica sulle cause del collasso dell’argine del fiume Secchia avvenuto il giorno 19 gennaio 2014 presso la frazione San Matteo”) which revealed the possible influence of animal burrowing in the creation of the breach. The study gains a better insight on the influence of animal burrows on groundwater flow and stability analysis.

In the Investigative Evaluation Report, entrances of animal burrows along the section that failed on 19th January 2014 are illustrated. They belong to European Badgers, Foxes and Crested Porcupines. The entrances, located along the inner and outer slope, have maximum distance of 10 meters: it is likely that they form a unique connected system with the function of a main sett of reduced dimension. Moreover, the Investigative Evaluation Report presents the burrow entrances deduced by aerial photos of the levee in 2010 and 2012; when the breach took place, in 2014, the system was likely more developed with a new entrance located below the maximum water level at the outer slope and connected to the main sett.

The analyses performed in the current study consider the possibility of Instability of the Inner Slope, Micro-Instability and Internal Erosion to occur, with and without animal burrowing. The input parameters are derived by field and laboratory tests and made available in the Investigative Evaluation Report. Insufficient tests results are published to statistically determine a reliable lower bound of the strength parameters.

First, in the performed analyses the dike shows to be safe to macro-instability: the safety factor is largely above one, with and without animal burrowing. Second, in all the performed transient groundwater flow analyses, with water level changing in the river and rainfall which happened before the event, the water level presents no seepage point exiting above the inner toe. Also when implementing the animal burrows, the water flow doesn’t exercise forces against the inner slope which could start eroding it. For this reason, we concluded that micro-instability unlikely occurred. As a matter of fact, the analyses performed with the available information give such high safety factors, that the uncertainty in the strength is not likely to cause failure due to micro- or macro-instability.

Finally, we concluded that internal erosion was the likely mechanism leading to failure. No tests are performed to determine the parameters for the Hole Erosion Test. However, this is the only mechanism that leads to failure with realistic soil parameters. The connected underground system with burrows running from the outer to the inner slope and the entrance of a burrow located below maximum water level gave the conditions for water to fill the burrow and erode the tunnels in the whole connected network. In view of the performed analyses, we found that hole erosion after animal borrowing is a most suitable explanation for the collapse of the San Matteo levee.

References

1. L. D’Alpaos et al., Relazione tecnico-scientifica sulle cause del collasso dell’argine del fiume Secchia avvenuto il giorno 19 gennaio 2014 presso la frazione San Matteo (2014)
3. A. W. Byrne et al., Royal Irish Academy, The ecology of the European Badger (Meles Meles) In Ireland - a review, 112 (2012)