Effects of Burrowing Animals on Seepage Behavior of Earthen Dams

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Abstract

Earthen dams are made of natural soils, and they are natural habitats for rodent animals. These types of dams may be burrowed by rodents from the soil surface or below the water surface. This can affect the integrity, stability, and the performance of the structure. This study investigates how seepage behavior of earthen dams is affected by animal burrows. To this end, a typical earthen dam is analyzed for seepage using a finite element software with and without burrows. The dig tunnels of badger, beaver and muskrat are considered. The changes in the seepage rate, phreatic surface and pore water pressures are investigated. The findings of the study show that the animal burrows in embankments have adverse effects on the seepage rate and the pore water pressures.

Keywords: Earth-fill dams, rodent animals, burrows, seepage, phreatic surface

1. Introduction

Earth-fill dams are the most preferred dam types around the world since they can be constructed at almost every site conditions. The material of these dams is soil, which can be easily obtained from the nature. However, since they are natural habitat for rodent animals such as muskrat, beaver, badger, gopher, etc., earth-fill dams tend to be damaged or even destroyed by them. The dig tunnels and holes of these animals on earthen dams can extend into the dam body up to couple of meters. Large cavities can cause preferential flow paths and increased seepage rates through the body which may result in piping. Besides, cavities may collapse after a heavy rain or snow melt which may result in settlements or decreased slope stabilities. The effects of the rodents on embankment dams cannot be neglected in both short and long terms. The burrows may lead to the failure of the structure which may result in huge economic losses or even loss of lives. Therefore, it is crucial to take into consideration their effects during the design process of the structure.

Many of the studies in the literature define rodent animals active on dams and their impacts. Bayoumi and Meguid (2011) reviewed harms of wild animals on earthen structures considering both technical and economic aspects and discussed existing wildlife management methods. They found yearly cost of the effects of rodents on earthen structures to be greater than one billion dollars. In an experimental study, Saghaee, Meguid and Bayoumi (2012) investigated the effects of animal burrows on the settlement of an existing earthen dam with an experimental model of a levee. They simulated animal burrows with cylindrical shaped openings formed by a centrifuge technique and found that the proposed modeling technique was successful in simulating the animal burrows in earthen structures.

To our knowledge, no study has numerically investigated the effects of rodent animals on seepage through earth-fill dams. The objective of this research is to reveal the effects of rodents on pore water pressure distribution throughout the dam body, phreatic line position, seepage rate passing through the dam and the length of the seepage face developing at the downstream side of the dam. Comparisons are made between burrowed and undisturbed dam body cases for the rodents considered.

2. Burrowing Animals Active on Earthen Dams

In the nature, there are several types of rodent animals that damage embankment dams and cause various seepage or stability related problems. Almost all types of rodents affect these structures and their components in an undesired way. In this study, we consider only three of the common ones, which are badgers, beavers, and muskrats. These three types of burrowing animals have different effects on embankment dams due to their varying digging properties. All three rodents have different dig hole diameters, lengths, and depths, and the influences of their actions to the embankment vary. According to Bayoumi and Meguid (2011), muskrats can dig large burrows up to 3 m below the water surface on the upstream face of the dam. Montana Watercourse and Department of Natural Resources and Conservation (no date) states that muskrats can dig burrows with diameters ranging from 15 cm to 46 cm. Moreover, their digging direction changes according to the location of the phreatic surface of the seepage. When the phreatic surface elevation rises, they dig towards the upward direction. Similarly, beavers are active in the upstream side of the dam. They have a relatively large body; their length varies between 0.60-0.75 m whereas their weights are around 20 to 27 kg. They can dig holes 0.3 to 1.2 m below the water surface with a diameter around 30 cm. The hollows of beavers have some bad influences on the spillway since they reduce its capacity. Another rodent we consider in this study is badger. Typical burrows of badgers basically have a plugged entrance. On the contrary of muskrats and beavers, badgers dig for shelter from the downstream side of dam. Their burrow lengths range from 1.5 m to 9.0 m with a diameter of 20 to 30 cm having shapes like the letter “D”. An illustration is provided in Figure 1 for the burrows of muskrat and badger in an earth-fill dam.

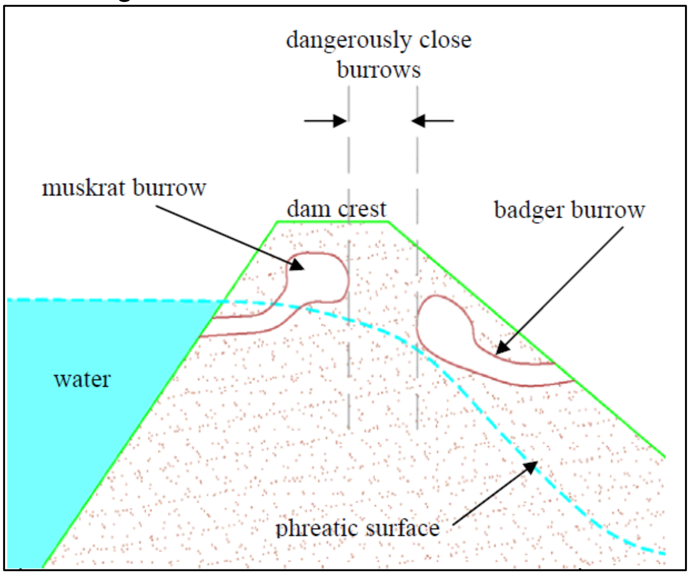

Figure 1. Demonstration of burrow of muskrat and badger (Montana Watercourse and Department of Natural Resources and Conservation, no date)

3. Modeling of Seepage

In the scope of the study, the burrows of badgers, beavers and muskrats are considered in a typical earth-fill dam. The dam is analyzed for the seepage passing through its body. This phenomenon can be modeled using Darcy’s law (Richards, 1931). The constitutive equation of this law is provided below.

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y \frac{\partial H}{\partial y}\right)+Q' = \frac{\partial \theta}{\partial t} \quad (1)$$

where, H is the total head, K_x and K_y, are the hydraulic conductivities in x and y directions, respectively, Q' is the external boundary flux, θ is the volumetric water content, and t is the time. Using the initial and boundary conditions and appropriate numerical methods, Eq. (1) can be solved to determine the pore water pressures, total heads, and flow rates in an earth-fill dam. In this study, the software SEEP/W (Geo-Slope Int Ltd, 2013) is used to conduct steady-state seepage analyses. It is a comprehensive computer aided design software, developed by Geo-Slope International Ltd., for analyzing groundwater flow, seepage, excess pore-water pressure dissipation problems within porous media. The software allows modeling of both saturated and unsaturated flows. It adopts finite element method to solve the nonlinear governing differential equation of the seepage given in Eq. (1). The details about the solution method utilized by this software can be found in Papagianakis and Fredlund (1984) and Geo-Slope Int Ltd (2013). In modeling of the seepage, a saturated/unsaturated soil model is adopted. To this end, van Genuchten Method (van

Genuchten, 1980) is utilized to determine the characteristics of the unsaturated part of the embankment.

4. Application Study

4.1. Earthen Dam Model

In the study, a homogenous 20.5 m high earth-fill dam is selected as the application problem. The dam is considered to be at its normal operation condition with an 18.25 m of water in its upstream and there is no tailwater. The dimensions and side slopes of the dam are determined using USBR's small dam design specifications (USBR, 1987). The upstream and downstream side slopes are selected as 1V:2H. The foundation of the dam is assumed to be impervious bedrock. The fill material is selected as isotropic sandy clay which is suitable for homogeneous fill dams due to its low hydraulic conductivity. The cross-sectional layout of the dam is provided in Figure 2. The geotechnical and hydraulic characteristics of the fill material are determined using the related literature. The saturated hydraulic conductivity is determined as 0.12 cm/hr (Carsel and Parrish, 1988). The van Genuchten curve fitting parameters α and n are selected to be 3.6 kPa and 1.23, respectively (Ghanbarian-Alavijeh *et al.*, 2010). The saturated and residual water contents, θ_s and θ_r, are taken as 0.38 and 0.10 m^3/m^3, respectively (Carsel and Parrish, 1988).

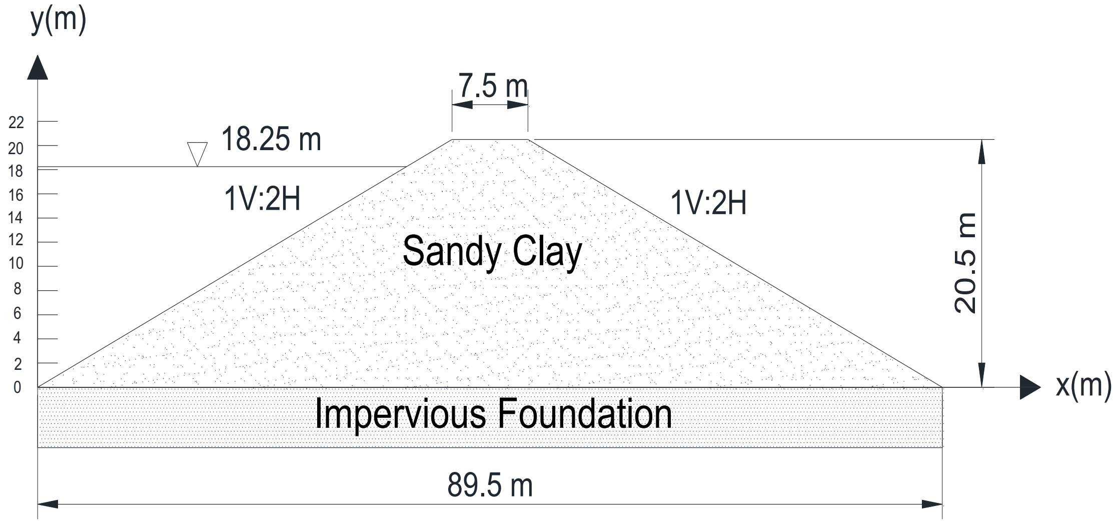

Figure 2. The geometry and material properties of selected dam body

4.2. Burrow Simulation

In the application part of the study, four different cases of the embankment dam are considered, i.e., undisturbed, disturbed by a badger, a beaver, and a muskrat. At first, the undisturbed case of the embankment dam is modeled as shown in Figure 3. In this model, it is assumed that there are no burrows or dig holes created by rodent animals.

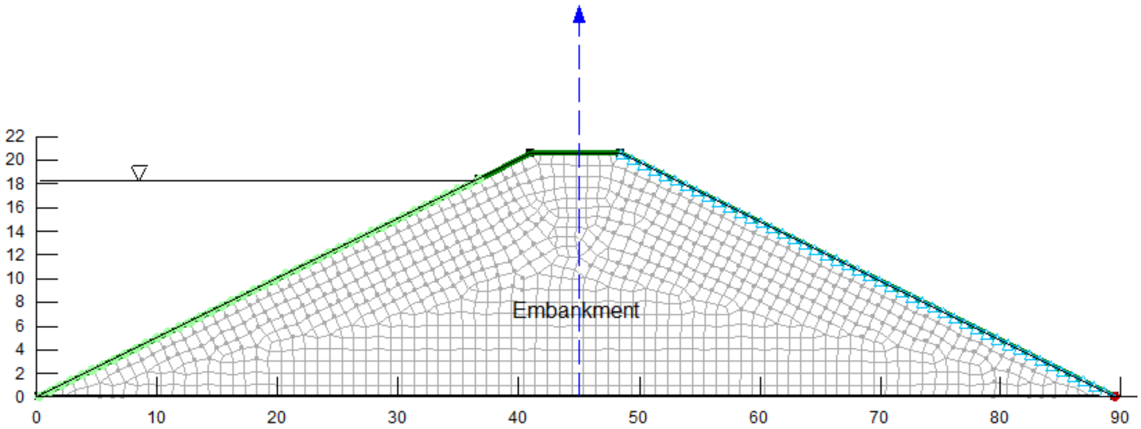

Figure 3. The model of the undisturbed embankment dam

The same embankment dam is modelled for seepage of the cases including burrows of badger, beaver and muskrat. For the burrow sizes, shapes, places, directions, and orientations, the information provided in “Burrowing Animals Active on Earthen Dams” section are applied. In order to simulate the burrows in SEEP/W software, the parts disturbed by rodents are kept empty in the dam geometry. The models of the disturbed cases of the embankment dam for badger, beaver and muskrat are given in Figure 4, Figure 5, and Figure 6, respectively.

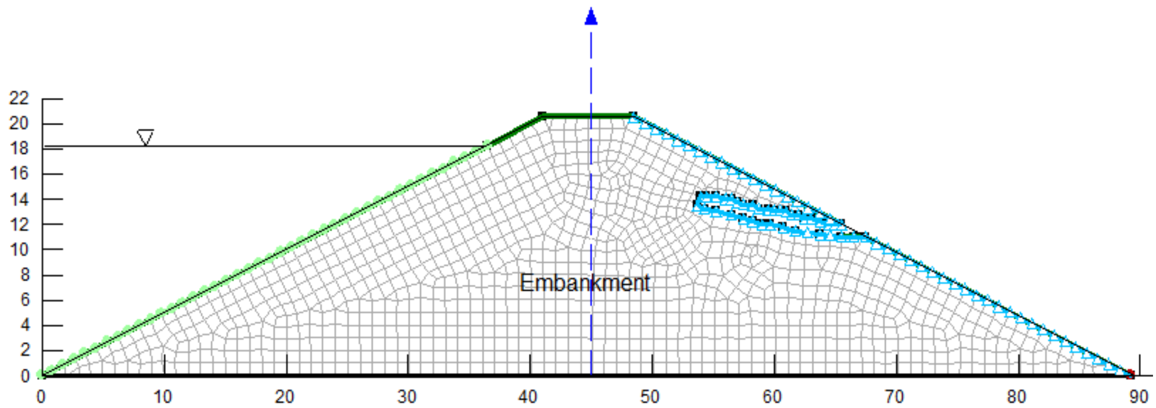

Figure 4. The model of the disturbed embankment dam by badger

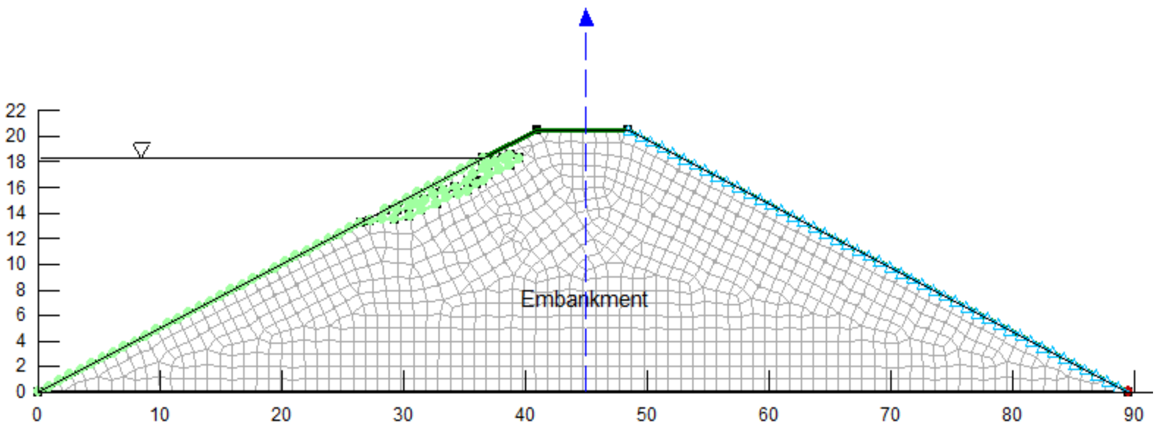

Figure 5. The model of disturbed embankment dam by beaver

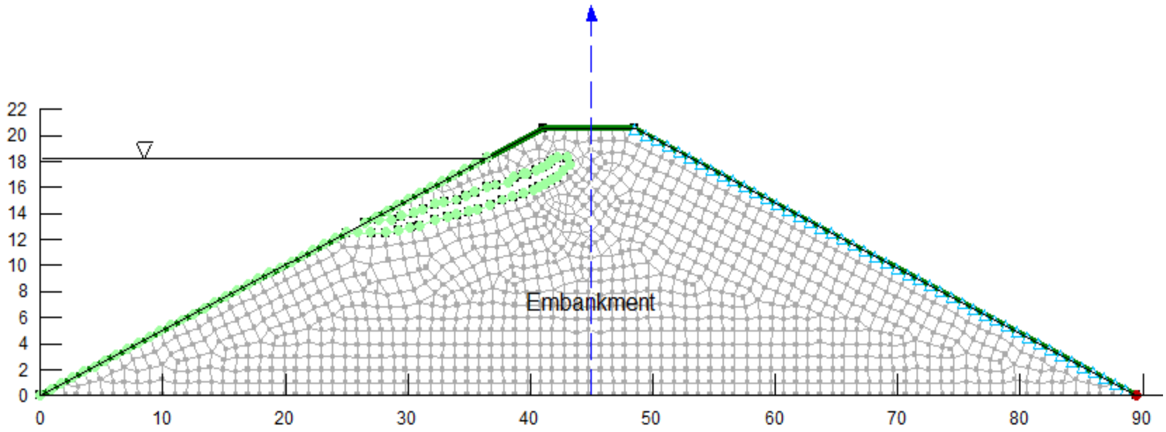

Figure 6. The model of the disturbed embankment dam by muskrat

5. Results and Discussions

In the scope of the study, selected cases are analyzed for steady-state seepage through the embankment dam body. The results included the phreatic surface locations, the seepage rates passing through the dam centerline, the lengths of the seepage faces, and the pore water pressures at pre-determined points.

The effect of three burrowing animals on the phreatic line of the seepage is presented in Figure 7 along with that of the undisturbed case. According to the results, the phreatic lines of the models which represent burrows of beaver and muskrat shift upwards, whereas that of obtained from badger burrow case shifts downwards. Both beaver and muskrat dig holes from the upstream side of the dam and the direction of these holes are towards the crest of the dam. This fact resulted in an increase in the elevations of the phreatic surfaces. In these cases, the upstream end of the phreatic lines extend horizontally up to dig holes. Then, lines follow paths with a higher gradient when they are compared with that of the undisturbed case. Contrary to these cases, badgers dig holes from the downstream side of the dam and this results in a decrease in the downstream end elevations of the phreatic line of this case. This also causes a slightly higher gradient in the phreatic surface of the badger burrow case.

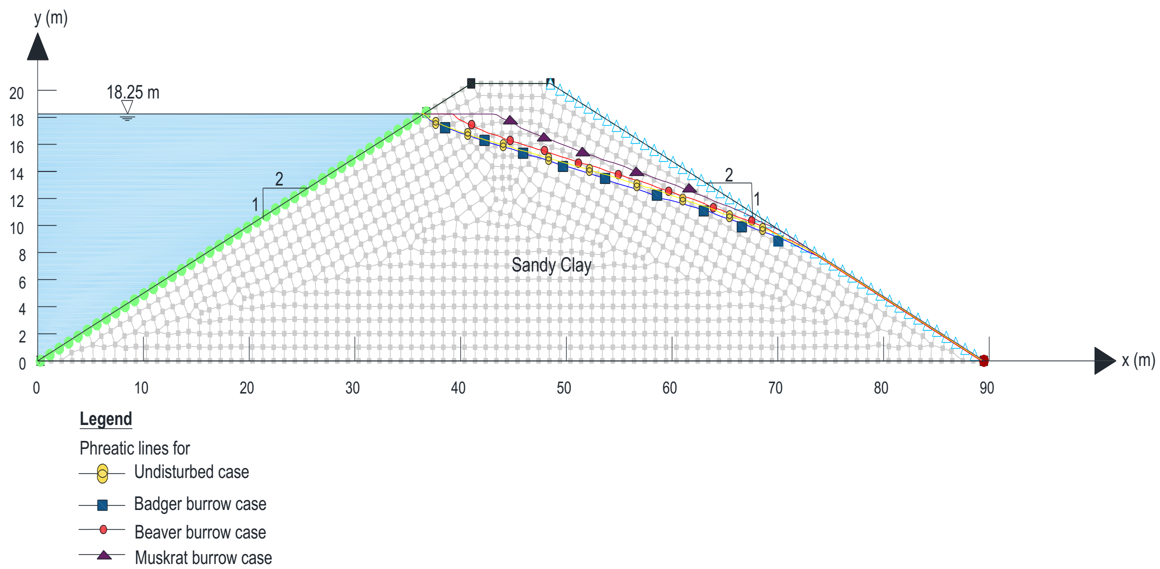

Figure 7. Phreatic surfaces of four different cases

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Throughout the analyses, seepage rates and seepage face lengths are also obtained for all cases. The seepage rates passing through the centerline of the dam are provided in Table 1, and the seepage face lengths are presented in Table 2. Also, the change in seepage at centerline and the seepage face length for all considered cases are graphically presented in Figure 8 and Figure 9, respectively. The results showed that fluxes at the dam centerline increase when the dam body is burrowed by three different rodents. This is due to the increased hydraulic gradients through the dam body. The increased hydraulic gradients are caused by steeper phreatic lines of these cases. The increases in the seepage rates are determined to be 4.0%, 6.7% and 19.0% for badger, beaver and muskrat burrow cases. The greatest seepage rate is obtained from muskrat burrow case and this burrow is the biggest in its diameter and length among other animals' burrows. When the size of the dig hole increases, the seepage rate passing through the dam increases. Besides, under rodent animal impacts, the embankment dam faces with longer seepage faces at its downstream side, except for the badger burrow case. The dig holes created from the downstream side of the dam do not result in longer seepage faces. On the contrary, the burrows on the upstream side of the dam extend the length of the seepage face. The results showed that burrows in the upstream side affect the seepage behavior of the dam more than those of created in the downstream part. Also, the size of the burrow affects the dam body in a negative way since there is an increase in the seepage rate and length of the seepage face when the size increases.

Table 1. The seepage rates passing through the centerline of the dam

Undisturbed case	Badger burrow case	Beaver burrow case	Muskrat burrow case
91.4 lt/day	95.1 lt/day	97.5 lt/day	108.8 lt/day

Table 2. The length of the seepage faces of each cases

Undisturbed case	Badger burrow case	Beaver burrow case	Muskrat burrow case
17.9 m	16.4 m	19.2 m	21.4 m

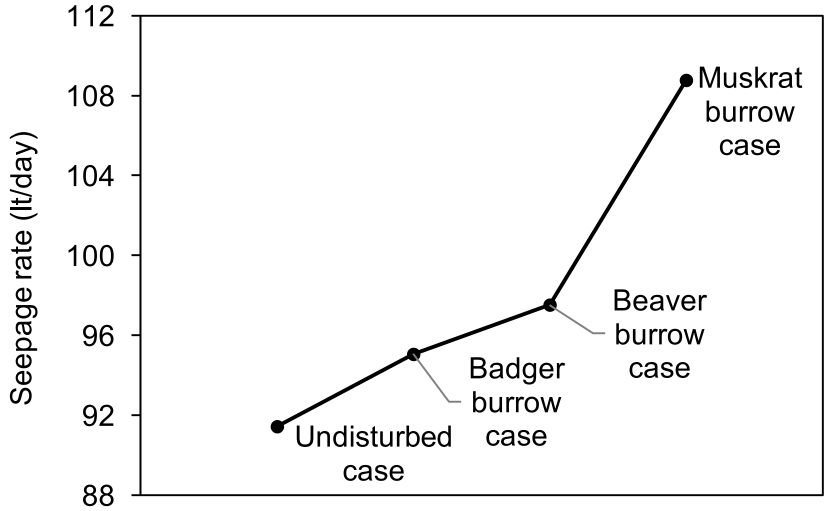

Figure 8. Seepage rates passing through the centerline for four different cases

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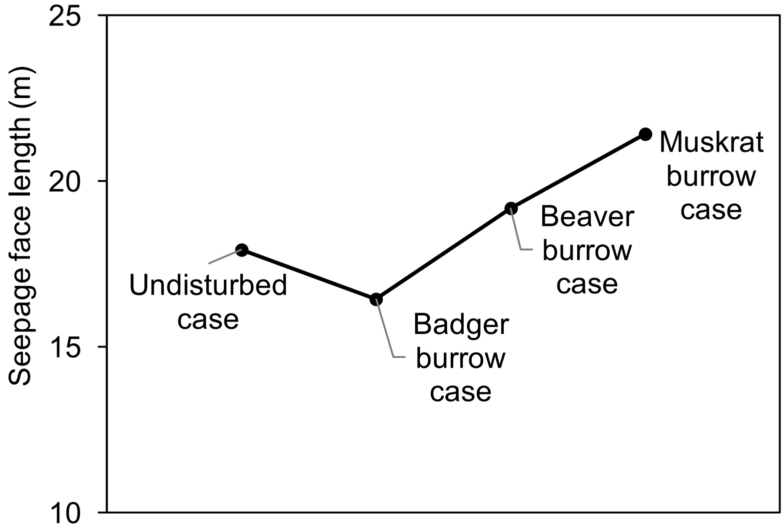

Figure 9. Seepage face lengths for four different cases

In order to observe the effects rodents on pore water pressures throughout the dam body, pressures are obtained at six different selected points. The locations of these points are shown in Figure 10. The coordinates of the points and the pore water pressures obtained for four different cases are listed in Table 3.

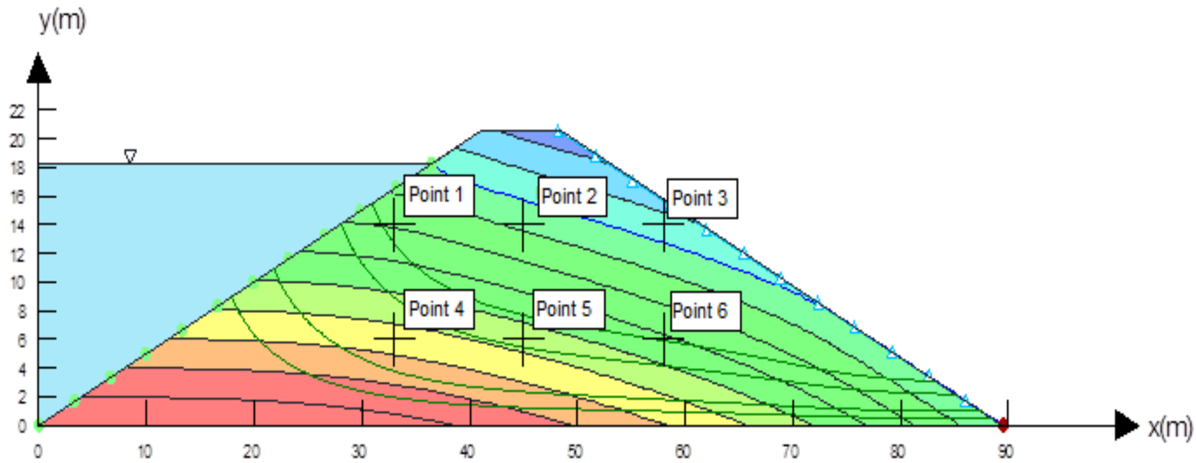

Figure 10. Pore water pressure reading points

Table 3. Pore water pressures at specified points for various burrow effects

Points	x (m)	y (m)	Undisturbed case	Badger burrow case	Beaver burrow case	Muskrat burrow case
1	33	14	37.3	38.2	40.3	46.7
2	45	14	14.9	13.2	21.3	29.3
3	58	14	-14.4	-13.0	-6.7	-1.8
4	33	6	109.3	109.4	113.4	113.7
5	45	6	92.7	87.9	93.1	99.1
6	58	6	63.1	60.4	64.1	69.1

Note: The pore water pressure values are in kPa.

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Besides, the change of pore water pressures at pre-defined points for three different burrow cases and undisturbed dam body are provided in Figure 11. Moreover, the percent difference of pore water pressure values between three disturbed cases and the undisturbed case are shown in Table 4. As it can be seen from these tables and figures, the burrow of badger caused slight decreases in the pore water pressures at most of the points. However, the dig holes of beaver and muskrat increased the pore water pressures. The maximum changes in pore water pressures are observed in the muskrat burrow case. Similar findings were presented for the location of the phreatic surface. When the size of the burrow increases, the changes in the pore water pressures increase. These changes generally result in increases in the pressures. The increase in pore water pressures may result in a decrease in the stability of the side slopes of the dam (Calamak and Yanmaz, 2014). Further analysis should be conducted to assess the stability behavior of dams subject rodent animal activity. This is outside the scope of the current study.

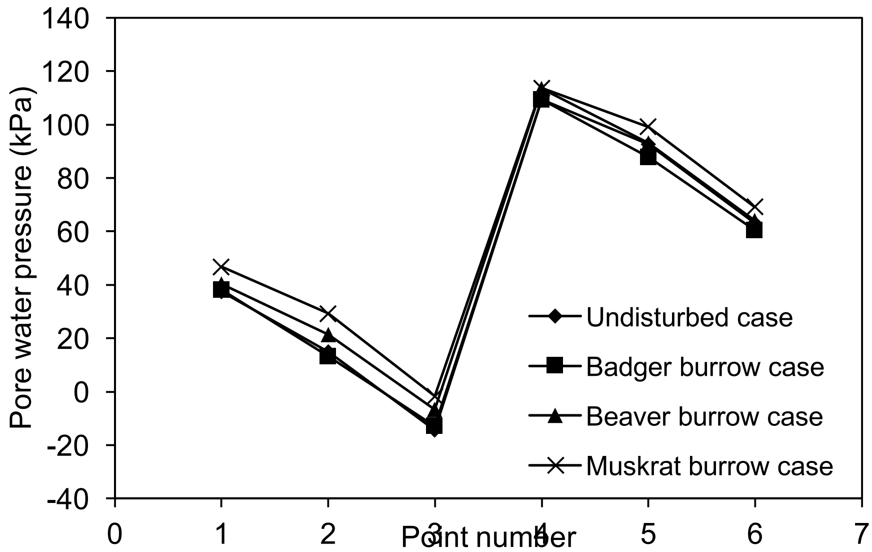

Figure 11. The change of pore water pressures with respect to different cases

Table 4. The percent differences in pore water pressures for each case with respect to undisturbed case

Points	Badger burrow case	Beaver burrow case	Muskrat burrow case
1	2.3	8.0	25.0
2	-11.8	42.6	96.3
3	-10.1	-53.6	-87.8
4	0.03	3.7	4.0
5	-5.2	0.4	6.9
6	-4.4	1.5	9.6

Note: All the values above are in %.

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6. Conclusion

This study investigated the impacts of burrowing animals on steady-state seepage characteristics of embankment dams. The seepage behavior of the dam was numerically investigated in an application problem which is subject to rodent animal activity. The analyses were conducted using SEEP/W considering three rodents, i.e., badger, beaver, and muskrat. The seepage behavior of the dam considered was examined by obtaining and interpreting the variations in the location of phreatic surface, seepage rate, seepage face length, and pore water pressures throughout the dam.

The results of the analyses showed that the rodents adversely affect the seepage behavior of the dam. The location of the phreatic surface changes in some degree depending on the size of the burrow and the rodent. If the burrows are created from the upstream side of the dam, commonly, the elevations of the phreatic surface increases. This also causes an increase in the pore water pressures throughout the dam body. Vice versa, when the burrows are based at the downstream part, the elevations of the phreatic surface slightly decrease. Similarly, this results in slight decreases in the pore water pressures. Moreover, rodent activities also change the seepage rate passing through the dam. The hydraulic gradients increase when a dam subject to animal burrows and this cause an increase in the seepage rate. All rodents considered, independently from where they are active, caused an increase in the seepage rate. However, the changes in the seepage face length are seen to depend on the place where the rodent is active. If the burrows are on the downstream side of the dam, the seepage face length may decrease. Contrary to this, when the dam is burrowed from the upstream side, seepage face length increases. When the size of the rodent and the burrow increases, the adverse effects of them on the seepage characteristics of the dam increase. Among the considered rodents, the most hazardous rodent is seen to be the muskrat due to its impacts on pore water pressures, seepage rate, and seepage face length.

The stability of the slopes of the dam may also be affected from burrowing animals since the pore water pressures change throughout the body. Further analyses are suggested to be conducted to reveal these effects.

References

Bayoumi, A. and Meguid, M. A. (2011) ‘Wildlife and Safety of Earthen Structures: A Review’, *Journal of Failure Analysis and Prevention*, 11(4), pp. 295–319. doi: 10.1007/s11668-011-9439-y.

Calamak, M. and Yanmaz, A. M. (2014) ‘Probabilistic Assessment of Slope Stability for Earth-fill Dams Having Random Soil Parameters’, in *Hydraulic structures and society - Engineering challenges and extremes*. The University of Queensland, pp. 1–9. doi: 10.14264/uql.2014.16.

Carsel, R. F. and Parrish, R. S. (1988) ‘Developing joint probability distributions of soil water retention characteristics’, *Water Resources Research*, 24(5), pp. 755–769. doi: 10.1029/WR024i005p00755.

Geo-Slope Int Ltd (2013) *Seepage Modeling with SEEP/W*. September. Calgary: Geo-Slope International Ltd.

Ghanbarian-Alavijeh, B., Liaghat, A., Huang, G.-H. and van Genuchten, M. T. (2010) ‘Estimation of the van Genuchten Soil Water Retention Properties from Soil Textural Data’, *Pedosphere*, 20(4), pp. 456–465. doi: 10.1016/S1002-0160(10)60035-

5.
Montana Watercourse and Department of Natural Resources and Conservation (no date) *Animal and Rodent Control*. Helena.
Papagianakis, A. T. and Fredlund, D. G. (1984) ‘A steady state model for flow in saturated–unsaturated soils’, *Canadian Geotechnical Journal*. NRC Research Press, 21(3), pp. 419–430. doi: 10.1139/t84-046.
Richards, L. A. (1931) ‘Capillary conduction of liquids through porous mediums’, *Journal of Applied Physics*, 1(5), pp. 318–333.
Saghaee, G., Meguid, M. A. and Bayoumi, A. (2012) ‘An experimental procedure to study the impact of animal burrows on existing levee structures’, in *Eurofuge 2012, Delft, The Netherlands, April 23-24, 2012*. Delft University of Technology and Deltares.
USBR (1987) *Design of Small Dams*. U.S. Dept. of the Interior, Bureau of Reclamation.
van Genuchten, M. T. (1980) ‘A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils1’, *Soil Science Society of America Journal*, 44(5), pp. 892–898. Available at: https://www.soils.org/publications/sssaj/abstracts/44/5/892.