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Geotechnical Study of the Dikes on the Left Bank of the Ikopa River in Antananarivo, Madagascar

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Abstract

The objective of this study is to reduce the risk of flooding in the capital of Madagascar from the study of the left bank of IKOPA which is often broken during the periods of floods of this river. In order to carry out this work, two hand auger drillings at 8.00 m depth with a pressure test every meter were carried out. In both drillings, a permeability test of the Lefranc type (NF P 94-132) was carried out. At point RGT1, the site consists of a micaceous yellowish clayey silt with a limiting pressure varying from 0.11 to 0.18MPa, blackish peaty clay with a limiting pressure varying from 0.23 to 0.24 MPa, fine slightly grey clayey sand with a limiting pressure varying from 0.52 to 1.24 MPa, the permeability coefficient (KL) is 8.20 10^{-5}m/s. At RGT2, the site consists of brown, reddish to yellowish micaceous clayey silt with limiting pressure ranging from 0.06 to 0.10MPa, yellowish micaceous silty clay to blackish peaty clay with limiting pressure ranging from 0.17 to 0.24 MPa, gray fine sand with limiting pressure ranging from 0.11 to 0.70 MPa. The coefficient of permeability (KL) is 5.30 10^{-5}m/s. The results are not consistent with the overall stability of the bank. Thus, it does not resist during the flood, by this fact, the principle of embankment construction should be controlled to avoid the breach of this bank.

Keywords

Flooding, Permeability Coefficient, Survey, Soil, Madagascar, Indian Ocean

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1. Introduction

The vulnerability of cities can be explained by a combination of several factors, including human activities, urban growth, absolute impoverishment and the continuous and uncontrolled urbanization of flood-prone areas, the rise of rivers and the opening of dykes during rainy periods. Each year, the seasonal cycle exposes tropical countries like Madagascar to a period of about five months of very high rainfall [1, 2]. During this period, the Commune located on the left bank of the Ikopa River in Antananarivo is always threatened by the floods of this river [3]. Disasters sometimes occur in the Commune, but no precautionary measures are taken to minimize them. In addition, the downstream parts of this watershed experience an overflow of water. The dikes have been breached several times when the maximum height and flow were reached [4, 5]. Our problem is the overall stability on the left bank of the Ikopa River.

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The realization of this study passes by the localization of the site from the point of view of the cartography of the floodable zones, by type of event: inundability of the plain of Antananarivo by the floods of Ikopa and its affluents - twenty-yearly floods (Q20), inundability of the plain of Antananarivo by the floods of Ikopa and its affluents - fifty-yearly floods (Q50) and then a series of pluviometric data and extreme floods.

It seems that the floods would manifest themselves from the rupture of the left bank of Ikopa to Anosimahavelona, the afternoon of January 14, 2007. 2007-2008 Flooding of the left bank valley by the breach of Anosimahavelona which has not yet been filled and 2016-2017 overflows in left bank of Ikopa to Anosimahavelona [6].

The breach of the dike comes when it is not resistible to moisture, it is not sustainable. And during the period of the extreme floods, the dam does not support the blow of the water course then that causes the rupture. The results obtained show that the cross-section of the soil in place, the pressiometric parameters and the Lefranc permeability test do not correspond perfectly to the overall stability of the dike [7, 8]. Actions such as the construction of dikes with suitable materials are therefore essential to avoid failure in order to mitigate the risk of flooding in the urban commune of Antananarivo.

Our working hypothesis is based on the risk of flooding in the lower part of the town near the left bank of Ikopa due to the destruction of the dike. This context has led us to a geotechnical study of the left bank of the dikes of IKOPA in order to put in place measures and management adapted. [9, 10].

2. Material and Methods

2.1. Hand Augering and Pressuremeter Tests

In accordance with the NFP 94-110 standard [11], this test is an in-situ loading test which allows to have the two intrinsic parameters (E: pressure modulus and Pl: limit pressure) [11].

The hand augering test allows to have first the geological section in depth of a site and to serve as a pre-hole to the pressiometric measurement every meter of depth by a radially dilatable probe under the effect of a liquid pushed by a compressed gas [12].

By interpreting the effect of the action (radial pressure of the probe) and the reaction (measured layer), the two parameters E and Pl are obtained. The purpose of these two parameters is to determine the work rate σs and the settlement of the foundation soil [13, 14].

Figure 1. On-site photos.

2.2. Lefranc Permeability Test (NFP 94-132)

The test consists first of all in making a cylindrical borehole to the depth where the permeability is to be measured [15], then in introducing a watertight tube to the roof of the cavity where the flow takes place, and finally in measuring the variation in the water level in the borehole and the volume of water exchanged (brought in or taken out). In accordance with the NFP 94-132 standard, the analysis of the results of the measurements makes it possible to determine the permeability of the soil. [16, 17].

The flow rate Q(t) percolating through the wall of the cavity is, at a given time, proportional to the Lefranc permeability coefficient KL of the soil; to the variation h(t) of the hydraulic load and to the diameter B of the cavity. It is given by the relation:

$$Q(t) = m \times KL.h(t) \times B$$

The factor m depends only on the shape of the cavity and the position of the cavity in relation to the aquifer boundaries.

3. Results and Discussion

3.1. Results of the Investigations on the Left Bank of the GTA1

The sounding point is located at about 1 km from the Fonkotany Ambaniala Itaosy going towards Anosizato.

Borehole RGT1 was carried out at 1.80 m from the bank of Ikopa (GPS coordinates: S 18°55'37.4" - E 047°29'30.5"). The results of the investigations carried out on the left bank of Ikopa at sounding point RGT1 are as follows:

1) Section of the soil in place

The sounding datum is taken at the level of the natural ground. The soil section obtained during the drilling with a hand auger shows the following profile (from surface to depth): From 0.00 to 0.10m: topsoil; From 0.10 to 4.00m: Yellowish micaceous clayey silt; From 4.60 to 6.60m: Blackish peaty clay; From 6.60 to 8.30m: Fine grey clayey sand; The water table was detected at a depth of 3.60m.

2) Pressuremeter parameters

The pressuremeter parameters obtained during the drilling on site RGT1 are shown in table 1.

Table 1. Pressuremeter parameters for site RGT1.

Depth (m)	RGT1	
	Pl (MPa)	**Pl (MPa)**
1	0.11	2.15
2	0.21	5.85
3	0.16	2.73
4	0.18	1.93
5	0.24	1.94
6	0.23	1.47
7	0.52	3.30
8	1.24	10.47

(Legend: E: pressure modulus, Pl: limit pressure)

It appears from this table that the pressure modulus (E) and limiting pressure (Pl) vary from 1.47 to 10.47 MPa and from 0.11 to 1.24 MPa respectively. The site is thus constituted of a yellowish micaceous clayey silt with a limiting pressure varying from 0.11 to 0.18MPa, blackish peaty clay with a limiting pressure varying from 0.23 to 0.24MPa, fine sand slightly grey clayey with a limiting pressure varying from 0.52 to 1.24MPa.

3) Lefranc permeability

The measurement of the Lefranc permeability coefficient at point RGT1 was carried out at 1.80 m from the bank. In the layer of micaceous yellowish clayey silt located at 2.23 m depth, the Lefranc permeability coefficient is KL = 8.20 10^{-5} m/s.

3.2. Results of the Investigations on the Left Bank GTA2

The sounding point is located approximately 500 m upstream of the Ampasika bridge. The sounding RGT2 was carried out at 1.70 m from the bank of Ikopa (GPS coordinates: S 18°54'53.6" - E047°29'42.4"). The results of the investigations carried out on the left bank of Ikopa RGT2 are as follows:

1) Section of the ground in place

The sounding zero is taken at the level of the natural ground. The soil section obtained during the manual augering has the following profile (from surface to depth): From 0.00 to 0.05m: Topsoil; From 0.05 to 0.40 m: Brown micaceous clayey silt; From 0.40 to 0.70 m: Reddish micaceous clayey silt; From 0.70 to 2.10 m: Yellowish micaceous clayey silt; From 2.10 to 4.80 m: Yellowish micaceous silty clay; From 4.80 to 6.20 m: Blackish clayey peat; From 6.20 to 8.00 m: Grey fine sand. The water table was detected at 4.00m depth.

2) Pressuremeter parameters

The pressuremeter parameters obtained during the drilling on the two RGT2 sites are shown in table 2.

Table 2. Pressuremeter parameters of site RGT2.

Depth (m)	RGT2	
	Pl (MPa)	**Pl (MPa)**
1	0.06	1.08
2	0.08	1.47
3	0.10	4.24
4	0.17	4.08
5	0.18	2.00
6	0.24	4.00
7	0.70	18.59
8	0.11	1.08

(Legend: E: pressure modulus, Pl: limit pressure)

It appears from this table that the pressure modulus (E) and limiting pressure (Pl) vary from 1.47 to 10.47 MPa and from 0.11 to 1.24 MPa respectively. The site is thus constituted of a yellowish micaceous clayey silt with a limiting pressure varying from 0.11 to 0.18MPa, blackish peaty clay with a limiting pressure varying from 0.23 to 0.24MPa, fine sand slightly grey clayey with a limiting pressure varying from 0.11 to 0.70MPa.

3) Lefranc permeability

The measurement of the Lefranc permeability coefficient at point RGT1 was carried out at 1.80 m from the bank. In the layer of micaceous yellowish clayey silt located at 2.23 m depth, the Lefranc permeability coefficient is KL = 5.30 10^{-5} m/s.

The results obtained on the two sites (RGT1 and RGT2) on the left bank show that the sites are almost composed of a yellowish micaceous clayey silt. From 4 to 6.80 m depth, we find very compressible blackish peaty clays with average strength but low bearing capacity. The coefficient of permeability is about 10^{-5} m/s; this shows that these layers are less permeable. This type of soil is very sensitive to the consolidation phenomenon. Therefore, if the bank is submerged and it is exposed to the following risks: Departures of the fines of the material (cement, sand...) constituting the embankment; movements of shrinkage-swelling of the embankment materials; evolution of the mechanical characteristics of the immersed soils which can lead to the instability of the embankment to failure; collapses of the embankment. The departure of fines is observed when the embankment is crossed by a hydraulic gradient and also during the movements of lowering of the water level. Indeed, water can carry away the finest elements when the soil is not very coherent and also when the fine fraction is not very abundant in the soil. Therefore, the fill material should be insensitive to water and have a continuous, skeletal grading curve with moderately to poorly plastic fine elements [18].

Table 3 shows the classification of soils according to the NFP 11-300 standard

Table 3. Soil classification (NFP 11-300)。

FINE Soils A *dmax≤50* mm *and* *d35 < 0,08* mm	*VBS ≤2,5 ** or *IP ≤12*	A1: silt not very plastic, alluvial silts, lightly polluted fine sands, low plastic arenas...
	*12 < IP ≤25 ** or *2,5 < VBS ≤6*	A2: fine clay sands, silts, clays and marls not very plastic, arènas...
	*25 < IP ≤40 ** or *6 < VBS≤ 8*	A3: clay and marly clays, silts very plastic...
	IP > 40 * or *VBS > 8*	A4: clay and marly clays very plastic
Sandy soils or gravelly with fine B *dmax ≤50* mm *or* *d35 ≥0,08* mm	*d12 0,08* mm *d70 < 2* mm *0,1 ≤VBS≤0,2*	B1: silty sands...
	d12 ≥0,08 mm *d70 < 2* mm *VBS* > 0,2	B2: clayey sands (low clay content)...
	d12 ≥0,08 mm *d70 <2* mm *0,1 ≤VBS ≤0.2*	B3: silty gravels...
	d12 ≥0,08 mm *d70 ≥2* mm *VBS > 0,2*	B4: clayey gravels (low clayey)...
	d12 < 0,08 mm *≤d35,* *VBS ≤1,5 ** or *IP ≤12*	B5: very silty sands and gravels silty...
	d12 < 0,08 mm *≤d35,* *VBS > 1,5 ** or *IP >12*	B6: sand and gravel clayey to very clayey.
Soils with fines and large elements C *dmax > 50* mm	*d12 < 0,08* mm or *d12 > 0,08* mm and *VBS > 0,1*	C: Flint clays, millstone clays, scree, moraines, coarse alluvium.
Soils insensitive to water D *VBS ≤0,1* *d12 ≥0,08* mm	*dmax ≤50* mm *d70 < 2* mm	D1: alluvial sands clean, dune sands...
	dmax ≤50 mm *d70 ≥2* mm	D2: alluvial gravel clean, sands...
	dmax > 50 mm	D3: alluvial gravel clean coarse gravel, glacial deposits...

(*parameter whose choice is to be privileged)

The results obtained correspond to fine soil type A and its stabilization requires such. Thus, to avoid recurrent flooding in Antananarivo, we must use D soils for materials usable in embankment. They must be used, especially at the level of the floodable part because this type of soil is insensitive to water.

It is important to note that the identification tests allow the soil to be qualified by a more precise name (clay, sand, clayey silt,...) [19]. Such a name is useful because, for each type of soil, one must know the properties to be studied, the possible risks and the main aptitudes. Thus, a clay and a clayey silt are a priori suitable for the construction of the watertight zone of a dam; a sand is not suitable; subject to a certain cleanliness, a coarse sand can be suitable for the construction of the drain of a dam; a fine soil is more compressible than a coarse soil; a fine soil is more sensitive to water than a coarse soil from the point of view of implementation [18, 19].

4. Conclusion and Suggestions

In summary, we can say that the coefficient of permeability and the usable soils determine the overall stability when these waters penetrate into the embankment body, so it is necessary to respect the constructive provisions and to choose the embankment materials well. Our result is classified on the fine soils A which are sensitive to water. It is important to use soil types D which are resistant to moisture. Such as, gravelly soils, alluvial sands and other coarse alluvial materials, low clay gravels; pozzolanic materials; alluvial sands Dmax< 50 mm and passing 2 mm >70%, low clay sands with 2 mm sieve > 70% and 80 µm sieve < 12%.

Actions such as the construction of dikes using this type of water-insensitive material and the enlargement of stream drains should be applied in the field with the aim of mitigating flood risk in Antananarivo.

The management of flood risks involves several actors who interact from the State to the local population at the base of a given space. Infrastructures and protection works for hydraulic safety go with the control of dykes. Provided that the operators are the first responsible, they must be reinforced by the equipment but also in terms of capacity building in the field.

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