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Assessment of the Infiltration capacity of a Retention pond by the TDR measurements

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ABSTRACT: Four years after the construction of a storm-water retention pond of a highway, TDR measurements were performed on the bottom surface of the pond. The distribution of water content in the surface layer is very variable but once of the electrical conductivity proves that the surface is characterised by three different values. These three values of electrical conductivity correspond to three zones of different texture so three zones of different permeability. The correspondence between the coefficient of permeability and the electrical conductivity of the soil shows that the values of the coefficient under estimate the infiltration rate of water in the basin. The infiltration capacity of the retention pond is under estimates by the value of the saturated soil coefficient of permeability. During the filing of the basin, the distribution of the water content becomes lesser variable as shown the water migration in the upper layer of the sealing layer. Thus it is noticed that TDR measurements can locate wetlands in surface layer and track its migration into the deeper layers.

1 INTRODUCTION

During many years, studies have been conducted on the permeability of manufactured products like GCL or geomembrane, for the realization of sealing layers of waste containers and retention basins. These sealing systems are difficult to maintain and difficult to repair. So it is projected to built the sealing system of a highway retention pond with the natural soil material as loam or run pit. Usually, these soils, after compaction, have not a very low coefficient of permeability.

Two local materials are proposed as sealing product. The first is produced during the pond excavation and the second is from a quarry near the site. To get information on these soils, several geotechnical tests are carried out in the laboratory. These results are used for the earthwork during the pond construction. Many standard permeability tests are carried out to evaluate the compacted soil permeability. The results of these tests prove that the coefficients of the permeability are low enough for using as sealing products for the pond.

To detect the water movement in the sealing layer of the pond, thirty TDR probes are embedded on three levels, ten probes by level. The TDR measures are acquired automatically every thirty minutes and stored on computer. Four years after pond installation, surface TDR measurements are performed to correlate

water content on the bottom of the pond and in the sealing layer. Water content repartition on the surface is compare to that observed in the sealing layer. One day after surface TDR measurements in the basin, a rainfall event has caused the filling of the basin. Process water migration in the sealing layer is described by the water content increase according to the water height in the basin. The decrease of the water height in the basin is used to determine the infiltration rate and the change in the coefficient of permeability during the upper layer saturation in the basin. The limit value of the permeability coefficient is compared with the value assessed by the electrical conductivity of the soil on the basin surface.

2 DESCRIPTION OF THE TESTED HIGHWAY ROAD RETENTION POND

The surface of the water retention pond is about 2000 m² (76m length, 26m width). The barrier thickness is 400mm. To reduce the number of probes, long rod probes made in laboratory are used. The rods have 2m length with a diameter of 5mm and there is 13mm between the rod axes as shown on Figure 1b. TDR probes are installed in five trenches. Two probes are put on three levels in every trench. The sealing material used in the basin is from a quarry near the basin. The geotechnical analyses allow identifying it as

clayey gravel. The compaction tests on the used material allow reaching a dry density of 2g/cm^3 in the wetting natural water content. Standard permeability tests prove that the average value of the saturation coefficient of permeability is 10^{-7}m/s . This value can be decreased to 10^{-9}m/s when the soil material contains more fine grains than the average value of fine grain content in the samples used for the standard permeability tests.

Once the sealing layer achieved, the excavated soil is brought into coverage and seeded with grass. Geotechnical tests on the excavated material used allow identifying it as clayey sand. Compacted at its natural water content to a layer of 20cm, the average value of dry density reaches 1.85g/cm^3 . Standard permeability tests performed on the samples of excavated soil show an average value of coefficient of permeability of 10^{-9}m/s when it is wetted at the natural water content.

The photo on Figure 1a represents the basin after TDR probe installation. Layer of 300mm of the excavated soil is compacted as the barrier system. So the pond can retain 1.50m height of water. The level gauge installed in the oil separator chamber allows the monitoring of the water level in the basin.



Figure 1. Photos of the basin after TDR probes installation and type of long length probes used

3 TDR MEASUREMENT TECHNIQUES

TDR probes allow the measurements of the volumetric water content and the electrical resistance of the soil. These measures are obtained with the relationships between soil dielectric constant and water content and between the reflection coefficient of an EM wave and soil electrical resistance. When the probes are composed of short rods of length less than 50cm, the most commonly used relationship is that of Topp et al. (1980). In this condition the dielectric constant is determined by the transit time of the EM wave in the probe. So the apparent dielectric constant which is the relative real part of the permittivity can be computed by:

$$\varepsilon_r = \left(\frac{c}{v}\right)^2 = \left(\frac{ct}{2L}\right)^2 \quad (1a)$$

where t is the transit time, L the length of the probe and c light speed in free space.

The load of the transmission line Z_L embedded in the investigated soil can be calculated with the voltage reflection coefficient ρ defined by:

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (1b)$$

Z_0 is the characteristic impedance of the cable

The ρ values can be read directly on the signal curve for large propagation time. So the load Z_L can be calculated and converted to σ_a by using probe's geometric constant. The geometric constant K_c , is experimentally obtained by immersing the probe in a solution of known salinity σ_a , measuring the impedance Z_L by TDR, using an equation identical to one of Rhoades and Schilfgaard (1976):

$$K_c = \sigma_{ref}(25^\circ) Z_L / f \quad (1c)$$

f is temperature correction; $\sigma_{ref}(25^\circ\text{C})$ is the permeant electrical conductivity; $\sigma_{ref}(25^\circ\text{C})$ is the permeant electrical conductivity.

For probes made of rods of large length, the TDR signal inversion method is used to obtain the distribution of the soil impedance along the probe (Pereira Dos Santos 1997). When the medium tested has low dissipation, soil impedance change along the probe is given by:

$$Z(t) = Z_c \exp(2\rho(t)) \quad (2a)$$

where the voltage reflection coefficient between probe entrance time t_i and exit time t_f ; Z_c is the cable impedance.

The measurement position at the time t is defined by:

$$z(t) = L \times \frac{\int_{t_i}^t Z dt}{\int_{t_i}^{t_f} Z dt} \quad (2b)$$

The two equations (2a) and (2b) give the value of the soil impedance at the position $z(t)$. The dielectric constant is obtained by the ratio:

$$\varepsilon(t) = \frac{Z(t)}{Z_a} \quad (2c)$$

Z_a is the impedance of the probe in the air.

The relationship between the soil dielectric constant and the volumetric water constant used, is one proposed by Topp et al. gives by the following equation:

$$\theta = -0.053 + 0.29\varepsilon - 5.5 \cdot 10^{-4}\varepsilon^2 + 4.3 \cdot 10^{-6}\varepsilon^3 \quad (3)$$

4 TDR MEASUREMENT TECHNIQUES

TDR measurements allow obtaining the distribution of the volumetric water content and the electrical conductivity of the soil. The distribution of electrical conductivity indicates the permeability of different zones of the basin. The distribution of coefficient of permeability is used to explain the water movement in depth.

4.1 *Distribution of volumetric water content in the basin bottom*

The distribution of the water content on the basin bottom surface is obtained by TDR measurements carried out on 40 points. The measurement points are made up of mesh of 5m side lengthwise and 3m in the direction of the width of the basin. Measurements were performed after one week without rain. During a rainfall event, the filling of the basin by the runoff water occurs, entering by the eastern zone and exiting by the western zone. The water content distribution shown in Figure 2 proves that the zone of the entrance of the runoff water remains wetter than the exit zone after the basin becomes empty. In the entrance zone, it is found water content value near the saturation value. Low values of the water content are located in the exiting zone. Water content distribution is characterised by the moisture value variation in the surface layer of the basin. These different values of the volumetric content must be correlated to the coefficient of the permeability. Alimi et al. (2012), shows that the value of the soil coefficient of permeability can be described by the electrical conductivity value of the soil.

4.2 *Distribution of electrical conductivity in the basin bottom*

The distribution of electrical conductivity in the surface layer of the basin in Figure 3 shows that three

main zones of different electrical property can be distinguished. The values of the electrical conductivity decrease from 5mS/cm in the water inlet zone to 3.8mS/cm in the water outlet zone of the pond. While the distribution of the water content in the surface layer of the basin is characterised by six different values that of the electrical conductivity is represented by three values. This shows that the electrical conductivity is rather influenced by the texture of the soil than by the arrangement of the soil grains. Simultaneous measurements of the electrical conductivity and the permeability coefficient on compacted soil samples show that the two physical quantities may be related as shown in Table 1.

It is noticed that the coefficient of permeability decreases when the electrical conductivity increases. So the distribution of the electrical conductivity proves that the central zone on the surface layer in the basin is more permeable than the inlet and outlet zones of the retention basin. This distribution of estimated coefficient of permeability in the surface layer can be verified by examining the distribution of the water content in the upper layer of the sealing layer during infiltration.

Table 1. Correlation between electrical conductivity and coefficient or permeability

Electrical Conductivity (mS/cm)	3.8	4	4.5	5
Coefficient of Permeability (m/s)	6.58×10^{-8}	6.40×10^{-8}	5.95×10^{-8}	5.50×10^{-8}

5 DISTRIBUTION OF WATER CONTENT IN THE UPPER LAYERS OF THE SEALING LAYER

In effect after the TDR measurements on the surface of the basin, 04/28/2004 from 11:30 to 16:23, the basin received rain that begins 04/28/2004 at 23:00 and ends the 04/29/2004 at 10:00. It notes a water level of 35cm in the basin 9 hours after stopping the rain.

The distribution of the water content in the upper layer of the sealing layer presented in Figure 4 proves that the central zone is more wetted than inlet and outlet of the retention pond. That means this zone receives more infiltrated water from the surface layer. The water migration through the surface layer is in agreement with the distribution of the values of coefficient of permeability estimated by the distribution of the soil electrical conductivity. It is shown that TDR measurements on the basin surface allow estimation of permeability coefficients and to locate the zones of higher permeability during retention pond maintenance.

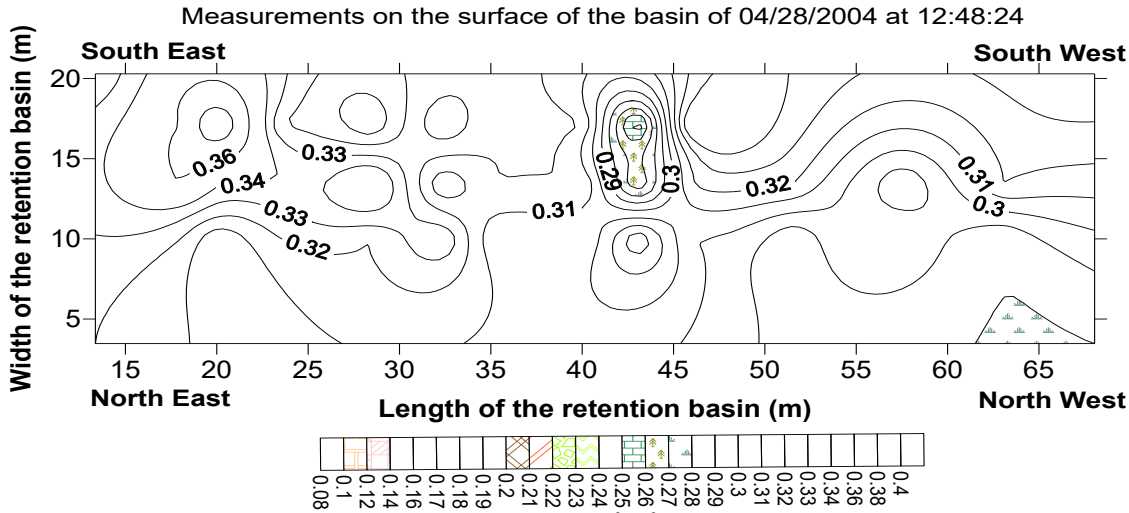


Figure 2. Distribution of the volumetric water content (m^3/m^3) in the surface layer of the retention basin after a week without the rainfall event

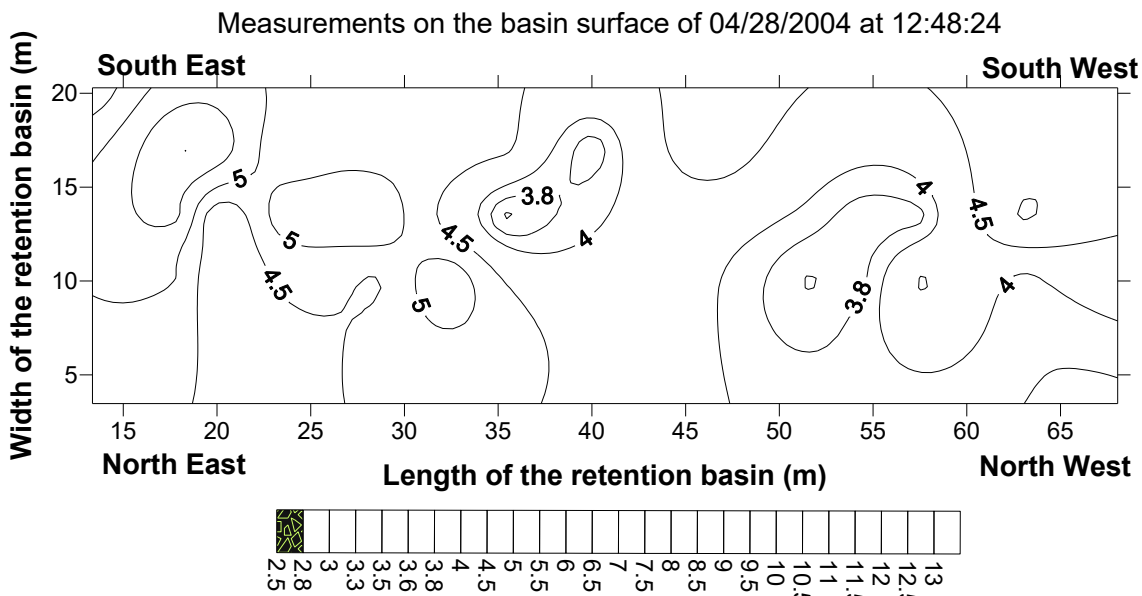


Figure 3. Distribution of the electrical conductivity in the surface layer of the retention basin after a week without the rainfall event

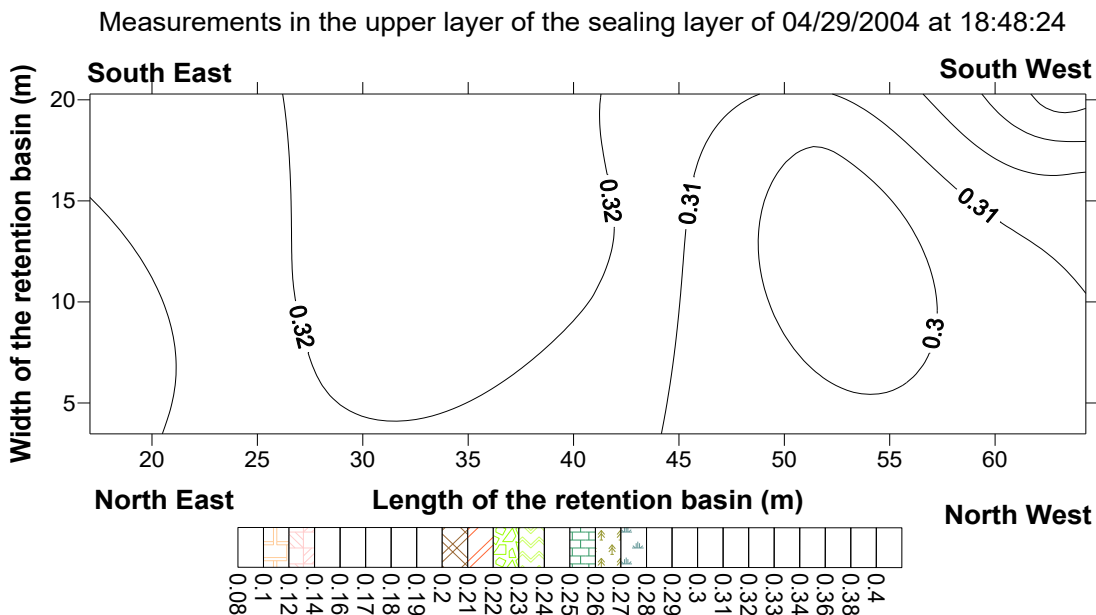


Figure 4. Distribution of the volumetric water content (m^3/m^3) on the retention basin after 9 hours the rain stop



Figure 5. Photos of the retention pond during surface TDR measurements and 9 hours after the rainfall began

Figure 5a shows the pictures of the basin during TDR measurements on the surface of the pond bottom and 9 hours after the end of the rain the next day. It is noticed that the grass on the surface of the pond bottom does not reveal the zones of different textures except when there are pebbles. The filling provides uniform coverage of the pond surface with runoff water (Fig 5b). The average value of water level reached at the end of the rain is 0.37m and real infiltration is observed 9 hours after. In this time the average level water decreases to 0.346m. This means that the average infiltration rate can be assessed to $7 \cdot 10^{-7}$ m/s. Average value of the coefficient of permeability of the surface layer of the basin, estimated to $6 \cdot 10^{-8}$ m/s, proves that the gravity water movement inside the layer remains slow compared to infiltration. It is always observed that the coefficient of permeability computed with the infiltration rate is early higher than the coefficient of permeability of saturated soil. It decreases during long time of infiltration to reach the value of saturated coefficient of permeability of the soil. The high infiltration rate in early time proves that the coefficient of

permeability of the saturated soil underestimates the soil layer infiltration capacity.

When the water content distribution in the upper layer of the sealing layer is examined, the change in water content values appeared 4 hours after the rain begins. The average water level value in this time reaches 0.16m. The change is not in the all zones at the same time. The water infiltration is delayed according to the soil permeability in the probe position in the upper layer of the sealing layer. But, considering water content distribution in sub layer, the moisture migration continues in depth before the saturation of the upper layer of the sealing layer. This kind of water migration increases the layer capacity of infiltration.

6 CONCLUSION

The purpose of this study is to identify the surface moisture state of the bottom of a retention basin to predict the movement of water in the soil during the filling. The rain that fell overnight after the surface TDR measurements gave the opportunity to examine the movement of water in the soil once the initial state of the soil moisture compiled. Despite the sod on the retention pond bottom, the distribution of moisture in the surface layer is more varied. This means that the surface layer is formed of different zones of different structures. But the water migration in depth revealed by the TDR probes in the upper layer shows that during the filling of the pond the moisture distribution becomes less variable. It is characterised by three values of water content in the upper layer of the sealing layer.

The TDR measurements also enabled the estimation of values of permeability coefficients of the bottom surface soil layer of the retention basin. It is discovered that the surface layer of the basin has zones of different texture. The estimated average value of saturation permeability coefficient is low compared to the average infiltration rate. Then it can be said that the infiltration capacity of the retention basin is higher than might indicate the value of permeability coefficient.

7 REFERENCES

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