Tietê River sediments: Properties of local materials for pollutant containment
Sédiments du Fleuve Tietê: Propriétés de matériaux locaux pour la contention de polluants

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ABSTRACT: Tietê River flows across the metropolitan region of São Paulo and collects wastes of its 18 million inhabitants and 39 thousand industrial plants. Up to 2 million cubic metres of sediments are dragged from the bottom of the river per year and disposed of at natural or artificial depressions around the city. Recent studies have shown high concentration levels of heavy metals in the sediments' pore water, which indicates the need to consider pollutant migration through local soils, liners and covers in the choice and design of disposal sites. This report presents studies that are being carried out to provide technical and scientific tools to fulfill those needs and, at the same time, expands the body of knowledge about the behaviour of compacted lateritic soils.

RESUME: Le fleuve Tietê reçoit les déchets des 18 millions d'habitants et des 39 mille industries de la ville de São Paulo. Près de 2 millions de metres cubiques de sédiments sont extraits du fleuve par an et déposés dans des dépressions naturelles ou artificielles autour de la ville. Des études récentes ont révélé des hautes concentrations de métaux lourds dans l'eau interstitielle des sédiments. If fault donc considérer la migration des polluants à travers des sols naturels et les barrières d'encapsulement pour atteindre de bons projets et pour bien choisir les locaux de déposition. Cet article présente des recherches en cours pour etablir des bases techniques et scientifiques pour améliorer le projet des locaux de déposition finale, en avouant la contamination du sous-sol. Il contribue aussi pour la compréhension du comportement des latérites compactées, lesquelles sont, par ailleurs, fort utilisées dans la construction routière au Brésil.

1 INTRODUCTION

Potable water will possibly become a most precious natural resource in the years to come, mainly because of the continuous increase in water demand and the progressive deterioration of the environment. Groundwater is generally the primary source of potable water. Despite being more protected from pollution than surface waters, subsurface aquifers are subject to deterioration, specially as a result of soil contamination. In the metropolitan region of the city of São Paulo, the open-air disposal of sediments dragged from the bottom of Tietê River can represent a significant factor of soil contamination. International regulations adopted in Brazil for the design of waste disposal sites provide general guidelines for design, but understanding the peculiarities of Brazilian soils and climate is essential to check the applicability of such regulations to specific sites. A prospective final disposal area was chosen for the research: a former sand borrow pit located in the outskirts of the City, near Guarulhos International Airport, partially surrounded by slums, sided by a water course and exhibiting a shallow water table.

2 TIETÊ RIVER SEDIMENTS

The material dragged from the bottom of Tietê River in order to minimize the disastrous floods that frequently overwhelm São Paulo is a black sludge emitting an unpleasant smell, with high concentration of organic compounds and large amounts of rubbish. After pre-treatment consisting of drainage, open air exposure to enhance organic matter deterioration, sieving, and temporary storage in intermediate disposal areas, the sediments can be classified as uniform fine sand (SP) by the Unified System of Soil Classification (USCS), and exhibit a clean appearance, normal colour and no particular smell.

Biochemical analises were carried out to determine the presence and the concentration of metals, volatile organic compounds, mononuclear and polinuclear aromatics in the pre-treated sediments. Solubility and leaching tests conducted according to Brazilian regulations indicated the presence of aluminum, cadmium, iron, manganese, mercury and zinc in concentrations higher than the maximum allowable limits.

3 SUBSOIL CONTAMINATION BY SURFACE WASTE DISPOSAL

Transport of pollutants dissolved in water in unidimensional flow through a homogeneous and isotropic saturated soil can be described by the following equation:

$$\frac{\partial c}{\partial t} = D_{hl}\frac{\partial^2 c}{\partial z^2} - u\frac{\partial c}{\partial z} \pm \Phi \qquad (1)$$

c ... solute concentration in pore water
t ... time
D_{hl} ... coefficient of hydrodynamic dispersion
z ... flow direction
u ... flow velocity (=v/n, v .. Darcy velocity)
Φ ... chemical reactions

In most waste disposal problems, only adsorption, generally represented by the linear isotherm K_d coefficient, is considered respective to chemical reactions; equation (1) then becomes:

$$\left(1+\frac{\rho K_d}{n}\right)\frac{\partial c}{\partial t} = D_{hl}\frac{\partial^2 c}{\partial z^2} - u\frac{\partial c}{\partial z} \qquad (2)$$

K_d ... coefficente of distribution
ρ ... soil density

Despite its limitations, equation (2) can be satisfactorily applied to many real cases characterized by nearly unidimensional flow, high soil saturation degree, and non-reactive pollutants.

For the study of pollutant transport though cover, liner and subsoil layers in the aforementioned disposal site, these assumptions can be considered acceptable, since the area is large, the subsoil layers fairly horizontal and the water table high. In a proper design a clay liner is considered mandatory to protect the subsoil, inasmuch the water level is practically superficial. Therefore the study was focused on the behaviour of a compacted clayey Brazilian red soil, a natural candidate for a liner; permeability, batch, diffusion and dispersion tests were carried out to assess the parameters of equation (2).

4 GEOTECHNICAL CHARACTERISTICS OF THE CLAYEY SOIL

The soil is a red lateritic clay widely available in the outskirts of the City of São Paulo. 77% of the total mass of dry soil presents diameters smaller than 0.075 mm, and 62% smaller than 0.002 mm (clay fraction). Liquid and plastic limits are, respectively, w_L = 51% and w_P = 34%, classifying the soil as an inorganic clay of high plasticity (CH) according to USCS. A standard Proctor compaction test yielded 14,65 kN/m^3 and 26,5% as, respectively, the maximum dry unit weight and the optimum water content. Lateritic soils have been much used in the last decades as material for road bases and subbases in the state of São Paulo, and cover a large extension of Brazil.

The specimens used in the permeability, diffusion and dispersion tests were compacted statically at varying moulding water contents, from -2,5% to +2,5% relative to the optimum standard Proctor water content, and at compaction degrees varying from 95% to 103% relative to the maximum dry unit weight at standard Proctor energy.

Permeability tests were performed in triaxial cells (flexible wall permeability tests). Preliminary tests indicated a not very significant variation of the measured permeability as a function of the applied confining pressures and gradients; test duration could therefore be reduced while still ensuring reasonable accuracy of results.

The diffusion tests followed the procedure described by Barone et al (1989). The specimens were compacted directly in the moulds, saturated by capillarity and seepage, and submitted to about ten days of diffusion. The diffusion mould had a reservoir for the pollutant solution topping the soil specimen and no possibility of seepage, so that ions were expected to migrate from the solution through the soil, driven only by a concentration gradient; at constant time intervals samples were taken from the fluid reservoir to monitor the solution composition.

Dispersion tests (column tests), as described by Freeze & Cherry (1979), were conducted on the same specimens used for permeability tests, substituting water by a solution of metal ions in distilled water. The tested solutions were synthetic mixtures of the six metals foun in high concentrations in the disposal material pore water (see item 2 above). Different concentrations of each metal and various relative proportions of the six metals were used, since the adsorption of a group of metals is not necessarily equal to the sum of the adsorptions of each separate metal.

Batch tests were performed in accordance with USEPA guidelines.

5 RESULTS

The permeability coefficient of the red soil is about 10^{-9} m/s at the optimum compaction conditions. Such a high value when compared to clays with similar Atterberg limits and grain size distribution curves, may be explained by the porous microstructure of lateritic soils. The permeability of this soil depends drastically on moulding water content and compaction degree, showing variations of 3 orders of magnitude for the range of tested compaction conditions. The relevance of this conclusion is enhanced by the experimental evidence that deviations from the specifications usually occur in the field, even when compaction is well controlled, and that significant spacial variation of permeability is the rule for compacted soil layers (Rogowski, 1990 apud Benson & Daniel, 1994).

Diffusion tests are being carried out and no final conclusions can be set forth yet. Lateritic soils are highly enriched with iron and aluminum oxides and hydroxides throughout the intense weathering, which is a characteristic of the process of soil formation known as laterization. These oxi-hydroxides occur as "concretions", assembling clay particles in arrangements usually regarded as physically and chemically stable.

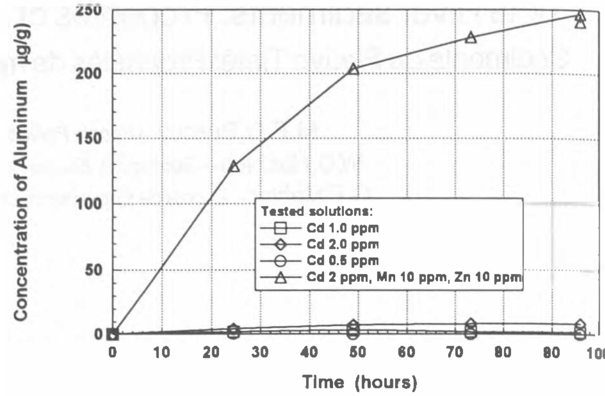

Figure 1. Aluminum concentration in the fluid reservoir after 4 days of diffusion

However, pure diffusion through the soil of the metal ions utilized in the tested solutions seem to be accompanied by more complex phenomena derived from the contact of the concretions with an acidic environment. This speculation is enticed, for example, by Figure 1, which shows the measured concentration of aluminum in the fluid reservoir for four specimens compacted statically at standard Proctor optimum conditions, each topped by a different synthetic solution. The initial solutions consisted of cadmium or a combination of cadmium, manganese and zinc, and had pH values ranging from 1 to 2. It should be pointed out that aluminum was not present in any of the synthetic solutions, and that its initial concentration in the specimen pore water was below 1 µg/g. Repeatability of the results of Figure 1 was verified in 32 different tests.

Batch tests seem to indicate low adsorption capacity, as might be expected from the soil mineralogy: kaolinite, which is almost inactive, is the predominant clay mineral in lateritic soils.

6 CONCLUSIONS

The consideration of the pollution transport mechanisms of diffusion, mechanical dispersion, advection and adsorption is very important for the improvement of the design of waste disposal sites. More research is necessary before lateritic soils, one of the most frequently and extensively used type of soil for compacted fills in Brazil, can be effectively used as clay liners. Advection can be the dominant phenomenon, since drastic variations in permeability can result from small deviations from the specified compacted conditions. More investigations are needed to account for the chemical reactions that may take place when such soils are exposed to acidic solutions, and that might turn out to be as significative as the diffusion and adsorption mechanisms.

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