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Extended summary

Analysis of factors affecting the hydraulic performance of plastic diaphragms for side containment of polluted soils

Curriculum: Materials, Water and Soil Engineering

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Abstract

Plastic diaphragms made of water-cement-bentonite mixtures (CB) are widely used as barriers against migration of pollutants in polluted sites. In the present work some of the main factors affecting the hydraulic performance of such passive barriers have been studied. In particular, the studies concerned the hydraulic efficiency of diaphragms with casting discontinuities, the influence of slag percentage of blast furnace slag cements on the hydraulic performances of the mixture and the migration of sulphate solutions (with particular focus on salt and acid solutions). By means of numerical modeling, the migration parameters of sulphate and potassium were investigated.

Tests of hydraulic conductivity, column tests and batch tests were performed on samples of CB mixture. The batch tests were performed with the aim of evaluating sorption mechanisms of the chemical species considered, taking also into account the variation of the curing time of the diaphragm.

On the basis of long-term testing, carried out on mixtures permeated with different sulphate solutions, the durability of diaphragms was investigated and a general criterion is proposed aimed at designing site containment of polluted soils.

Keywords

Cement-bentonite mixtures, sulphate solutions, sorption, diffusion, casting discontinuities.

1 Problem statement and objectives

The performances of plastic diaphragms made of cement-bentonite (CB) mixtures depend on various factors which can be classified in three main categories: intrinsic factors, construction factors and environmental factors.

Intrinsic factors are associated to the types and dosage of components, and to the mixing procedures (e. g. the specific energy, the sequence of mixing).

Construction factors are associated, for instance, to soil and groundwater englobing inside the barrier during the construction ([1]; [2]), or to the need of casting fresh mixture in contact with cured mixtures. This last problem is particularly of major concern because a casting discontinuity can compromise the functionality of the diaphragm, but it is bound to happen in barrier construction (e. g. closure panel, or excavation by primary and secondary panels). Casting discontinuities occur in case of work interruption or to repair fractured diaphragms. Literature data available on CB mixtures refer mainly on the hydraulic behavior of the diaphragms when they are short-term cured and only few studies are focused on the long-term performances of the mixtures or on problems associated to possible loss of performance of barriers that are in service since long time ([3]; [4]).

In addition to the intrinsic and construction factors, also the environmental factors (as weather, temperature, stress conditions and level, type of contaminant in contact with the mixture) can influence the efficiency of CB mixtures.

The type of pollutant that migrates through the barrier is of particular importance; in fact the migration parameters (as the diffusion coefficient or sorption parameters) change with the type of pollutant and consequently the transit time through the barrier.

Although the widespread use, few data are available in literature ([5]; [6]; [7]) on the long-term performance of the CB diaphragms and on migration parameters for the most common chemicals.

In the present work various mixtures (different for type and quantity of components) have been studied, all of them prepared in the laboratory using III/A or III/B blast furnace slag cement.

By means of long term hydraulic conductivity tests (some of which carried out up to 1 or 2 years), the hydraulic performance was investigated as a function of the mixture composition (in particular the slag percentage).

Referring to the construction factors, the current research work in the SIMAU Department of Università Politecnica delle Marche about casting discontinuities has been widen, with the aim to foresee the hydraulic conductivity of a diaphragm, both at short and long-time curing time, as a function of the types and dosage of the components, of the composition of blast furnace slag cement and of the difference in the curing time between castings.

Finally, with reference to environmental factors, the migration of sulphate solutions have been studied. In particular the migration parameters of sulphate and potassium through CB barriers were investigated.

A further aim of the present work was the estimation of durability of CB diaphragms in sulphatic ambient and the determination of a general method for designing a barrier to be constructed in chemically aggressive sites.

2 Research planning and activities

In order to study the influence of the casting discontinuities and of the cement composition, various mixtures have been investigated (all of them without additive), prepared in the laboratory according to the procedures reccomended by ETC8 [8].

The mixtures are different for type and dosage of components and have cement/water ratios between 0.19 and 0.24.

Samples with and without discontinuity were prepared, and then subjected to falling head hydraulic conductivity tests in flexible wall permeameters.

Considering also the results of the research in which this study is included, differences in the curing time ranging from two week and one/two years were investigated.

The experimental results obtained from hydraulic conductivity tests have been interpolated by means of the following relation that associates the permeability (k) to the curing time (t) of a CB mixture ([3]):

$$k(t) = k_R \left(\frac{t}{t_R} \right)^{-\alpha} \qquad (1)$$

where k_R [L/T] is the hydraulic conductivity at the reference time t_R [T] and α is a dimensionless coefficient that indicates the reduction rate of the permeability with time and it is function of the cement type and content.

The measured hydraulic conductivity (k_m) of each sample with casting discontinuities has been compared with the “perfect” hydraulic conductivity (k_p), that is the conductivity of the sample without preferential flux through the discontinuity. The perfect hydraulic conductivity has been calculated by the equation (1) on the basis of the results obtained from the study of the sample without discontinuity, considering the different curing time between castings.

With reference to the migration of sulphate solutions, a mixture prepared with III/B blast furnace slag cement and activated Na-bentonite has been investigated. This mixture has good hydraulic performance and a good workability. After a brief curing time in tap water at room temperature, the samples were tested performing batch tests specifically set up for CB mixtures and column tests with solutions of K_2SO_4 and H_2SO_4 at different concentrations.

The hydraulic conductivity with curing time and the breakthrough curves of sulphate and potassium have been obtained by column tests.

Since contaminant migration trough a cement-bentonite barrier can be strongly modified by sorption, batch tests have been carried out, with the aim to investigate sorption capacity of the mixture with reference to sulphate solutions, varying: type of solution, concentration, solid-liquid contact time, mixture curing time.

The sorption isotherms have been used to model, by means of program POLLUTEv7, the experimental breakthrough curves to evaluate the migration parameters of the sulphate and potassium ions.

With POLLUTE software it is possible to model the contaminant migration through a porous media taking into account advection, diffusion, mechanical dispersion and sorption. Furthermore, the software permits to consider the variation of the seepage velocity with time as really happens in the CB mixtures.

3 Analysis and discussion of main results

To evaluate the influence of cement composition on the hydraulic performances, the permeability test results carried out on samples with same type and dosage of components but cements with different chemical composition, have been compared.

Furthermore the values of the α coefficient obtained by interpolation of experimental data were compared, to determine the influence of the chemical composition on the long-time curing.

In the processing of the results the mixtures with different type of blast furnace slag cement (III/A o III/B) have been divided.

With reference to the part of the research related to construction factors, to evaluate if and how a casting discontinuity can change the hydraulic performances of the mixture with time, the values of α coefficient related to the samples with and without discontinuity were related to the cement/water ration and to the difference in the curing time between castings.

For every mixture the ratio between measured hydraulic conductivity and “perfect” hydraulic conductivity were showed as a function of curing time.

The results show that the effects of a discontinuity, in terms of reduction of hydraulic performances, are more evident the longer the time between castings and the better the hydraulic performances of the mixture.

The behavior of the mixture with reference to a casting discontinuity has also been studied as a function of the chemical composition of cement (for both III/A and III/B types).

With regard to the column tests carried out with sulphate solutions, after a curing time of about 2 weeks in tap water, the mixture samples were put into flexible wall permeameter and were permeated under a constant hydraulic gradient (i = 30).

Concentration of sulphate (SO_4^{2-}) and potassium (K^+) (in case of potassium sulphate solutions) in the effluent liquid have been measured to obtain the breakthrough curves.

The samples, permeated with sulphate solutions, are characterized by an initial decrease of the hydraulic conductivity with time, mainly due to gypsum formation, produced by the reaction between sulphate and calcium dioxide.

During the first days of permeation the gypsum formation causes the pore clogging and then the decrease of hydraulic conductivity. After this decreasing there is a fast permeability increase, caused by the subsequent ettringite formation ([9]) that occurs by the reaction between tricalcium aluminate (C_3A) and gypsum. The secondary ettringite, with its expansive action, produces an increase in volume of sample and consequently the formation of fissures. The results show that, in presence of chemical aggressive species, during the design process it is necessary to study and foresee the hydraulic performances of the mixtures with time, to evaluate the durability in the long-term (fundamental in case of self-hardening diaphragms).

In the present study a general criterion has been found and proposed that is useful to design a site containment of polluted soils.

By the batch tests the sorption isotherms that better describe sorption of sulphate and potassium by a CB mixture in case of potassium sulphate solution and sulfuric acid were obtained. Furthermore it has been studied how the curing time can influence the sorption capacity of CB mixture.

Using the program POLLUTEv7, the breakthrough curves were modeled, obtaining a good fitting of the experimental data, from which the diffusion coefficients (D*) and hydrodynamic dispersion coefficients (D_H) of sulphate and potassium were estimated.

4 Conclusions

Notwithstanding the widespread use of water-cement-bentonite mixtures for the confinement of polluted sites, relatively few data are available in the literature on the hydraulic performance of damaged diaphragms (e.g. fractures due to drying or to the soil movement). Moreover, with reference to the pollutants commonly in contact with the barriers, few data about the migration parameters are available.

In the present work, some of the main factors affecting the hydraulic performance of CB diaphragms have been studied. In particular, the influence of casting discontinuities, of composition of blast furnace cement and the migration of sulphate solutions (potassium sulphate and sulfuric acid) were investigated.

In CB diaphragms the hydraulic conductivity decreases with time. The reduction is modelled by a coefficient called α, which depends on the cement/water ratio and on the percentage of blast furnace slag in the cement. Using the correlations between α and the cement/water ratio obtained for type III/A and III/B cement, it is possible to estimate the mixture's hydraulic conductivity with time and to predict the long-term hydraulic performance of the CB barrier.

In the mixtures with type III/A cement, the blast furnace slag percentage can vary in a relatively wide range (36 – 65 %) and therefore, unlike mixtures with type III/B cement, the variation of the cement composition can yield different hydraulic performances.

With reference to the constructions factors, it's frequent to have the necessity of casting fresh mixtures in contact to cured ones. Generally, if the second cast is carried out within two weeks, the hydraulic performance of the barrier is not affected, but for longer time intervals between casts, the barrier performance can be worsened.

This effect becomes evident increasing the curing time and it is more evident the longer the time between castings and the better the hydraulic performance of the mixture.

In the study of the sorption mechanisms of potassium sulphate and sulfuric acid solutions important results have also been obtained.

For type III/B cement, even though the composition has no influence on the hydraulic performances of the diaphragms, it can modify the sorption of the pollutants by the mixture.

In the presence of potassium sulphate solutions, sorption of the K^+ ion is well represented by a linear isopleth and doesn't change with curing time. A good representation of the sorption of the SO_4^{2-} ion is obtained through the Langmuir isopleth. The sorption of the SO_4^{2-} ion decreases as the curing time of the diaphragm increases.

On the basis of the test results obtained with potassium sulphate and sulfuric acid solutions, the influence of the curing time on sorption was demonstrated. This influence plays an important role in the study of the migration processes through a self-hardening diaphragm. This aspect was taken into account by modeling the breakthrough curves obtained from column tests, carried out with solutions of potassium sulphate. The migration parameters of the chemical species, knowledge of which is very important for the design of a CB cut-off wall, were determined by fitting of experimental data with a numerical model. In particular, by modeling the sulphate and potassium breakthrough curves, values of the diffusion coefficients D* of the same of magnitude as compacted clay soils (10^{-6} cm^2/s)

were found. Additionally, for K_2SO_4 concentration higher than 5 g/l, relatively high values of the tortuosity factor (from 0.2 to 0.5) were found.

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