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Development of grout for additional seal embankment dams

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Abstract

The technology of sealing sand and gravel by chemical injection has been known and used for a long time. Chemical grouting is however expensive and sometimes the use of cement does not lead to the desired effect. That is why we are trying to find new materials and methods of injection. Clay and cement are added to a mixture save chemical products. Clay-cement mixes are used not only because they are better quality, but also because these mixtures have a tendency to penetrate better into incoherent sediments that would need an additional sealant of a chemical injection. In order to reduce cost in future, ordinary clay is replaces in the mixture secondary raw materials can be a suitable substitute for ordinary clay to a certain extent. This is true above all for fly ash. This paper deals with the appropriateness of using fly ash (secondary raw material), cement and lime (binders) and liquefying additives and examining their properties in the mixture. The aim of the paper is to propose the optimal injection mixture for additional sealing of earth dams.

Keywords: additional sealing earth dams; injection; grout; clay; clay suspensions; lime; cement; ash; yield fluidity; consistency; contraction; strenght

1. Introduction

Embankment dams according to Embankment dam [1] are one of the simplest types of water works. They are very common in the Czech Republic. In most cases, they are small dam water works, such as ponds, reservoirs, etc. Embankment dams were mostly constructed in the 60th to 90th of the 20th century, therefore now there are often leaks and losses of stability. We could see this especially in 1997 and 2002 during the catastrophic floods. For this reason, it is highly desirable that the embankment dams are remediated. Due to the fact that the waterworks are

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relatively small and there are a lot of them, the traditional injection has been selected as the optimum remediation technology. The technology was selected according to an optimization calculation. In damaged dams, seepages appear which can have catastrophic consequences that can occur over weeks or months. Close monitoring and securing of the dams is therefore necessary.

When choosing a remediation technology of the embankment dams, it is good to think of such technologies that will cause no further damage to the dam. In choosing the appropriate material composition, secondary energy products are preferred as a partial replacement of clay. It is also important to choose material that is soft and fine enough to penetrate into the discontinuities in the dams (voids, cracks, cavities etc.), and fill them. After the suitable materials have been selected, the composition of the mixture is suggested. Afterwards, it is necessary to carry out tests to see if the requirements for the grout are met. By reviewing individual tests, the optimal composition of the injection mixture for the rehabilitation of earth dams will be selected.

2. Fundamental characteristics of grouting mixes

If the seal of earth dams is to perform its function, the adapted injection mixture, according to Hobst et al. [2], must be selected according to the type of the dam and it must suit many local conditions. This can be achieved by e.g. the choice of the construction materials, modification of technological processes and identifying the best location for the sealing of the dam construction.

Verfel, Tkany [3] says that the seal of sand or gravel – i.e. just using chemical injection, has been known for a long time. However, the costs of this method of injection are increasing. Moreover, the use of cement often does not lead to the desired results. We are therefore trying to find new materials and new technologies of grouting procedures. Cement and clay are added to the mixture in order to save chemical products.There are many types of mixtures that are suitable for sealing alluvia, for example the clay-cement mix, and chemical mixes of synthetic resins, etc. The choice of the mixes is always based on the grain-size curve of the injected and the environment specific surface grains, the level of porosity, etc.

According to the rheological behaviour that determines the applicability of the mixture, the grouting mixes are divided into an unstable suspension, a stable suspension, colloidal solutions (evolutional), pure solutions (non-evolutional) and gaseous emulsions (expanding mixes which greatly increase in volume). The correct mix design and its pumping are important. It is also vital that sedimentation in the injection does not occur before its solidification. According to Keller [4], it is mainly the clay-cement and the clay-lime mixes that do not sediment, and they have enough liquid and they have sufficient resistance to flooding after pumping when they are designed properly. It is however not so simple to achieve all these conditions in practice.

During the injection, a large amount of the mixes is consumed. Therefore, it is necessary for economic reasons to design and choose the type of the mixture properly. When reviewing the main parameters of grouting mixes, the important parameter is water decantation. When using a suitable grout there is no decantation. The examples of such stable suspensions according to Keller [4] are:

- Clay-cement suspensions of clay or bentonite,
- Chemically stabilized clay or bentonite suspension (only for sealing),
- Cement suspensions based on superfine cement.

3. Grouting loose soils

The grouting mix can be used only to seal permeable gravel-sand alluvia dams. Thus formed inhomogeneous sediments form pores which need to be injected, in order to avoid leaks. A wide enough air curtain has to be made during the grouting process. This is achieved by creating a multi-line grout curtain. The external lines are injected first, followed by the injection of the inner lines. This procedure prevents the leakage of the injection mixture from the inner lines from the area of the air curtain. The alluvia are thus sealed. The grouting mix is therefore chosen according to the permeability of the environment that needs injecting. This is mostly based on the grain-size curves.

3.1. Grouting methods in loose soil

One of the most technologically and economically appropriate ways of repairing dams, is using the classical injection technology. This method is very widespread because of the simplicity and efficiency of this technology. It is used, for example, in the implementation of sealing walls, micro piles, rock bolts, etc. The properties of foundation soils are thus improved, and also leakages are thus reduced.

Classical grouting

As it has been said, the grouting technology improves the properties of foundation soils. *Building foundations* Maceková [5] describes the injection where the injection mixture is injected under pressure into the dam. The discontinuities in the embankment that can cause leakage are filled in this way. The discontinuities can be e.g. layering gaps, cracks, fissures and others. The physical-mechanical parameters of rocks are improved by filling this empty space by grouting. Thus the compressive strength and the deformation modulus are improved and the permeability is decreased.

The used injection mixtures can be either made of clay grout alone, or they can be stabilized cement mixes, which are stronger, or clay-cement mixtures used for sealing. In order to reduce or to prevent the permeability, the largest grain of injection mixture should be at least 3 times smaller than the pores of the injected area so that the grains can easily penetrate into the discontinuities, cavities, voids etc. Larger grains prevent penetration, and the accumulation of such grains can build a barrier that makes transmission of the mixture to the right place impossible. Grouting would thus be inefficient.

3.2. Grouting tests

In order to determine the appropriate composition of the grouting mix, it is necessary to do a series of tests in the laboratory. It is necessary to know the interaction between these components, etc. The mixture recipe should be determined for each site separately. The consistency, viscosity, decantation, unconfirmed compressive strength etc. are determined by testing.

At first, the properties of materials are tested in order to design the grout, especially its *grain-size*. Next, grouting mix in raw state are tested. This includes the *yield value, the consistency, the viscosity, the decantation, and the volume weight*. Finally the properties in the hardened state are tested. This includes the unconfined *compressive strength, the volume weight, the contraction, the permeability –i.e. the filtration coefficient, the ecotoxicity, and the leachability*.

4. Grouted medium

The main raw material for grouting is clay. Thanks to its mineralogical composition, it is used as the basic building unit of the injection mixture. The consumption of the mixture is high in the implementation; therefore, it is advisable to choose materials which are easily available in order to avoid high cost of the implementation. As it is stated in Drochytka, Cerny, Venhodova [6], raw materials for the grout could be divided into three main categories:

- Sealing materials – high swelling pressure, low coefficient of filtration,

- Binders – high compressive strength and flexural strength,
- Fillers – optimal maximum volume weight at a given humidity.

It is important that the final mixture is plastic. According to French experts (Cambefort, Isch, Caron), only the clay whose yield value is at least around the value 60 % can be used to produce the clay-cement, the clay-lime or the clay-chemicals mixtures.

4.1. Clay Ge

When designing the grouting mix, attention must be devoted to the selection of suitable clay. Hobst et al. [2] says that from the viewpoint of granulometry, the clay cannot have more than 5 % of the grains of 0.02 mm in diameter or larger. Ge clay is a typical representative of montmorillonite-illite-kaolinite clay. The Ge clay yield fluidity is about 85 %. It contains classical montmorillonite clay, illite and minimum kaolinite. The presence of illite gives the Ge clay its plastic properties, due to which it can be classified in the category of clay with very (or extremely) high plasticity according to the standard ČSN 75 2410. Clay Ge according to ČSN 73 6850 belong between very impermeable soil. Thanks to its excellent properties (swelling, plasticity), Ge clay is used as the main material in the design of the injection grout.

4.2. Ash, fly ash

When designing grouts, the economic aspect is an important factor. Therefore, there is the effort to replace the main raw material, which is clay. It could be done by using an alternative that will fulfil similar functions and will not deteriorate the mixture parameters. Such a suitable alternative material is ash. It is a very fine-grained powder (grain size 0 – 1 mm). Ashes can be divided into (ordinary) ash and fluid ash. As with clay, when using fly ash, it is also important to know the physical, the chemical and the mineralogical properties before we use it. The selection of ashes was based on their perspectivity. The authenticated ash from the power plant (ETU) represents a new source of ordinary ash, and that is why it was chosen as an alternative to substitute clay. The other is fly ash (ETI). This fly ash was chosen for comparing with ordinary ash.

4.3. Binders

Igles, O. and Metcalf, J. in their book [7] list the five most important qualities that the mixture must have to be suitable for use. They are: strength, stability, permeability, durability and versatility. Suitable representatives of earth stabilizers are precisely those that can be broadly used for various types of soil or clays and which are inexpensive. Cement and lime meet these parameters. During stabilization of clay with lime, rapid reactions occur on the surface of clay grains. These reactions can change the heaviest clay soil immediately after mixing. The stabilization by lime has a tendency to change clay soils that would otherwise soften, disintegrate and dissolve in water into a solid and waterproof material. In addition to increasing the strength of the soils, lime also improves their permeability, erosion resistance and it significantly improves their dimensional stability. Despite the advantages of using lime, it is necessary to mention that the strength does not increase as much as when cement is used.

5. Mixtures based on Ge clay , ordinary ash (ETU) and fly ash (ETI)

The following figures show the recipes and demonstrate how adding water changes the consistency according to Marsh cone in the range of 60 ± 20 s. The basic raw material used was the standardized quality Ge clay (montmorillonite-illite) which was mixed with ash and fly ash (25 %, 50 %).

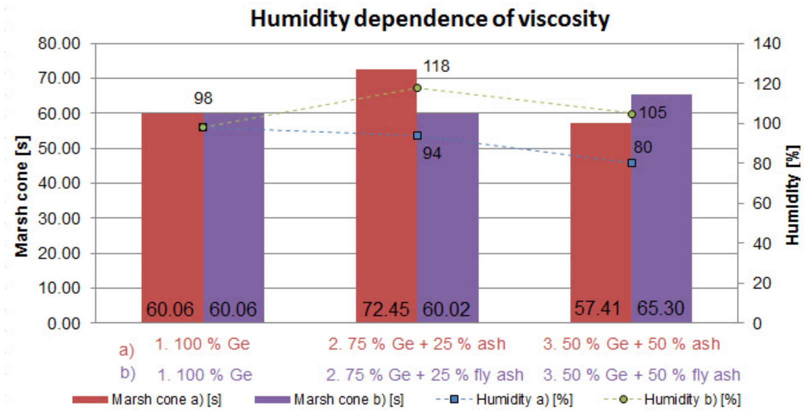

Fig. 1. Humidity dependence of viscosity suspension based on Ge clay, ash and fly ash.

Figure 1 shows that the required amount of water decreased when the ash amount increased. Due to its greater fluidity, clay has a tendency to bind larger quantities of water. It could be seen in its consistency. When comparing ash with fly ash, we can see that the increase of the amount of fluid fly ash required the increase of the necessary amount of water, in order to determine the consistency by means of Mars cone. Ash improved rheological properties but it also increased decantation. Therefore, when designing a mixture, it is suitable to select such quantity of fly ash that will not increase water decantation, but which partly improves the rheological properties of the mixture. The optimum amount of ash is up to about 25 %. The presence of fly ash greater than 50 % deteriorated the rheological properties of the mixture, thereby making increased amounts of water necessary. We can say that the addition of more than 50 % fly ash is ineffective, because the mixture parameters deteriorate.

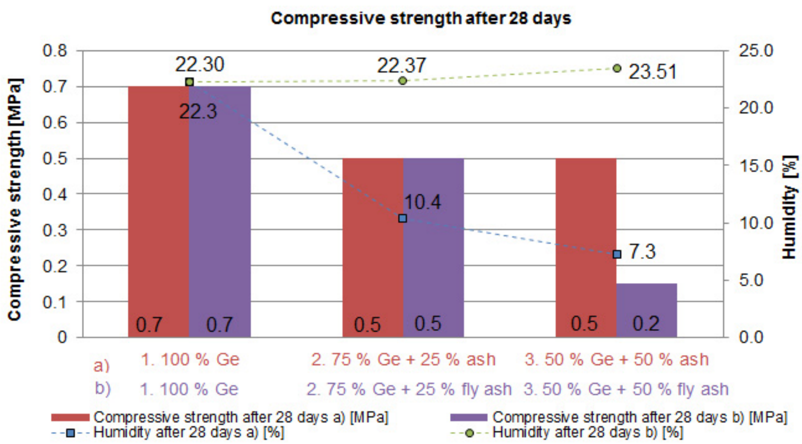

Fig. 2. Results of the strength determination and humidity of samples based on Ge clay, ash and fly ash.

Strength decreased when the ash amount is increased. The bonds of clay and ash are weaker due to the decline of strength. So it is evident that the optimum amount of ash, which can be added to the mixture is about 25 %. Fluid fly ash was the strongest. This was because of the higher content of more reactive CaO, which is the strength bearer in fly ash.

6. Mixtures based on Ge clay, ash, lime and plasticizing additive

In the next stage, the impact of plasticizers and lime was tested. The amount of added ingredients was verified. It is good to use plasticizing additives if they do not increase the cost of the mixture. The following figure shows the test results of the mixes.

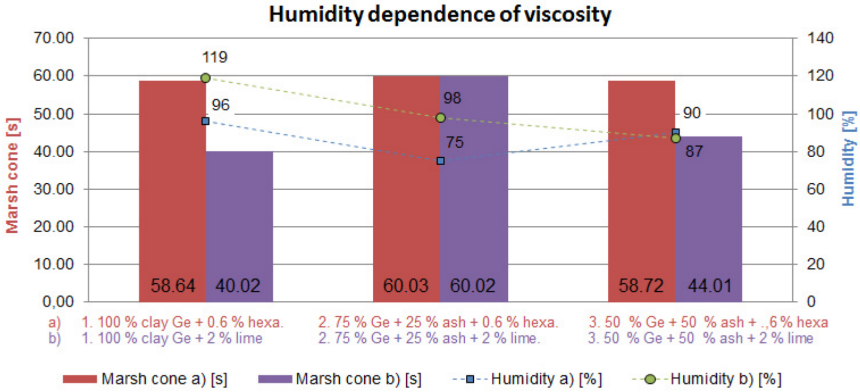

Fig. 3. Humidity dependence of viscosity suspension based on Ge clay, ash, pl. additives and lime.

In Fig. 3 we can see the relationship between the viscosity and the humidity of the mixture. It seems best to use 0.6 % of the plasticizing additives. The used additives slightly decreased the amount of water necessary to achieve viscosity. However, flow agents do not affect the amount of mixing water as much as was expected. An important parameter was the observation of the effect of additives on particle sedimentation. Particles were evenly dispersed and stayed so until the mixture hardened. The used additive stabilizes the mixture, and this could be seen in the samples in form of the decrease of decantation.When determining the consistency of the mixture, a slight decrease of workability was observed. There was, however, also a slight decrease of decantation. This was due to the presence of lime which reacted immediately in contact with water. This was reflected in the test for determining the viscosity, when the added amount of lime affected the amount of the needed moisture, which grew in its presence. On the other hand, its amount fell slightly with the growing amount of ash.

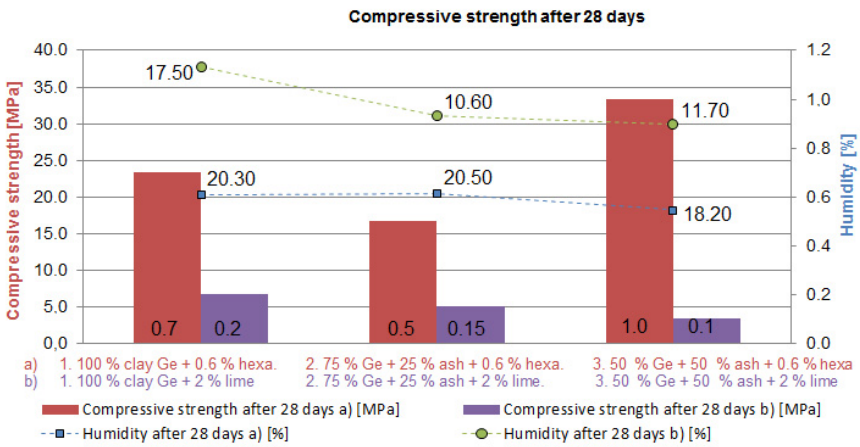

Fig. 4. Results of the strength determination and humidity of samples based on Ge clay, ash, pl. additives and lime.

In Fig. 4 we can see the influence of plasticizing additives and lime on the strength of the resulting mixture. There are no significant changes in comparison with the previous mixtures. Some mixtures showed a slight increase in the compressive strength after 28 days of ripening, in comparison with the previous mixture where the plasticizer was added. Individual particles were evenly dispersed until the hardened state, and this led to slight increase in strength in certain mixtures. In Fig. 4 we can see that the lime chemically attacks the clay. In its presence the clay lost its properties. Above all, this means that the strength of the mixture decreased after 28 days of curing. The presence of fly ash together with clay did not affect the strength of the mixture.

7. Conclusion

The main raw materials for remediation of embankment (incoherent) dams are clay suspensions. Clay suspensions are made from mixtures of clay, water, suitable alternative materials, binders and chemicals (plasticizing additives), which allow coagulation of the mixture after certain time. After pumping this mixture into the pores of the soil, the mixture has virtually no strength, but is able to withstand high water pressures. The requirements regarding the mixture vary according to the state of the dam. An important parameter for choosing the individual raw materials is their granulometry and mineralogical composition. In current practice, it is the clay that meets the requirements for the design of the grouting mixture. Ash and fly ash are potential alternative raw materials, which would partly replace the clay and thereby reduce the cost.

Granulometry of the individual components may influence their sedimentation, which would lead to segregation, and this is to be avoided. We are talking about the fact that the mixture needs to be stabilized. Suitable materials which stabilize mixtures are binders and plasticizing additives. Laboratory measurements showed that the optimum amount for stabilization of the composition is 0.6 % of the plasticizing additive of sodium hexametaphosphate and 2 % of lime. The results show that the presence of plasticizing additives, especially sodium hexametaphosphate, influences the rheological properties of the mixture, especially the presence of the plasticiser as the stabilizer. A reduction in decanting could be seen in the mixtures. We also observed the absence of particle sedimentation. This affected the final strength of the mixtures. It has also influenced the final strength which differed from the other mixtures. Yield value was not significantly influenced by the addition of plasticizing additives. Currently a dam is being chosen from the catchment area of Moravia, where these recipes can be tested in the near future on a small water reservoir. It can be assumed that after further optimization, the mixtures will be used on chosen constructions in thee catchment area of Labe.

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