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Geotechnical Characterization of Grout in Different Compositions for Extensometer Applications

Hasan Fırat Pulat, Simon Dehout, Anne-Catherine Dieudonné, and Julia Gebert

Abstract Globally, a significant portion of waste is still disposed of in sanitary landfills. Aeration is considered an effective strategy to accelerate waste biodegradation, enhancing waste stabilization and bringing end of aftercare forward in time. Waste consolidation and subsequent landfill settlement are indicators for waste biodegradation and enable monitoring of the progress of waste stabilization. Different methods, such as topographical measurements, drone-based technology, and computer simulation, can be used for this purpose. Borehole extensometers enable monitoring of depth-dependent settlement or heave in rock, soil, or other types of structures. This system is capable of detecting waste consolidation, provided that the extensometer is tightly coupled to the waste using a suitable grout mixture. In this study, the geotechnical properties of such a grout to be used for extensometers on an aerated landfill site in the Netherlands were investigated. Portland Cement CEM I and activated bentonite were used for laboratory tests. The consistency limits, unconfined compressive and bending tests were performed for samples with different recipes to find adequate grout composition.

Keywords Extensometer · Grout composition · Sanitary landfill · Settlement

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1 Introduction

Settlements in landfills are caused by loading from the designed barrier and several processes, including chemical and microbiological effects. These processes are deemed time-dependent and are regulated by parameters including leachate composition, organic matter content, pH, temperature, and moisture [1–3].

Landfill settlements occur in two primary sequential forms. The first is immediate settlement, a load-related process that takes place during the post-closure phase. If the waste is saturated and liquid drainage is possible, compression occurs as water is expelled, leading to primary settlement, which depends on the waste's permeability. Secondary settlement, occurring over the long term, results from biodegradation and mechanical creep. Notably, secondary settlement serves as a key indicator of advanced biodegradation, which is crucial for landfill operations and management.

Different methods, such as topographical measurements, drone-based technology, and computer simulation, can be used to determine surface settlement. However, for a better understanding of the behavior, the settlements along the depth should also be determined. Therefore, borehole extensometers which can measure settlement at different depths come forward to form 3D spatially differentiated measurements of settlement [4].

The main objective of this study is to measure the settlement of a landfill in the Netherlands using a magnetic targeted inclinometer system (Fig. 1). Installed around the exterior of the inclinometer casing, the corrugated pipe with target magnets attached serves as an extensometer. After that, grout is used to backfill the annular area between the corrugated pipe and the borehole wall.

The primary challenge of using grout as a contact material between the waste body and the corrugated pipe lies in material compatibility. Accurate settlement measurements require optimizing the properties of the grout and its interfaces with both the waste and the pipe. Therefore, the key factors in selecting the appropriate mix are the deformation modulus (stiffness), workability, flowability, and ensuring optimal interfacial contact with the pipe and waste body.

2 Materials and Methods

2.1 Materials

Since there will be no possible sulfate or alkali attack in the environment where the grout will be used, it would be reasonable to use Portland Cement CEM I. The bentonite is an actuated bentonite, created from a normal calcium-bentonite, which has been transformed into a sodium-bentonite by means of soda-activation. The main mineral of the active clay, montmorillonite, helps to stabilize, lubricate, increase the viscosity of water and effectively seal cracks. In order to avoid any differences, it is planned to use the same tap water in both experiments and storage applications.

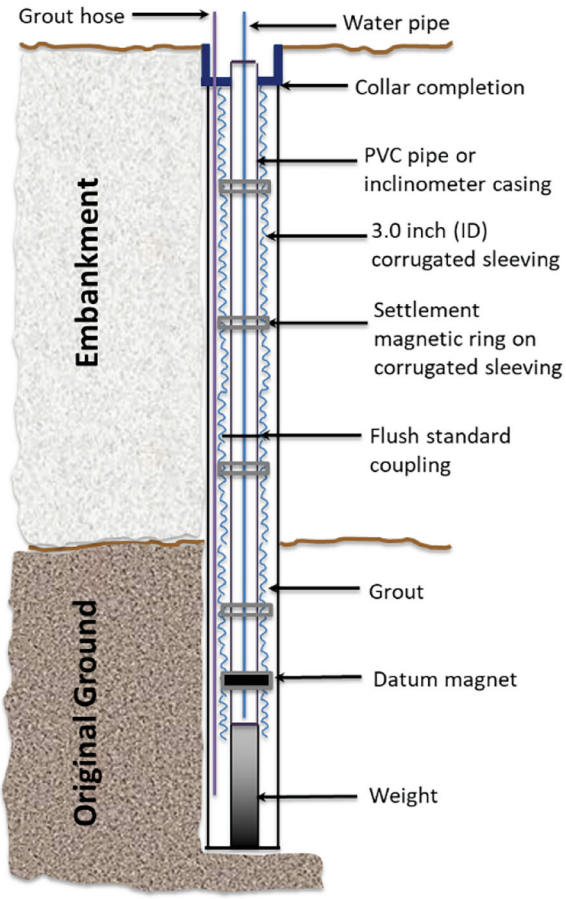

Fig. 1 Borehole extensometer with magnetic target

2.2 *Methods*

The water-to-cement ratio varies from the extreme for softer soils (W/C = 6.6) to the one for stronger soils (W/C = 2.5) in Table 1, Groups A to D. With a constant bentonite-to-cement ratio and a decreasing water-to-cement ratio, the cement and therefore the bentonite content rises from Group A to Group D. These groups were determined to examine how a change in the water/cement ratio would affect the mechanical and rheological properties. It was also examined to what extent the bentonite content affects the grout behavior in groups E to H.

Preparation of the grout. The high water-to-cement ratio needed to match the rigidity of the waste material makes the entire grout preparation process quite difficult. The Hobart mixer is a standard device with three fixed mixing speeds and a maximum capacity of approximately 5 L in its stainless steel bowl. Different beaters can be

Table 1 Design mixtures of different water-to-cement and bentonite-to-cement ratios

Mixture	W/C ratio	B/C ratio
A	6.6	0.4
B	5.0	0.4
C	4.0	0.4
D	2.5	0.4
E	6.6	0.5
F	6.6	0.7
G	5.0	0.5
H	5.0	0.7

Note W = water, C = cement, B = bentonite

attached depending on the material being mixed. For concrete, a stainless steel "B" Flat Beater is used when combining it with mixing water. In contrast, for bentonite, due to its finer particle size and the need to prevent clump formation, a "D" Wire Whip is preferred when mixing with water. Cement powder is gradually introduced into the water and mixed thoroughly until a uniform gray suspension is obtained. Subsequently, powdered bentonite is added slowly to prevent the formation of clumps. If clumping occurs, the addition of bentonite should be paused until the clumps dissolve completely. Once all the bentonite has been incorporated, the grout mixture should be allowed to thicken for 5 to 10 min before further processing. Finally, hydration rates were determined to consider the hydration of the grout components on their own before mixing [5].

Mechanical properties of the grout. The compressive strength representing the maximum load that each grout prepared with different recipes can carry before it deforms and enters the plastic regime should be determined. The tests were carried out in cylindrical molds with a height/width ratio of two to one in order to ensure that the grout samples were suitable for both hydraulic press machines and standards. To ensure that the samples were well hardened and testable with a hydraulic compressive machine usually used on samples with higher strength and cement content, the grout design mixtures were tested 39 days after mixing. It was crucial to adjust the initial load and loading rate for each grout design formulation in accordance with the cement and bentonite content. The hydraulic loading rate was determined to be 0.01 kN/s for the gentler grout design formulations (Mixture A, Mixture B, Mixture E, Mixture F, and Mixture G), with an initial load of 0.01 kN. A loading rate of 0.05 kN/s with an initial load of 0.1 kN is considered adequate for the stronger samples.

Rheological properties of the grout. Marsh funnel tests were performed for the grout recipes created according to literature studies and trial tests. Approximately one liter of grout is poured into the funnel from its larger side through the sieve. The grout mixture is then allowed to flow into the graduated bowl, and the time it takes to fill one quart (946 ml) is measured. For Marsh Funnel viscosity measurements, it

is recommended to take the average of two consecutive test results. As a result of the tests the effect of the increase in W/C and B/C ratios on the flow behavior is examined. Before being pumped into the borehole, this viscosity can thereafter be compared to the grout that was selected on the field. The Marsh funnel tests measure viscosity in seconds per quart. To relate this measurement to an effective viscosity in the standard unit of milli-Pascal-second (mPa·s), the following equation can be used for field applications [6].

$$\mu_e = \rho(t - 25) \tag{1}$$

where

- μ_e is the effective viscosity for drilling fluid on site. Effective viscosity being the analogous average viscosity of a liquid,
- ρ is the average density of the fluid measured in the laboratory,
- t is the Marsh funnel time recorded to fill up one quart (946 ml).

3 Results

3.1 Mechanical Characterization

In the first set of results, Groups A through D are shown alphabetically and in decreasing order of water to cement ratio, indicating an increase in cement content. The graph analyses the effect of increasing cement ratio on the grout samples (Fig. 2).

The unconfined compressive strengths (UCS) obtained from this study and the results compiled by Mikkelsen [7] from different studies in the literature are very similar in terms of behavior [7]. However, it should not be ignored that bentonite content affects the strength negatively.

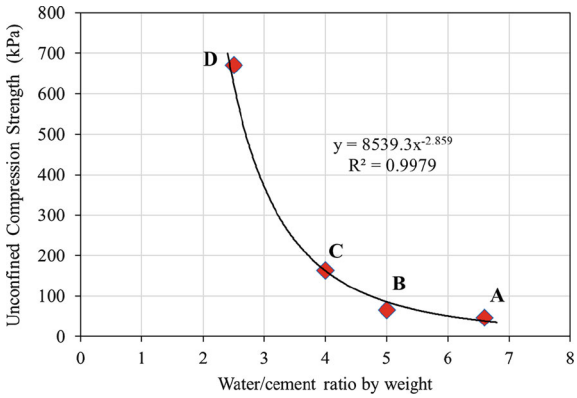

Fig. 2 Effect of water/cement ratio on the unconfined compressive strength of grout design mixtures

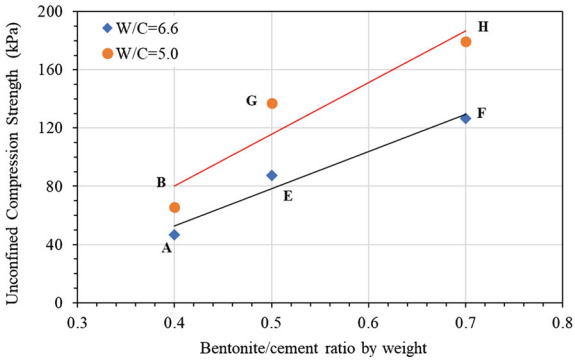

Fig. 3 Effect of bentonite/cement ratio on the unconfined compressive strength of grout mixtures

The addition of bentonite does not significantly enhance the strength of the grout. However, it influences the consistency and pumpability of the mixture. The graph showing the UCS of the samples with different bentonite/cement ratios is presented in Fig. 3.

3.2 Rheological Behavior

The flow time for one quart (946 ml) of grout mixture passing through the Marsh Funnel is shown in the findings below. These results show the flow time of each grout mixtures immediately after mixing. The effect of water/cement ratio on the flow time is shown in Fig. 4. Tests on samples of four different recipes showed that an increase in the water/cement ratio significantly reduced the viscosity.

The effect of bentonite/cement ratio on viscosity was tested on samples with the same water/cement ratio and the results obtained are presented in Fig. 5. Although the results obtained were in a relatively narrow range, the increase in bentonite/cement ratio increased the viscosity.

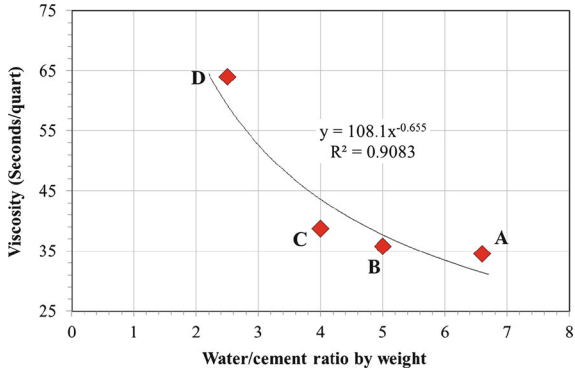

Fig. 4 Effect of water/cement ratio on the viscosity

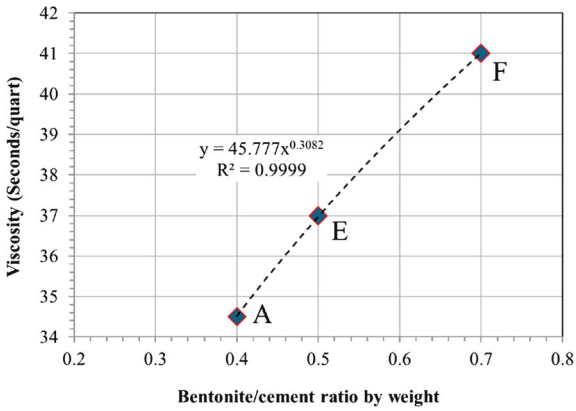

Fig. 5 Effect of bentonite/cement ratio on the viscosity

Table 2 Effective viscosities for different grout recipes

Group	W/C	B/C	Flowtime (s)	Effective viscosity (mPa.s)
A	6.6	0.4	33.4	9.24
B	5.0	0.4	35.8	13.50
C	4.0	0.4	38.7	20.55
D	2.5	0.4	65.0	64.00
E	6.6	0.5	37.00	14.40
F	6.6	0.7	41.00	20.00
G	5.0	0.5	38.00	18.20
H	5.0	0.7	58.00	47.85

Effective viscosity measurements calculated from Marsh funnel flow tests for grout mixtures prepared with different recipes are summarized in Table 2.

4 Conclusion

The behavior of the backfill in borehole instruments is crucial for precise measurements, thus it needs to be given careful consideration. The waste body and the measuring equipment must make the best possible contact with the grout. If the grout filling between two distinct materials is either excessively hard or soft, no effective interaction occurs between the waste and the extensometer. The axial force supported by the borehole grout column can be either smaller or greater than that of the material it replaced, depending on its stiffness. If the stiffness or applied force is excessively high, displacements will be reduced, potentially resulting in axial measurements lower than those of the surrounding soil formation.

There is still much to learn about the optimal composition for borehole backfill materials. However, this study highlights several key findings. The mechanical and fresh properties of grout including workability, bleeding, flow time, viscosity, shrinkage, and rheological behavior are significantly influenced by factors such as the water-to-cement ratio, bentonite to cement ratio, additive content, and mixing procedures.

Notably, the exclusive use of bentonite as a borehole backfill material should be avoided, as it is not volumetrically stable and may affect displacement measurements due to its tendency to continuously hydrate or desiccate under stress. In applications such as slope stabilization or ground strengthening, grout typically consists of cement and water, serving the primary function of enhancing ground strength by forming a stiffer and more resilient structure than the surrounding environment. However, in the context of this study, the grout must not only achieve a specific strength but also exhibit precise rheological properties to ensure accurate settlement measurements. Therefore, further research is needed to investigate the incorporation of natural pozzolans such as bentonite and kaolinite with cement and water, determining their potential to achieve the required properties for reliable extensometer-based displacement monitoring.

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