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The use of foam glass for a lightweight fill and highway foundation on soft soil conditions

L'utilisation de verre mousse pour un remblai léger et une fondation d'autoroute sur des sols mous

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ABSTRACT: In soft soil conditions, the construction of embankments may cause significant subsidence during lifetime of the construction. The standard procedure to avoid large remaining settlements after project completion is pre-loading, often in combination with vertical drainage. However, this approach is time-consuming, costly, and has a considerable carbon footprint. For a highway in the province of Zeeland (The Netherlands), an alternative solution was found using foam glass as a lightweight fill material. The subsoil consists of highly compressible clay and peat layers with an average thickness of 8 m. Foam glass was also used to construct a stabilized foundation layer for support of the road construction. The stabilization consists of a mixture of foam glass, cement, in situ clay and the Geosta® additive. This innovative approach accelerates the building process and reduces the carbon footprint of the project considerably. Furthermore, the stabilized foam glass forms a foundation layer with considerable strength and stiffness, which may reduce the required asphalt thickness.

RÉSUMÉ: Dans des conditions de sol mou, la construction de remblais peut provoquer un affaissement important pendant la durée de vie de la construction. La procédure standard pour éviter les tassements importants après l'achèvement du projet est le préchargement, souvent associé à un drainage vertical. Cependant, cette approche prend du temps, est coûteuse et a une empreinte carbone considérable. Pour une autoroute dans la province de Zélande (Pays-Bas), une solution alternative a été trouvée en utilisant du verre mousse comme matériau de remplissage léger. Le sous-sol est constitué de couches d'argile et de tourbe hautement compressibles d'une épaisseur moyenne de 8 m. Du verre mousse a également été utilisé pour construire une couche de fondation stabilisée destinée à soutenir la construction de la route. La stabilisation est constituée d'un mélange de verre mousse, de ciment, d'argile in situ et de l'additif Geosta®. Cette approche innovante accélère le processus de construction et réduit considérablement l'empreinte carbone du projet. De plus, le verre mousse stabilisé forme une couche de base présentant une résistance et une rigidité considérables, ce qui peut réduire l'épaisseur d'asphalte requise.

Keywords: Stabilisation, Geosta®, foam glass, embankment, compressible

1 PREAMBLE

The municipality of Borssele, located in the southern part of the Netherlands, intends to construct a new road around the village of Hoedekenskerke. This new road is required because of the increasing traffic in the centre of this village.

The new road will be built on an embankment on soft soil. The municipality, in collaboration with contractor Traas en Ovaa, sought to find an economical yet sustainable solution, where the carbon footprint is reduced using innovative solutions.

Traditionally, road construction in such areas would involve creating an embankment of sand, topped with an aggregate layer and asphalt. The soft soil conditions however would urge to pre-load the soil with sand or granular material. Preliminary assessments indicated that sand fills up to 8 meters high would be required to meet settlement requirements post-project completion. This approach would not only lead to significant delays but also result in a substantial carbon footprint, primarily due to the extensive need for sand transport. Additionally, concerns about traffic noise, vibrations, and pollution in the small village could potentially provoke considerable local protests. In response to these challenges, an alternative was found in the use of lightweight fill materials and a lightweight foundation layer but with a strength and stiffness larger than traditional foundation layers.

2 SOIL CONDITIONS

The geotechnical investigation for the proposed road construction in Borssele was comprehensive, involving Cone Penetration Tests (CPT), boreholes with undisturbed sampling, and an extensive laboratory testing program that included triaxial and oedometer tests. The CPTs were conducted using ISO 22476-1 Class 2 equipment. Figure 1 presents a typical CPT profile from the site, illustrating the subsurface stratigraphy. The results revealed soft, compressible soil layers extending to approximately 8 meters below ground level. These layers belong to the Holocene epoch and are primarily composed of normally consolidated clay, interspersed with organic material in some strata.

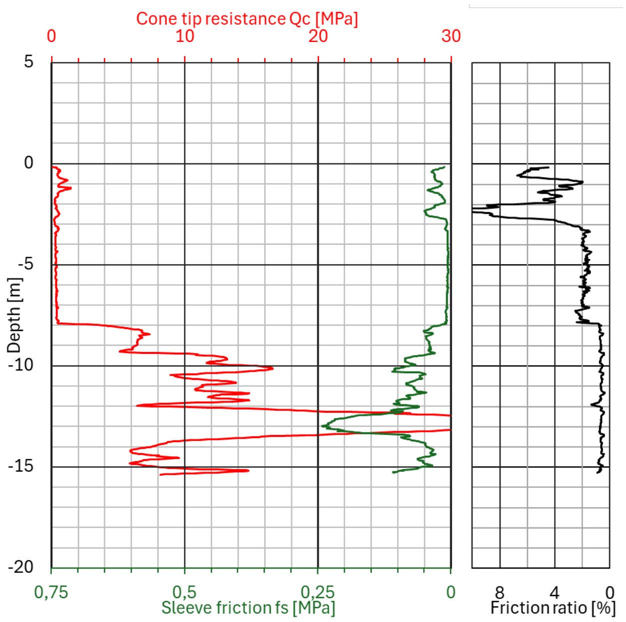

Figure 1 - Typical CPT at project location.

3 DESIGN

3.1 The material foam glass

Foam glass is a porous glass foam material. It is made by heating a mixture of crushed or granulated glass and a blowing agent (chemical foaming agent) such as carbon or limestone. Near the melting point of the glass, the blowing agent releases a gas, producing a foaming effect in the glass. After cooling the mixture hardens into a rigid material with gas-filled closed-cell pores comprising a large portion of its volume. The grain shape of the material can be compared to natural sand.

Glass foam has a dry unit weight of 2 kN/m^3. The foam consists of closed cells, which prevents water attachment to the glass particles. In theory, the unit weight of the material in an embankment would remain at the original value. However, when placed below groundwater levels, some water intake may occur over the lifetime of the construction. This absorption can increase the unit weight of the material to approximately 7 kN/m^3. In this case study the foam glass was only used above groundwater levels, so this would not be a problem. As a safe approach, a unit weight of 4 kN/m^3 was adopted in the design of the embankment and the settlement calculations, which is still considerably lower than usually adopted sand as fill material (unit weight 18 kN/m^3 when compacted).

Foam glass is an environmentally safe material and causes no pollution when (in long term) used in embankments. The environmental aspects of the foam glass material are described in Rood and Klein (2014).

3.2 Embankment fill with foam glass

The practical experience with foam glass in the construction of embankments on compressible soils is described in Gold and Dietrich (2014).

The embankment for the new road utilizes foam glass as its primary fill material, capitalizing on its unique properties to address the challenges posed by the underlying soft soil. The key advantage of using foam glass in the embankment is its significantly lower unit weight compared to traditional fill materials, such as compacted sand or gravel. This reduced weight decreases the vertical stress exerted on the soft subsoil, minimizing the risk of excessive settlement and instability. Additionally, the closed-cell structure of foam glass offers excellent resistance to water absorption, maintaining its low weight and structural integrity even in varying environmental conditions.

In the construction of the embankment, careful attention was given to the layering and compaction of foam glass to ensure uniformity and optimal load distribution. The design also took into consideration the drainage and erosion control aspects, ensuring the longevity and durability of the embankment. By choosing foam glass, the project not only addresses the geotechnical challenges but also contributes to sustainability, as foam glass is often made from recycled materials.

3.3 Stabilised foundation layer

The foundation layer of the new road is a composite structure, stabilized with a mixture of foam glass, cement, in situ clay, and the Geosta® additive. This innovative approach creates a foundation layer with enhanced strength and stiffness, suitable for supporting the road structure while distributing loads evenly across the underlying soft soil.

The stabilization process involves thoroughly mixing the components, where the foam glass provides volume and reduces the overall weight, while cement acts as the primary binding agent. The addition of Geosta® enhances the mixture's properties, improving flexibility and load-spreading behaviour, crucial for road foundations over soft soils. The use of in situ clay in the mix helps in achieving an eco-friendly solution by recycling existing materials and reducing the need for importing new fill materials.

The layer's design ensures it has sufficient bearing capacity to support the road and traffic loads without undergoing significant deformation or settlement. The stabilized foundation layer also contributes to a reduction in the required thickness of the overlying asphalt layer, leading to cost savings and a further reduction in the project's carbon footprint. This layer represents a fusion of traditional and modern construction techniques, resulting in a durable, resilient, and environmentally sensitive road foundation.

4 SOIL STABILISATION PRINCIPLE

4.1 Use of Geosta®

Geosta® is a mixture of inorganic salts, that in combination with hydraulic binders such as Portland cement or lime, is applied in soil stabilisation. By adding Geosta® to the cement a noticeable improvement of the soil stabilisation is realized (Omotosho, 2005), especially in flexibility and load spreading behaviour. Geosta® is a mixture of zeolites, oxides (aluminium, magnesium, and silicon oxide) or chlorides (magnesium, sodium, potassium and calcium chlorides). A regular formula is a mixture of 1.5 – 2.0 kg Geosta® with 100 kg cement per m^3 of soil.

Geosta® stabilised soil is applied as a hardstand foundation for several wind farms in the Netherlands (Brouwer and van der Veer, 2021).

4.2 Lime pre-treatment

In cases where the stabilization involves clayey soil, a pre-treatment with lime is often necessary. Clay particles tend to exhibit a delayed and often incomplete chemical reaction with cement and lime. Pre-treating the clay with lime leads to a more effectively stabilized product. This is attributed to the chemical interactions between lime and clay particles, as represented by the following reactions:

$$CaO + H_2O \rightarrow CA(OH)_2 \quad (1)$$

$$CA(OH)_2 + CO_2 \rightarrow CACO_3 + H_2O \quad (2)$$

where:

- CaO presents (quick) lime.
- H_2O is water.
- $Ca(OH)_2$ is hydrated lime.
- $CaCO_3$ is calcium carbonate.
- CO_2 is carbon dioxide.

This process leads to an upgrade of the clay material with considerably lower water content and a more granular-type behaviour.

5 TESTING

5.1 Laboratory

Prior to the design of the embankment and road foundation, samples were made in laboratory circumstances. Figure 2 shows 2 samples that were constructed. The mix consisted of clay, as found in the top layer at the project site, foam glass, cement and the Geosta® additive. The relation between the amount of foam glass and clay varied between 1:2 and 1:3.

Figure 2 – Sample of stabilised foam glass.

The above mentioned samples were tested in the laboratory for compression strength. The results showed that the unconfined compression strength (UCS) varied between 1.9 and 2.1 N/mm^2. A clear distinction between the several used mixtures in terms of relation between foam glass and clay could not be made.

5.2 Test site

A test site was constructed by the contractor on a location close to the new road. Soil conditions at the test site were comparable to the final road location.

At the test site, a mixture was made (mixed in place) consisting of the locally available clay, Portland cement, Geosta® and foam glass. The ratio between clay and foam glass was initially set on 1:2. The mixture furthermore consisted of 150 kg Portland cement and 1.5 kg Geosta® per m^3 soil/foam glass. The stabilised layer had a thickness of 400 mm and was constructed on top of the clayey subsoil.

Figure 3 - Test site 1

For the design of the road construction, the unconfined compression strength UCS and the static flexural stiffness $E_{stat,flex}$ was required. Plate load test according to DIN 18134 were carried out on the test site with a plate diameter of 300 mm to derive the static stiffness modulus. The results proved to be on the lower site. An average E_{v1} modulus of 85 MPa was derived, which is considered very low for a cement stabilised soil. This value was sufficient for the road deign design but insufficient to reduce the thickness of asphalt layers.

Additionally, cores were drilled to assess the strength of the layer in the laboratory. The drilled samples exhibited significantly lower unconfined compression strength (UCS) values, ranging between 0.4 N/mm² and 1.1 N/mm²

5.3 Comparison with literature and database

Numerous publications exist on the topic of the correlation between strength and stiffness of stabilised soils. A very large variation in correlations can be observed (Biswal et al, 2018).

The Geobest in-house database contains a large number of tests on Geosta® stabilised soil samples where UCS as well as flexural stiffness is determined in the laboratory. Based on these results, a correlation can be determined between both parameters. The results are graphically shown in figure 4. A distinction was made between soil stabilisation with granular and cohesive materials.

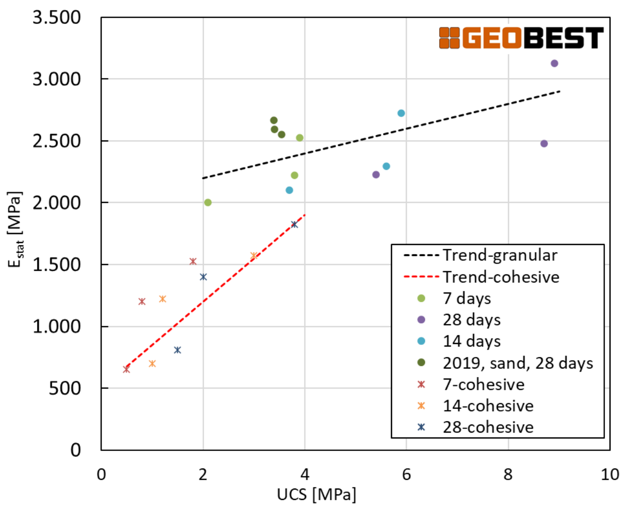

Figure 4 – Static flexural E-modulus based on UCS tests.

Based on the correlation for cohesive soils, a stiffness of between 500 and approx 750 MPa could be expected. This is considerable higher than the above mentioned values form the plate load tests.

The large difference between the E_{v1} modulus determined in the field and the E-modulus in the correlation can be explained by a number of reasons:

- The modulus from the plate load test is a purely settlement related parameter and may be regarded as an short term oedometer stiffness rather than a flexural stiffness.
- The plate load test has an influence depth of 2D-3D, so in the worst case 900 mm. With a layer thickness of 400 mm, the compressible subsoil will influence the outcome significantly.
- The relationship from figure 4 was derived under ideal laboratory conditions and therefore may not fully reflect the values that can be reached in practice.
- The execution of the test site was not ideal in terms of compaction, water saturation and particle size of the glass foam particles.

Based on these findings, it was decided that an additional test site was required and that further study on the flexural stiffness would be beneficial for the project.

6 CONCLUSIONS

This example demonstrates the potential of foam glass as a sustainable alternative for embankment construction in soft soil conditions.

The use of foam glass in a stabilised foundation layer is still an innovative and new solution. Additional research has to be performed towards the ideal mixing circumstances and the strength and stiffness parameters that can be obtained. The method is promising and may lead to a reduction of foundation and asphalt thickness, which is beneficial in terms of reduction of costs and carbon footprint.

At this moment the municipality of Borssele is in the process of decision making on this project. Construction of the road may take place in the second or third quarter of 2024. First step is to construct an additional test site, where the lessons learned from previous test sites are incorporated. The additional tests will lead to an upgraded design where all the benefits of this innovative method are included.

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