THE USE OF THE ENVIRO-WALL-MAT COMBINATION IN SOFT SOIL CONDITIONS FOR MARSHALLING AREAS, CRANE HARD STANDS AND LAY DOWN AREAS

J.W.R. Brouwer, Geobest BV, Vianen, The Netherlands, +31650740785, roel.brouwer@geobest.nl
H.W.H. Engelen, Geobest BV, Vianen, The Netherlands, +31628521605, hugo.engelen@geobest.nl

ABSTRACT

This paper presents the study towards a new foundation concept, named ”the Enviro-Wall-Mat combination”. This concept is based upon the successfully adopted Enviro-Mat horizontal soil stabilization, combined with vertical trench formed walls.

The Enviro-Mat is realised by in situ mixing of (local) soil, cement and a stabilizing additive that promotes stronger bonds between the soil and cement particles. In this way a stabilised layer is created with a low carbon footprint as local soil is used. The Trench Formed Wall is created by means of a deep trenching machine, that creates a trench with a maximum depth of 15 m. The outcoming soil is transported to ground level and the trench can be simultaneously filled with a low strength slurry that is mixed on surface level.

By combining both techniques, a fully supported stabilised layer can be created that is capable to withstand high and irregular loads even in very compressible soils. The Enviro-Walls act therefore as a deep foundation for the Enviro-Mat.

The concept has first been analysed by means of finite element calculations with program Plaxis 3D. The conclusion was that the concept should be feasible. Based on these positive results, it was decided to perform a full scale load test. This test was performed in August 2021. This paper describes the initial Plaxis analyses and the results of the field test.

Keywords: soft soil, stabilization, wall, mat

PREAMBLE

For almost 10 years now, the Enviro-Mat concept has been successful as a pavement option in heavy duty loading projects. By means of in-situ mixing of local soil, cement, water and the Geosta additive at ground level, a stabilized layer is created. Although in certain load cases the Enviro-Mat can be used in soft soil conditions, it remains sensitive for excessive differential settlements. In order to try and make this concept work reliably in very soft soil conditions, the Enviro-Wall-Mat is developed.

STABILISATION PRINCIPLE

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

A typical recipe for the Enviro-Mat consists of 150 kg Portland cement and 1.5 kg Geosta additive per cubic meter. This recipe was first tested under laboratory circumstances in 2017 with different soil types as base material. From each base material, three separate samples are prepared and subsequently tested on compressive strength. Results are presented as average values in Table 1.

Table 1. Typical compression strength values of Enviro-Mat in different soils

Base material	Compressive strength		
	7 days MPa	14 days MPa	28 days MPa
Peat	0.5	1.0	1.5
(River) clay	0.8	1.2	2.0
Silt	1.8	3.0	3.8
(River) sand	2.1	3.7	5.4
Crushed rubble	3.8	5.6	8.7
(River) gravel	3.9	5.9	8.9

In cases where the stabilization involves clayey soil, pre-treatment with lime (2 – 3%) is a good option to achieve strength values that are comparable with granular materials. 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 and clay particles.

As a light-weight alternative, foam glass mixed with soil can be used as a base material. This method is described in Brouwer et al. (2024).

PRINCIPLE ENVIRO-WALL-MAT COMBINATION

The Enviro-Wall-Mat is a combination of the Enviro-Mat and trench formed walls. Trench formed walls are created using a deep trenching machine, that is able to create trenches with a maximum depth of 15 m. The outcoming soil is transported to ground level and the trench can simultaneously be filled with a low strength concrete slurry that is mixed on surface level.

The principle is shown in figure 1 and corresponds to the actual design used in two field tests conducted in Zeewolde (2021). Walls with a length of 5 m were applied for this project. The elevations in the figure are related to NAP (Nieuw Amsterdams Peil), which is the standard reference level in the Netherlands.

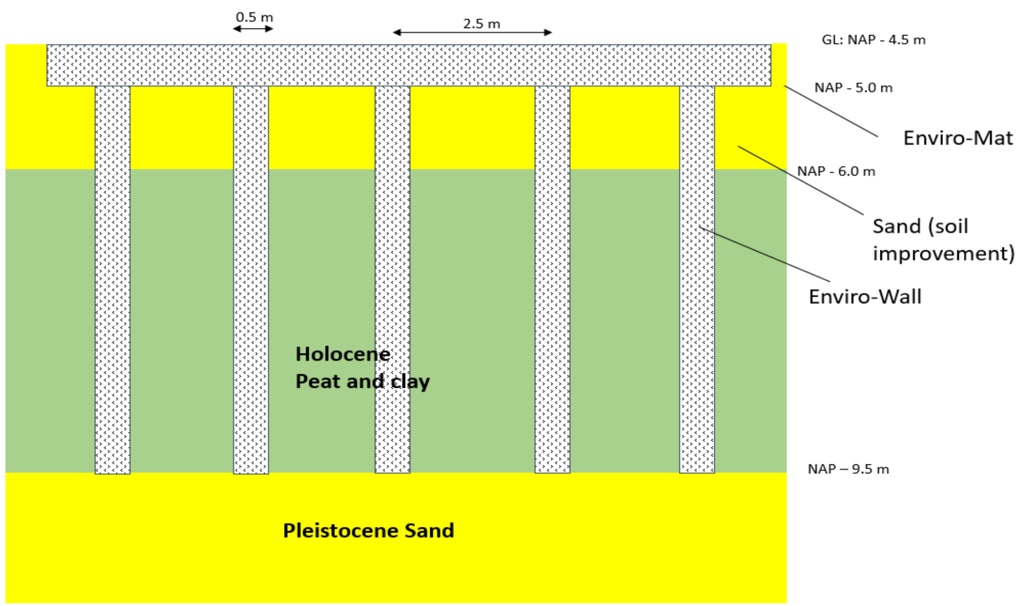

Figure 1: Principle of Enviro Wall-Mat as tested in Zeewolde (NL) in 2021

By combining both techniques, a fully supported stabilised layer can be created that is capable to withstand high and unevenly distributed loads even in very compressible soils. The trench formed walls act therefore as a deep foundation for the Enviro-Mat with the tip elevation in a sufficiently dense sand layer. As an alternative, a somewhat higher tip elevation may be chosen in the softer layers. In this case, the walls act as a settlement reducing solution, that can be compared to a raft foundation. In the latter case, the whole structure may settle more than in the first option, but considerably less than without walls.

The original application of the Enviro-Wall-Mat combination was expected to be in the field of onshore wind energy in The Netherlands as wind turbines are predominantly placed in areas with soft, virgin soils.

Due to the increase in size and capacity of offshore wind farms, the demand for high bearing capacity marshalling areas where monopiles and transition pieces can be stored has also increased. The Enviro Wall-Mat can be an effective foundation solution for these storage areas where large bearing capacities in combination with small settlements are required.

DESIGN

The soil conditions at the Zeewolde site consisted of very soft Holocene clay and peat layers until a depth of 5 meters below ground level, followed by medium dense Pleistocene sand layers. A typical CPT is presented in Figure 2. The blue line represents cone resistance, the red line sleeve friction. The orange line on the right represents friction ratio. The elevations in the figure are related to NAP.

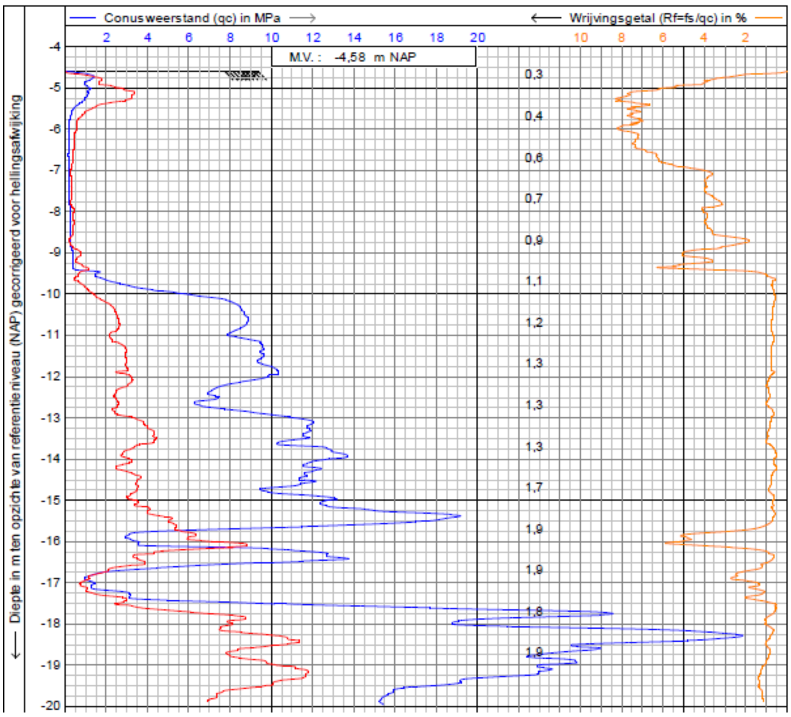

Figure 2: Typical CPT at project location

The Enviro-Wall-Mat design has been explored by means of a complete finite element analysis performed using Plaxis 3D. In 2019, multiple Enviro-Mat field tests are conducted in Zeewolde. As a result to the post-analysis of these tests, a Plaxis 3D model with an accurate soil stratigraphy with corresponding strength and stiffness parameters was available. By adding the Enviro-Wall-Mat to this Plaxis 3D model, both the modelling of the concept could be elaborated whilst at the same time the deformations could be compared to the interpretation of the Enviro-Mat field tests.

The configuration consisted of five trench formed walls with a width of 0.5 m and a length of 5.0 m (tip level at approx. NAP – 9.5 m). The centre-to-centre distance was 2.5 m. The Enviro-Mat with a thickness of 0.5 m was constructed on top. The Enviro-Mat is modelled directly on top of each trench formed wall to ensure direct contact between the Enviro-Mat and the trench formed walls.
For the compression strength of the Enviro-Mat and the walls, a value of 4 N/mm^2 was adopted, given the fact that a sand layer is installed prior to the installation of mats and walls. The Enviro-Mat is made with this sand as base material.

The Plaxis 3D modelling of the Enviro-Wall-Mat is presented in Figure 3.

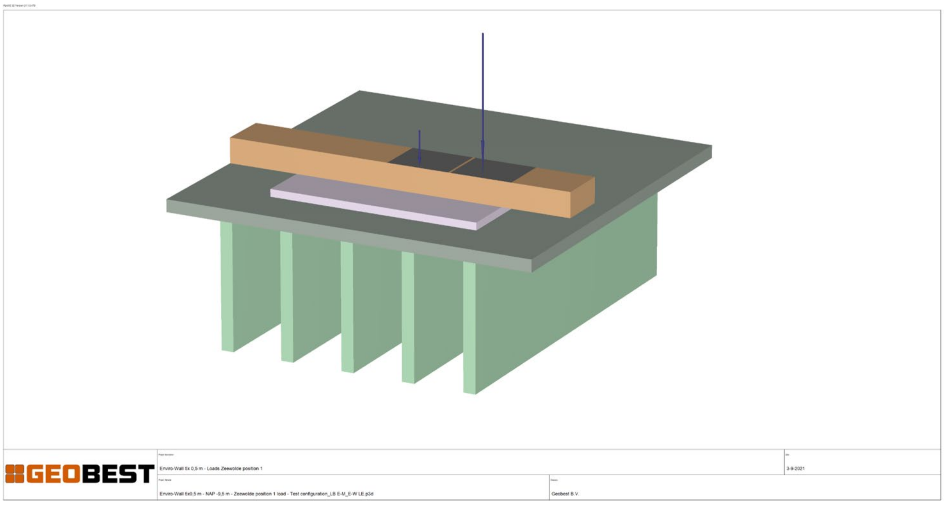

Figure 3: Plaxis 3D modelling Enviro-Mat-Wall

Loads correspond to a single crawler load that is common for onshore wind turbine construction.

Calculated deformations (maximum value approximately 15 mm) are given in Figure 4 and reflect the behaviour of the Enviro-Wall-Mat under fully undrained circumstances (short-time loading) as is expected during short time crane loading.

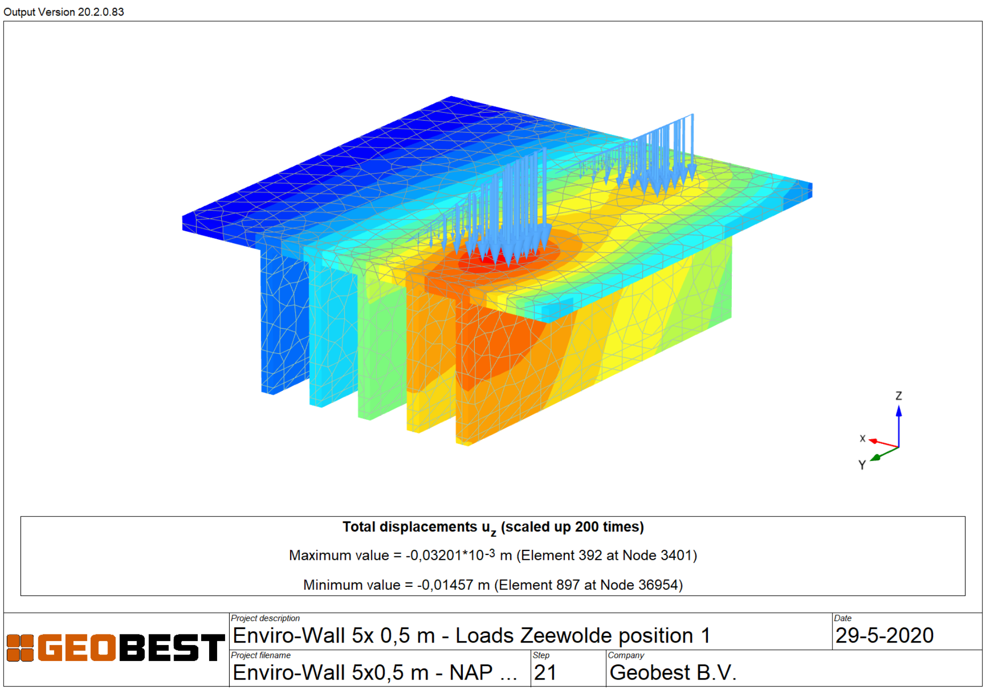

Figure 4: Plaxis 3D - deformations

FIELD TESTING

Based on the positive results of the Plaxis 3D design calculations, two field tests were initiated. These field tests were carried out on the same location as used for the Enviro-Mat tests. The two field tests consisted of separate load configurations, based on a single Enviro-Wall-Mat design:

- Test 1: simulating the crane tracks being placed perpendicular to the walls
- Test 2: simulating the crane tracks being placed parallel to the walls.

The test configuration consisted of steel mats with two steel gantry beams on top. Following the load was increased in steps by placing ballast plates up to a total load of approximately 3400 kN. A cross-section of the test configuration is presented in Figure 5.

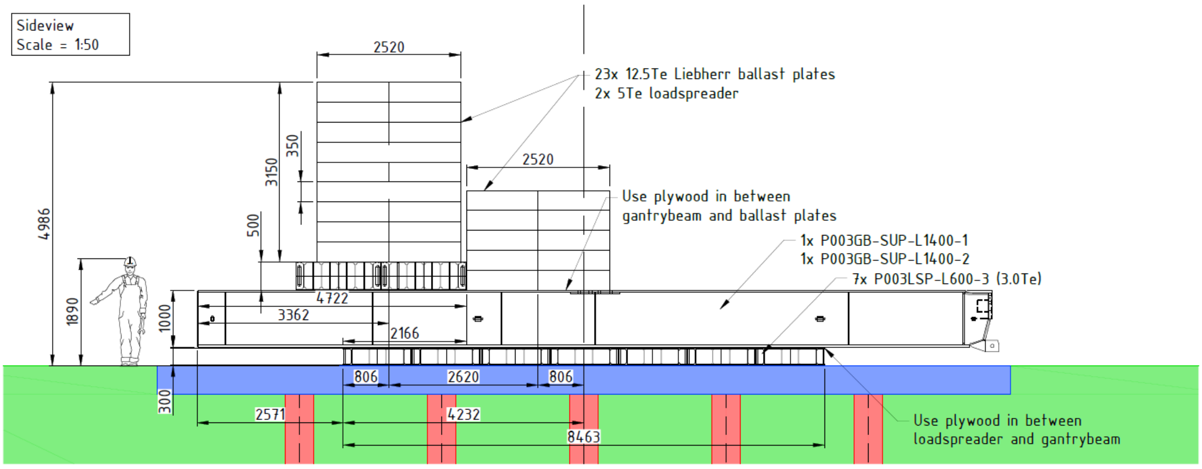

Figure 5: Cross-section Enviro-Mat-Wall and test configuration

The corresponding maximum pressure beneath the gantry beams is at least 270 kN/m^2 (27 T/m^2), depending on the actual load spreading capacities of the steel mats.

The ballast loads were put in place in a period of about 4 hours. The loads stayed in place for a period of about 16 hours. At both load tests the deformation was measured at several locations during loading and unloading.

It is clear that the lay-out from test number 1 represents a worst-case condition. The centre of the load is placed exactly between two walls and therefore the load on the Enviro-Mat is maximised. The lay-out of test no. 2 gives a much lower load on the Enviro-Mat as the load is perfectly placed on the walls.

An impression of the actual test load is presented in figure 4.

Figure 6: The actual test configuration in Zeewolde in 2021

Besides overall stability and bearing capacity, settlement and differential settlement (i.e. rotations) are the main items when considering the suitability of a crane hardstand. It was therefore decided to focus on the deformations (vertical and horizontal) during the load advance in the test by means of automatic total station measurements of deformation prisms.

A time-settlement curve of two governing prisms (at different locations denoted as MP11 and MP12N) during test number 1 is given in Figure 7. Most deflections occur during the build-up of the load in the first 4 hours (240 minutes). In the following 16 hours, some creep is detected, with an increase in settlement under the constant load.

In general it can be concluded that the measured short-term settlements (15-25 mm) are in the same order of magnitude as the Plaxis 3D prediction under fully undrained circumstances. The application of this solution for longer term loading has to be investigated further by means of a long duration test set-up.

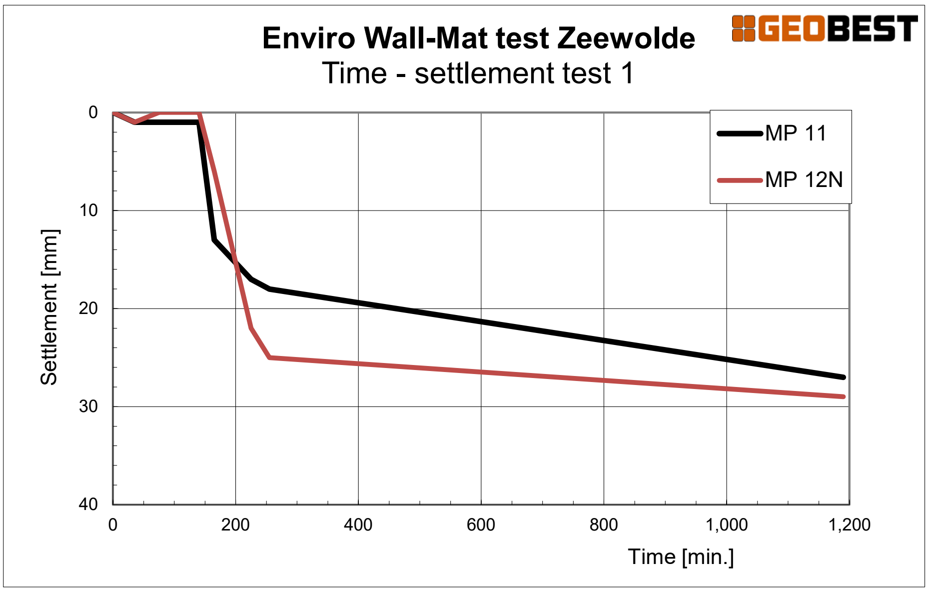

Figure 7: Measured deformations in field test

CONCLUSIONS

The Zeewolde field test shows that the concept of the Enviro-Mat supported by Enviro-Walls is a viable method for crane hardstands, laydown areas and marshalling yards in very compressible subsoils. The worst-case load test resulted in small deformations. Two years before the project described here, a load test was performed without supporting walls at a nearby location with comparable soil conditions and loads. During this test, settlements in excess of 250 mm were calculated in Plaxis and measured in the field. This leads to a settlement reduction factor of approximately 10 .

The deformation pattern of the Enviro-Wall-Mat can be explained in the Plaxis simulation. The adopted Plaxis model is in line with the field test results.

Additional study may lead to a further optimisation of the concept, especially the material as used in the walls.

On the basis of this study, the Enviro-Wall-Mat combination shows a lot of potential for future heavy duty pavement projects in soft soil conditions. Very often these contracts, especially when dealing with soft soil conditions, comprise an additional full-scale field test. This provides new data that will be very helpful for further study on this concept.

ACKNOWLEDGMENTS

The authors would like to thank Mammoet BV and Heavy Duty pavements BV for their cooperation in realising this article.

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