Adjusting the soil stiffness with stabilisation to minimize vibration at Maxlab IV – Asynchrotron radiation facility in Sweden

Ajustement de la rigidité du sol par stabilisation pour minimiser les vibrations à Maxlab IV, un centre de rayonnement synchrotron en Suède

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ABSTRACT: In Lund a new next-generation synchrotron radiation facility are under construction, MAX IV. This facility requires extraordinary techniques for the earthworks at site. The vibration requirements are very stringent compared to traditional earthwork standard. The tolerance is 26 nm (1 s rms above 5 Hz) and this requires a very good damping from external and internal vibrations. Different solutions were discussed and simulated during the design phase and the best performance was achieved with a four meter thick layer of stabilised soil below the concrete foundation. The soil consists of clay till with high clay content. During the design phase many different binder combinations were tested to meet the design criteria regarding seismic modulus. In order to achieve a monolith the binders' setting time was critical since the soil is stabilised in 0.35 meter layers were the next layer are mixed into the layer below. The binder to best meet both design and construction requirements were a combination of quicklime and ground granulated blast furnace slag (GGBFS).

RÉSUMÉ : Un nouveau centre de rayonnement synchrotron de dernière génération, MAX IV, est en cours de construction à Lund. Ce centre nécessite des techniques exceptionnelles pour les travaux de terrassement sur le chantier. Les exigences de vibrations sont très strictes par rapport à la norme de terrassement traditionnel. La tolérance est de 26 nm (valeur efficace 1 s rms au-dessus de 5 Hz), ce qui nécessite un très bon amortissement des vibrations internes et externes. Des solutions différentes ont été discutées et simulées au cours de la phase de conception et la meilleure performance a été réalisée avec une couche épaisse de quatre mètres de sol stabilisé en dessous de la fondation en béton. Le sol se compose de till argileux à forte teneur en argile. Au cours de la phase de conception, de nombreuses combinaisons de liants différents ont été testées pour répondre aux critères de conception concernant le module sismique. En raison de la réalisation d'un monolithe, le temps de durcissememt était critique puisque le sol est stabilisé en couches de 0,35 mètre dont la couche suivante est mélangée dans la couche de dessous. Le liant qui répondait le mieux aux exigences à la fois de conception et de construction était une combinaison de chaux vive et de laitier granulé de haut fourneau (SLGHF).

KEYWORDS:Soil stabilisation, sesmic testing, vibration, P-wave.

1 INTRODUCTION

Max-lab is a Swedish facility for materials research based on synchrotron radiation. The new version, Max IV, will be 100 times more efficient than any now existing comparable synchrotron radiation facility in the world. The location of the new Max-lab is placed just outside the city of Lund in southern Sweden. The geology consists of 12 to 16 meters of soil (clay till) on top of the bedrock. Close to Max IV runs a major highway which will introduce ground vibrations. Since the facilitiesare sensitive to vibrations an extensive measurmet program of background vibrations vere executed.

Several foundation alternatives vere discussed and some of them were tested with FEM-simulations to determine which alternative that fullfilled the requrement of damping both external and internal vibrations. The alternative that best fullfilled external and internal damping was a 4 meter thick stabilised layer underneath the concrete slab.

1.1 *Geotechnical testing*

The pre-investigation of the geology included geotechnical sounding as well as geophysical measurements as well as core drilling through the soil layers down into the bedrock. After the in-situ investigation and evaluation a geological model for the site was developed. From this model minor excavations were performed for soil sampling. The soils were classified and an extensive testing was performed to evaluate which binder or binder combination that was optimal for the soils. The major parts of the soils were clay till with layers of silty sand till.

Three different binders were tested, lime; cement and slag. The slag was ground granulated blast furnace slag (GGBFS). The clay till contained up to 40% clay and the sandy silt till has low clay content. The high clay content indicated that lime should be used to break up the clay. However, lime alone would not work with the sandy silt till. The clay till from this area have been tested in a earlier study and the combination of lime and slag was discovered to be efficient in this type of soil (Lindh, 2004).Two different binder recipes were chosen from the initial laboratory testing;

- Cement/slag (80/20)
- Lime/slag (50/50)

During the construction phase of the mock-up, cement and slag were chosen due to the current weather conditions and the time schedule for the mock-up. During the seismic testing of the mock-up cracks were found in the stabilized material. The results indicated that the cracks were introduced during construction of the stabilised layers. The layer in question was milled 50 mm down into the layer below to ensure interaction between layers. The binder's working period was not sufficient to guarantee that the next layer could be milled into the stabilised bottom layer without causing cracks. This resulted in a change of binder to a combination of lime and slag (50/50).

FE-calculations as well as seismic measurements performed on the mock-up showed that a shear wave velocity needed to be at least 900 m/s in the stabilised soil.In this case it corresponds to a compression wave velocity (P-wave) of 1430 m/s. The seismic velocity testing was performed according to a methodology developed at Lund University and tested on cement stabilised soils (Rydén*et al.*, 2006).New samples were prepared to measure the early strength development, see Figure 1.After more than 1200 hours the samples were removed from the plastic mould that supported the samples during compaction and in the beginning of the curingperiod of the samples. This resulted in a small drop in P-wave velocity.

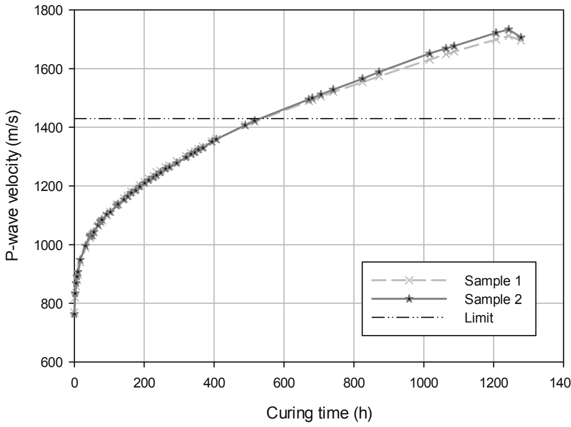

Figure 1.The figure shows the development of compressive wave velocity with time. The drop in velocity after 1240 hours is caused by removing the samples from the plastic mould.

The seismic measurements of the prepared samples were performed several times every 24 hours for the first 400 hours. In Figure 2 the measured frequency is shown together with higher frequency modes.

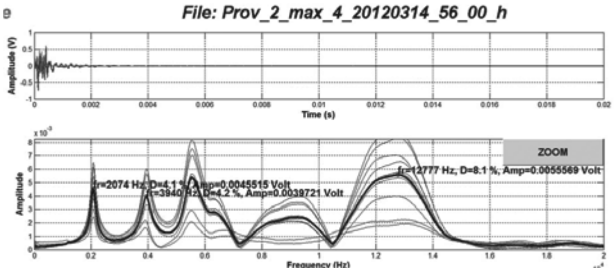

Figure 2.Different frequency modes for sample number 2 after 56 hourscuring. The lowest frequency peak corresponds to a fundamental mode longitudinal resonance frequency of 2074 Hz which corresponds to a P-wave velocity of 1043 m/s.

The longitudinal resonance frequency of 2074 Hzcorresponds to a P-wave velocity of 1043 m/s for sample 2. The samples needed approximately 500 hours of curing in 20 degree Celsius to meet the requirements regarding P-wave velocity.

2 IN-SITU MEASUREMENTS

The quality testing in-situ was done both as ordinary testing with binder content, MCV, pulverization and E_{vib} measurement with the compaction roller. The testing procedure also included sampling from the stabilised soil when the mixer had made two mixing passes. The stabilised soil that would be tested was excavated and transported to a field laboratory for compaction in plastic moulds. After compaction the P-wave velocity was measured and compared with the laboratory mixed samples. Most of the production samples (PS) were stored in room temperature to ensure the same conditions compared with the laboratory compacted samples.

There was a great variation in the development of P-wave velocity versus curing time for different samples, see Figure 3. The causes of this variation were a combination of different parameters such as;

- Variation in water content
- Variation in density
- Variation in grading (clay content)
- Variation in the degree of pulverization

In order to study the development of P-wave at different temperatures two pairs of specimens were manufactured. One pair was stored in room temperature and the other pair was stored at outside temperature. The difference in P-wave development is shown in Figure 3. The different samples are denoted PS9 and PS11 in the figure. The sample PS 9 was stored at room temperature and the sample PS 11 was stored at outside air temperature.

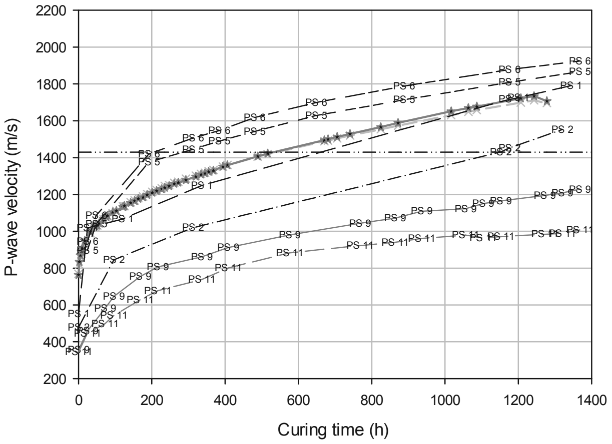

Figure 3.Development of compressive wave velocity with time for reference and production samples.

The production sample denoted PS9 required more than 2400 hours achieving the limit value of 1430 m/s and the sample PS 11 did not achieve the required limit. However, storing a specimen in an outside air temperature is not fully correct compared to the in situ conditions due to larger volume of stabilised soil and in the in-situ case the heat transfer is one dimensional. It does however give an idea of how low temperature will affect the stabilised soil in-situ.

An example of the in situ seismic measurements is shown in Figure 4.

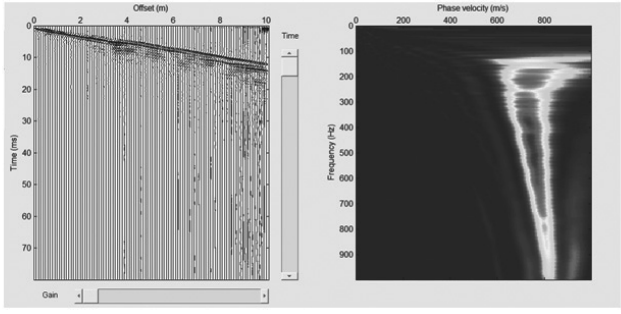

Figure 4.A result from seismic in-situ measurement along the surface of the stabilised layer is presented in the figure. The top layer has almost reached a surface wave velocity (~0.92Vs) of 800 m/s at the time for measurement. The target shear wave velocity after curing is 900 m/s.

The in-situ measurement of the stabilised soil is performed with the same equipment as used for sample testing. However, the in-situ testing involves the whole volume and gives a true value of the stabilised soils' performance. The seismic testing will be followed up in future with testing on the concrete slab.

3 CONCLUSIONS

Soil stabilisation with binders increases the stiffness (E-modulus) of the soil and thereby changes the resonance frecuency of the soil. In this project the soilstabilisation has been a key issue to meet the requrements regarding vibrationsin a cost effective way.It has been proven that it is possible to achieve a homogenius stabilised monolitic ring with a circumference on 528 meters and a depth of 4 meters.

The homogenity of the stabilised material is a result of an extensive testing program in both laboratory and full scale. The binders' working period has also been an important issue to ensure a crac-proof construkton.

It has also been shown that seismic testing works very well for both laboratory and in-situ testing of stabilised soils.

4 ACKNOWLEDGEMENTS

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