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Stone columns in very soft clays in Sweden

Dr. Jimmy Wehr
Keller Holding GmbH, Germany

Magnus Eckert, Marcus Dahlström
LCM AB, Sweden

Prof. Michal Topolnicki
Keller Polska, Poland

ABSTRACT: Scandinavian countries are famous for dry deep soil mixing. Only recently the vibro replacement technique or stone columns have been introduced in Scandinavia. Several sites with soft and very soft soils have been executed successfully already in Sweden.
Examples are presented including a road embankment on premixed grouted stone columns in Frövifors, stone columns as ground improvement for tanks of sulphuric acid in Helsingborg and stone columns under an embankment of road 73 from Stockholm to Nynäshamn.
Finally recommendations are given for vibro works in very soft sensitive clays.

1. FRÖVIFORS, SWEDEN - PREMIXED GROUTED STONE COLUMNS

Ground Improvement by premixed grouted stone columns was used for a road embankment over a swampy forest area in 2005. The Road Department in Sweden ordered a new road outside the small village Frövifors due to heavy traffic caused by a paper factory.

1.1. Project

Along the road 641 an area of 50m x 40m needed to be stabilized for a road embankment with a final height of 9m. LCM was asked for an alternative to lime cement columns and found grouted stone columns as well suitable. The site was cleaned from obstacles and frozen ground and then a 50cm working platform was built.

1.2. Soil Conditions

The working platform was built four weeks before production started to pre-load the top peat layer. After the pre-loading, the compression modulus of the 1m peat layer was evaluated to M=1MPa. The soil profile was as

follows: 2.5m of silty clay, c_u=8-14kPa, w_n=70% and compression modulus of M=0.5MPa which was followed by 4.5m of silty sand with E=8MPa. At approx. 9m depth started a thin layer of moraine, E=30MPa on top of the bedrock.

1.3. Design

The grouted stone columns were created by crushed stones, cement and water. The Young's modulus in the columns was evaluated to E=26,000MPa. The maximum load on a single column was limited to 100tons for a min. diameter of 51cm. Due to the very soft soil conditions and to create the right compaction effect in the columns, an average diameter of 75cm and a length of 13m was installed. On top of the columns two layers of woven geotextile of polyester type Stabilenka with a 10cm thick separation layer of gravel were placed. The scope of the geotextiles was both to distribute the load on top of the columns and to reduce the horizontal load of the columns. The road embankment was build up in layers of 2m consisting of compacted blast rock, E=50MPa, φ=45°.

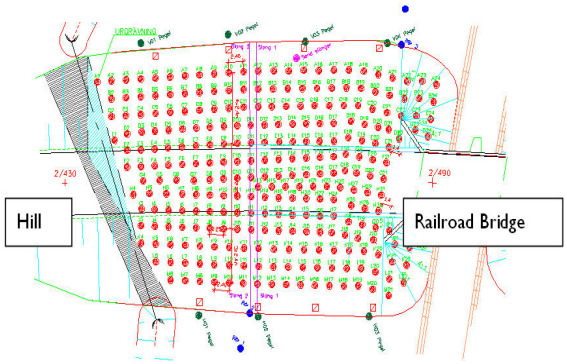
1.4. Execution

The construction work was executed by a Vibrocat, a mixing plant and a silo. Specially produced gravel was pre-mixed together with cement and water in a computer controlled mixing plant and thereafter transported by a wheel loader to the hopper on the Vibrocat. Depending on the load conditions the spacing ranged between 2.0m and 2.4m from centre to centre.

To improve the soft soils before construction of the grouted stone columns, vibro gravel drains were installed with the vibrator in short lifts of 1m height. This procedure has been found to be absolutely necessary to produce columns of equal diameter without liquefying the soft soil around the columns.

1.5. Testing

To monitor the calculated deformations under the embankment, 7 inclinometers at the slope end and 2 horizontal flexible tubes were installed to measure the settlement after treatment. Measured horizontal movements of the inclinometers were 15mm. Measured vertical deformation between the columns was 20mm. Concrete cubes were taken from the mixture and tested in the laboratory by unconfined compression tests which reached approx. 23MPa.



Pic. 1 - Layout of columns

Pic. 2 - Site set-up

Pic. 3 - Cross-section of grouted stone column

Pic. 4 - Build-up of embankment

2. KEMIRA I, HELSINGBORG, SWEDEN - VIBRO REPLACEMENT STONE COLUMNS

Ground Improvement for 7 new storage tanks in the harbour of Helsingborg in Southern Sweden was performed. Kemira Chemicals is located in an area where sulphuric liquid is produced.

2.1. Project

The cylindrical steel construction of the tanks has a diameter of some 20m and a height of 18m. Due to the previous collapse of one storage tank filled with sulphuric acid the demand of ground improvement was unique. The ground improvement should be resistant against high sulphuric content and low pH-values as well as marine stress. A total area of 2,840 m^2 needed to be treated.

2.2. Soil Condition

The Kemira Factory area was partly man made. The soil profile had a top layer of some 3-5m of fill followed by sandy organic clay (gyttja) underlying by silty sand with an E-modulus of 45 MPa. Additional borings were made before down to 20m without reaching any rock.

The relative density (D_r) in the fill was classified as loose to medium dense. The relative density in the sandy organic clay (gyttja) layer was classified as very loose with an organic content of 7-19%. The underlying sand was classified as medium dense to dense. The modulus and density in the fill is E=20MPa, γ=18kN/m³ and in the gyttja, E=8MPa, γ=16kN/m³ followed by E=45MPa, γ=18kN/m³ in the sand layer.

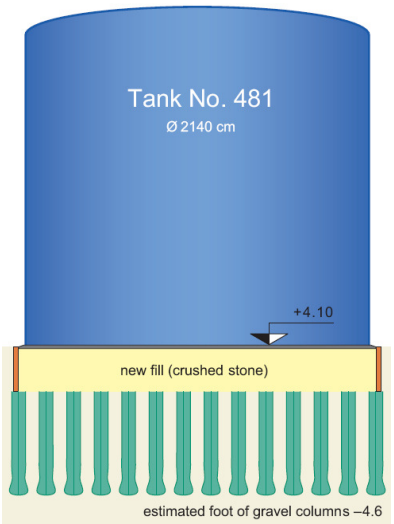
2.3. Design

The columns were installed with an average spacing of 1.7 times 1.7m under the tanks, the load on the slabs was 365kPa and the unit weight of the acid is 18.5 kN/m^3. The design was jointly prepared by Keller and LCM and approved by WSP. The allowable maximum differential settlement along the tank periphery should be below 1/800 (3cm) and the total settlement was calculated to 10cm. Tests were executed by CPT's in the centre of the column and in the surrounding soil on a random basis. Measured cone resistances were approx. 24 MPa in the surrounding soil. The Young modulus was evaluated to be E=60 MPa between the columns and 100 to 200 MPa in the columns.

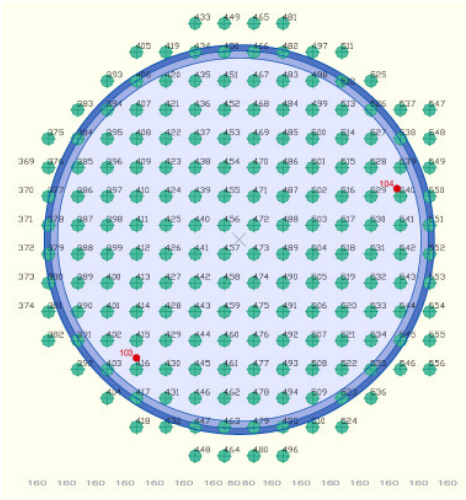
2.4. Execution

The gravel columns were executed by using the technology of vibro replacement (bottom feed system). The columns were constructed by using specially mixed nature gravel 4 to 25mm grain size, which created an average column diameter of 600mm. The foot of the column is placed on the sand layer in approx. 5.5m depth.

Pic. 5 - Site set-up



Pic. 6 - Tank with stone columns



Pic. 7 - Layout of stone columns

3. NATIONAL HIGHWAY NO. 73 BETWEEN STOCKHOLM AND NYNAS-HAMN, SWEDEN

This project has been started 2006 and is still under construction. A road embankment on stone columns has been planned next to a bridge on piles.

The thickness of the soft clay is about 10m having a minimum undrained cohesion between 15 and 25 kPa. The sensitivity of the clay is normally below 20, in one region it ranges between 20 and 40. In the critical area a test field was planned. The third loadstep out of five of the construction of the embankment has now been completed. All settlement gauges show values lower than predicted. Final results will be published soon.

4. RECOMMENDATIONS

It is recommended to take great care executing vibro stone columns in soft clays in Sweden. Monitoring and testing as described in the European standard EN 14731 should be followed strictly. Furthermore bottom feed systems with an adjustable frequency of the depth vibrator are absolutely necessary.