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Technical report – Soil nailing

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1 GENERAL

Special Session on Soil Nailing was held on November 16th, 2001 from 9:30 – 12:30 am. The Chairman of this session was R. Jewell and the secretary was N. Kotake. The program of this session is shown in Table 1. After a brief introduction of the plan of this session, five selected papers were orally presented. Then, following the introduction on main topics, three panel presentations were performed. One of the panelists, Prof. Vucetic (USA), could not participate in this symposium owing to unavoidable circumstances; many of those in the floor may have been disappointed. Abstracts of their presentations including that of Prof. Vucetic are shown later in this report. Main topics brought up at the discussion sessions with panel and floor were a) Equipment and Materials, b) Applications, c) Seismic Loading, and d) Analysis.

Table1 Program of the special session on soil nailing

1. Introduction / R. Jewell, Belgium
2. Oral Presentation of Selected papers

(1.1) An Example of a High Soil Nailed Wall in Plastic Clayey Soil / P. Kvasnicka, Croatia
(1.2) Innovative Solution for a Kei Cutting Problem / G.V. Price, South Africa
(1.3) Soil Stabilization with High-Performance Steel Wire Meshes in Combination with Nails and Anchors / R. Ruegger, Switzerland
(1.4) Seismic Ductility of Cut Slope Reinforced by Soil Nailing / A. Takahashi, Japan
(1.5) Stability Analysis of Reinforced Slopes Considering Progressive Failure / T. Yamagami, Japan

3. Panel Presentations

(2.1) Introduction and Themes for Panel Session / R. Jewell, Belgium
(2.2) Some Recent Experiences with Soil Nailing in South-East Asia / W. Cheang, Singapore
(2.3) Some Recent Experiences with Soil Nailing in Europe / A. Lottman, Germany
(2.4) Performance of Soil Nailed Excavations under Earthquake Loads / M. Vucetic, USA
(2.5) The Finite Element Method of Analysis for Soil Nailing Walls / S. Bang, USA

4. Discussion with Panel
   Open Floor Discussion
   Concluding Remarks / R. Jewell, Belgium

2 ABSTRACTS OF PANEL PRESENTATIONS

2.1 *Some Recent Experiences with Soil Nailing in South-East Asia / W. Cheang*

The presentation was based on three very recent soil nailing case histories and schemes. In each of these soil nailing schemes, interesting features were highlighted and discussed. Some of these projects were still ongoing at the time and currently being investigated by the Soil Nailing Research Group in NUS. As a preliminary to the above, a short presentation on some of the common construction practices and ground conditions in Singapore was highlighted.

<u>Case 1: USJ-19 Soil Nailed Excavation in Soft Soils</u>
- The use of jacked-in pipe inclusions (i.e. Displacement Nails) in soft ground conditions -

The first documented use of jacked-in pipe reinforcements in soft residual soils. These passive inclusions which can be categorized as displacement nails as in contrast to the normal convention drill-and-grout which is generally of the replacement type were used in conjunction with cast in-situ contiguous bored pile wall for the stabilization of a deep excavation. It is suspected that soil setup due to soil disturbance during the initial jacked-in installation process and the subsequent re-equalization of pore water pressure could have caused the increase in the effective interfacial axial resistance. It can't be denied that the stiff structural facing has played a role in the stabilization of the excavation and the stability of the geostructure lies in the combined effect of the steel pipes (the reinforcing material), the jack-in method (the installation technique) and the cast in-situ wall.

Case 2: Prince George's Park Stabilization Scheme

- Drilled-and-grouted soil nails and half-pyramid earth buttresses -

To maximize spatial land utilization very steep vertical cuts were required and when space is not of constraint, half-pyramid earth buttresses were constructed mainly to support the steep face through the formation of lateral soil arch and as well the minimization of soil removal. Fully bonded soil nail inclusions of the drilled-and-grouted kind were used in this scheme. A geotechnical instrumentation scheme was implemented whereby the deflection of the wall structure and the internal stresses of the passive inclusions were monitored with inclinometers and vibrating wire strain gauges respectively. Predominantly the tensile resistance of the of nail played a major role in the stabilization of the excavation and as the staged excavation progresses towards the final level, migration of the point of maximum tension force was observed. Bending resistance was observed but only of minor contribution to the whole soil nail system.

Case 3: Bukit Batok Slope Stabilization Scheme

- Drilled and grouted soil nails and difficult ground conditions-

Currently this project and the collection of field data are still ongoing. Installation and construction problems encountered during construction of the soil nails due to variable and difficult ground conditions will be highlighted.

As part of the sustained research effort of the Soil Nailing Research Group in NUS in soil nailing, two sections were monitored to investigate slope movements and the mobilization of the internal soil nail stresses. As part of the ongoing research by the afore-mentioned research team on the mechanism of shear transfer, investigation is currently being carried out on the fundamental assessment and prediction of the interfacial axial resistance (bond stress) of soil nails in tropical residual soils. Two pullout models (NUS-E Model and NUS-EP Model) were developed previously and instrumented pullout tests conducted in the field will be used to verify these models.

2.2 *Some Recent Experiences with Soil Nailing in Europe / A. Lottman (Germany)*

The first example is a stabilization of a cutting slope with soil nails. During the construction work for a high speed railway line a cutting slope with a height of 23 m and an inclination of 1:1.75 was stabilized with soil nails (ϕ50 mm). The soil nails were set in a grid of 2.5 m x 2.5 m and had a length up to 24 m. With the load of joint water the calculated stability was comparatively low. The stabilization with nails was therefore supplemented by a system of drainbores. The slope movement was controlled with inclinometer and extensometer measurements. The nails were drilled with a special drilling machine, which allows the drilling of 20 m depth without changing the linkage. The nails are ending 0.5 m below the ground level. A lining at the surface or nail heads are not necessary, because the inclination of the slope is relatively low and the nails are stabilizing the soil by means of shear forces over their whole length. The advantage of this kind of soil nailing is that at the final state no elements of stabilization can be seen.

The second example shows the stabilization of a railway embankment using self-drilling nails. Because of the lower costs and easier handling in many cases self-drilling pipe nails with lost bits are used. The drilling rod remains in the borehole as a tendon, and cement grout is used as a drilling fluid, which connect the nails with the borehole wall. The main advantage of these nails is that the machinery necessary for their installation is not very heavy and can be used even on very steep and wooded slopes. The drilling machine is attached to a vehicle at the top of the embankment, or a lightweight drilling rig is fixed on the boom of an excavator or crane having already the dip of the nails. This picture shows the cross section of a self-drilling nail after excavation. The hollow steel and the surrounding cement grout are recognizable.

The next two examples show soil nails in combination with prefabricated concrete part linings with two ways of installation. The construction of a new federal highway made it necessary to cut a natural slope in mica slate in a length of 380 m and an excavation depth of maximally 20 m. The geological reconnaissance showed that the mica slate was extremely jointed and weathered. So it became necessary to install stabilization from the beginning of the excavation works. It was decided to reinforce the slope using long soil nails in a grid of approximately 2.5 x 2.5 m. The lengths and the cross-section of the nails was determined assuming that a sliding wedge could move most disadvantageously on a slip plane activated when the excavation was nearly finished. Threaded construction steel bars (ϕ 63.5 mm) with lengths up to 20 m were used. The nails were arranged vertically in a way that their ends standing out of the slope surface could be used for threadening the prefabricated lining wall elements later. The weathered and jointed rock surface between the nails was stabilized during the works to protect the workspace using steel mesh, shotcrete, and short soil nails of 22 mm diameter. About the installation of these elements was decided at the site after each excavation step using lining classes with different shotcrete thickness and nail lengths. After the end of the excavation works the prefabricated vertical elements were installed and fixed. Then the horizontal cast beams were placed between the columns on consoles. Finally the lining wall was backfilled, and the vegetable mould was brought on the beams.

In the course of the improvement of the access roads to the city of Stuttgart a cutting into a steep natural slope became necessary. The slope was formed by siltstones and claystones. For the stabilization of the slopes a concrete part system was used like in the project before, but a new technique for the abutment construction was developed. The vertical beams were supported using prefabricated concrete abutments kept in place by a part of the nails (ϕ50 mm threaded tie bars). The nail grid was 2.5 x 2.5 m, and the nail length was between 7.7 m and 11.3 m, depending on the height of the cutting slope.

2.3 *Performance of Soil Nailed Excavations Under Earthquake Loads / M. Vucetic (USA)*

There is relatively little evidence on the performance of the soil-nailed excavations during earthquakes. One of the more comprehensive studies was done following the 1989 Loma Prieta Earthquake in California (Vucetic et al. 1998). This study showed that the soil-nailed excavations designed and built according to standard recommendations and practices (Bruce and Jewell, 1986; 1987; FHWA, 1996) performed very well. This study also showed that relatively little is known about the behavior and possible mechanism of failure under earthquake loads and that, consequently, the existing seismic stability analysis could not have been verified.

To gain more insight into the seismic behavior of soil-nailed excavations, an extensive dynamic centrifuge testing program was conducted on various configurations of soil-nailed excavations (Tufenkjian and Vucetic, 2000; Vucetic et al., 1993; Vucetic et al., 1996). In this way, instead of waiting for possible earthquake-induced failures, a series of failures was produced in dynamic centrifuge on 18 models. The following effects on the seismic stability were investigated: length of the nails, density of the nails, rigidity of the nails, inclination of the nails, reduction or increase of the nail length with the height of the excavation, and the rigidity of the facing.

The presentation covers: main characteristics of the centrifuge models, testing procedure, kinematics of facing and nailed soil mass under cyclic shaking and patterns of failure.

2.4 *The Finite Element Method of Analysis for Soil Nailing Walls / Hoe S. Bang (USA)*

This presentation considers the application of the finite element method to the analysis and design of soil nailing. Comments were made on potential limitations of more simplified limit equilibrium based methods that are commonly used for design.

In particular, the presentation discussed

* The importance of construction sequence simulation, including incremental excavation and construction.
* The importance of unloading and reloading in constitutive relationships.
* Two-dimensional versus three-dimensional analysis for skewed soil nails.
* The simulation of facing for permanent soil nailing walls.
* The combination of soil nailing with other earth retaining systems, such as tie-backs.
* The determination of potential slip surfaces from finite element analysis.

This presentation illustrated how finite element and other numerical methods are becoming more common in geotechnical practice. Indeed, there are certain types of design uncertainty that can only properly be investigated via numerical methods. However simpler calculation methods, such as limit equilibrium analysis, continue to be the basis for most routine design work. The insights provided by more detailed finite element analysis into simpler design methods are also a very useful outcome of this more sophisticated modeling of behavior.

3 DISCUSSION

Main five topics were brought up at the discussion session with floor. The main and related topics are shown below:

Topic 1: Equipment and Materials
- * Self-installed nails
- * Non-metallic nails
- * Injection fluids
- * Facing methods and materials
- * Environmental aspects
- * Corrosion and degradation

Topic 2: Applications
- * Mixed applications
- * Nailing in clay soils
- * Treatment of perched water tables

Topic 3: Seismic Loading
- * Nailing layout modification
  - Larger and longer nails
- * Stability
- * Cumulative deformation

Topic 4: Analysis
- * Stability during construction
- * Stability analysis
  - Limit equilibrium
  - Numerical
- * 2D/3D numerical modelling

Topic 5: General Discussion Topics
- * Codes, Standards, Guidelines, TC 9 ...

The characteristics of new materials presented by the panellists and advantages in their use were discussed. Also, as a contribution from the floor, a case history of reinforced excavation in India was presented.

4 CONCLUDING REMARKS

Soil nailing technique seems to be mature in practical design and execution. On the other hand, the equipment and materials have been improved so as to fulfill engineering requirements to reinforce the earth by nailing in specific regions such as difficult geological conditions, environmental reservation, neighboring construction and others. Also, seismic and numerical analyses have been extensively conducted. Thus, it may be promising that the nailing technique will catch up the engineering needs in the fields.

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