Analysis of the results of in-situ soil nailing test projects

Analyse des résultats des expérimentations de clouterre en chantier

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ABSTRACT: Soil nailing has been more and more widely used in China for the support systems in building excavation and slope stabilization. The tensile forces along nails during construction were measured on two construction sites using strain gauges and vibrating wire stress meters respectively. The obtained measurements were used to analyze the behaviours of soil-nailed retaining structures, including nail force distribution along nail length, maximum nail force and its location, the potential failure surface as well as changes in nail forces with time during construction.

RÉSUMÉ: Récement la techique CLOUTERRE est devenue de plus en plus populaire en conception de systèmes de soutènement pour des fossés de construction et la stabilisation de talus. Les forces de tension le long des clous étaient mesurées en chantier pendant la construction en utilisant des jauges de déformation et des tensiomètres à fil vibratoire. Les résultats ainsi obtenus étaient utilisés pour analyser les comportements des structures de soutènement construites par cloutage. Ceux-ci incluent la distribution de force le long du clou, la force de tension maximale, sa point d' action et la surface de rupture potentielle ainsi que leurs changements au cours de construction.

1 INTRODUCTION

Soil nailing refers to reinforcing elements (a regular array of metal rods) inserted horizontally or subhorizontally into the cut face, as staged top-down excavation proceeds. The inserts improve the shearing resistance of the soil by being forced to act in tension. Soil nailing is becoming more common in China because the method brings about economy in both time and materials.

At present, various methods are available for soil-nailed wall design, such as Wang Buyun Method, Bridle' s Method and Juran's Kinematical Limit Analysis. Whatever the method used in design, it is essential in the first place to determine the maximum nail forces and their location (the potential failure surface), the earth pressure acting on the face, as well as their changes with time. Therefore study and unveiling of soil-nailed wall behavior by in-situ tests has practical and theoretical significance.

2 TEST PROJECT DESCRIPTION

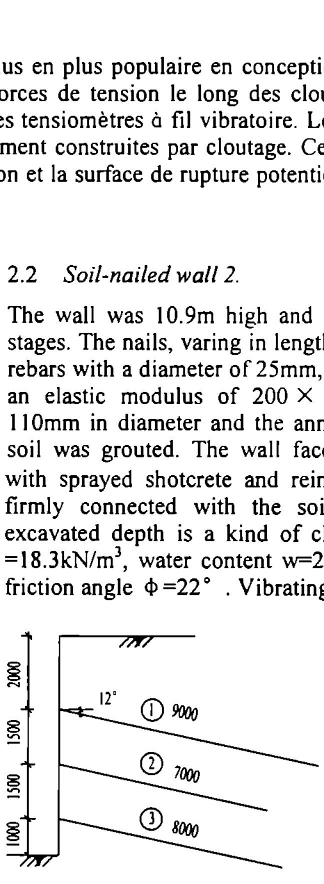
The two soil-nailed wall test projects described in this paper were carried out in Shenzhen, China, 1998. They formed parts of the temporary support systems for building foundation excavation.

2.1 *Soil-nailed wall 1.*

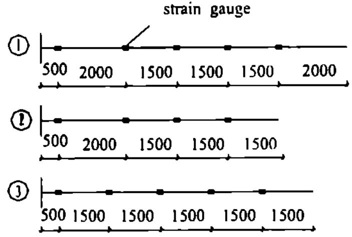
The related parameters are: height of vertical wall = 6m, number of nails in a vertical section = 3, maximum nail length = 9m and inclination angle of nail = 12° . The soils involved consisted of fill to a depth 1.8m, followed by clay with sandy clay which was underlain by decomposed gneiss. Strain gauges affixed on the nails were used to measure the axial nail forces under working conditions. Figure 1 illustrates the cross section of the soil-nailed wall and the layout of strain gauges.

2.2 *Soil-nailed wall 2.*

The wall was 10.9m high and was constructed in seven 1.5m stages. The nails, varing in length between 9.0-12.0m, were steel rebars with a diameter of 25mm, a yield strength of 310MPa and an elastic modulus of 200×10^3MPa. The nail holes were 110mm in diameter and the annular void between the nail and soil was grouted. The wall face was 90mm thick constructed with sprayed shotcrete and reinforcing wire mesh which was firmly connected with the soil heads. The soil within the excavated depth is a kind of clayey material with density γ =18.3kN/m^3, water content w=20%, cohesion c=50.0kPa and a friction angle Φ=22° . Vibrating wire stress meters were axially



(a)

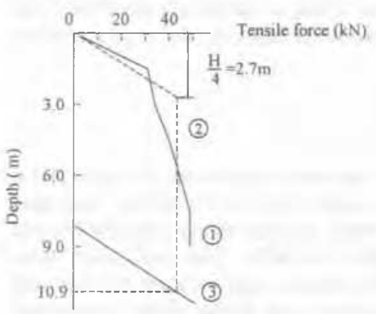


(b)

Figure 1. Cross-section of nailed wall 1 and location of strain gauges (mm)

Figure 2. Cross-section of nailed wall 2 and rebars stress meters layout (mm)

Figure 3 . Distribution of the axial forces and potential failure surface (wall 1 and wall 2)



① measured maximum nail force.
② suggested by Terzaghi & Peck for a braced excavation.
③ obtained by Rankine earth pressure theory.

Figure 4. Variation of measured maximum nail forces with depth at end of construction (wall 2)

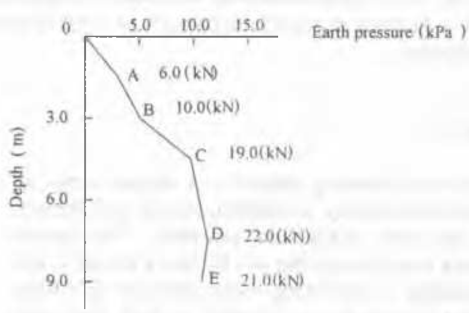


Figure 5. Earth pressure distribution (wall 2)

welded along the nails at relevant intervals to measure the nail loads mobilized under testing conditions, as shown in Figure 2.

3 TESTS DATA AND ANALYSIS

The main objectives of the tests made and analyzed are : (1) the axial force distribution along nail length ; (2) the maximum force and its location in each nail as well as the shape and location of the potential failure surface in the wall; (3) the nail head force and earth pressure acting on the wall face; and (4) changes of nail forces with time.

3.1 *Axial force along nails*

Figure 3 presents the distribution of the tensile forces along the nails at the end of construction. Please note the changing shape of the force curves, the point where the axial tensile force reaches its maximum value and the point where the axial force is reduced to zero due to shear resistance mobilized between the grouted nail and soil.

3.2 *Maximum nail forces*

The maximum nail forces are of the basic data necessary in soil-nailed wall design. Figure 4 shows the variation with depth of the maximum mobilized nail forces in the rebars at the end of construction(Soil Nailed Wall 2).It can be seen that the nail force distribution along depth is nearly trapezoidal and approximates the pressure distribution for a braced excavation suggested by Terzaghi and Peck.

Figure 3 also shows the potential failure surface as obtained by connecting the maximum nail force positions on the force-nail length curves and as compared with the Rankine failure surface. It is to be noted that the wall soil mass can be divided into two zones by the potential failure surface, i.e. the active zone and the resistant zone. In these two zones, the friction forces acting on the nails are respectively directed toward and away from the wall facing. The active body is smaller than that predicted by the Rankine failure surface, and the ratio of the distance between the intersection point of the maximum nail force line with the top of the soil-nailed wall and the wall shoulder (edge) to the height of the wall (H) is equal to about 0.36 as can be seen from the Figure 3b.

3.3 *Nail head force and earth pressure acting on the facing*

Because of the difficulty in placing earth pressure cells on a nearly vertical wall face, the earth pressure was instead calculated using the nail force measured at about 0.5m behind the facing and taking into consideration the nail force distribution along the nail length. The results are presented in

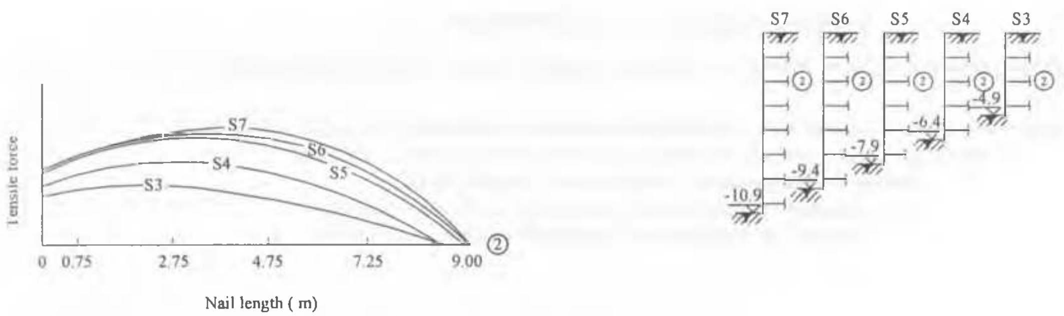


Figure 6. Variation of forces in level 2 with excavation depth (wall 2)

Figure 5 where for each nail the number in brackets is the corresponding nail head force which is about 50% the maximum nail force.

3.4 *Variation of nail forces with wall construction*

Table 1 shows the measured nail force changes in nail level 2 caused by excavation of the lift from depth Z=6.4m to Z=7.9m. Also shown are the measured stabilized nail forces which had resulted from the preceding stage. It can be seen that the nail forces increased rapidly at first as removal (excavation) of the lift soil of that stage took place, the increase rate soon slowing down and the nail forces levelling off toward stabilized values in about one day after completion of lift removal. This result tells us that in soil-nailed wall construction design, determination of appropriate excavation lift heights and quick stage construction including lift excavation, nailing and wall facing are essential in terms of full use of both soil and nail strength, prevention of undesirable soil deformation as well as reduction of construction time.

The foregoing observed results constitute a discrete example of the remobilization and subsequent restabilization of the nail in a previous level triggered by the excavation and wall construction of an individual lower stage. In a generalized way, it can be said that the forces in the nails of a previous level (stage) undergo a process of repetitive increasing and stabilizing as stage by stage downward wall construction proceeds. Figure 6 shows the variation of the nail forces in nail level 2 with the excavation of each successive lift below that level. It can be seen that the closer the subsequent excavation lift, the more significant the influence of the downward advancing excavation on that level of nails. It was estimated that about 90% of the maximum stabilized force in nail level 2 was reached after two excavation lifts.

4 CONCLUSIONS

1. The failure surface intersects the top of the soil-nailed wall at a distance of approximately 0.36H from the edge of the wall which is smaller than that predicted by Rankine's theory.

2. The distribution of the maximum nail force is analogous to that of a braced excavation suggested by Terzaghi and Peck.

3. The nail head force and earth pressure acting on the facing are of considerable magnitudes. In other words they are not too small to be negligible in soil-nailed wall design.

Table 1. Measured nail force (kN) changes in nail level 2 due to excavation from Z=6.4m to Z=7.9m.

Meter number	January 15 Z=6.4m	January16 * Z=7.9m	January17* Z=7.9m	January18* Z=7.9m
1#	12.8	12.7	16.5	16.0
2#	15.0	16.5	19.5	19.4
3#	12.7	15.8	18.1	18.4
4#	6.5	7.7	9.2	9.9

* The nail forces of January 16, 17 and 18 were measured at 3, 22 and 53 hours after the 5 th level excavation (Z=7.9m) respectively

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