Optimised Design for Soil Nailed Walls[1]

J A R Ortigao[1] and E M Palmeira[2]

[1] Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

[2] University of Brasília, Brasília, Brazil

INTRODUCTION

The first application of soil nailing for slope stabilisation in Brazil dates back to 1970 for a tunnel portal, carried out by tunnel engineers (Ortigao et al, 1995). Unfortunately, almost no publicity was given to this development. On the other hand, a lot was publicised on the effectiveness of tieback walls in Brazil and thousands of them were used throughout the country. In mid 80's, geotechnical engineers in Brazil started to become aware of a cost-effective alternative to tiebacks and interest on soil nailing increased. Several walls have been constructed since then, many without proper analysis of the effect of the reinforcement, and the design has been carried out based on previous experience and engineering judgement.

The next decade brought a new era for soil nailing in Brazil: the trend now is towards optimised design in which nail length and facing design are optimised, but nail corrosion still needs further considerations. The following aspects will be discussed in this paper: soil-nail interaction and nail length and stability analysis, facing design and corrosion.

SOIL-NAIL INTERACTION

The authors take only nail tension into account, since in their experience, for the dimensions of nails usually employed, bending effect has only a very small effect and can be disregarded (Ortigao et al 1995 a & b).

Nail tension depends on so many aspects that only site specific testing can give reliable values of the soil-nail unit friction q_s. However, pull-out testing before construction never occurred in the author's experience, and the evaluation of an *a priori* value for q_s has been necessary in most walls. Testing always come afterwards to confirm, or not, pre-construction values and today pre-estimation of q_s are carried by the authors from the data in Figure 1. This figure relates unit friction with *N* values from Standard Penetration Tests (SPT). Despite being a very crude test the SPT is the sole site investigation in most small and medium projects in Brazil, therefore data in Figure 1 can be very useful for preliminary design stage.

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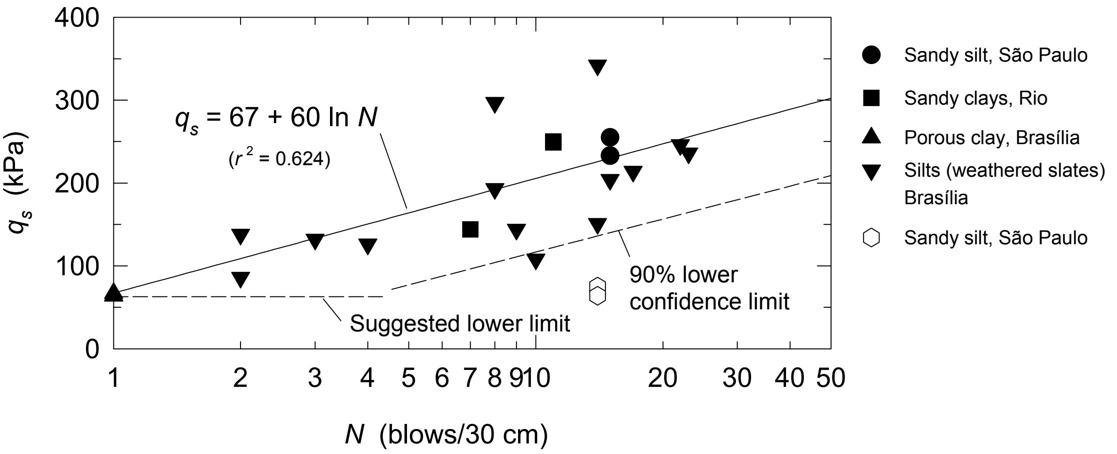

Figure 1 Pull -out tests results

NAIL LENGTH AND STABILITY ANALYSES

Existing slopes to be stabilised deserve in general little deformation concern. The problem is to ensure stability and an adequate factor of safety for the reinforced slope. This is the case of the example in Figure 2. This slope required very little excavation to reach the final geometry. However, since a building nearby was going to be constructed, the slope had to be stabilised to increased its safety. The site is close to the Congonhas Airport in São Paulo, where a there is a porous clay deposit, found in many locations in Brazil (Ortigao et al , 1996a)

The distributed surcharge on the slope was 40 kPa. For a preliminary analysis, soil parameters were evaluated from previous experience with these clays: c' taken equal to 10 kPa, ϕ' was 26 degrees and the unit weight γ was 15 kN/m^3. The water table was found very low and the analysis has shown it had little effect on the results. This yielded a factor of safety for the unreinforced slope of 1.080 using Bishop's method of analysis.

The analysis of the reinforced slope was carried out with *Rstabl* (Ortigao et al, 1995b) employing Bishop's and Janbu's method. Nails were 32 mm steel bars in 100 mm grouted boreholes. The soil-nail friction was estimated using the chart in Figure 1 as 120 kPa. The analysis started by introducing nails from the bottom of the slope upwards and carrying out global stability analyses until the required factor of safety was obtained. It was found that the minimum length of the bottom nail layer was 21 m. The other nail layers with 18 and 15 m long were assigned in the next step leading to a factor of safety (FS) close to 1.5.

In the upper part of the slope there was a 6 m high vertical cut to be carried out. Since it was very close to the top where the 40 kPa surcharge was to be applied, deformation became of concern and three layers of 9 m long nails were designed. The FS for this part of the slope is close to 1.6.

In summary, the technique adopted by the authors is to carry out successive analysis starting from a global analysis and following the slope upwards. This certainly minimises nail length and ensure stability.

Later during construction, it is of utmost importance that pull out tests on sacrificial nails are carried out. These data will enable the designer to adapt his design to actual measured conditions.

An opposite situation occurs when deformation is of major concern, as it is the case shown in Figure 3. This wall was proposed to be excavated very close to an existing road on the top.

Local soil was a silty sand with *N* values around 8, too low. Wall deformation could lead to cracks on the pavement, which was undesired.

Therefore, a mixed soil nailed structure employing nails and soil anchors was designed to

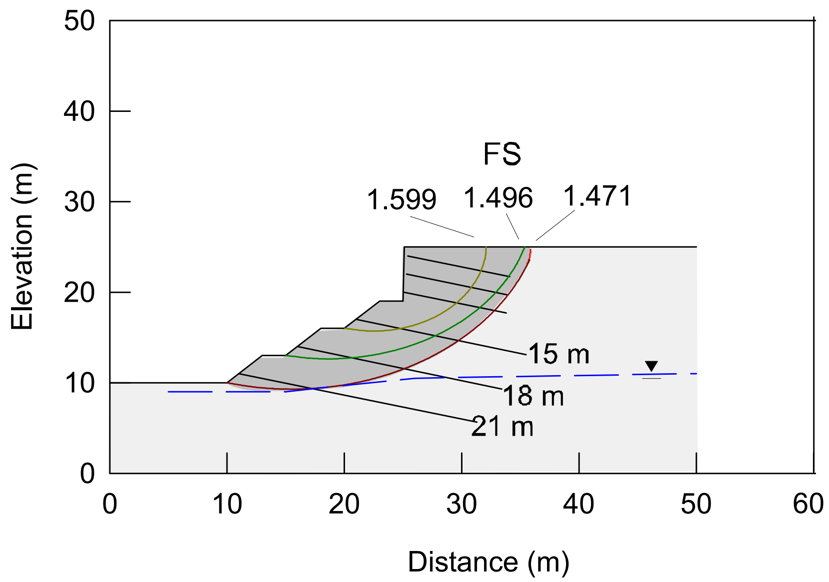

Figure 2 Example of wall close to Congonhas Airport, São Paulo

increase stiffness and, consequently, to reduce deformation (Ortigao et al, 1995b).

Soil parameters were estimated as: unit weight 18 kN/m^3, cohesion was taken as 10 kPa and friction angle equal to 26 degrees.

Table 1 Stability analyses of mixed soil nailed wall

Condition	***Calculated FS***			
	Rstabl		***Prosper***	
	Bishop	Janbu	FS	δ (mm)
No reinforcement	0.480	0.498	0.69	0
Nails only	1.481	1.478	1.50	16
Nails and soil anchors	1.499	1.483	1.50	11

Rstabl results in Table 1 were compared with a different method of analysis developed at the Laboratoire des Ponts et Chaussées and described by Delmas et al (1986) incorporated into the Prosper program. In Prosper nails are treated according to the Winkler model, as a beam supported by non-linear springs. Tension, bending and shear are considered. The FS calculation iterates until the necessary nail deformation δ is calculated to give a specified FS equal to 1.50. The resulting δ values in Table 1 are small, indicating that the proposed wall is acceptable. The calculated slip surface is different from the one obtained by *Rstabl*. Computed FS values with Bishop and Janbu's methods are close.

STEEL FIBRE REINFORCED SHOTCRETE

Vertical or nearly vertical walls require a flexible facing and in most cases shotcrete has been used. In the last years there has been a considerable progress in the use of steel fibre reinforced shotcrete (SFRS) (Vandewalle, 1993) which presents advantages in relation to the use of mesh reinforcement.

Fibres are high tensile strength steel elements having 30 - 50 mm in length and 0.5 mm in diameter with hooked ends, that are mixed in the concrete as an aggregate with a dosage in the range of 35 to 60 kg/m^3. It can be used in either dry or wet sprayed concrete mix. The fibres have no effect in the compressive strength of the concrete, but increase ductility, enabling to take into account flexure tensile strength. The market offers a variety of fibre types, but only some with a very high length to diameter ratio achieve high performance. Some are glued forming small clusters with 30 to 40 fibre pieces stuck side by side. These bundles are mixed in the concrete and are separated in contact with water after one or two minutes of mixing. This leads to a better fibre random distribution and better concrete workability.

The final SFRS product is a homogeneous material with increased crack and corrosion resistance. SFRS saves the labour for the mesh placement and saves total concrete volume in

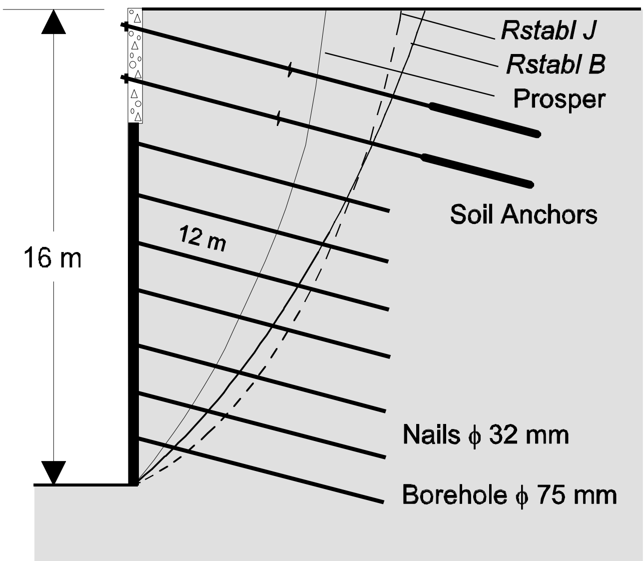

Figure 3 Mixed soil nailing structure proposed for an excavation in medium sandy-silt

relation to mesh reinforced shotcrete. SFRS complies with soil or rock surface irregularities, saving total concrete volume, as compared to the use of a steel mesh.

SFRS is being applied with considerable success at the portals and at the lining of a 2.2 km long Covanca Tunnel in Rio de Janeiro. A series of preliminary laboratory tests conducted on SFRS samples confirmed the properties of the concrete mix and additional testing and evaluation are underway. It is expected that SFRS will replace most of the steel meshes today still employed for slope stabilisation and soil nailing.

NAIL CORROSION AND FRP

The first tieback wall in Brazil was constructed in 1957 and since then, Brazilian experience can be summarised as follows. Yassuda (1994) presented several cases in which corrosion took place in multi-strand anchors close to the anchor head and caused failure of the structure. These and other evidence led the Geo-Rio, the Rio de Janeiro Geotechnical Office, to ban this type of soil or rock anchor in this City. However, there had been no evidence of corrosion in a 25 (or more) mm diameter steel bar used for tiebacks, although there had been cases of deterioration of the anchor head protection leading to corrosion of the nut and supporting steel plate.

Double protection, in which the steel bar is sheathed in corrugated plastic and grouted, has not been common in this country.

The ultimate solution for corrosion certainly is the use of *fibre reinforced plastic* (FRP) nails, as described by Ortigao (1996). FRP’s are a composite material obtained by an industrial process called *pultrusion* that combines the fibre reinforced elements, usually glass fibres, with different types of resins. The final product can be of any shape with very high tensile strength, usually three times steel strength, low modulus and low unit weight. Bars and tubes are produced for geotechnical applications. FRP’s have a very high corrosion resistance, easy cuttability, but its cost is still high as compared to steel.

FRP’s have already found some applications in tunnelling in Brazil (Ortigao, 1996) but, none to the authors' knowledge, in soil nailing. However, since the cost of the nail bar alone may have little effect on the overall cost of the stabilisation project, FRP’s will find their way in slope stabilisation works, leading to long-term corrosion-free and safer walls.

CONCLUSIONS

This paper discussed soil nailing design optimisation according to three different aspects. The first, concerns stability analysis and deformation compatibility of a soil nailed wall. The soil friction data in Figure 1 enable the selection of *a priori* friction value based on the *N* value from the SPT for a particular soil, but its value has to be confirmed *a posteriori* through pull-out tests.

Stability analyses should be carried out in several levels of the structure from the bottom upwards, ensuring safety and adequacy of the FS value at each level. Existing slopes or those subjected to little excavation have little deformation concern. Vertical excavations close to sensitive structures should be more rigid and avoid excessive deformation. The authors have combined nails *and* anchors at the top to limit deformation.

Steel fibre reinforced shotcrete has been used in Rio de Janeiro with considerable cost and time saving. SFRS should be considered in most projects where a concrete facing is necessary.

Finally, long term corrosion should receive additional consideration. Reinforced plastic technology seems to be the ultimate solution but, since the cost is higher than steel, it is likely to find applications in aggressive environments or by the imposition industry standards. Some aspects of FRP long term behaviour, such as creep and interaction with grout, seem to deserve further investigation

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