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National report on codes of practice, regulations and authoritative reports on braced excavations in soft ground – South Africa: Southern Africa region

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SYNOPSIS: Braced excavations, including the use of ground anchors and soil nails, are common in Southern Africa. Anchored excavations in soft ground have been successfully constructed to depths of 20m and soil nailed excavations to depths of 14m. This report summarises the state of practice in South Africa and the Southern Africa Region.

1 COUNTRY AND AUTHORSHIP OF REPORT

This National Report is for the Republic of South Africa which is situated in the African Region.

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2 OCCURRENCE AND NATURE OF SOFT SOILS

Soft soils are widespread throughout South Africa. These soils may be broadly classified as transported or residual.

2.1 Transported Soils

Over most of the interior of the country, the transported soils are generally thin (less than 3m deep). The lower portion of the transported profile is often ferruginised. This, together with the partially saturated nature of the profile, results in excavations less than 3m deep requiring little or no lateral support.

Notable exceptions are the estuarine deposits in the coastal regions and the aeolian sands of the semi-arid western parts of the country and neighbouring Botswana.

The deep alluvial deposits along the coastline are the result of sea level changes in the Neogene period. The present sea level is approximately 100m higher than that during the Weichsellian regression resulting in the filling of many deeply incised river valleys along the coast with sandy and clayey sediments. The rivers along the Natal Coast on the eastern side of the country, the Durban and Richards Bay areas in particular, are examples of this phenomenon. The water table in these sediments is typically a few metres below ground level resulting in the instability of most excavations more than a few metres deep.

The aeolian deposits in the semi arid areas on the western side of the country generally consist of fine silty sands which may extend to depths of 20m or more in places. In many instances, the sands are lightly cemented and exhibit a collapsible grain structure. The water table is generally deep and the partially saturated soils have sufficient cohesion to permit the formation of vertical sided excavations several metres deep.

2.2 Residual Soils

Over much of the sub-humid and humid eastern interior of the country, deep residual soil profiles have developed. Arguably, the most common on these profiles are those developed on the granites and those derived from the weathering of basic igneous rocks.

The residual granite profile comprises a deep layer of partially saturated, friable silty medium and coarse sand with frequent bands of gravelly pegmatite. The material is characterised by a high angle of shearing resistance (33 - 38°) and low cohesive strength. Most of the highly developed northern suburbs of Johannesburg are underlain by weathered granite. Leaching of the granite leads to a collapsible grain structure which, together with the demand for underground parking area, makes the provision of basements below structures an attractive proposition. Weathered granite soils, although more clayey, are also encountered on the steep mountain slopes in the highly developed areas around the city of Cape Town. Many deep excavations are formed in the slopes to create level areas for residential and commercial development.

Deep residual soil profiles are also derived from the weathering of igneous rocks such as diabase and andesite. Within the Johannesburg CBD, these soils may extend as deep as 35m on the diabase and up to 60m on the andesitic lavas within the Johannesburg graben. The depth of these soils makes piling uneconomical and the provision of deep basements is common practice. The residual soils are generally clayey or sandy silts with a moderate angle of shearing resistance (20 - 28°). Although the intact material has a relatively high cohesive strength (25 - 50kPa), the presence of relict joints makes the use of more than a small fraction of this cohesion in the analysis of lateral support inadvisable. Severe collapse of sidewalls of excavations and bored pile holes occurs along such joints below the water table.

3 POPULARITY OF BRACED EXCAVATIONS

The lateral support market in South Africa is currently worth approximately R10 - 20 million (US$3 - 7 million) per annum. This represents the value of the lateral support and does not include the cost of excavation. More than 90% of the market is for temporary support with a design life of less than two years. There are three or four major contracting firms active in this market.

In the interior of the country where partially saturated soil profiles are present, most deep excavations in soft soil are supported either by ground anchors or, more recently, by soil nails. Diaphragm walls are popular in the costal regions where a high water table is present. The use of sheet piles is confined mainly to temporary works such as bridge foundation excavations due mainly to the high material cost of the sheet piles, most of which are imported. Since the development of high capacity soil anchors, the use of struts in excavations is generally limited to trenches or small holes. Nevertheless, one of the largest basement excavations in central Johannesburg (the Carlton Centre) was supported in this manner.

Ground anchors are usually used in conjunction with predrilled soldier piles installed prior to commencement of excavation. Typical soldier pile spacings are between 1,8m and 3,2m. In many instances, only the upper few metres of the excavation face is planked and the lower material is left unsupported between soldier piles. High pressure, re-injectable grouted anchors are used in soft soils with capacities of 300 to 600kN.

4 EARTH PRESSURE CALCULATION

The lateral pressures acting on anchored or nailed faces are generally evaluated using limit equilibrium techniques involving the analysis of single or multiple failure wedges. Anchor and nail lengths are checked using slip "circle" analyses to check the overall stability of the system.

Semi-empirical methods (Terzaghi and Peck, 1967) are generally used for strutted excavations and for determining the loads exerted on the permanent structure.

Finite element methods for calculating lateral support requirements have not gained wide acceptance probably due to the lack of accurate input data required for all but the simplest analyses. This method has, however, been used for predicting ground movements with a fair degree of success.

5 DESIGN PROCEDURES

5.1 Wall depth and strut loads

In the case of single anchored sheet pile or diaphragm walls, the depth of the wall is generally determined using the free earth support method. The bending moments in the wall and the strut loads are reduced in accordance with the flexibility of the wall in accordance with the recommendations of Rowe (Rowe 1952).

In the case of multiple anchored walls, the method of Littlejohn, Jack and Sliwinski (1971) has been used. However, the bending stiffness of the wall is generally found to be a limiting factor in the application of this method.

5.2 Base heave and piping

Piping and loosening of the founding soils at the base of the excavation are generally controlled by limiting pore pressure gradients to acceptable levels. This is achieved either by dewatering from the base of the excavation or by increasing the depth of wall embedment.

Most South African soils are too stiff for base heave due to shear failure to be a significant design consideration.

5.3 Earth pressure distributions

Earth pressure distributions behind strutted walls are generally assumed on the basis of the semi-empirical Terzaghi and Peck diagrams. In the case of single anchored and cantilever walls, Rowe's method is applied.

For multiple anchored walls, there are no fixed rules for the distribution of anchor forces on the face. However, most designers tend to provide a reasonably uniform distribution of force over the lower two thirds of the wall height with lower pressures near the top of the wall where the installation of high capacity anchors is impractical or undesirable. This distribution has the advantage over a triangular distribution in that it tends to limit the deflection of the edge of the excavation.

Where the simple wedge method is used to assess the support requirements for multiple anchored walls, the wedge is assumed to extend to the level of the bottom of the excavation. Any embedded length of the soldier piles below the bottom of the excavation is generally assumed to contribute only to the vertical equilibrium of the wall.

5.4 Design of soldier piles

As mentioned above, Rowe's method is generally used for cantilever piles and single anchored walls. However, in the case of multiple anchored soldier pile walls, considerable savings can be achieved by the use of plastic or ultimate limit state design methods for the soldier piles.
Five to ten years ago, most soldier piles were designed using beam on elastic foundation theory. However, this method results in a severe over estimation of the section modulus of soldier piles. This lead to the adoption of ultimate limit state design methods where the bearing capacity of the soil in the immediate vicinity of the anchor is assumed to be fully mobilised over just sufficient length of the soldier pile to carry the anchor load times an appropriate load factor. A pile section (generally consisting two steel "I" beams) can then be chosen to ensure an adequate ultimate bending and shear capacity behind the anchor.

An alternative method (Howie et al 1994) assumes the bearing pressures behind the soldier pile to be determined using the modulus of subgrade reaction of the soil. The variation in the modulus of subgrade reaction with applied stress is determined by in situ plate load tests. Plastic hinges are permitted to form in the soldier pile and a suitable margin is provided to prevent the formation of a mechanism.

The application of these methods has resulted in savings of up to 40% on the weight of steel soldiers from that required by conventional (beam on elastic foundation) methods.

5.5 Ground movement

In most instances, ground movements are not calculated. The adoption of reasonable factors of safety in the calculation of support requirements is assumed to limit the deflection of anchored walls to approximately 0.1% of the height of the face and of soil nailed walls to 0,2% of the face height.

Linear and non-linear finite element analyses have been used with some success. However, the accuracy of the input data for such analyses generally does not warrant the sophistication of the approach. The major source of error is the estimation of the virgin stress field prior to commencement of excavation.

6 MONITORING AND INSTRUMENTATION

Most lateral support contracts require the monitoring of both vertical and horizontal movements of the edge of the excavation. Monitoring points are generally installed about 1 - 2m back from the face at 6 - 10m intervals. On occasions, additional lines are established H/3 and H from the excavation face (where H is the final depth of excavation). Movements lower down on the face are sometimes determined using inclinometers in the soldier piles or by survey of targets fixed to brackets attached to the soldier piles.

Requirements for monitoring of excavation movements are laid down by certain of the larger local authorities and in the S.A. Institution of Civil Engineers' Lateral Support Code. The normally accepted limit for horizontal movements on street faces in built up areas is 35mm (SAICE 1989).

Monitoring of adjacent structures is generally by means of precise level survey. Lateral movements of any buildings within H/2 of the excavation face are usually also recorded. In the case of major excavations in built up areas, existing damage to adjacent structures is recorded and photographed prior to commencement of the excavation.

Anchor forces are generally determined by means of lift off tests in which the load in the anchor is determined from the jack pressure. Most contracts required 3 or 7 day lift off tests on all anchors and 28 day tests on selected anchors. Load cells are seldom used except in permanent applications.

7 CODES OF PRACTICE

Most of the lateral support contracts in South Africa are based on the Code of Practice on Lateral Support in Surface Excavations (SAICE, 1989). This code is a revision of the 1972 code which was understood to have been the first of its kind in the world.

The code covers site investigation, selection of lateral support systems, earth pressures, design procedures, ground water control, monitoring and legal requirements. Case histories of excavation movements have also been provided in tabular form.

Copies of this code are available from the Institution and may be obtained by contacting either of the authors of this report.

8 CONTRACT PROCEDURES

The majority of the lateral support contracts in South Africa are "design and construct" contracts where the contractor provides his own design. The lateral support contractor is often a sub-contractor of the excavation contractor. However, it is considered preferable to separate the excavation and support contract from the building contract for the remainder of the structure.

Monitoring of the excavation movements is generally undertaken by a registered land surveyor appointed by the contractor. On occasions, independent checks are carried out by a surveyor appointed by the employer.

In view of the absolute liability which the owner of land has for the removal of lateral support to adjacent property, lateral support insurance is generally taken out in the joint names of the employer and contractor. Lateral support is generally excluded from the contractor's all risk cover. Designers are required to provide professional indemnity insurance.

9 MAJOR PROJECTS

Examples of strutted excavations in soft ground include the 23m deep Carlton Centre excavation (Heydenrych and Isaacs, 1967) and the 18m deep Standard Bank excavation (Heydenrych and Yawitch, 1967). The 19m deep Joubert Park Post Office excavation (Day 1990) is an example of an anchored excavation in soft soil. The deepest vertical soil nailed excavations include Sandton Square (granite) and Iscor Pretoria (diabase and shale), both of which were in excess of 13m deep. A 19m deep face inclined at 80° has been successfully completed in the Cape granites at Hout Bay, Cape Town.

Novel methods of support include the grout jacked arches used for the 29m deep Trust Bank excavation (Stander, 1967)

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