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Italian national report on braced walls

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SYNOPSIS: The Italian practice for design, construction and monitoring of braced walls in soft and loose soils is illustrated, with reference to the occurrence of such formations in the Italian geological situation.

1 OCCURRENCE OF SOFT/LOOSE SOILS IN ITALY, THEIR GEOLOGY AND ENGINEERING PROPERTIES

Soft and loose soils in Italy have been originated mainly within three geological environments, with different modes:

a) Continental and marine deposits.

b) Eluvial and colluvial deposits from soft sedimentary rocks.

c) Pyroclastic deposits associated to volcanic activity.

The geographic distribution of these environments is shown in figure 1, adapted from A.G.I. (1985).

The largest continental deposit is the Po valley and the adjacent venetian plain; minor deposits can be found along other rivers in the peninsula. Marine deposits are frequent along the coasts and in tectonic depressions aside the Apennine range. While the former are frequently recent and normally consolidated, the latter consist mainly of overconsolidated clays and silty clays of the Pliocene and Miocene ages.

The grain size decreases from west to east in the Po valley and from north to south in the venetian plain; the loosest and softest soils are found in the zones adjacent to the coasts. The mineralogical composition of these deposits reflects the varying nature of the parent rocks distributed along the Alps granites, diorites, gneiss, limestones, dolomites and others).

In the Appennines widespread soft sedimentary rocks (mudstones, clayey marls, very heavily O.C. clays, flysch) can frequently originate relatively thin eluvial and colluvial fine grained deposits superimposed to the parent rock, scattered along major and minor valleys, mainly east of the main longitudinal divide.

In a similar way, restricted zones of soft redeposited clays have originated within larger overconsolidated marine clay deposits.

The volcanic zones around Rome and Naples exhibit a large presence of pyroclastic deposits, both loose (pozzolanic sands and silts) or cemented (tuff): they can originate respectively remoulded or redeposited pozzolanic soils and clayey residual soils, the density of which is furtherly decreased by the presence of voids within the grains of volcanic ashes.

2 THE USE OF BRACED WALLS IN ITALY

Braced walls have been widely in use in Italy for underground construction in many types of works, and typically for:

- subway lines and stations;
- road underpasses;
- underground car parks;
- water intakes;
- harbour facilities.

The vertical retaining structures are generally obtained by diaphragm walls or cast in situ piles. Micropiles, heavily reinforced by steel pipes, are adopted where diaphragm walls are not feasible. Jet-grouting columns have been recently introduced in association with micropiles in granular soils (Ground Engineering 1992); walls obtained by deep mixing of cement in granular soils and placing vertical steel H beams in the fresh mix have also been experimented with success and in urban sites can be more economical and environmentally safe than diaphragm walls.

Steel sheet piles are relatively rare, their use being confined to temporary works and to some cases of harbour works; soldier piles with timber lagging are practically unknown.

For excavation widths up to 10 m steel or r.c. struts are adopted, as in the so called "Milan method" largely used in the construction of the first metro line in Milan in the late fifties: the diaphragm walls, at each side of the tunnel were mutually braced by the upper r.c. slab, before the excavation was continued down to the bottom.

Grouted anchors are generally preferred to the struts for wider excavations.

The above mentioned Milan method can be considered as a top-down construction and has also been applied to some underground multi-level car parks.

In wider excavations a bottom-up construction is generally preferred, unless the need of restoring the former use of the surface as soon as possible is of primary importance.

3 DESIGN PROCEDURES

The Terzaghi and Peck approach is seldom used,
and only for strutted walls. For simple cases, with one level only of struts or anchors, the design is based on the limit state pressures; "passive" pressures are affected by a reduction factor of 0.5 to 0.67 and "active" pressures can be incremented at an intermediate value between "active" and "at rest" if horizontal displacements of the soil have to be limited. The "fixed earth support" condition is generally preferred to the "free earth support".

For multi-level anchored walls the most common design procedure is based on a Winkler 2-D soil model, with bi-linear elasto-plastic "springs". The stiffness of the wall and of the anchors (struts) is taken into account and the sequence of the construction phases is considered. Calculations are carried out by appropriate computer codes on p.c.

The depth and flexural resistance of the wall, the size and prestressing of the anchors (struts) have to be defined prior to the calculation, so the final dimensions are determined by trial and error.

In special applications, where a precise evaluation of the soil movements around the excavation is required, a F.E.M analysis is run. The factor of safety versus soil strength is evaluated by the ratio of the limit passive thrust to the mobilized soil force, as given by the area of the active pressure at respectively of the limit passive pressure against the buried depth of the wall.

For a single anchor or strut level, the depth of the wall is such that a fixed end condition is reached; for multi-level anchored or strutted walls the minimum acceptable depth is that providing the balance of active and passive pressure at wall bottom. If a water table is present, the depth of the wall has also to be checked versus piping.

Vertical spacing of anchor lines is often dictated by the position of the floors in the building inside the excavation, as they will eventually act as permanent struts. Horizontal spacing depends on the flexural strength of the horizontal connecting beams. 1.50 m can be regarded as a minimum for both spacings and 4.00 m/6.00 m as a maximum for horizontal/vertical spacing respectively, for most common applications.

Earth pressure distribution above cut depth is assumed as in the active state if the wall is allowed to move horizontally; in case the horizontal displacements are limited, earth pressure will result accordingly comprised between the active and the at-rest value.

This pressure distribution below cut depth will vary from the passive pressure just below the excavation bottom to lower values at greater depths, as defined by the analysis. Anchor load is defined by the calculation, allowable loads are calculated on the basis of soil strength and anchor dimensions and checked by pull-out tests. The load on struts depends on their interaction with the soil and the wall and has to be checked against strut buckling.

All limits to horizontal and vertical movements of ground around the excavation are defined on the basis of distance and sensitivity to settlements of existing constructions. No fixed rules are given for excavations in free field conditions.

4 INSTRUMENTATION AND PERFORMANCE STUDY

Major braced excavations in urban areas are generally subject to some form of instrumentation with the aim of directing worksite operations and of preventing or limiting litigation with adjacent properties.

Generally, vertical and horizontal movements at grade level are measured by repeated topographic surveys.

Few major projects have been followed by more complete instrumentation, comprising: inclinometer pipes, deep settlement sensors, load cells at some of the anchors, strain gauges on the reinforcing bars of r.c. diaphragm walls, load cells at the soil/wall contact (Gatti and Cividini 1978; Ceccoli et al. 1981).

Monitoring programmes normally include:
- Accurate preliminary inspection of the adjacent constructions, with mapping and survey of any apparent evidence of structural disease:
  - fissures, out of plumbs, misalignments.
- Levelling of benchmarks on the adjacent structures.
- Readings of extensometers installed on old - if any - and possibly new fissures detected on adjacent buildings.
- A zero reading has to be taken before any activity on the site; measures have to be recorded and entered in a relevant step of the works:
  - Execution of diaphragm walls or vertical micropiles along the perimeter.
  - Each phase of excavation.
  - Anchors drilling, grouting and tensioning.
  - Water table lowering.

5 CODES AND MANUALS

The Italian law (Presidential decree 7/1/1956 n°164) compels to brace the excavations deeper than 1.50 m if persons have to work in, and soil consistency does not provide "satisfactory guarantee of stability".

The rules do not describe how the stability of the excavation walls has to be checked.

Accidents and even casualties are relatively frequent on minor excavation for buried services, due to inexistent or poor bracing, even in ditches shallower than 1.5 m where personnel often works in a bent posture.

Braced walls must comply with the only italian law dealing specifically with geotechnical aspects of civil engineering: the P.W. Ministry decree 11/3/1988. The decree rules soil investigations, design of foundations, of retaining walls (diaphragm walls included) and soil anchors; it gives general principles and guidelines. A stability analysis is required for excavations exceeding 2 m in depth; the stability of the bottom versus heave has to be checked for braced excavation and if diaphragm walls are used, also taking into account piping actions.

For works near to existing buildings soil displacements and their effects on the buildings must be evaluated, taking into account also the consequences of water table lowering, if necessary.

A preliminary geotechnical investigation has to be planned and carried on; the soil "directly or indirectly influenced by the construction" has to be studied. If the excavation lies in a slope, a geological report is also requested; in any case the results of soil investigation, studies and calculations must be collected in a geotechnical report. If anchors are used, their capacity has to be checked by
pull tests; if they are anchored in soils, their behaviour has to be checked versus time also. The preliminary pull tests for design have to reach the ultimate resistance of the soil-tendon system; the tests for approval have to reach 1.2 times the service load.

The Italian Association for Prestressed Concrete (AICAP) has issued a detailed guide for design, construction and testing of soil anchors. The main public agencies dealing with civil engineering works have issued their technical specifications for construction, comprising also items typical of braced walls: diaphragm walls, piles and micropiles, soil anchors. So have done:
- ENEL (National Electricity Board).
- ANAS (State Agency for National Roads).
- FS (State Railways Company).

Fig. 1
6 IMPORTANT PROJECTS EXECUTED BY BRACED EXCAVATIONS

Milan Metro
The "Milan method" has been adopted extensively in line no.1, and for some sections of lines 2 and 3 and for the underground regional railway link across the town. All together about 35 km of line and 60 stations have been constructed by braced diaphragm walls, for a total amount of about 1.5 millions sq.m of diaphragms.

Naples Light Metro
Four stations have been built or designed with use of diaphragm walls and anchors, totalling about 16,000 sq.m. of diaphragms.

Rome Metro and Genoa Metro also have adopted braced walls in some sections of their lines and for some stations.

Underground car park in Milan
The excavation has reached the depth of 22 m; a peripheral diaphragm wall is secured by 3 levels of grouted soil anchors (Gatti and Cividini 1978).

Pump house for a thermal power station at Monfalcone (Trieste)
The excavation was 10 m deep, 8 m below the water table. Peripheral diaphragm walls were braced at their top by r.c. beams, later included in the permanent structure (Fantoma et al. 1983).

New harbours at Cagliari and Gioia Tauro

REFERENCES