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## DIAPHRAGM WALLS AND PILES EXCAVATED IN BENTONITE SUSPENSION: FIRST CASE HISTORIES IN SLOVENIA.

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### Summary

*In these last years has been brought in the Slovenian market the constructing technology of concrete diaphragm walls and piles excavated in bentonite suspension. In the paper the technology will be described, as well as some statical features and the main fields of use of this versatile technology; moreover two real cases will be shown: the construction of deep foundation and subsoil floors of two large buildings in Lubiana.*

### Introduction

In these last years, thanking to the joint action of GPG d.d. (Gradbeno Podjetje Grosuplje) of Lubiana and ICOP s.p.a. of Udine (Italy), has been successfully brought in the Slovenian market the constructive technology of concrete diaphragm walls and piles excavated in bentonite suspension. In the following the technology will be shown, pointing out the advantages and disadvantages with regard to alternative methods, and the first applications in Lubiana, in the field of building constructions (deep foundations and support of excavation edges of subsoil floors) will be described.

### The technology

The realization of bulkheads by placing circular piles one near the other is well known in the common practice; the same result, or a better one, can be obtained by placing elements of rectangular section one near the other; the elements altogether will form continuous vertical walls.

The support of the lateral edges during the excavation shows remarkable difficulties especially when rectangular sections of sizeable dimensions are dug.

The problem has been successfully solved by the introduction of a mud, a bentonite suspension that, filling the excavation while it proceeds, supports the lateral edges.

With this technology excavations of any shape of section, and particularly circular and rectangular ones, can be done.

Diaphragm wall, as a whole, can be understood as an artificial membrane constructed in the ground, in the presence of fluid bentonite, by elements placed side by side that are filled of concrete after the insertion of the designed steel cage.

The construction is carried out from the ground surface by means of mechanical devices equipped with hydraulic or mechanical grabs, of various dimensions, with which the excavation is made. At the end a steel cage (that will be the reinforcement of the reinforced concrete section) is inserted in the excavation and the concrete is casted ascending from the bottom of the hole. In this way the concrete uplifts the bentonite suspension, lighter, that can be recovered and reutilized in the following excavation.

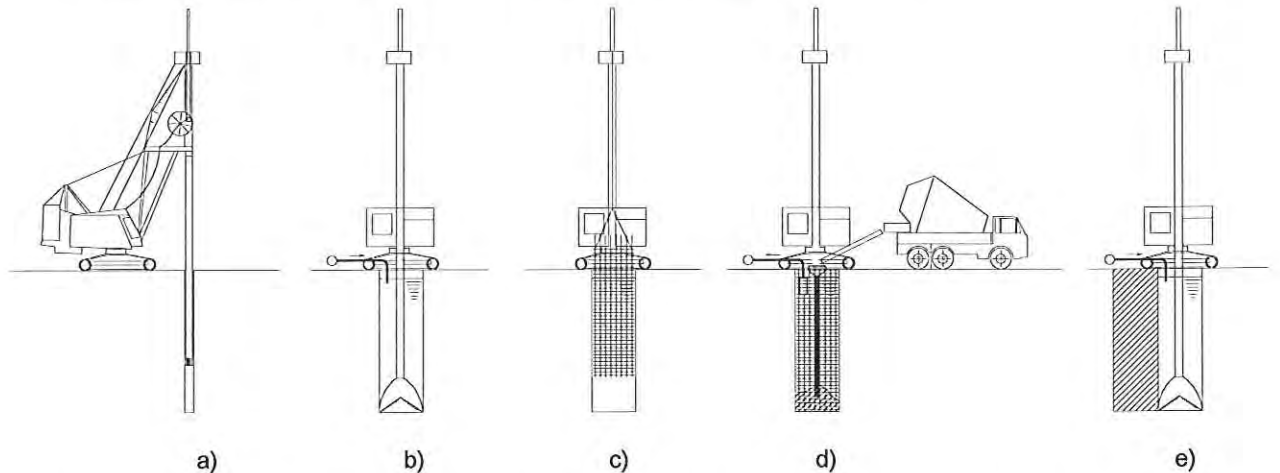


Fig. 1: constructive phases of a diaphragm wall: a,b) excavation by grabs in the presence of bentonite suspension; c) steel cage insertion; d) concrete casting from the bottom; e) execution of another element after the hardening of the concrete of the adjoining element.

The lateral edges support fluid, a bentonite suspension, with or without additives, has the property of making up, almost instantaneously, a membrane of very low permeability at the soil/liquid interface. This membrane allows the whole hydraulic pressure of the fluid to push against the edges of the excavation and, moreover, the penetration of bentonite in the ground (up to 100 mm) and the following gelling around the grains, gives cohesion to the ground belt around the hole, improving its stability.

## Applications

The technology fits to large diameter bored piles (from 0.8 to 2.0 m) and diaphragm wall elements of variable length (normally from 1.8 to 6.0 m), in function of the excavation stability, with thickness variable from 0.4 to 1.2 m. The height of the elements, piles or diaphragms, is a function of the devices utilized for the excavation; usually 25-30 m are reached, but diaphragm elements of more than 100 m have been builded.

The single diaphragm elements can be put together in the most diversified way. So it is possible to realize structures with different transversal sections, also of complex shape.

These elements can be used, for example, in the construction of harbour docks, of dams and anti-underwash dams, for the construction of surface tunnels, in the river lateral protections, for bridges and trestles foundations and particularly for deep foundations of buildings and special structures in the construction of subsoil floors, also under the water table.

## Soils

The construction of piles and diaphragm walls in bentonite mud is possible in all the different kinds of soils that are excavable by grabs; the best stability effect carried out by bentonite is obtained in fines (i.e. clays, silts and sands); cohesive soils of high granulometry and permeability (poorly graded gravels of large grain size) requires a bentonite suspension of higher viscosity and higher gelling strength than the one used in fines.

In very open soils (debris), as well as soils with rock blocks of large size or hard soils (rocks or conglomerates with resistance higher than 5 Mpa) the use of this technology is not recommended, mainly for grab excavation difficulties and because the use of heavy falling bits can unstable the excavation.

Also in those particular situations, however, it is possible to use bentonite diaphragms with the introduction of auxiliary works (i.e. circular pre-drillings or use of hydromills; expansive solutions), or to couple the diaphragm construction, in the excavable layers, with a different work in non-excavable hard layers (for example micropiles connected to the upper diaphragms).

## Groundwater

One of the main advantages of diaphragms excavated in bentonite suspension is the possibility to build them in presence of groundwater. An indispensable attention to be paid is that the level of bentonite suspension inside the hole must have a head over the water table level of at least 1.25-1.50 m. If not, the excavation could be unstable.

Another interesting aspect of this technology is that it allows the construction of impermeable underground walls, also under high water pressure.

The impermeability of the single diaphragm element is assured by the use of impermeable concrete that has not to be fissured by an excessive material stress, especially reinforcing steel stress. The impermeability of the whole bulkhead is assured by the position, between two adjoining elements, of a joint with a plastic water-stop insert.

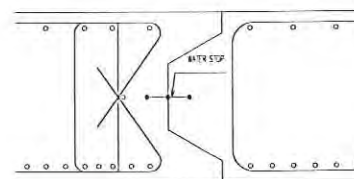


Fig. 2: joint between two elements: waterstop for impermeability and male-female shape for shear transmission.

## Statics

If the diaphragm elements are not connected between them, they show a "piano-keys" working, in which every single element works, in its vertical plane, independently of other elements. An horizontal connection can be obtained by building a concrete linkage beam over the head of the elements and by a suitable shape of joints so to allow shear transmission between adjoining elements.

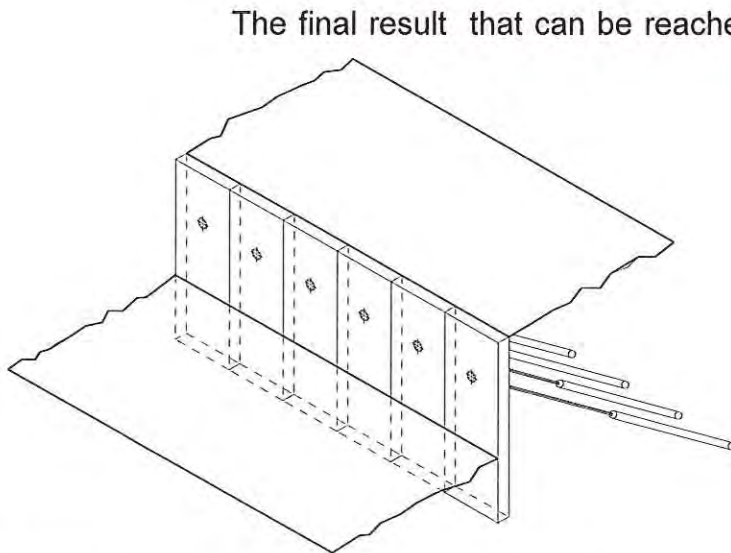


Fig 3: diaphragm wall supported by one row of soil anchors.

The final result that can be reached is of a wall, connected at the top, that works in bending and shear in the vertical plane and only shear in the horizontal one.

On the vertical plane, when the inner excavation has been carried out, the diaphragm can work as a bracket with a fixed end in the ground or, as usually happens, the positioning of one or more rows of soil anchors along the one side excavated diaphragm surface allows to take in account a rough static scheme of a beam

over many bearings.

Nowadays the computation of bulkheads is carried out by finite element software that allows a detailed description of the main hydro-geotechnical parameters and an incremental analysis of all the constructing phases. The software then allows the forecast of horizontal displacements, a very important data when the bulkheads are set near already builded structures (there can be a problem of movement of the old foundations). Moreover hydraulic phenomena, such as seepage or boiling at the excavation bottom, can be considered.

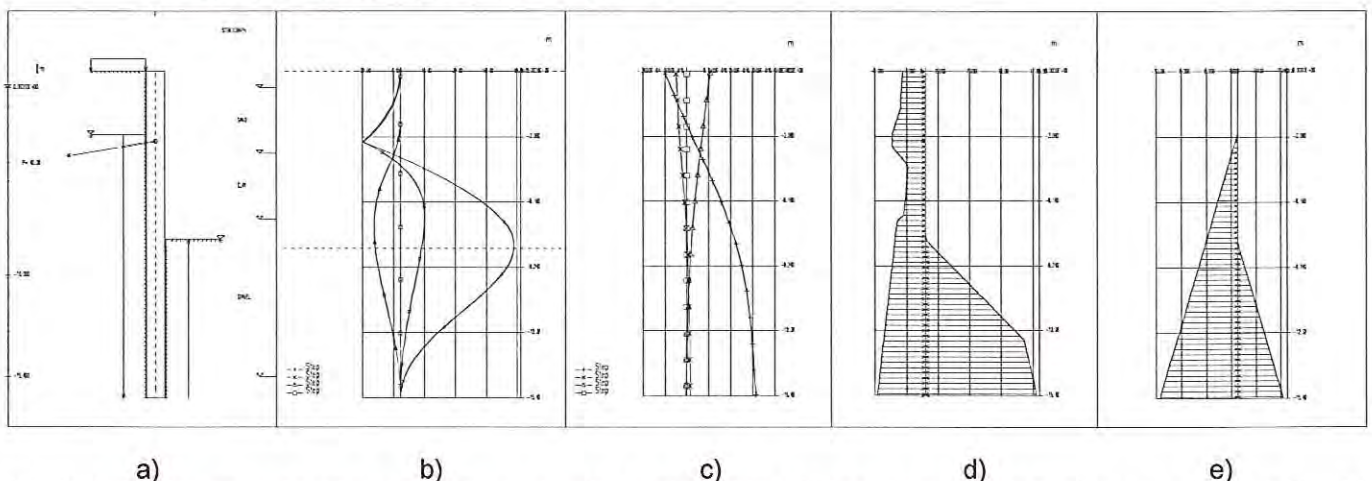


Fig. 4: finite element program output concerning the computation of Langusova street diaphragms: a) geometry; b) bending moment (envelope) [KNm/10]; c) horizontal deflections (envelope) [m]; d) effective pressure (last phase of excavation) [KPa/10]; e) pore pressure (last phase of excavation) [KPa/10].

Remarks can be done in relation to the use of diaphragms or piles bored in bentonite suspension as deep foundation elements with vertical loads.

It can appear, indeed, that the use of bentonite that produces an extremely lubricating wall membrane with very low mechanical resistance, could affect the lateral friction resistance between the concrete of the element and the surrounding ground. It has been widely proved that this is not what happens and that the friction resistance of piles bored with bentonite suspension is the same, and also sometimes higher, of the one of piles bored with common methods (for example lined piles as "Benotto"). The reasons of

such a good friction resistance are many. One of them is that the external bentonite membrane is fully removed by the concrete while its rising inside the hole. This because the shear stress, due to the friction and the cohesion that the concrete exerts on the wall of the hole, is much higher than the adhesion of the bentonite on the same wall. Besides the soil during the excavation never appears to be completely decompressed (as can happen in lined piles) thanking to the presence of a complete hydrostatic pressure of the bentonite fluid: this increases both lateral friction and bottom resistance.

### The reability of the technology

The construction technology of piles and diaphragms bored in presence of bentonite mud has a long experience; it has been tested, investigated and technologically improved and the reability has been verified. The manifold aspects of this construction method need, however, a carefully design based on a good hydro-geotechnical site knowledge and an execution carried out by experienced workers able to take the right quick action when executive problems arise. However the technology is becoming widespread around the world; this is a proof of its versatility and economical interest.

### First case histories in Slovenia

Last year the above described technology has been widely used in the construction of the underground floors and foundations of a building in Langusova street in Lubiana.

The building, of a nearly rectangular plan shape (60\*68 m), shows areas with a differen number of floors (9-5) starting from the ground level and, because of that, with different load values over the foundations; on the whole plan an excavation of 8 m has been executed for the construction of two underground floors.

The soil of the area is formed, for the first 7 m, by backfills and silty sands; under them by highly compressible clays until 17.5 m and than by gravels; the watertable level has been found 3.0 m under the ground level.

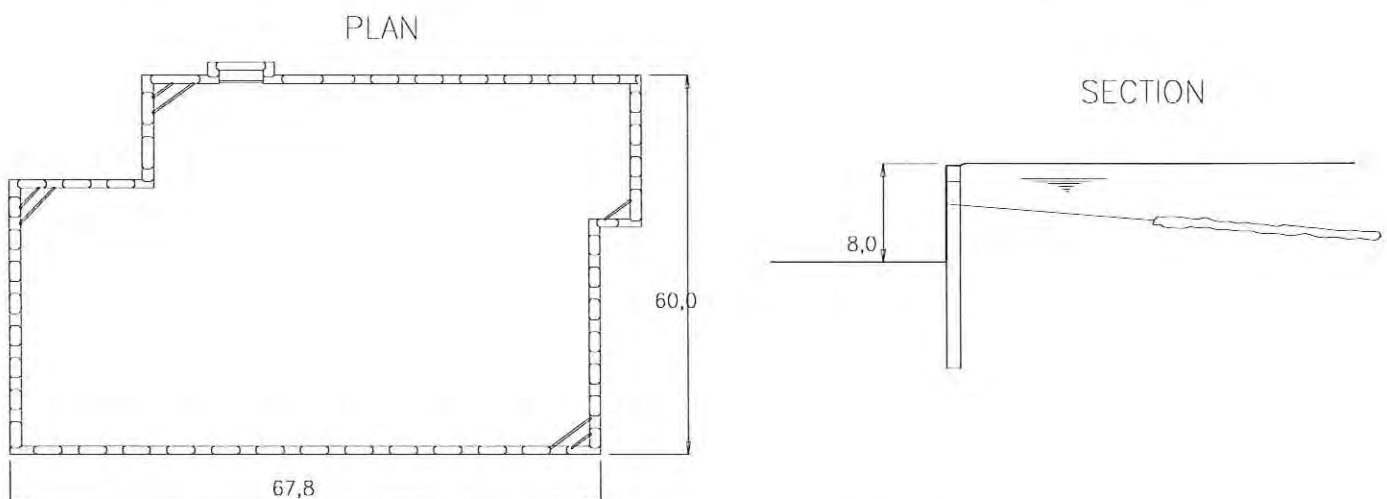


Fig 5: plan and vertical section of diaphragm walls in the building of Langusova street in Lubiana.

The excavation of the two underground floors had to be carried out near existing roads and buildings; so it was planned to use peripheral diaphragms that could assure, compared to alternative solutions such as adjoined piles or jet grouting columns, an higher safety against possible water infiltrations and moreover allow, as peripheral walls of the building, to take up the relating vertical load.

To undertake the horizontal thrust of the soil, it has been executed a row of temporary soil anchors, that has been connected to the lateral ground by jet grouting almost horizontal columns.

All the foundations have been executed with piles or diaphragm elements: the versatility of the technology allowed to make different foundation (section and hight) in function of the single load (same displacement criteria). Some elements, heavily loaded (over 10 MN), have an hight of almost 30 m.

The deep foundation elements have also been designed to anchor the bottom slab of the building that, after the stabilization of water pressures, could be pushed upward by uplifting pressures of more than 50 KPa.

The bottom slab has been connected to the heads of foundation elements and, laterally, to the peripheral diaphragms through steel anchorages so to achieve a structural continuity between slab and diaphragms; the impermeabilization between the two casting has been made by the interposition of bentonite waterstops.

The construction of a watertight "empty box", with peripheral diaphragms and bottom slab, allowed then a quick construction of the building, starting from 8 m under the ground level and with a water head of 5 m.

A second case history, still under construction, is interesting for the unusual coupling of diaphragm walls and micropiles because of the presence, at variable levels, of conglomerate strata near the bottom of the inside excavation of the building. This case history regards the new hotel "World Trade Center" of Lubiana. It is a building of 12 floors over the ground level and 3 floors under the ground level, with a plan dimension of 75\*40 m.

It has been designed an excavation of 11.20 m under the ground level. The stratigraphy presents an upper layer of 7 m of thickness made by gravels, an underneath layer of clay of 2 m and, finally, a conglomerate gravels layer. Ground water has not been detected.

Also in this case it has been decided to use diaphragms for the undoubtable advantage of having a peripheral wall already built before the inner excavation and for statical reability. But there was a problem: the presence of conglomerate gravels at a variable levels could prevent to excavate the diaphragm elements until the

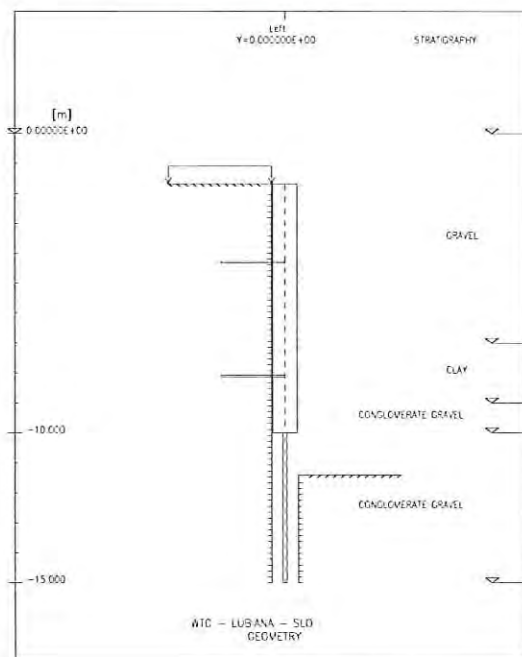


Fig. 6: geometry of WTC peripheral diaphragms and micropiles.

necessary depth and the inner excavation could undergo the bottom of the elements.

In such areas, to complete the peripheral walls, underpinning of diaphragms had to be done. To execute this operation at a good safety level and to connect vertically the diaphragm to conglomerate layers, it has been decided to build micropiles under the diaphragm elements after the completion of these last ones.

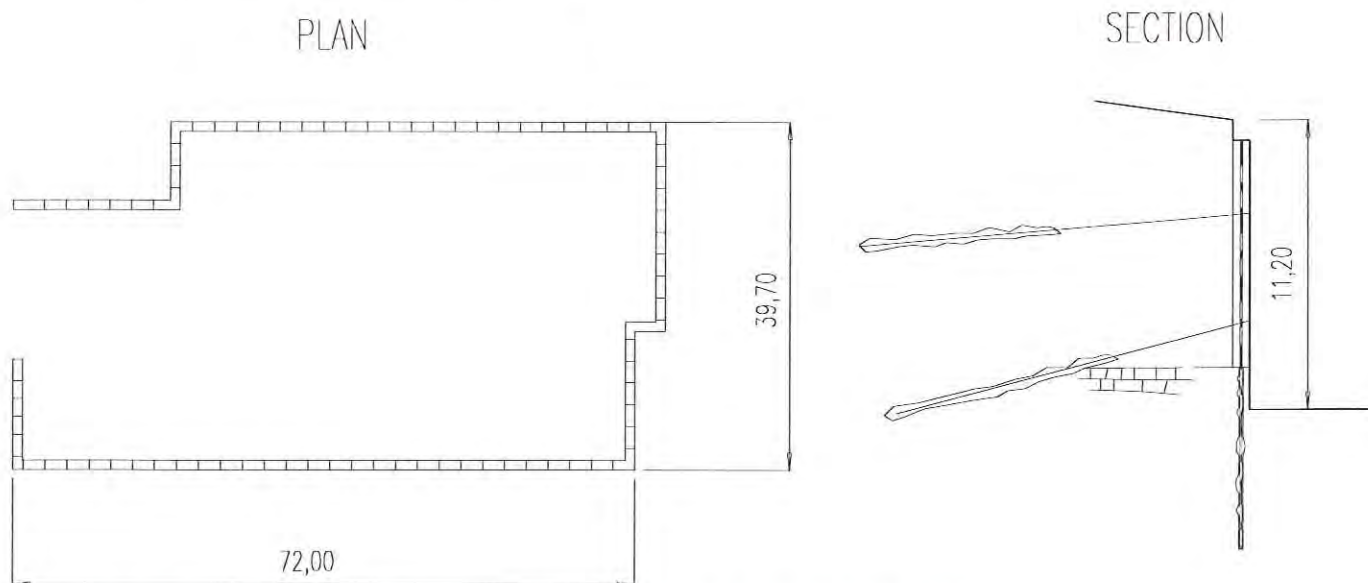


Fig 7: plan and vertical section of diaphragm walls and micropiles in WTC hotel in Lubiana.

The whole micropiles plus diaphragm elements will be then, during inner excavation phases, anchored to the surrounding soil by two rows of temporary soil anchors.

Also in this case the construction of the building will start from the bottom of the inner excavation (in this case there will be direct foundations over the conglomerate) with the same building easiness of starting from ground level.

Another peculiarity of this case is that the height of diaphragm elements could not be known in advance for the high variability of the upper level and resistance of the conglomerates (not high resistance conglomerates could be excavated). So it has been necessary to organize the design and the building yard operations to allow a very quick adjustment of steel cages to the height of the element just excavated.

## Conclusions

We tried above to illustrate the main features of the construction technology of piles and diaphragms bored in the presence of a bentonite suspension; the two case histories carried out in Lubiana show the versatility of this technology and represent two basic examples for its spread in Slovenia. Particularly, the diaphragms show an high structural value and make easy the following constructive phases of large buildings with more than one floor underground, to be executed in grounds with or without water. And, if the international market has welcomed this technology, also the economical aspect should be favourable.

Relaying on a suitable use of this technology in Slovenia, GPG d.d. and ICOP s.p.a. have constituted GEOSOND d.o.o. in which the specific competences of the two firms are summed up.

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