Deep Foundations in Mexico City at the Early XXI Century

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ABSTRACT: A general overview of several foundation procedures, used in the first decade of the XXI century in Mexico City are presented. Although they are not new developments, fresh approaches solve demanding situations: higher loads, deeper excavations, which become a serious challenge considering the soft soils found in the area. Examples of each technique are included: slurry walls and secant piles for deep shafts, slurry wall bearing cells, barrette type piles, and slurry walls as bearing elements.

1 INTRODUCTION

Growth of large cities is a common place worldwide, especially during the XXth Century. Mexico City is not an exception, demanding more infrastructure in water, energy, transportation, and housing; therefore, construction requirements become more challenging: buildings in more tight spaces, in urban environments, deeper basement requirements for buildings, higher loads at foundation level, and faster construction schedules.

All these items become more complex, when Mexico City subsoil conditions are added: extremely soft and compressible soils, regional subsidence, reaching up to 40 cm/year in some areas, and seismic conditions.

Foundation engineering has overcome to these challenges, since the early XXth Century, with ingenious foundation systems and construction procedures. In this paper, some solutions are included, from a geotechnical construction point of view.

The drainage system of the city is formed by a large network of interceptors and collectors. Construction of shafts for this purposes soft clays of Mexico City is a difficult challenge for geotechnical engineers and special techniques have had been developed including: indian well, floating method, precast rings, slurry walls and soil improvement (Moreno, 1991; Santoyo and Sánchez, 1992; Auvinet, 2006; Auvinet et al, 2007). Floating and ring shafts are mentioned as background; special emphasis is made in slurry wall shafts, and secant pile wall shafts, even though the latter has not been yet used for this application in Mexico.

For transportation purposes, barrettes and load bearing cells were adapted and some developments are presented; examples include a new subway line and a roadway in the southern portion of the city.

The use of slurry walls as bearing elements is well known (Xanthakos, 1979), but its use has been extended to peripheral walls for buildings in tight urban environments. Some examples are presented.

2 DEEP SHAFTS

2.1 *Floating Shafts*

Construction of tunnel shafts by the flotation method was conceived by J. Cravioto and A. Villareal in 1969 (Moreno, 1991). This method and some of its variants have been used in Mexico City to build more than 30 deep shafts with a diameter of up to 19m and maximum depth of 35m, in very difficult geotechnical conditions.

The flotation method was designed to control the potential failure mechanisms that affect deep excavations in very soft soils, including collapse of walls and bottom of the excavation. It was proposed after some problems were encountered when using other techniques. Failures by extrusion of the soft soil through the joints between contiguous panels of cast-in-place concrete walls were registered in several instances. Bottom shear failure was also found difficult to control for deep excavations constructed by other methods.

The different stages of the construction process are as follows (Auvinet et al 2007):

- A guide-wall formed by two concentric rings is built in order to be able to excavate with precision a polygonal (practically circular) trench, figure 1a.
- The excavation is performed with a guided clamshell grab. The extracted soil is substituted by bentonite slurry, figure 1b.
- The interior guide wall is demolished and the central cylindrical nucleus of soil is excavated with a free clamshell grab. The excavation is kept filled with bentonite slurry.
- A metallic structure forming an inverted cylindrical tank is then placed in the upper part of the excavation (Figure 1c). This tank works as a pressurized air chamber and constitutes the base for the construction of the shaft concrete structure.
- The bottom slab and a first portion (2m or so) of the cylindrical concrete vertical wall of the shaft are constructed on the tank. During this operation, the tank is temporarily fixed by horizontal beams connected to the guide-wall, Figures 1d and 1e.
- After the concrete has set, the molds are removed and air is injected in the tank until a flotation condition is attained. The horizontal beams are then displaced laterally to set the tank free. Air is extracted in order to immerse the constructed part. During this movement, the tank is guided using small cranes. When immersion is completed, the tank is fixed again using the horizontal beams and a new portion of the shaft wall is built.
- Cycles of construction and immersion are repeated until the desired depth is reached.
- When Archimedes thrust tends to exceed the weight of the constructed part, the structure is ballasted with a volume of water or slurry sufficient to proceed with the operation.
- Finally, starting from the bottom, the bentonite slurry within the tank and in the annular space around the structure is substituted by mortar. The ballast is removed and the shaft is ready, Figure 1f.

Time required for shaft construction using this method varies between four and six months.

Some details of the constructive procedure may be modified depending on the local conditions and specific aspects of the project. For deep (35m) excavations in very soft soils it has been considered convenient to build a concentric mortar and/or plastic concrete annular wall around the excavation before proceeding to step 1.

(a) guide wall construction

(b) annular excavation with clamshell

(c) placement of flotation tank

(d) bottom slab reinforcement

(e) reinforcement steel for first castin of shaft wall

(f) finished shaft

Figure 1, Floating shaft construction

2.2 Ring shafts

Floating technique suffers of some disadvantages related with the stability of the bottom of excavatoins, sedimentation of soil debris from walls, tilting and bentonite mud loss.

To overcome this issues, in the 1990´s an alternate procedure was developed (Zemva, 2012), known as ring shafts, where initially a first lining is placed, made of precast concrete rings –in order to avoid wall and bottom failure, and afterwards, a second an definitive lining is cast in place. More than 23 shafts have been constructed successfully with this technique. General sequence is as follows:

- Excavation of shaft under bentonite mud (similar to floating shaft), Figures 2a and 2b.
- First ring is installed at the bottom of excavation, among guides for placement of subsequent rings, Figure 2c. Bottom slab is tremie pipe casted.
- Subsequent rings are placed, with aid of guides, Figure 2d, up to the ground level.
- Annular space between soil and shaft wall is grouted, Figure 2f.
- Second and definitive shaft lining is cast in place, Figure 2e.

It is noted that with this procedure, stability risks are lowered, given that the whole process is made under bentonite mud. Disadvantages include the under-mud bottom slab casting, and difficulty to keep a good bentonite mud quality, avoiding sedimentation of coarse particles between the end of the excavation and the cast of bottom slab.

Additionally, this technique requires a great amount of space at job site, in order to precast the rings for primary lining, among with high capacity cranes for handling and placing rings.

(a) annular excavation with clamshell, within guide walls

(b) nucleus excavation under bentonite mud

(c) placement of guidance structure for rings

(d) rings placement using guidance structure

Figure 2, Ring shaft construction

(e) ring shaft; inner view

(f) grouting of annular space between soil and rings

Figure 2 (cont.), Ring shaft construction

2.3 *Slurry walls*

Circular slurry walls are constructed with the same techniques that are used to build plane walls. They are built in situ, under a drilling fluid, which stabilizes the excavation. The surrounding soil acts as the formwork for the concrete elements. A deep panel trench is first excavated to the desired depth, the reinforcement cage is installed and concrete is tremie poured from the bottom displacing the lighter bentonite slurry. The stability of the trench is ensured by both the slurry and the arching of the soil on each side of the excavated panel. Accordingly, the trench length is limited in order to take advantage of the arching, such that the slurry wall is built through a series of independent panels. Water stops and interlocking joints are installed between panels to ensure the water tightness of the wall and shear transfer between panels. Excavation of the inner portion of the shaft begins after the panels have achieved design strength.

The tools used to excavate the panels have a rectangular shape, the length of which is on the order of three meters (figure 3a). In practice, the panels are generally made of three positions –or "bites"- of the tool: two independent bites, with an intermediate smaller position, to control clamshell alignment. Therefore, typical panel lengths are around 7m.

Circular walls provide several advantages compared to plane walls: they do not need supports such as struts or tie back anchors. Excavation works can be achieved quickly without complicated construction sequence or coordination between the excavator and anchor installer.

The design of circular slurry walls can require some unusual considerations which leads to a need for detailed analyses (Virollet and Gilbert, 2006; Guiot, 2011). Tied to the analysis is a rigorous control of construction tolerances. The stabilizing hoop force produces a normal compressive stress in the structure, which is limited by the strength of the concrete. This compressive stress is a function not only of the hoop force, but also of the thickness of the ring.

Each individual panel is excavated with a rectangular shape clamshell (Figure 3a) so it is not possible to build a perfect circular shape. Even more, the excavation of the panels is done with a specified vertical tolerance, which makes the shape of the wall deviate further from the ideal geometry with depth (Figure 3b). It is essential to be able to control as much as possible the verticality of the clamshell, which depends on the experience of the operator, but also on the type of equipment: mechanical or hydraulic grab, or hydromill, type of soil (boulders, stiffness of the soil, etc.), and the quality control during excavation. Typical tolerance in deviation is around 1% of the wall height, but 0.5% can be achieved in practice.

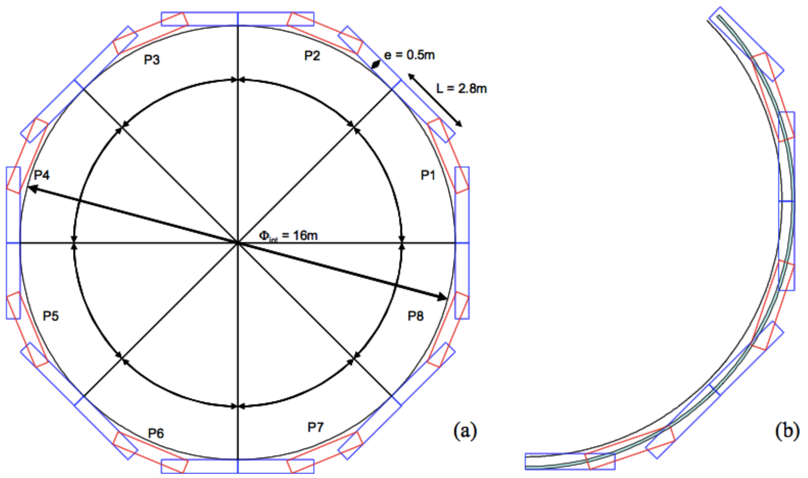


Fig 3, Shape of a circular diaphragm wall, including (a) grab geometry without deviations; (b) grab geometry and deviation (after Virollet and Gilbert, 2006)

Some shaft projects have been performed with this method; in Table 1, examples of the application of this procedure are shown, including several in Mexico City. Special mention is given to the recent sewer system expansion, known as TEO (after Eastern Discharge Tunnel, in Spanish). Figure 4 shows the general construction procedure for slurry wall shafts.

TEO consists in a 62 km tunnel, including 24 shafts, and will increase the drainage capacity of the city in 150 m^3/s. Shafts are up to 150 m deep, and were built with a combination of several techniques, including slurry walls –both with clamshell and hydromill equipment, and conventional excavation.

Table 1. Circular shaft projects; with information from Virollet and Gilbert (2006), Guiot (2011), Paniagua (2010), Carmona (2009), and Ponce (2010)

Project´s name		Diameter, m	Depth, m	Thickness, m
Huang Pu Bridge, China		73.0	43.7	1.2
Ville dÁvray Carrousell Shaft, France		7.8	63.0	1.0
Viroflay Socatop Shaft, France		40.8	46.9	1.0
Dubaï Palm STEP, EAU		76.2	22.0	1.0
Beni Haroun STEP, Algeria		28.0	55.0	1.0
Hong Kong Package 7 Tower, China		76.0	89.0	1.5
Blackpool 2 Tanks, UK		36.0	46.0	1.0
Ivry s/Seine SIAAP Shaft, France		22.5	56.5	1.5
Bordeaux Pkg Gds Hommes, France		57.0	24.5	0.8
Colombes GCN Interceptor, France		22.5	74.4	1.5
Paris Pkg Harlay, France		31.0	52.0	0.8
Hong Kong MRTC 501 Lantau, China		50.0	70.0	1.5
Sangatte Shaft, France		58.0	21.0	1.0
Pumping plant El Caracol, Mexico		16.0	49	1.0
		16.0	50	1.0
		20.0	54	1.2
		20.0	55	1.2
Storage silo, Mexico		18.2	15	0.4
TEO Sewer system, Mexico	L-3A	16.0	48	1.0
	L-5	16.0	40	0.8
	L-13	16.0	47	1.0
	L-20	16.0	120	1.2

(a) clamshell and reinforcement cage

(b) guide walls; reinforcement inside excavation. Note interlocking joints at the ending extremes

(c) two tremie pipes during concrete casting

(d) Koden equipment for soil wall geometry measurement

Figure 4, Slurry wall shaft construction

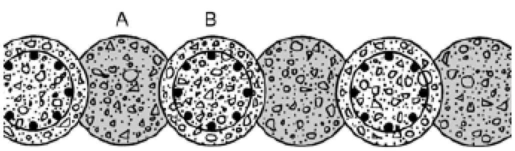
(e) finished slurry wall shaft

(f) job site overview; excavation with hydromill

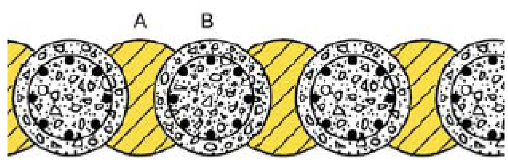
Figure 4 (cont.), Slurry wall shaft construction

2.4 *Secant pile walls*

Secant pile walls are formed by installing overlapping piles. These walls are constructed by first installing a number of primary piles, and then by returning to build secondary piles within the gaps between the primary piles, fig 5. The difference in pile diameter and pile spacing determines the amount of secondary pile cuts into the primary pile.



(a) Hard/hard technique



(b) Hard/soft technique

Fig 5, Secant pile walls, after Paniagua 2002

Secant pile walls can be constructed using several techniques; most common are (Suckling et al, 2005):

a) Standard rotary (SR). Thin walled single length temporary steel casings are used with standard rotary bored piling machines, fig 6a.
b) High torque rotary (HTR) piling. Thick walled segmental temporary steel casings with cutting teed, among with casing oscillators, fig 6b.
c) Continuous flight auger (CFA), fig 6c
d) Cased continuous flight auger (CCFA). High torque (higher than 160/230 kN-m) CFA auger used in combination with temporary steel casings, driven by separate rotary heads, fig 6d.

Types of secant pile walls are:

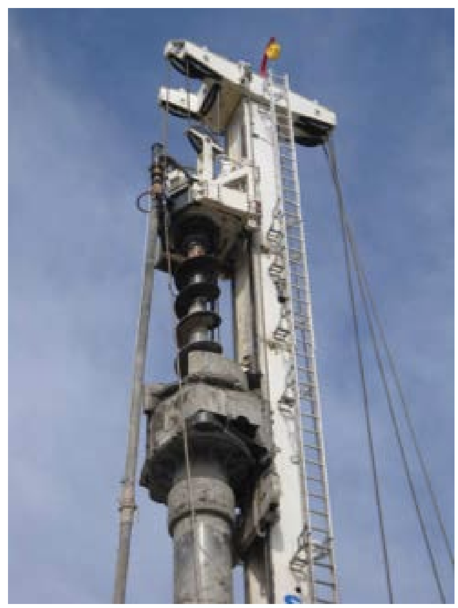
- Hard/hard, figure 5a; primary piles are built with reinforced or unreinforced structural concrete with secondary piles with reinforced structural concrete. Piles are usually constructed using HTR or CCFA methods.

- Hard/soft, figure 5b; primary piles are built within an unreinforced mix of cement/sand/bentonite/water, and secondary piles include reinforced structural concrete. Piles can be drilled using SR, HTR, or CCFA.

(a) standard rotary piling

(b) casing oscillator

(c) standard CFA



(d) cased CFA

Figure 6, Secant pile wall construction techniques

To achieve optimum positional accuracy, secant piles must be drilled through temporary guide walls, fig 7. For shaft walls, the geometry of the curved sides is related to the maximum diameter of the drilling tool, which will be where the cutting teeth are positioned. The use of this guide walls will limit the plan tolerance of the piles at the start, to less than 25mm.

The vertical tolerance on secant pile walls vary with piling method. In table 2 typical values are shown.

Figure 7, Guide walls for secant piles, after Pagliacci (2012)

Table 2. Achievable verticality tolerances, after Suckling et al (2005)

Secant wall type	Piling method	Verticality tolerance
Hard/soft	SR	1:100
	HTR	1:200
	CFA	1:75
	CCFA	1:150
Hard/firm	HTR	1:200
	CCFA	1:150
	HTR	1:200

The designer may decide whether to use different cages, whether to construct primary and secondary piles of the same diameter, and whether to use the same concrete or different mixes. Several examples are shown in Figure 8.

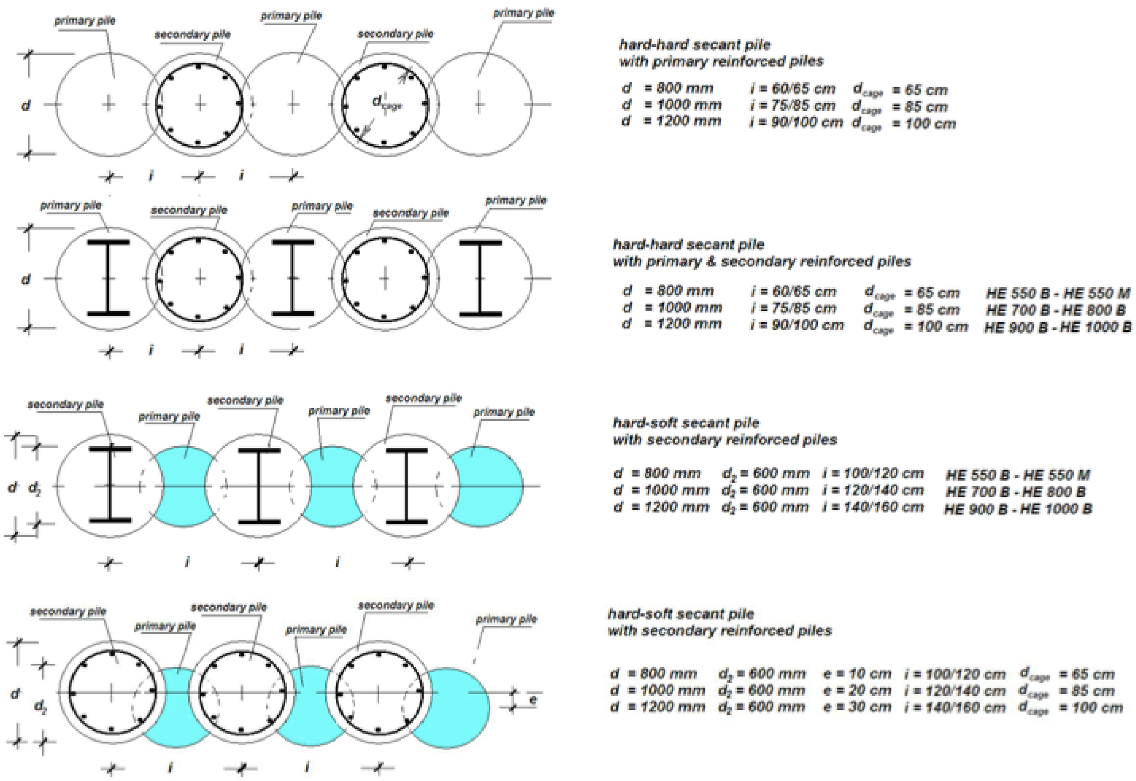


Figure 8, Examples of reinforcement solutions, after Pagliacci (2012).

To position the reinforcement cage, concrete features must comply with the strength parameters set by the design engineer, so the cage can be easily inserted. As a result, aggregates with a maximum diameter of 18 mm, and a grain-size curve within the grading envelope shown in Figure 9 must be used.

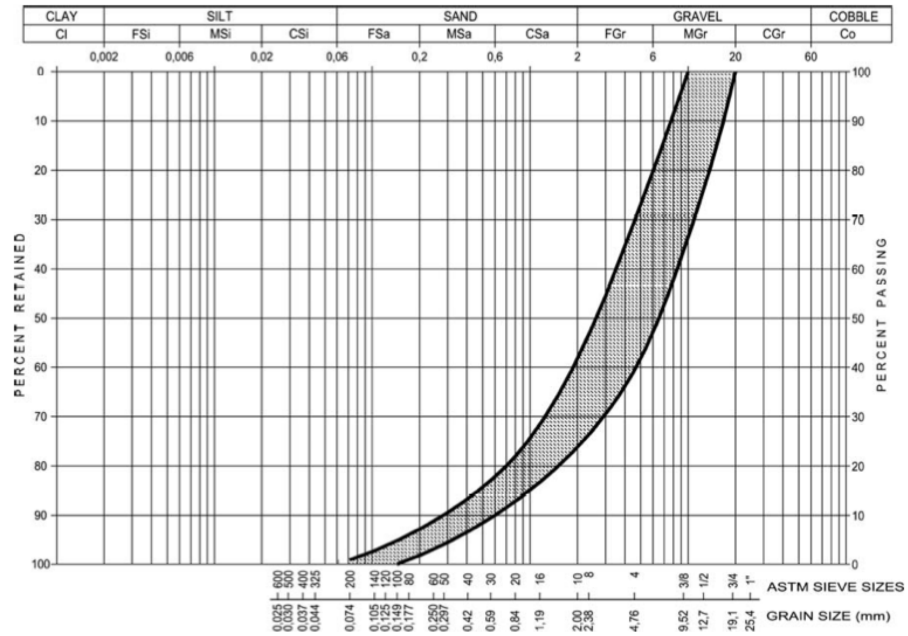


Figure 9, Grading envelope for CCFA, after Pagliacci (2012).

Plasticizers and retarders ensure a slump value suitable for cage positioning, which should be usually higher than 220 mm.

Cages as long as the maximum allowed depth of 27 m can be inserted only by using super- fluid concrete, which is not characterized by a specific slump value, but rather by a ‘pie’ size of more than 650 mm, after extracting the Abrams cone, and a time of less than 5 seconds to reach a 500 mm diameter pie.

Figure 9 shows a finished secant pile wall, forming a deep shaft. This type of foundation pile is already of regular use in Mexico, as isolated elements; it is only a matter of time to adapt this technique to shafts and other walls.

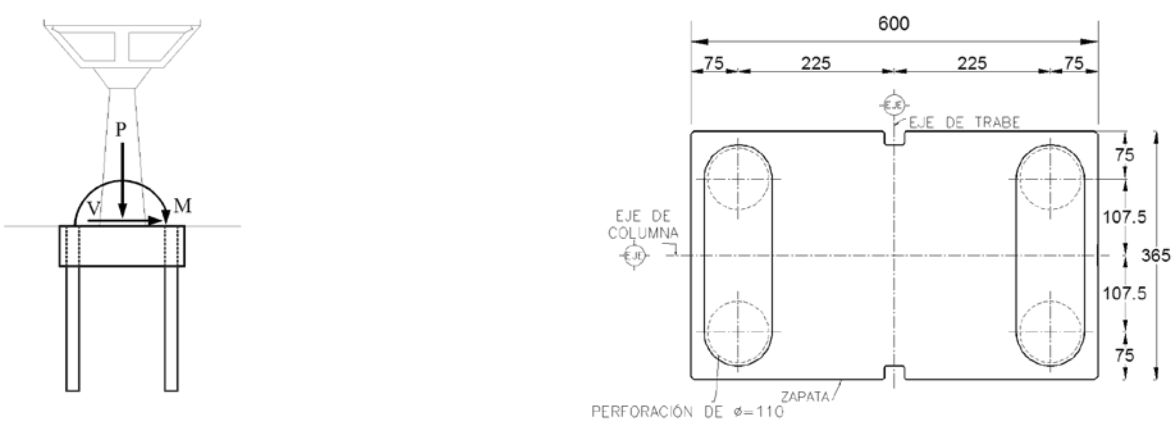
Figure 9, Secant pile wall with 20 m depth. Tolerance 1:440, after Suckling et al (2005)

3 FOUNDATIONS

3.1 *Barrettes*

Barrettes have been used since at least 30 years (Paniagua, 2001), but have been used recently to solve a particular and rather interesting problem. South of Mexico City, a roadway is projected. In certain areas, where high loads, geometrical constraints and particular soft soil conditions were presented, the foundation of the roadway columns was solved with barrettes.

Foundation general conditions are shown in figure 10. Two barrettes of 3.15m x 0.9m and 21m depth, support a concrete footing, which form a single element with a precast column. Typical soil conditions are shown in Figure 11.



(a) Actions on foundation *(b) two barrettes under each column*

Figure 10, Foundation general conditions in roadway, after Verduzco et al (2012).

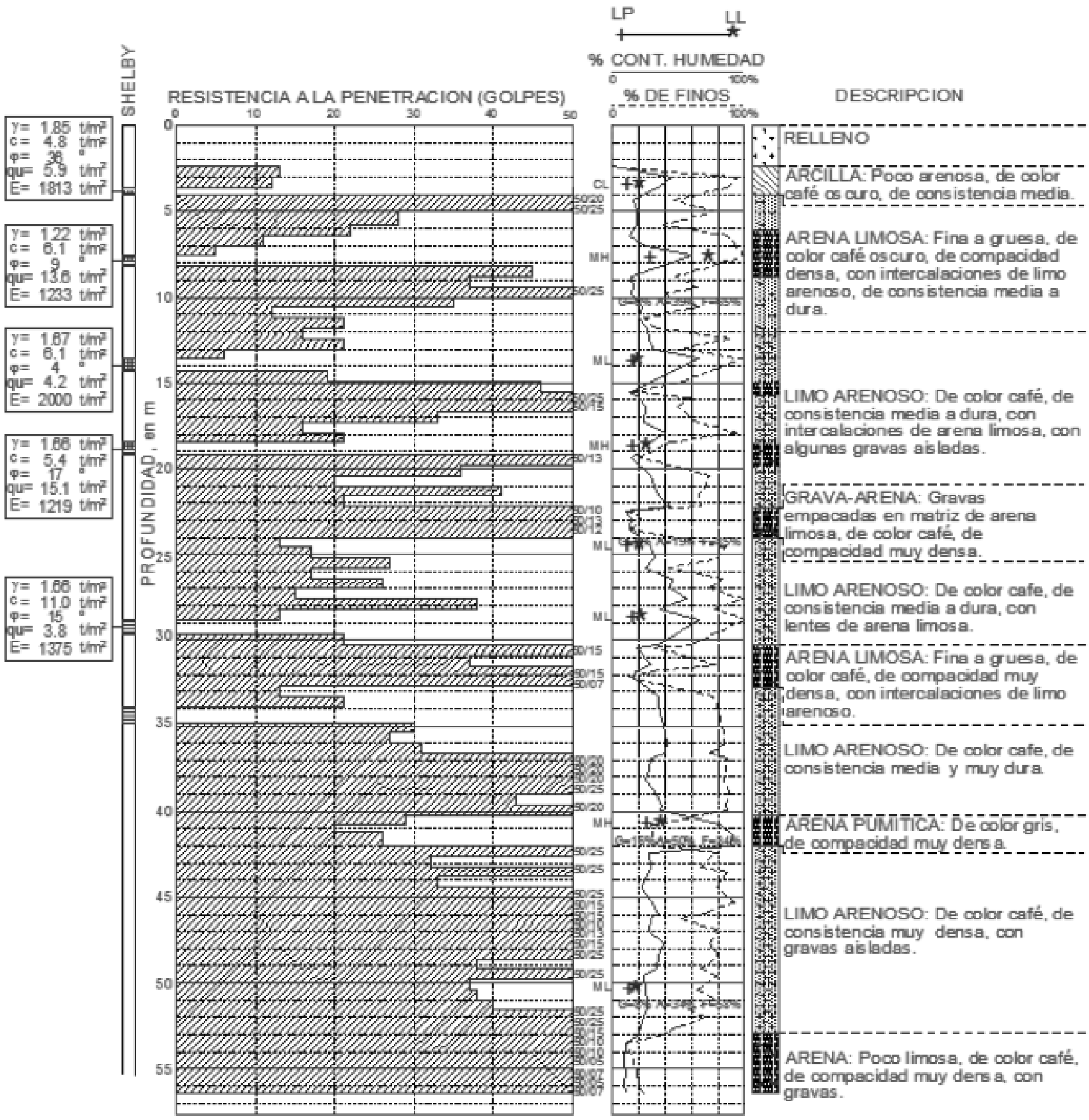


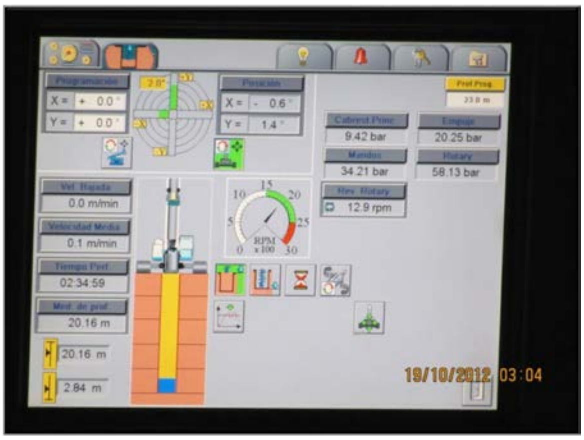
Figure 11, Typical soil conditions, after Prieto and Verduzco (2012)

Design details may be found in Prieto and Verduzco (2012) and Verduzco et al (2012). Construction procedure was within common practice in Mexico City (figure 12): preboring, using polymer or bentonite mud; clamshell excavation, reinforcement placement, and tremied concrete.

Special challenge was the tight construction time schedule, of only 6 hours during a night shift, in order to alternate the vehicle transit with construction works.

(a) clamshell during excavation

(b) preboring with core barrel



(c) electronic panel for verticality control

(d) reinforcement lifting

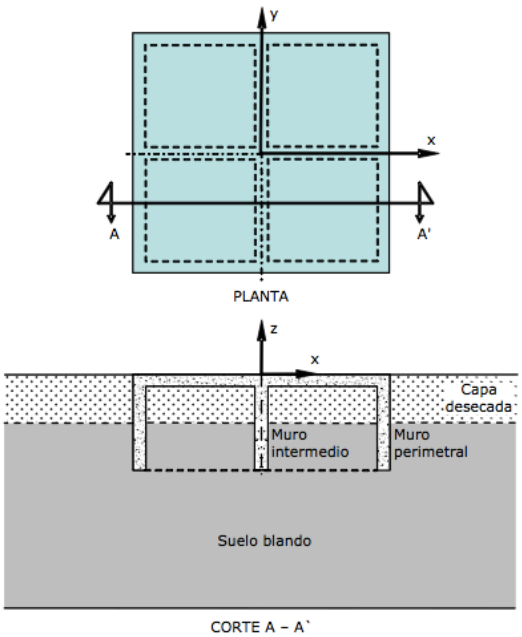
(e) reinforcement cage inside excavation

(f) tremie concreting

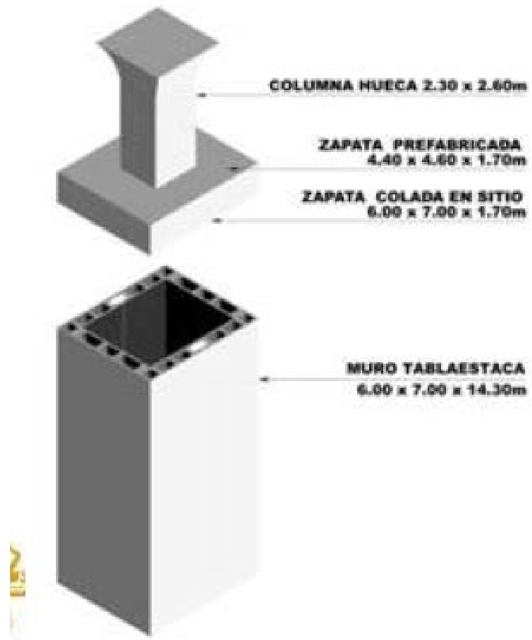
Figure 12, Barrettes construction sequence. Photos, courtesy of Mario Herrera

3.2 *Slurry wall bearing cells*

For a recent infrastructure project, subway line-12, an alternative slurry wall bearing cell was developed, consisting in peripheral slurry walls, connected to a slab on the top, without a bottom slab, figure 13. This solution was adopted after very soft soil conditions were founded, in up to 50m depth, among with regional subsidence. Slurry walls form a 6m x 6m box, with 14.6m depth and 0.6m thick, working as friction piles.



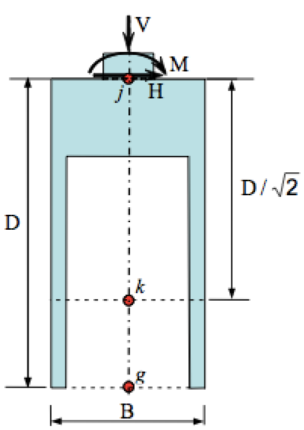
(a) after Martínez and Romo (2010a)



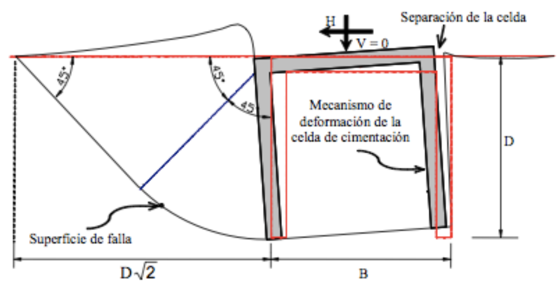
(b) after Ponce (2010)

Figure 13, Slurry wall bearing cell schematics

Geotechnical and structural design are beyond the scope of this paper (figure 14), and may be found in Martínez and Romo (2010a and b) and ICA (2010).



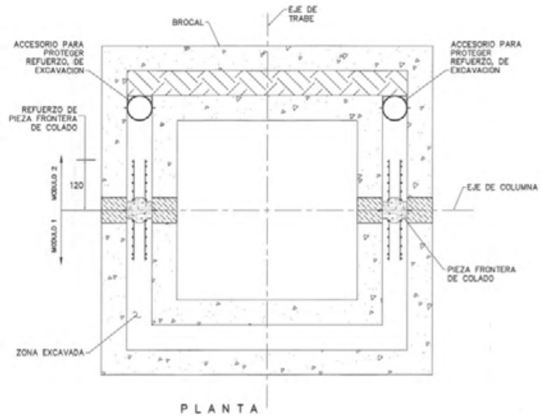
(a) load combinations to be considered



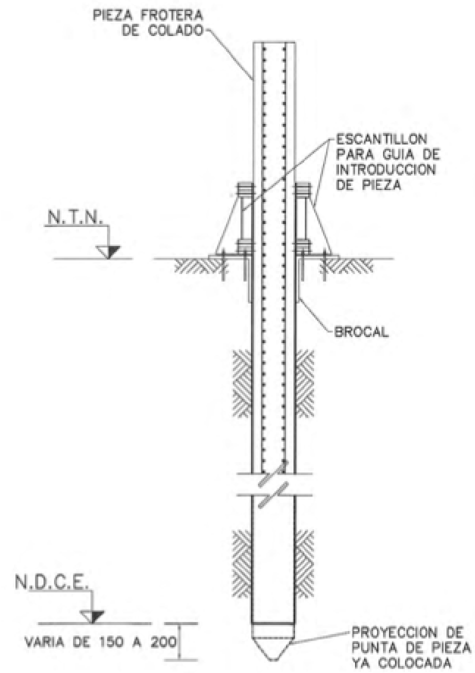
(b) simplified failure mechanism

Figure 14, Schematics for slurry wall bearing cell, after Martínez and Romo (2010b)

Structural continuity between adjacent walls was solved by means of a precast pile, with steel reinforcement on the sides, embedded within the slurry wall fresh concrete, figure 14.



(a) plan view; slurry walls and connecting precast piles



(b) front view, connecting precast pile

Figure 14, Slurry wall bearing cell details, after ICA (2010)

Slurry wall bearing cell was excavated in two stages; first, an “U” shape wall was built, with connection piles in the ending sides. Afterwards, the second “U” is excavated and built, closing the complete box shape.

Particular measures were taken to provide structural continuity to the walls, by means of the precast piles. In figure 15, some construction stages are shown.

Overall, 60 columns are supported with slurry wall bearing cells, providing an alternative solution for the foundation of this type of structures.

(a) excavation with clamshell and reinforcement cage placement

(b) bentonite slurry mud inside guide walls; cage and connection pile in place

(c) concrete tremied in slurry wall; note connection precast pile

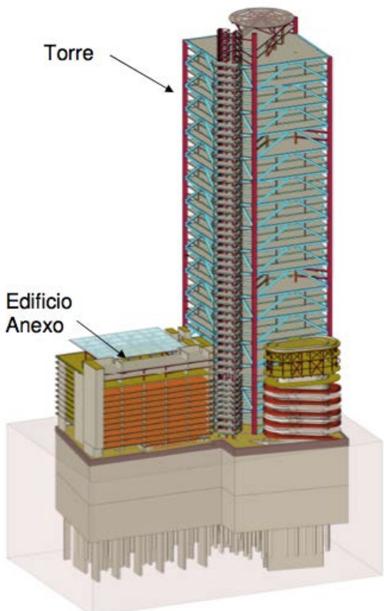
(d) finished subway line

Figure 15, Slurry wall bearing cell construction process. Photos, courtesy of JA Ponce

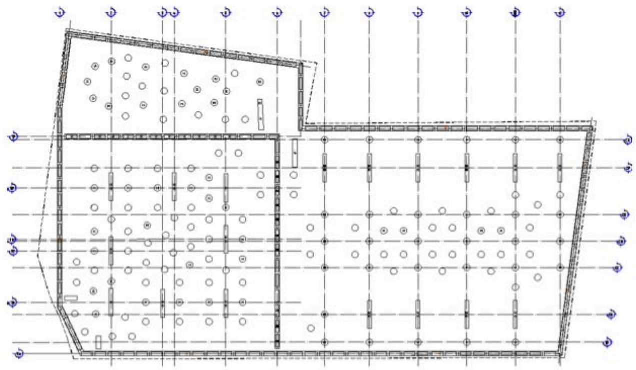
3.3 *Slurry walls as bearing elements*

The use of slurry walls as bearing elements is well known (Xanthakos, 1979), as prismatic elements, such as barrettes; however, the use of a peripheral slurry walls as a carrying capacity element on the foundation is not as extended. Furthermore, in several cases, the slurry walls complies a double purpose: to support an excavation (sometimes it is even the definitive wall) and to carry foundation loads partially or totally.

Typical building layout is shown in Figure 16a, for a 52 story building, with seven basement levels. In this particular case, additional to the slurry wall, circular drilled shafts are included (Figure 16b). Moreover, in several cases, top-down excavation method is used.



(a) general view



(b) plan layout

Figure 16, Typical building with peripheral slurry wall, used as part of the foundation, after Meza et al (2012)

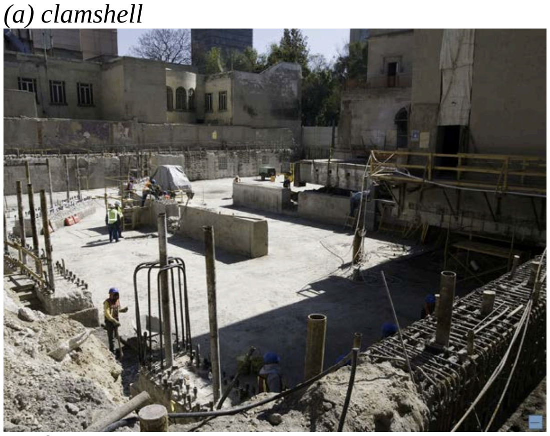
Table 3 shows several projects that include this type of solution; it is noted that increasing depth and wall thickness is achieved. In Figure 17, a sequence of another project with this solution is presented. Until now, clamshell rigs have been used, but introduction of hydromills is forecast, due to demands on vertical tolerance, and increasing depth requirements.

Table 3. Some projects involving peripheral slurry walls as bearing elements

Project	Year	Depth, m	Thickness, m
JV-1 and 2	2002	18.0	0.7
JV-3	2009	10.0	0.7
JV-J	2008	10.0	0.7
CB	2008	7.5	0.7
TP	2007	21.0	0.4
TR	2009	50.0	1.0
BC	2011	50.0	1.0
509	2013	64.0	1.2
128	2013	55.0	0.6

(a) clamshell

(b) excavated panel prior to concrete casting



(c) finished slurry wall and ground level slab

(d) opening in slab, for top-down construction

Figure 17, Peripheral slurry wall construction sequence, for TR project

4 CONCLUSIONS

Facing increasing demands in difficulty degree, foundation engineering in Mexico City and its environments found solutions for each task, either adapting well-known methods, or improving new ones. Even though, continuous applied research is needed, in order to develop particular solutions, or adapt existing ones from other countries.

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REFERENCES

Auvinet, G. (2006). "Construction of deep tunnel shafts by the flotation method", Invited Lecture, Proceedings, ISSMGE ATC-47 Pre-Workshop, pp. 41-50, Busan, South Korea.

Auvinet, G, Rodríguez J.F. y Rangel J.L. (2007). "Construction of deep tunnel shafts in Mexico City soft clays by the flotation method", ECCOMAS Thematic Conference on Computational Methods in Tunnelling (EURO:TUN 2007) J. Eberhardsteiner et.al. (eds.) Vienna, Austria, August 27-29, 2007.

Carmona R. (2009) "Reforzamiento del sistema de drenaje de la Zona Metropolitana del Valle de México", 25º Congreso Nacional de Ingeniería Civil, México.

Guiot P. (2011) "Construcción de lumbreras Planta de Bombeo el Caracol", Simposio Internacional sobre Cimentaciones Profundas, Sociedad Mexicana de Ingeniería Geotécnica y Deep Foundation Institute, México.

ICA (2010) "Memoria de cálculo de cajón estructurado. Zona geotécnica: Lago. Cad 13+731 al 14+633.

Martínez S. and Romo M. (2010a) "Capacidad de carga de celdas estructuradas: un método de análisis simplificado", XXV Reunión Nacional de Mecánica de Suelos e Ingeniería Geotécnica, Acapulco, México.

Martínez S. and Romo M. (2010b) "Capacidad de carga de celdas estructuradas sujetas a momento de volteo: un método de análisis simplificado", XXV Reunión Nacional de Mecánica de Suelos e Ingeniería Geotécnica, Acapulco, México.

Meza B., Clavellina G., De la Rosa J. and Paulín J. (2012) "Construcción de 7 sótanos mediante el procedimiento ´Top-down´para una torre de 52 niveles, ubicada en la zona del lago de la ciudad de México", XXVI Reunión Nacional de Mecánica de Suelos e Ingeniería Geotécnica, Cancun, México.

Moreno A. (1991). "Lumbreras y Túneles en suelos, Experiencias innovadoras en la Ingeniería Mexicana (Shafts and Tunnels in soils, Innovative experiences in Mexican Engineering)", Lecture for admission to the Mexican Academy of Engineering, Mexico City.

Pagliacci F. (2012) "Cased auger piles (CAP): an effective piling solution", Proceedings of the 37th Annual Conference on Deep Foundations, Houston, Texas, USA.

Paniagua W.I. (2001) "Construcción", chapter 5, in *Manual de Cimentaciones Profundas*, SMMS, México.

Paniagua W.I. (2002) "Tablestacas", chapter 4, in *Manual de Construcción Geotécnica*, SMMS, México.

Paniagua W.I (2010) " Diseño y construcción de foso con muro milán para silo de almacenamiento de grano", XXV Reunión Nacional de Mecánica de Suelos e Ingeniería Geotécnica, Acapulco, México.

Ponce J.A. (2010) "Evolución en México de Muros Milán en 40 años", Simposio Internacional de Cimentaciones Profundas, Sociedad Mexicana de Ingeniería Geotécnica y Deep Foundation Institute, México.

Prieto C. and Verduzco R. (2012) "Memoria geotécnica. Proyecto Autopista Urbana Sur. Tramo comprendido entre los ejes A269-A281 y A284-A291".

Santoyo, E. y Sánchez, B., (1992). "Una técnica de construcción de cárcamos profundos en Suelos Blandos (A construction technique of deep sumps in soft soils)", Proceedings, XVIth National Soil Mechanics Meeting, SMMS, Zacatecas, Mexico, Vol. 1, pp. 71-79.

Suckling T.P., Wren C.J., Troughton V.M. (2005) "Secant pile walls –a consistent approach to risk management", Proceedings of the 30th Annual Conference on Deep Foundations, Chicago, Illinois, USA.

Verduzco R., Prieto C., Herrera O. and Rivas R. (2012) "Ventajas de las pilas oblongas (barrettes) como sistema de cimentación para la Autopista Urbana Sur". XXVI Reunión Nacional de Mecánica de Suelos e Ingeniería Geotécnica, Cancun, México.

Virollet B., Gilbert C. and Deschamps R. (2006) "Recent Advances in Large Diameter Diaphragm Wall Shafts", Proceedings of the 31st Annual Conference on Deep Foundations, Washington, DC, USA.

Xanthakos P. (1979) "Slurry Walls", McGraw Hill, New York.

Zemva S. (2011) "Diseño y construcción de lumbreras en suelos blandos, por el procedimiento de los anillos prefabricados", Tesis para optar por el grado de Maestro en Ingeniería, UNAM, México.