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Use and Abuse of Post-Tensioned Anchors in Urban Areas

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Abstract. The use of anchor systems as a reinforcement procedure in excavations and retaining walls in urban areas has increased noticeably in recent years. This paper contains a general description of design and installation criteria for post-tensioned anchors, including some examples of successful application. Additionally, several cases of the use of this system in urban areas are shown, where there were issues due to different causes: public service installations, conflicting boundaries, unforeseen geotechnical and hydraulic conditions; the adopted solutions are mentioned.

Keywords. Anchors, history case.

1. Introduction

Post-tensioned anchors are extensively used to stabilize vertical cuts required at large excavations performed in all cities and, along with shotcrete, diaphragm walls, tangent and secant piles, reinforced steel beams, concrete, etc., compose the retention system that guarantees stability to adjoining constructions, public service installations and the excavation itself. Its tension capacity is determined, essentially by one of the following two criteria [1 y 2]:

$$\mathrm{F_a} = \frac{\pi\, D\, l_a(\alpha c + \sigma t g \emptyset)}{F_s} \qquad (1)$$

$$F_a = \frac{\pi\, D\, l_a\, p_i\, tg\, \phi}{F_s} \qquad (2)$$

where D is anchor diameter, l_a is bulb length, α and ϕ are the resistance parameters of the shear strength that develops during the grout-soil interface, σ is the effective medium vertical effort in the bulb area, p_i grout injection pressure and F_s is the security factor.

The difference between these two criteria is mainly for the first anchor levels; with the one that depends on injection pressure, greater loads are obtained than with the one that corresponds to effective stress. This difference is reduced in larger depths. We wish to emphasize that, for high injection pressures, the first criterion creates hydraulic fracking in soils.

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When designing the stabilizing system, it is necessary to determine the drilling and installation of anchor strand techniques; it is essential to carefully characterize the soil mass: existence of water table or the presence of a hanging water table, granulometry, plasticity limits, shear strength resistance, environmental aggressions that create corrosion on the anchor strands, etc. It is crucial to know the trajectory of public service installations such as power, telephone and primary water and sewage because the anchors are built outside the studied lot. There have been instability issues in many excavations due to waterlines and sewage working under pressure.

Figure 1. 54.5 m excavation.

2. Application in urban areas

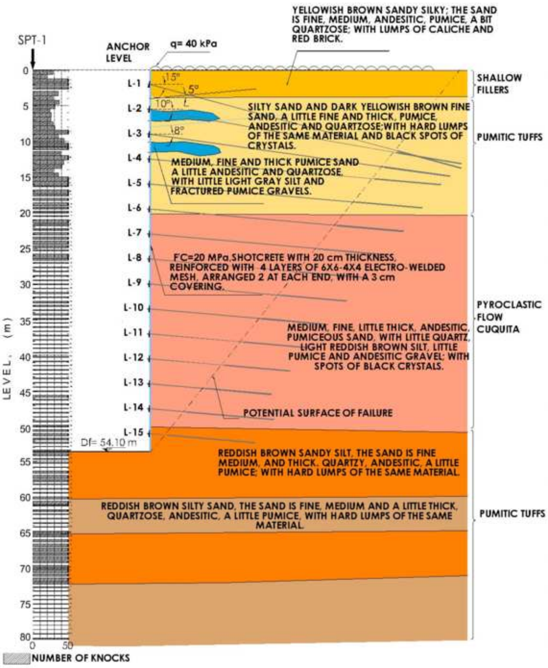
2.1. Success cases

The following are two cases in Mexico City. The first, located in the geotechnical area called *Lomas* (Hill zone), is a 54.5 m excavation in volcanic soil, stabilized with 14 levels of anchors complemented with a 20 cm thick shotcrete wall with 20 Mpa resistance, reinforced with two layers of 6x6-4/4 electro-welded mesh. The excavation is shown in Figure 1. In Figure 2 and Table 1, characteristics of the anchors and the stratigraphic conditions of design are specified.

Table 1. Geotechnical model case 1.

Stratigraphic Unit	**Description**	**Depth (m)**	**γ (kN/m^3)**	**c (kPa)**	**ϕ (°)**
Shallow filling	Fill (SM)	0.0 to 1.2	17.0	10	28
Volcanic Soils	Clayey Tuff (CL)	1.2 to 3.0	17.0	75	27
	Sandy and Clayey Tuff (SM y ML)	3.0 to 20.3	17.7	45	37
	Sandy Tuff (SM)	20.3 to 48.0	19.2	168	34
	Clayey Tuff (CL)	48.0 to 60.0	17.4	65	32

γ, volumetric weight; c, cohesion; ϕ, internal friction angle



Anchor Level	Depth (m)	Design force (kN)	Drilling length (m)	Effective length (m)	Post-tension (kN)
1	-2.0	2500 16 strands of 0.6"	45.0	9.0	2500
2	-5.5	2500 16 strands of 0.6"	44.5	9.0	2500
3	-9.0	2500 16 strands of 0.6"	42.5	9.0	2500
4	-12.5	2500 16 strands of 0.6"	41.0	9.0	2500
5	-16.0	2500 16 strands of 0.6"	38.0	9.0	2500
6	-19.5	2500 16 strands of 0.6"	35.5	9.0	2500
7	-23.0	2500 16 strands of 0.6"	33.0	9.0	2500
8	-26.5	2500 16 strands of 0.6"	30.0	9.0	2500
9	-30.0	2500 16 strands of 0.6"	27.5	9.0	2500
10	-33.5	2500 16 strands of 0.6"	25.0	9.0	2500
11	-37.0	2500 16 strands 0.6"	22.5	9.0	2500
12	-40.5	2500 16 strands of 0.6"	19.5	9.0	2500
13	-44.0	2500 16 strands of 0.6"	17.0	9.0	2500
14	-47.5	2500 16 strands of 0.6"	14.0	9.0	2500
15	-51.0	2500 16 strands of 0.6"	11.5	9.0	2500

PI, INJECTION PRESSURE DESIGN 1.5 MPa

Figure 2. Support and stratigraphy case 1.

The second case is located in the geotechnical area called Transition. It is a 38 m excavation shown in Figure 3, in an area where stratigraphy is characterized by the presence of alluvio-lacustrine deposits in the first 18 m, with a hanging water table and an underlying denser deposit, where transition occurs between alluvial soil and volcanic soil. The stabilization system was combined and composed of a slurry wall on the top, and shotcrete in the denser soils, reinforced laterally by post-tensioned anchors. In Figure 4, anchors and site stratigraphy are presented; in Table 2 the geotechnical model of the design is presented.

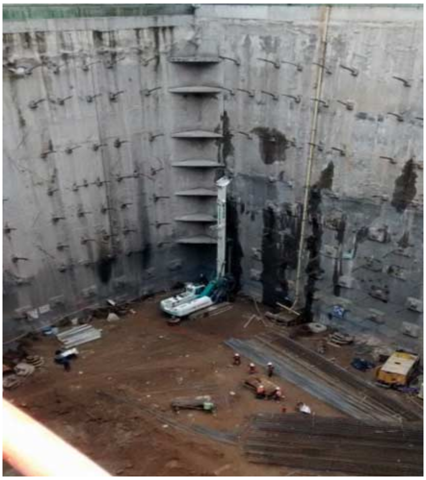
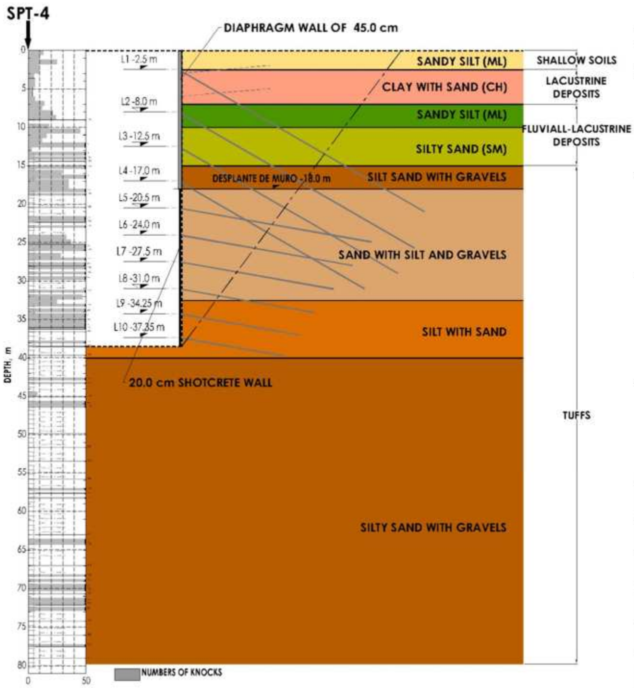


Figure 3. 38 m excavation in the transition area.



Anchor Level	Depth (m)	Design force (kN)	Drilling length (m)	Effective length (m)	Post-tension (kN)
1	-2.50	1450 10 strands of 0.6"	29.5	7.5	1450
		2100 14 strands of 0.6"	37.0	15.0	2100
		2450 16 strands of 0.6"	39.0	17.0	2450
2	-6.00	1700 11strands of 0.6"	27.0	8.5	1700
		2450 16 strands of 0.6"	35.5	17.0	2450
		1900 12 strands of 0.6"	33.5	15.0	1900
3	-12.00 y -12.50	1700 11 strands of 0.6"	24.5	8.5	1700
		2450 16 strands of 0.6"	33.0	17.0	2450
		1900 12 strands of 0.6"	31.0	15.0	1900
4	-17.00	1450 10 strands of 0.6"	20.5	7.5	1450
		2100 14 strands of 0.6"	28.0	15.0	2100
		2450 16 strands of 0.6"	30.0	17.0	2450
5	-20.50	2150 14 strands of 0.6"	25.5	13.0	2150
6	-24.00	2150 14 strands of 0.6"	23	13.0	2150
7	-27.50	2150 14 strands of 0.6"	20	13.0	2150
8	-30.65 y -31.00	2150 14 strands of 0.6"	18	13.0	2150
9	-33.75 y -34.25	2150 14 strands of 0.6"	16	13.0	2150
10	-36.85 y -37.35	2150 14 strands of 0.6"	14	13.0	2150

PI, INJECTION DESIGN PRESSURE 1 MPa

Figure 4. Support and stratigraphic case 2.

Table 2. Geotechnical model case 2.

Stratigraphic Unit	Description	Depth (m)	γ (kN/m³)	c (kPa)	ϕ (°)
Shallow Soils	Sandy Silt (ML)	1.0 to 2.5	17.0	35	30
Lacustrine Deposits	Clay with Sand (CH)	2.5 to 7.0	17.0	35	30
Fluvial Lacustrine Deposits	Sandy Silt (ML)	7.0 to 0.0	17.0	120	30
	Silty Sand (SM)	10.0 to 15.0	18.0	35	35
Tuffs	Silty Sandy with gravels	15.0 to18.0	17.0	60	35
	Sand with silts and gravels	18.0 to 32.5	18.0	60	37
	Silt with sand	32.5 to 40.0	17.5	175	35
	Silty sand with gravels	> 40.0	18.0	80	38

γ, volumetric weight; c, cohesion; ϕ, internal friction angle

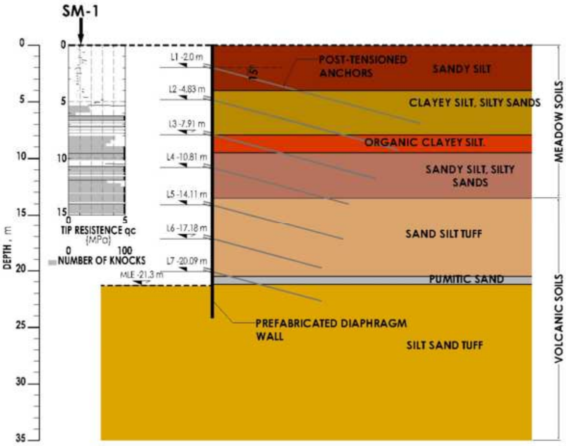
In both cases, the post-tensioned anchor retention system's benefits are noticeable. Indeed, there were no issues with excavation behavior and no conflict or interference with adjoining constructions. We wish to emphasize that, in both cases, the anchors were a temporary retention system that was later replaced with the slabs of the respective buildings.

2.2. Challenging cases

Four cases are described, all located in the Transition area in Mexico City, where cracks occurred on neighboring streets, as well as failures in the retention system.

The first case is a 21.3m excavation measured from the level of the sidewalk; there is alluvial soil from the surface to 13.5 m with underlying volcanic soil. Stabilization consisted of a pre-fabricated diaphragm wall, secondary beams and 5 levels of post-tensioned anchors. Figure 3 shows the finished excavation. Once finished, activities were suspended for approximately 3 years. The vertical displacements in adjacent buildings were between 2.0 and 3.5 cm; additionally, there was a 5.0 cm subsidence of an adjoining street, with 2.0 cm cracks parallel to the excavation that had to be grouted several times, even after the basements were built. In Figure 5, shows the finished excavation, Figure 6 contains the stratigraphic conditions and the anchor characteristics. Table 3 displays the geotechnical model.

Figure 5. Precast diaphragm wall with secondary beams and anchors.



Anchor Level	Depth (m)	Design force (kN)	Drilling Length (m)	Effective length (m)	Post-tension (kN)
1	-2.0	200 2 strands of ½"	19.0	10.0	120
2	-5.0	150 2 strands of ½"	17.0	10.0	120
3	-8.0	200 2 strands of ½"	15.0	10.0	120
4	-11.0	250 3 strands of ½"	12.5	10.0	150
5	-14.0	200 2 strands of ½"	10.0	5.0	150
6	-17.0	280 3 strands of ½"	10.0	7.0	150
7	-20.0	310 4 strands of ½"	10.0	8.5	150

PI, INJECTION DESIGN PRESSURE 2 MPa

Figure 6. Support and stratigraphic case 3.

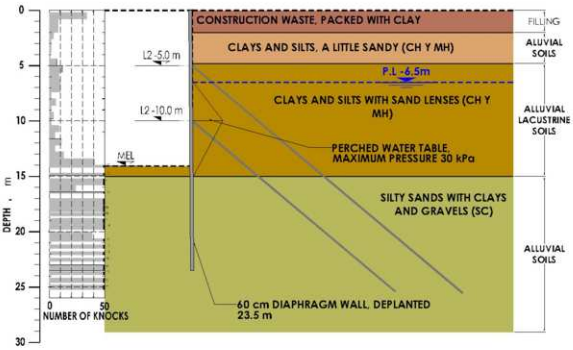
Table 3. Geotechnical model case 3.

Stratigraphic Unit	Description	Depth (m)	γ (kN/m³)	c (kPa)	ϕ (°)
Meadow Soils	Sandy silt (ML)	0.0 to 4.0	16.5	55	18
	Clayey silt and silty sands (ML y SM)	4.0 to 7.9	16.0	47	21
	Organic clayey silts (MH)	7.9 to 9.5	15.5	38	12
	Sandy silt and silty sand (ML y SM)	9.5 to 13.5	16.5	33	25
Volcanic Soils	Sandy Silty tuff (SM)	13.5 to 20.5	17.5	65	34
	Pumitic Sand (SM)	20.5 to 21.2	15.5	30	31
	Silty sandy tuff and silty sand (ML y SM)	21.2 to 29.8	18.0	78	37

γ, volumetric weight; c, cohesion; ϕ, internal friction angle

The second case is a 14.0 m excavation where stratigraphy is composed of landfill and superficial clay crust of 4.8 m, followed by lacustrine soil up to 15 m with underlying high resistance lacustrine soil. This area includes a hanging water table between 6.5 and 15.0 m. The retention system consists of a diaphragm wall and 2 levels of 40-degree sloped anchors. The excavation was abandoned for several years and, a short time after re-starting, the state of the anchor was not proved nor were the loads acting on them, a fault occurred on the wall, as shown in Figure 7, created by leaks in the neighboring rain water sewer system, working under pressure. Based on the comments from the engineers in the construction site, first the anchor wedges were expelled, unloosing the cables, at last making the wall fail by flexion. From the analyses conducted later, it was determined that a 25% increase in water pressure creates the limit state. In Figure 8, stratigraphic conditions and anchor characteristics are presented; meanwhile geotechnical design model is contained in Table 4.

Figure 7. Fault on the diaphragm wall and post-tensioned anchors.



Anchor level	Depth (m)	Design force (kN)	Drilling length (m)	Effective length(m)	Post-tension (kN)
DIAPHRAGM WALL					
1	-5.0	1220 8 strands of 0.6"	31.0	15.0	1220
2	-10.0	1220 8 strands of 0.6"	24.0	16.0	1220

PI, INJECTION DESIGN PRESSURE 0.3 MPa

Figure 8. Support and stratigraphic case 4.

The third project is a 28.7 m excavation. Stratigraphy consists of a 40 cm superficial landfill followed by alluvio-lacustrine soil basically composed of clays and sandy silts to a depth of 12.8 m, with underlying volcanic soil. The water table is located at a depth of more than 50 m. Stabilization consists of shotcrete with the same thickness and reinforcement of the finished wall and supported laterally by 9 levels of post-tensioned anchors. A sliding and twisting of the wall occurred while working on the 5th level, created by leaks from a neighboring rain water sewer system. The fault is shown in Figures 9 and 10.

Table 4 Geotechnical model case 4.

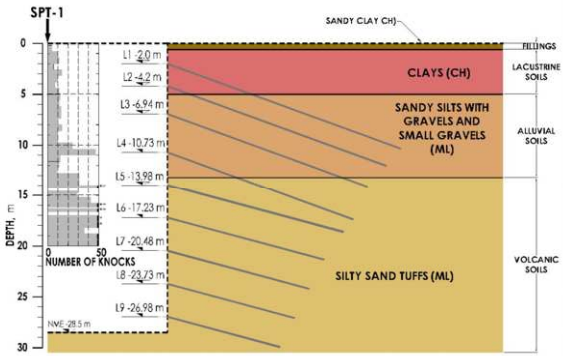
Stratigraphic Unit	Description	Depth (m)	γ (kN/m^3)	c (kPa)	ϕ (°)
Fill	Construction debris, packed with clay	0.0 to 2.0	17.0	10	20
Alluvial soils	Clays and silts with layers of sand (CH y MH)	2.0 to 4.8	14.0	22.5	17.5
Alluvial Lacustrine soils	Clays and silts with sand lenses (CH y MH)	4.8 to 15.0	12.3	36	0
Alluvial soils	Silty sands with clays and gravels.(SC)	15.0 to 29.6	18.0	100	39

γ, volumetric weight; c, cohesion; ϕ, internal friction angle

Figure 9. Twisted shotcrete wall; the surcharge of stabilizing material is appreciated.

Figure 10. Detail of the shotcrete wall cracks due lo sliding and twisting.

In Figure 11, stratigraphy and anchor characteristics are presented. Figure 12 shows the affected area of the wall, and Table 5 contains the geotechnical model for design.



Anchor Level	Depth (m)	Design force (kN)	Drilling length (m)	Effective Length (m)	Post-tension (kN)
1	-2.00	1100 7 strands of 0.6"	24.5	9.5	1100
2	-4.20	1100 7 strands of 0.6"	23.0	9.5	1100
3	-6.94	1100 7 strands of 0.6"	21.0	9.5	1100
4	-10.73	1100 7 strands of 0.6"	19.5	9.5	1100
5	-13.98	1100 7 strands of 0.6"	18.0	9.5	1100
6	-17.23	1100 7 strands of 0.6"	16.0	9.5	1100
7	-20.48	1100 7 strands of 0.6"	14.5	9.5	1100
8	-23.73	1100 7 strands of 0.6"	13.0	9.5	1100
9	-26.98	1100 7 strands of 0.6"	11.5	9.5	1100

PI, INJECTION DESIGN PRESSURE 0.6 MPa

Figure 11. Support and stratigraphic case 5.

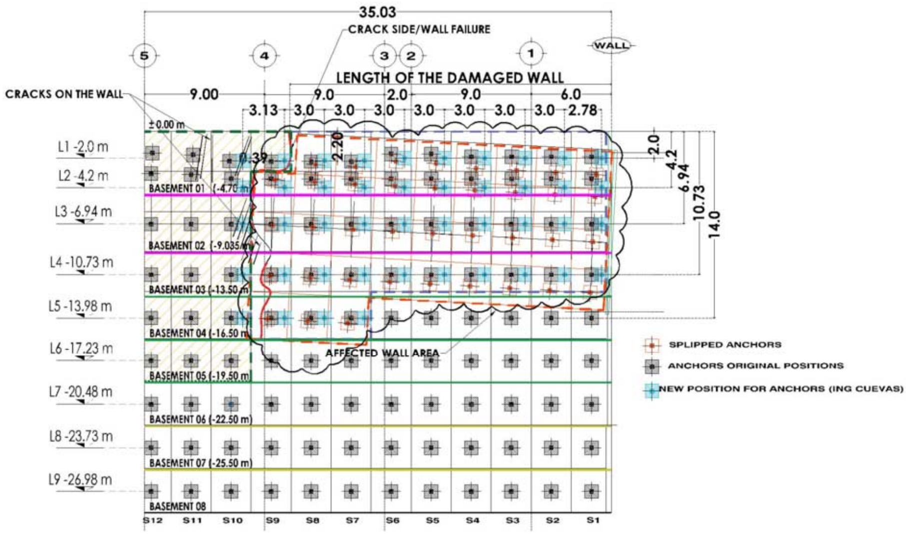


Figure 12. Area of the affected wall.

Table 5. Geotechnical model case 5.

Stratigraphic Unit	Description	Depth (m)	γ (kN/m^3)	c (kPa)	ϕ (°)
Fill	Sandy clay (CH)	0.0 to 0.6	17.0	30	25
Lacustrine soils	Clay (CH)	0.6 to 5.0	16.0	70	10
Alluvial soils	Sandy silts with gravels (ML)	5.0 to 13.2	17.5	50	28
Volcanic soils	Silty sandy tuff (ML)	13.2 to 30.0	17.5	50	35

γ, volumetric weight; c, cohesion; ϕ, internal friction angle

The fourth and last project, presents interspersion of fine alluvial soils in the first 14 m where the retention system consisted of a cast-in-place diaphragm wall. Subsequently, and up to 24.5 m, there are very thick alluvial soils where the retention required a 40 cm thick shotcrete wall. During the anchor work, contact with a neighboring building occurred which caused perforation of the basement structure. Due to this circumstance, the anchors were positioned with a different slope, Figure 13. Stratigraphic profile and anchor characteristics are shown in Figure 14. Table 6 contains the geotechnical model.

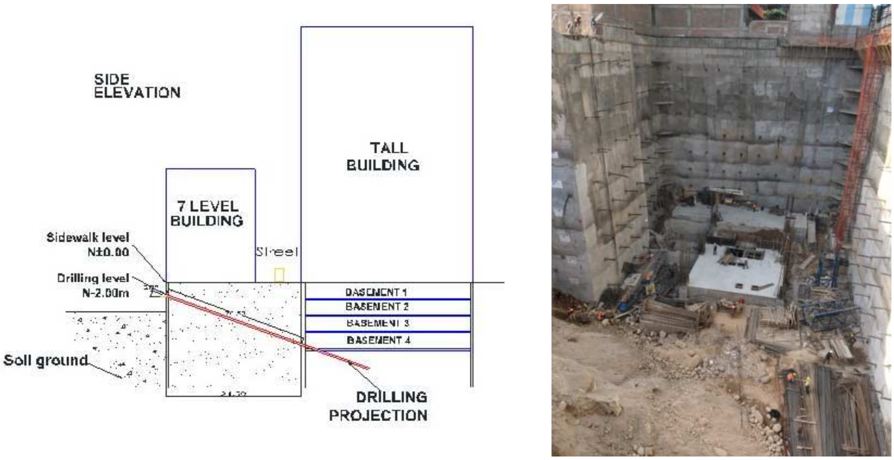
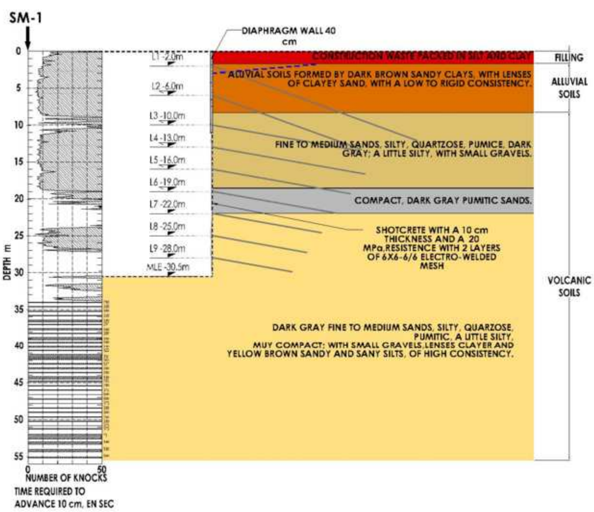


Figure 13. Cut showing the issue; general view of the project site.



Anchor level	Depth (m)	Design force (kN)	Drilling length (m)	Effective length (m)	Post-tension (kN)
1	-2.0	650 y 800 4 y 5 strands of 0.6"	23.5	6.0	650 y 800
2	-6.0	650 y 800 4 y 5 strands of 0.6"	21.5	6.0	650 y 800
3	-10.0	650 y 800 4 y 5 strands of 0.6"	20.0	6.0	650 y 800
4	-13.0	1850 12 strands of 0.6"	21.0	9.0	1850
5	-16.0	1850 12 strands of 0.6"	19.0	9.0	1850
6	-19.0	1850 12 strands of 0.6"	17.0	9.0	1850
7	-22.0	1850 12 strands of 0.6"	15.0	9.0	1850
8	-25.0	1850 12 strands of 0.6"	13.0	9.0	1850
9	-28.0	1850 12 strands of 0.6"	11.0	9.0	1850

PI, INJECTION DESIGN PRESSURE 0.8 MPa ON THE DIAPHRAGM WALL AND 1 MPa ON ON THE SHOTCRETE

Figure 14. Support and stratigraphic case 6.

Table 6. Geotechnical model case 6.

Stratigraphic Unit	Description	Depth (m)	γ (kN/m^3)	c (kPa)	ϕ (°)
Fill	Construction debris packed in silt and clay	0.0 to 1.2	17.5	15	25
Alluvial Soils	Sandy clay (CH)	1.2 6 to 8.0	17.0	57.5	6
	Clayey sand (SC)	8.0 to 8.5	17.0	10	25
Volcanic soils	Sandy silty tuff and sandy silt (SM y ML)	8.5 to20.5	17.8	65	37
	Pumitic sand (SM)	17.5 to 19.3	15.0	34	29.5
	Silty, sandy tuff and silty sand. (ML y SM)	19.3 to 40.0	18.0	72	38

γ, volumetric weight; c, cohesion; ϕ, internal friction angle

3. Conclusions

Several cases of the use of anchors in the Mexico City urban area are presented; in the first two, post-tensioned anchors solved the temporary retention issue during the excavation process with no major setbacks.

Additionally, four cases with issues were presented showing situations that are considered system abuse: in the first one, the excavation remained open over three years; in the second, water pressure from a defective public service installation occurred, besides the lack of re-tension tests, needed to estimate the reaction system conditions such as wedges, yews and strands; data of great importance due to the time the construction was suspended and the exposure it had to the environment; in the third case, geotechnical site conditions demanded a more rigid retention solution (diaphragm wall, for example); in the fourth, the adjoining lots significantly limited anchor installation.

Finally, we wish to emphasize the importance of considering each project's particular circumstances when deciding on a retention system for urban excavations. The presented cases show different conditions that limit the use of anchors in terms of space, time or geology.

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