INSTRUMENTATION OF AN EXISTING METRO LINE DURING CONSTRUCTION OF A NEW SUBWAY LINE

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The new subway line passes under an existing subway line and an under pass roadway. The new tunnel is going to be built with a tunnel boring machine (TBM) using the earth pressure balance (EPB) procedure. In order to define the geotechnical and mechanical effects that the construction of the new line might have on these structures, an instrumentation system was implemented.

To prevent any structural misbehavior on the existing under pass and the subway line, it is necessary to have a strict control of the TBM parameters, such as the face-support pressure and the slurry characteristics; hence, data from the machine sensors were stored. Knowledge of these parameters allows for monitoring of settlements during the construction process and that will lead to protection of the surrounding structures and eventually to predict the possible long-time subsidence effects.

Outside the structures, tiltmeters and topographic references were installed. Inside the tunnel, deformations were measured through an automated system to prevent any possible damage due to unexpected factors.

In this paper, the selection criterion, for the sensors used in the instrumentation system, is described. The monitoring process and the relevant data gathered from the system are presented and explained herein. Conclusions led to important correlations that can be used for future works.

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INSTRUMENTATION AND MONITORING OF AN EXISTING METRO LINE DURING CONSTRUCTION OF A NEW SUBWAY LINE

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ABSTRACT: The new subway line passes under an existing subway line and an under pass roadway. The new tunnel is going to be built with a tunnel boring machine (TBM) using the earth pressure balance (EPB) procedure. In order to define the geotechnical and mechanical effects that the construction of the new line might have on these structures, an instrumentation system was implemented.

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1 INTRODUCTION

New infrastructure developments require more attention to avoid damage on existing buildings and structures.

Although numerical models have provided the advantage to predict the response of soil and structure, it remains difficult to calibrate such models without physical models. Hence, instrumentation has become a very powerful tool to monitor structures and soil behavior and also to provide data that can be used to feed the numerical models e.g. Glisic et al. (2009); Mayoral et al. (2009); Phillip (1998)

1.1 Project description

A new metro line (Line 12) is being built in the city and it will meet several existing structures during along its way. Since soil conditions are very distinct it is important to verify the possible impact that the new project might cause to the existing structures. A

very particular cross is found at an existing subway line (Line 2). Figure 1 shows the plan view of both structures

Figure 1. Plan view of the subway lines

Line 12 was built in a shallow box-section while the Line 12 tunnel is built with a tunnel boring machine with earth pressure balance (TBM with EPB). The Line 12 tunnel is located 17 m below the tunnel of Line 2.

Given that Line 2 is already operating, it was important to assess the displacements caused by construction of Line 12. To do so, two resources were used: numerical modeling of the cross section and direct measurements of soil response to construction of Line 12. The first one was back fed with data from the latter. In this paper only the second one is described.

2 SOIL CONDITIONS

It is necessary to describe the existing soil conditions in order to understand the difficult construction process of Line 12. Several field and laboratory tests were carried out to determine its index and mechanical properties. A simplified geotechnical profile is indicated in Table 1.

Table 1. Geotechnical profile

Layer	**Depth (m)**		**Volumetric weight, γ (kN/m^3)**
Backfill	0.00	2.00	16.5
Cluster	2.00	8.00	14.2
Silty clay	8.00	12.50	11.1
Sand	12.50	13.00	18.0
Soft clay	13.00	15.50	11.4
Sand	15.50	16.00	18.0

Layer	Depth (m)		Volumetric weight, γ (kN/m^3)
Soft clay	16.00	21.00	11.7
Sand	21.00	21.50	18.0
Stiff clay	21.50	24.50	14.2

The water content exhibited by the soil profile is depicted in Figure 2. As shown there, high water contents are appreciated from 7 m depth to 20 m. Tunnel of Line 12 goes from 13 m to 23 m depth. Hence, it is located in the soft clays and lies into the stiff deposits.

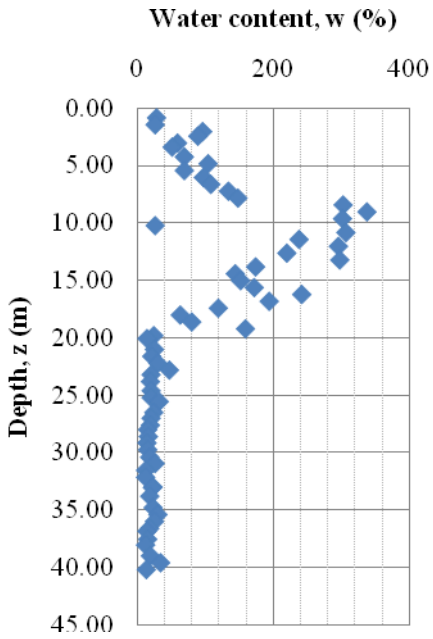


Figure 2. Water content variation with depth

3 INSTRUMENTATION

Several instruments were installed into the surrounding soil and the existing station: an inclinometer with a magnetic extensometer, a load cell with piezometer and a tiltmeter. Location of the instruments is shown on Figure 3. In this paper only data from the inclinometer, the extensometer and the tiltmeter are reported. Results from the load cell and pore pressure will be given in a subsequent article, for further references regarding this matter, the reader can refer to Wang, et. al., (1996).

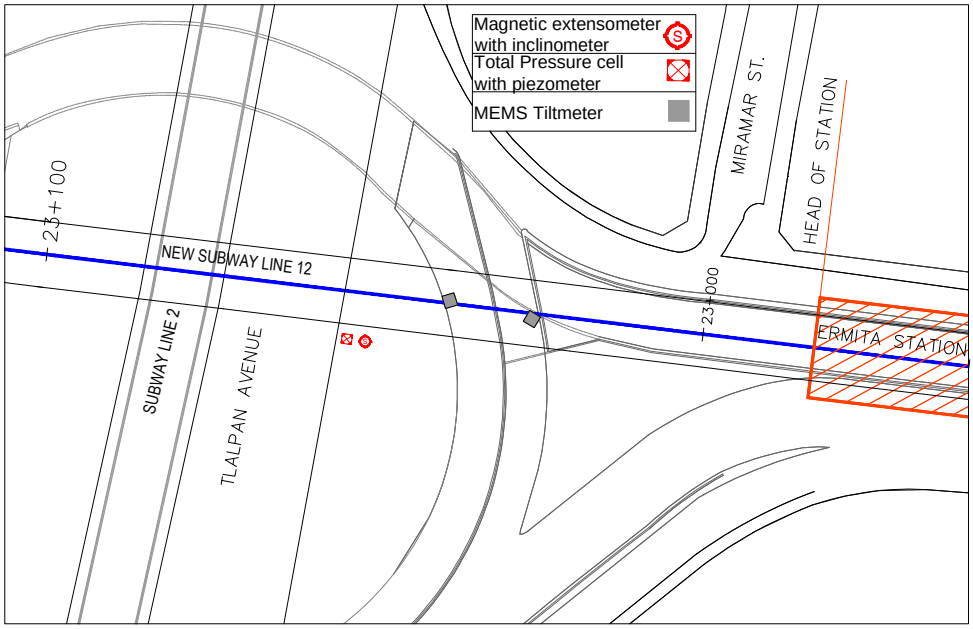


Figure 3. Plan view of the instruments

On the station, topographic controls were placed to observe the displacements on the walls and on the rails.

An automatic measurement of convergence and divergence system was proposed with tiltmeters. This system was specially developed for the Metro project and it is the only one of its kind in Mexico. It consists of six interconnected tiltmeters monitored by a datalogger and managed by specialized software (Figure 4).

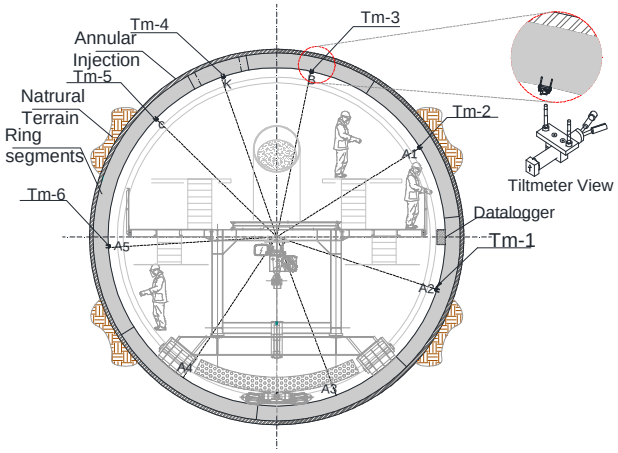


Figure 4. Convergence and divergence system

3.1 Inclinometer with magnetic extensometer

In order to measure horizontal and vertical movements of the soil mass surrounding the tunnel excavation, an inclinometer with magnetic extensometer was installed at 33.05 m depth. Details of the inclinometer and extensometer are depicted on Figure 5.

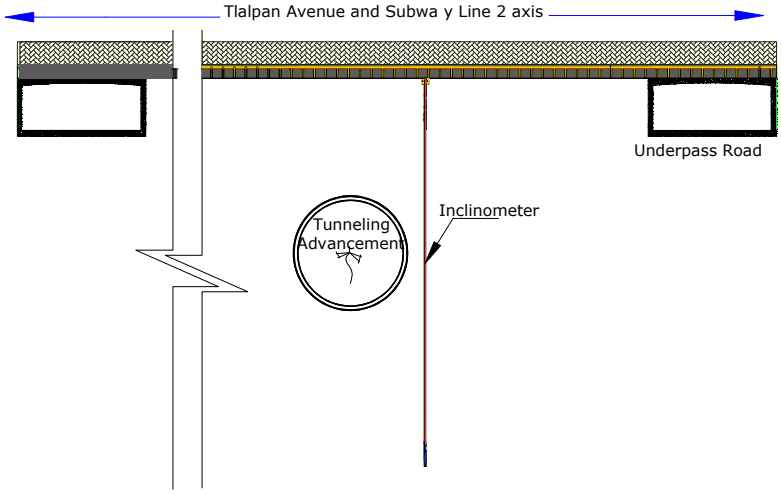
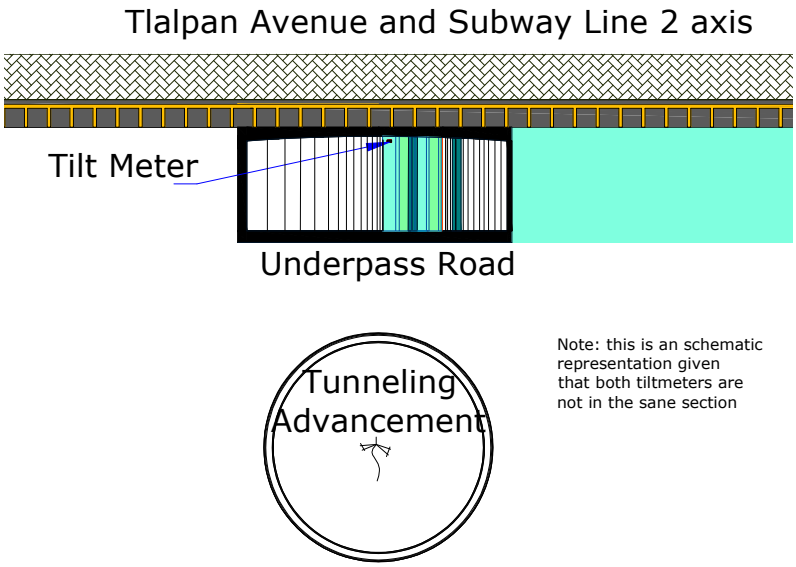


Figure 5. Cross section of the inclinometer

3.2 Tiltmeter

Two tiltmeters were installed on the walls of the existing station to check any inclination of the structure during the TBM advance. Tiltmeters are shown on Figure 7.



4 MEASUREMENTS

Instruments were installed before tunnel construction in order to check the existing subway line and prevent any damage.

As mentioned in section 3, topographic points were located on the subway lines-intersection and settlements were measured along the Line 2 axis and transverse to the Line 12 axis (Figure 8). It is seen that vertical displacements do not exceed 0.03 m after the construction of Line 12, which is acceptable for the structure of Line 2. However, the displacement history will be monitored to avert any long-term settlement.

The extensometer has five magnetic spiders that were located at different depths and allow to measure settlement at their respective depth. Figure 9 depicts the maximum settlement of 0.026 m at 17 m depth, while at 7.12 m there is a 0.023 m displacement. This behavior agrees with the reported stratigraphy and does not exceed 0.05 m even after the TBM pass.

As well as the topographic levels, it is important to keep monitoring the extensometer data since settlements will continue increasing even after the construction and operation of Line 12.

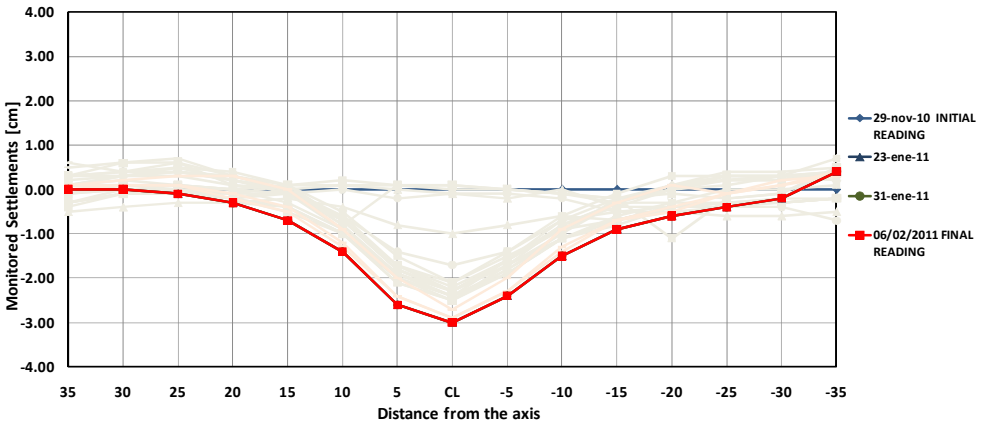


Figure 8. Settlements on the transverse section of Line 12

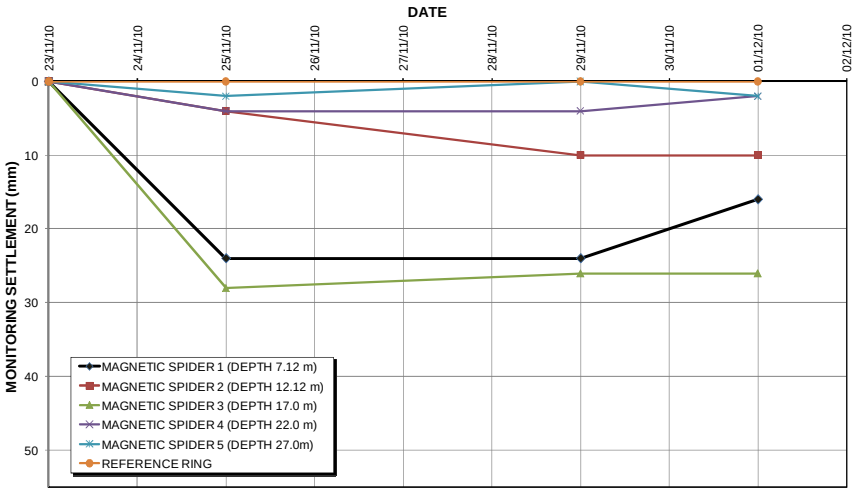


Figure 9. Reported measurements with the magnetic extensometer

The inclinometer reported deflections in two directions: longitudinal and transverse to the Line 12 axis. Figure 10 shows deflections transverse to Line 2 and longitudinal to Line 12. It can be seen that there is a deflection of 0.012 m after TBM advance which is under the allowed limits.

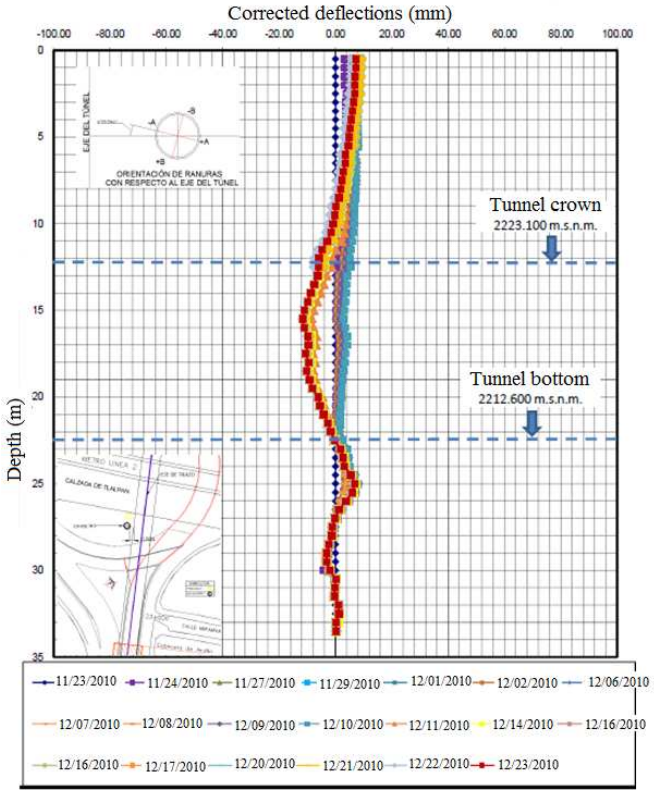


Figure 10. Inclinometer measurements

Two tiltmeters were installed on the walls of the underpass road that cross Line 2, tiltmeter 1 is located on the longitudinal direction of Line 2 and tiltmeter 2, in the transverse one.

Tiltmeter 1 indicates that the wall in the longitudinal direction of Line 2 is moving 0.002 m outwards and tiltmeter 2 indicates that the transverse wall is moving around 0.002 m inwards (Figure 11). This displacement is very small compared to the structure size and shows that construction of Line 12 did not cause immediate effects on the Line 2 structure.

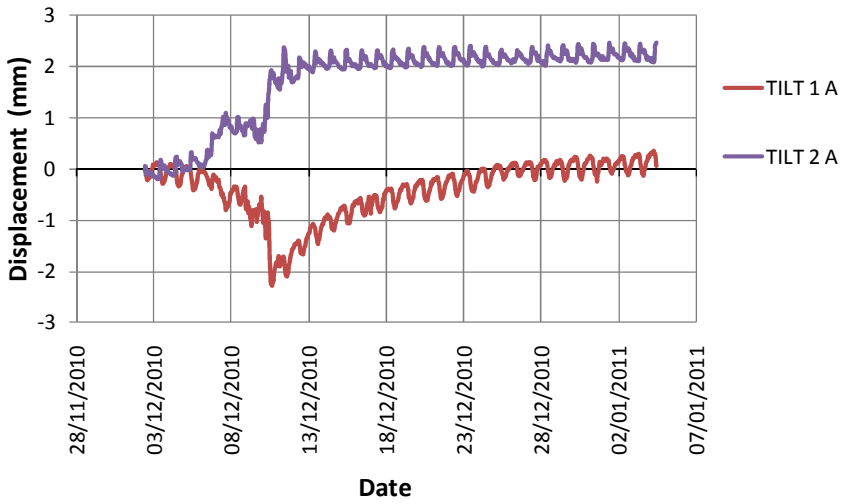


Figure 11. Tiltmeters measurements

Finally, convergences of the Line 12 tunnel diameter under the intersection with Line 2 are shown on Figure 12. Convergences and divergences are less than 0.001 m after installation of the segmental concrete lining. This apparently *egg-shape* is similar in magnitude to other sections of the tunnel, hence, presence of Line 2 does not significantly affect tunnel of Line 12.

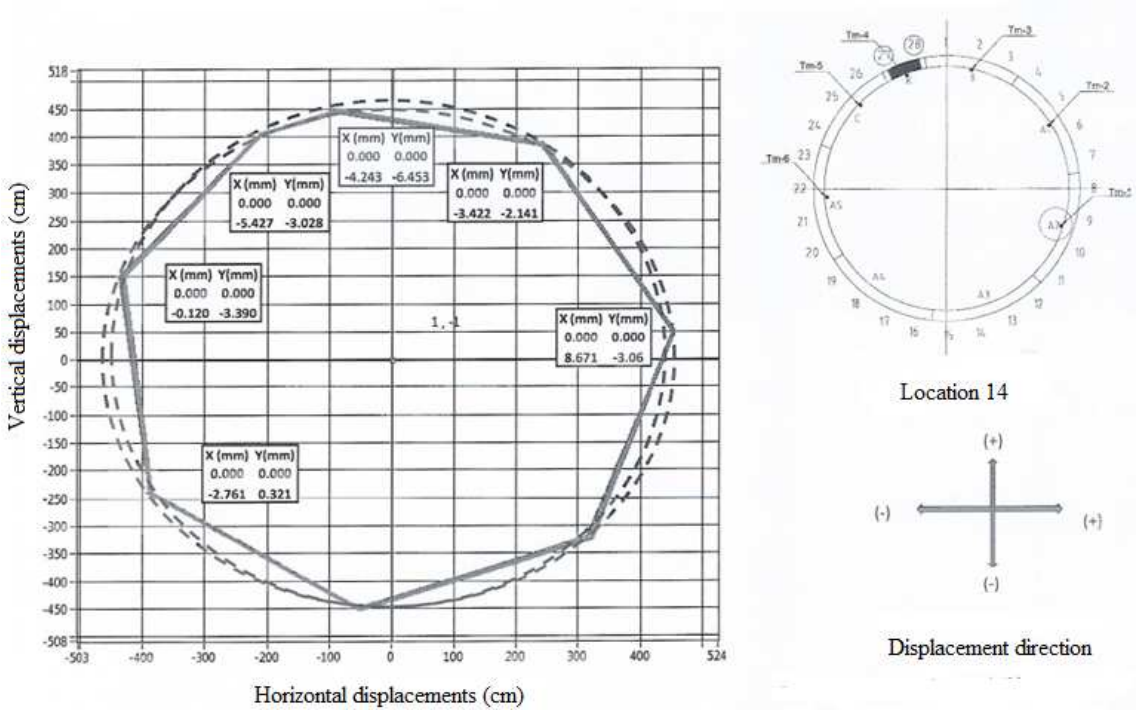


Figure 12. Diametral deformation of tunnel

5 CONCLUSIONS

After reviewing the data gathered from the installed instruments, it can be concluded that construction of Line 12 did not cause short-term effects on the structure of Line 2. However, given the soil conditions it is very important to keep monitoring the displacements since the major component of the settlement will be the one due to consolidation.

At first glance, it seems that TBM advance does not change significantly the conditions of Line 2 and there was no need of soil improvement. These results will be used to calibrate numerical models to foresee the expected long-term settlements and take actions to prevent them.

Selection of the instruments was based on the need for evaluate the stress state and deformation conditions of the soil mass surrounding the intersection. While the geotechnical instruments (inclinometer and extensometer) provided a good estimate of the soil conditions and the Line 2 foundation response, the structural instruments (tiltmeters) offered the response of the structure to the TBM pass.

By observing the parameters given by the TBM such as face pressure and back pressure it is possible to develop numerical correlations by relating the corresponding displacements with the data. These results provide a good insight into these kind of problems that arise frequently in populated cities.

6 REFERENCES

Glisic, B, Inaudi, D, and Casanova, N. 2009. SHM process: lessons learned in 250 SHM Projects, *4th International Conference on Structural Health Monitoring on Intelligent Infrastructure (SHMII-4)*, 22-24 July 2009, Zurich, Switzerland.

Mayoral, J, Alberto, Y, Mendoza, M and Romo, M. 2009. Seismic response of an urban bridge-support system in soft clay. *Journal of Soil Dynamics and Earthquake Engineering*, Volume 29, Issue 5, May 2009.

Phillip, LJ. 1998, Instrumentation to monitor building damage from excavation, *Department of Civil and Environmental Engineering, Bucknell University*, May 8, 1998.

Wang, RN, Chen, M, Moh, ZC. 1996, Pore pressures induced in soft ground due to tunneling. *Geotechnical Aspects of Underground Construction in Soft Grounds*, Mair & Taylor eds. Balkema Roterdam.