Diametric deformations in the concrete segment lining of a tunnel excavated in soft soils. Criteria for their evaluation and mitigation actions for their control

Déformations diamétrales dans le secteur du béton revêtement d'un tunnel creusé dans les sols mous. Critères de leur évaluation et des mesures d'atténuation pour leur contrôle

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ABSTRACT: A criterion is presented for the evaluation of diametric deformation that occurred at the initial support of a tunnel formed by pre-cast concrete segmented rings, placed in a very soft and high compressibility clay medium. This criterion is presented on a working graph, which involves the time factor with respect to the deformation rate, for several percentages of the diametric deformation, with respect to the initial diameter of the concrete segment lining. With available information it is possible to draw a line on the working graph and, depending on its particular location, it is possible to define the recommended mitigation action to be followed: only a continuous topographic monitoring if diametric deformations are minimal, additional grouting stages around the concrete segmented rings if they are more pronounced, or additional internal reinforcement structural systems if they seem dangerous for the lining's stability.

RESUME : On propose un critère d'évaluation de la déformation diamétrale du revêtement primaire d'un tunnel constitué de voussoirs préfabriqués et construit dans un sol mou et compressible. Ce critère est représenté sur un graphique de travail qui fait intervenir le taux de déformation pour et les pourcentages de déformation diamétrale par rapport au diamètre initial du revêtement primaire en voussoirs de béton. Les données disponibles permettent de tracer une ligne sur le graphique et en fonction de sa position de recommander les mesures de contrôle à prendre : un simple suivi topographique si les déformations sont faibles, des injections complémentaires autour du revêtement primaire si elles sont plus importantes ou un renforcement interne au moyen de structures adaptées si les déformations semblent indiquer un danger pour la stabilité du revêtement.

KEYWORDS: tunnel deformation, control strategy, lining's stability, soft soil, tunnelling.

1 INTRODUCTION

The case history is presented of a tunnel for the transport of residual water from Mexico City, with an excavation diameter of 8.70m. Its initial support consists of concrete segmented rings with exterior and interior diameter of 8.4 and 7.7m respectively, and 1.5m wide (6 pieces plus wedge).

During construction of the tunnel with an earth pressure balance (EPB) tunnel boring machine in very soft and highly deformable clayey soils of the Valley of Mexico, the periodic measurement over time was carried out of the interior horizontal and vertical diameters of each ring, recording their differences regarding their initial reading, at different dates, observing that the deformational behavior of their initial support depends substantially on the geotechnical properties of the materials it goes through, on the natural actions that occur in its neighborhood, such as soil "drying" and posterior "saturation" due to the effects of the absence or abundance of rain, and mainly due to the medium's own compression. Therefore, it is considered that the stability of the segmented rings that form the tunnel's initial support depends basically on the compression it receives from the neighboring soil where it is being built, and in particular on the differences in the value of the compression's components, horizontal and vertical. If for reasons inherent to the subsoil itself the difference between horizontal and vertical pressures is critical, for example when the horizontal component tends to cero, notable deformations are induced on the lining, which start with sudden increments of the deformation speed. Therefore, in case the increments are observed on the lining's diametric deformations, it is necessary to adopt control and mitigation measures, to thus avoid problems in the tunnel's structural stability.

A graphic criterion is presented in this document, to evaluate the deformational behavior shown by the segmented rings of the tunnel's initial support, and the corrective measures that were applied to achieve its stabilization.

2 DEFORMATIONAL BEHAVIOR OF THE SEGMENTS

The initial support of a tunnel excavated with an EPB machine in clayey soil of very soft consistency, and lined with segmented rings of reinforced concrete, is a classic example of "soil/structure" interaction, because without the segmented rings the hollow excavated by the tunnel boring machine would not be kept open and without the compression provided by the adjacent soil, the mentioned rings would not even support their own weight. The relative flexibility the segmented rings have in principle allows them to adjust conveniently to horizontal and vertical pressures induced on them by the neighboring terrain, with acting pressures being redistributed, the horizontal and vertical adjustment of their diameters as their answer, which in general tends to stabilization, without any major transcendence. As part of the segmented ring's deformational control, a periodic horizontal and vertical measurement of the diameters of each ring is carried out, the first reading being the one recorded when the ring is recently placed within the boring machine's shield, which is what the tunnel is excavated with. As result of these periodic measurements, it has been observed that the tunnel's initial support has various deformational behaviors that are linked mainly to the type of terrain it is in, and to the extraordinary events that occur in its neighborhood. It is important to point out that the largest segmented ring deformation occurs just when the ring leaves the shield, because it enters into contact with the natural terrain and receives the injection of mortar on its outer surface.

Although the general tendency of an initial support is toward its eventual stabilization, in the Valley of Mexico, for example, there are geotechnical zones of peculiar behavior, where subsoil tension cracks appear that are associated to superficial drying phenomena, and significant regional subsidence generated by the overexploitation of aquifers that exist in the subsoil. Further, the presence of channels that carry residual waters in the vicinity of a tunnel under construction can provoke significant changes on it due to the state of surrounding stresses, and eventually on its k_0 relation if, for example, dredging maneuvers are carried out on the channels, or if materials are loaded on their borders.

3 GRAPHIC CRITERION TO IDENTIFY THE DEFORMATIONAL BEHAVIOR OF A TUNNEL'S SEGMENTS

With the information resulting from diametric measurements of the mentioned drainage tunnel, a diagram was prepared, shown in Fig 1, which includes five zones among which the curves of "horizontal diameter increase" versus "time" can be set, as recorded for each ring of the tunnel's initial support. Table 1 shows an explanation of the control and mitigation measurements recommended according to the case of application.

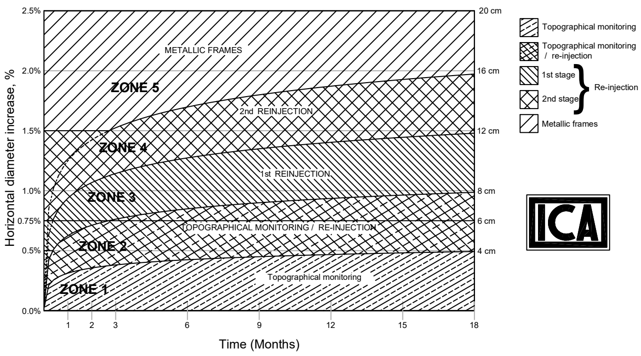

Figure 1. Diagram for deformational control of tunnel segments in soft soils

4 APPLICATION EXAMPLES

Figures 2 and 3 show examples of the application of the graphic criteria for the case of tunnels built in clayey deposits of the Valley of Mexico, where a stable and unstable behavior are observed. It is worth mentioning that the mitigation measures adopted to reach stabilization in the second case were through the application of re-injections at the point of contact of segmented ring and soil.

Figure 2 shows the variation in horizontal deformation of the primary lining with respect to time for the case of a tunnel with stable behavior. It was observed that initially there is an important deformation speed of 0.5 mm/day, but the stable tendency of the tunnel's deformation began to be observed in less than a month. Under these conditions there are no control or mitigation measures, only the follow up of the tunnel's deformation until it reaches its total stabilization.

Figure 3 shows two cases of tunnels with stable behavior, one since its construction, the other after reaching its apparent stabilization. In both cases, the deformation speeds were high, to the point that the deformation-time curve was located at zones where it is necessary to apply re-injection at the point of contact between segment and soil in order to ensure the tunnel lining's compression.

5 CONCLUSIONS

The deformational control of the initial support of an excavated tunnel in very soft and compressible soils, where there are also geotechnical aspects that can affect its relation with horizontal and vertical stresses around the tunnel under construction, is a useful tool to confirm their good behavior, or else to apply opportune mitigation measures that will allow reaching their desired stability, as was the case that occurred along a section of the drainage tunnel this work refers to.

Table 1. Deformational control and mitigation measures

Zone	Deformational behavior	Horizontal diameter deformation (%)	Mitigation action
1	Optimal, with marked tendency to stability	0.0 to 0.5	Topographical monitoring
2	Slightly less than optimal but with marked tendency to stability	< 1.0	Topographical monitoring and, in case there is no logarithmic behavior with tendency to stabilization, re-injection of ring's annular space
3	Not optimal	< 1.5	Topographical monitoring and first re-injection of ring's annular space
4	Notoriously not optimal	< 2.0	Topographical monitoring and second re-injection of ring's annular space
5	Critical, with marked tendency to instability	> 2.0	Additionally reinforce initial support by means of metallic frames

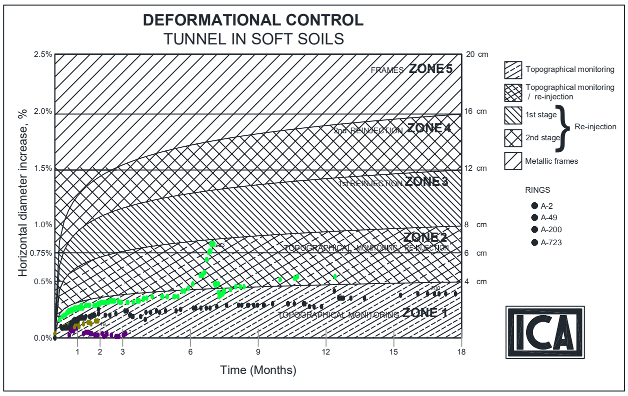

Figure 2. Curves: Increase of horizontal diameter *versus* time showing stable behavior

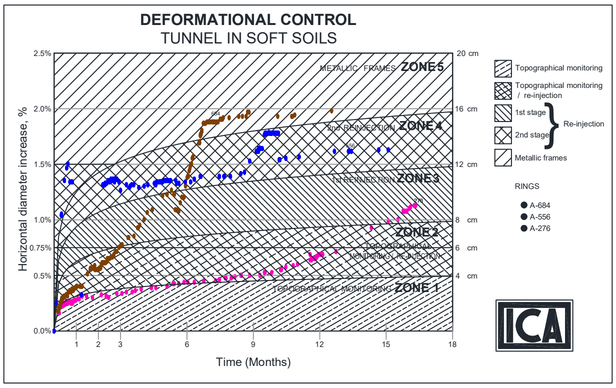

Figure 3. Curves: Increase in horizontal diameter *versus* time, showing unstable behavior whose tendency to deformation was mitigated by re-injection.

6 REFERENCES

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