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Geotechnical Problems in the Construction of Underground Structures

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Geotechnical Problems in the Construction of Underground Structures

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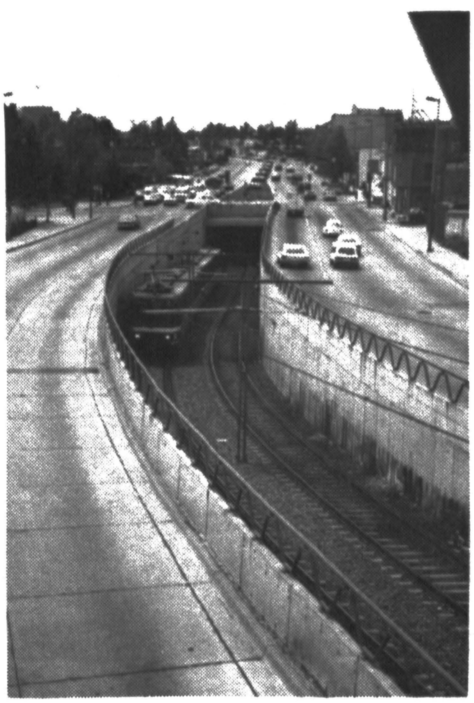
SYNOPSIS The paper describes, one of the typical cases in the construction of subterrain works in - the city of Guadalajara, Jalisco; México; placed in a big landfill of pyroclastic materials, that are good aquifers that is why in the subsoil exists important hydrological resources and is the reason that when digging underground structures that exceed the groundwater level there were a lot of problems. The case presented is of one of the stretches of the tunnel for the urban electric train, that since its construction had failures; these are analyzed, the solutions implemented are described, and the behavior of the structure is shown. It concludes that the problem were due to a project based on superficial studies that did not allow to detect the unfavorable geohydraulic conditions.

INTRODUCTION

The goverment of the State of Jalisco, constructed in its capital city, Guadalajara, the line 1 of the urban electric train in which development has a tunnel of approximately 8.0 km from which were constructed 7.0 km in the first step and - the rest during 1987 (Fig.1) in which it had to work in bigger depths than groundwater level that is why since the construction began, there were very serious problems.



g. 1 Tunnel in Operation

DESIGN AND CONSTRUCTION OF THE TUNNEL

In this stretch, located in the Calzada of Federalismo Norte, the tunnel has approximately 1.0 km lenght including the access ramp; its cross section includes a box of reinforced concrete of 7.4 x 5.4 m, which walls have a thickness of 0.40 m, the upper slab, 0.50 m and the floor - slab 0.45 m. The construction was made through sky open excavation and the use of a slidding form.

Due to the presence of high subterrain water volumes (Fig.2) solutions, as to place rockfills - in some places, in other, fillings surrounding - to the tunnel were grouted, install of pumping - equipments and place a section of a diaphragm - wall formed by cast in situ piles, had to be improvised.

Fig. 2 Water Inflow during Constructive Process

CONDITIONS AFTER OF THE CONSTRUCTION

After performing the box, fillings were made and the way was paved with hidraulic concrete slabs and seal works were performed in the tunnel. Nevertheless, the water inflows into the structure continued to appear in a superlative grade, reaching to store in the lower part, water volumes up to 1.0 m from the floor level, besides producing dragging of solid particles resulting from the surrounding subsoil to the tunnel and causing stability problems to the access ramp.

The water continued entering through the construction joints or openings of the false work - bad plugged, with a pressure that was making the access conduits more extended and with a major volume through the floor slab (Fig.3) and through the walls up to an approximately height of 3.0 m.

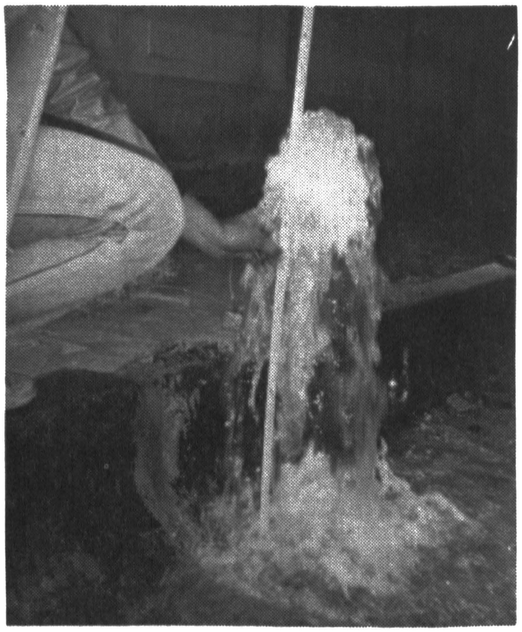


Fig. 3 Water Inflow Into the Tunnel

Because of the above, project information and - old dates of the zone was compiled and geotechnicals and hydrologics studies were performed.

RESULTS OF THE GEOTECHNICAL STUDIES

For this studies, a geological examination of - the zone was made, an analysis of old airphotos and the realization of 40 borings with a variable depth of 6.00 to 11.0 m that were distributed in both sides of the tunnel, forming a cuadricule, were included.

The borings consisted in standard penetration - tests with extraction of samples for field identification and laboratory tests. Additional to - each perforation a piezometer was installed for the hydrologic study.

The analysis of the air photos, taken in 1941, - showed that in this area it existed an important stream (Fig.4) affluenty from Atemajac River, in which development crosses twice the outline of - the tunnel, and is observe tracks of its stream bed, west of the structure. During the excavations a bridge that was used to cross the stream mentioned, was founded.(Fig.5)

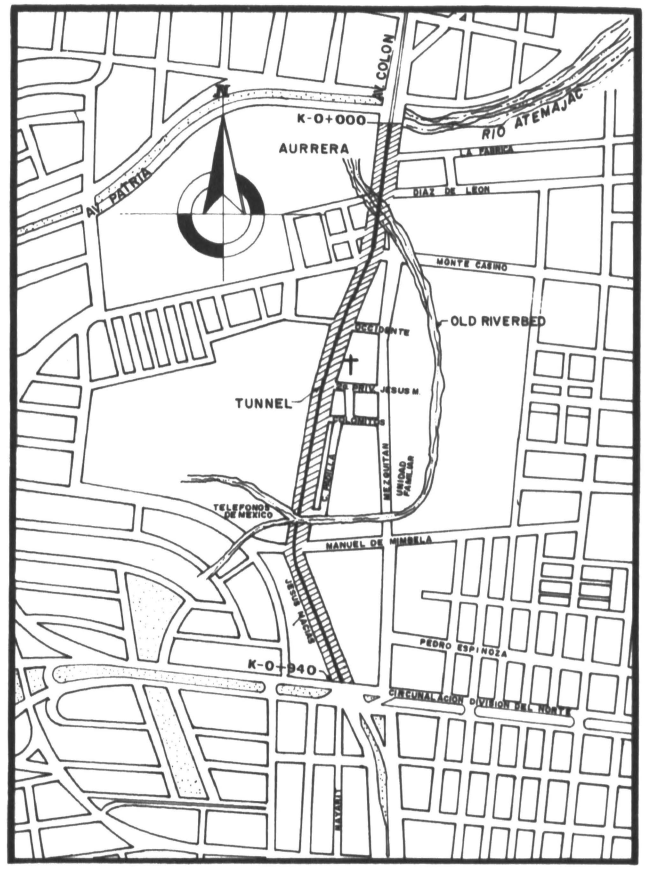


Fig. 4 Location of the Tunnel and Old Riverbed

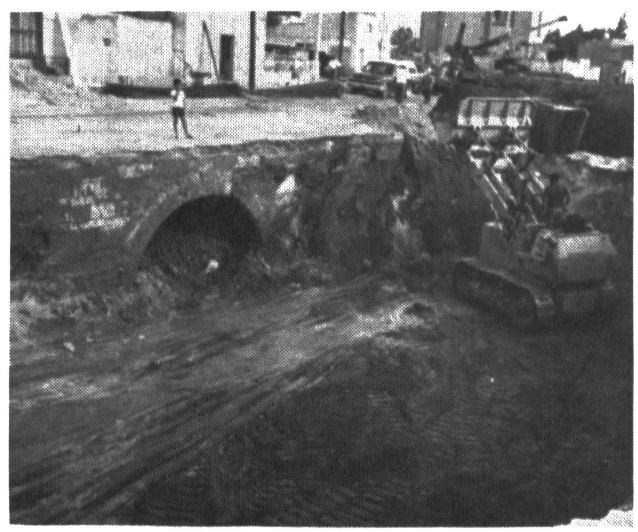


Fig. 5 Buried Old Bridge

Furthermore, the tunnel development passes by - the side of a spring called Los Colomitos, and nearby are operating some pumping wells.

From the studies of the subsoil exploration previous to the construction a typical profile is shown (Fig.6), in which can be seen the superior part of the subsoil formed by urbanization fillings with depths of 2.0 to 5.0 m, and from this level a layer of silty sand of medium relative density (12 to 30 blows standard penetration test) of approximately 3.0 m of thickness and from this cotta up to the finals of the boring, a sandy silt formation, light brown and relative density medium to high (more than 40 blows) is founded. The groundwater level was founded in a medium depth of 3.5 m.

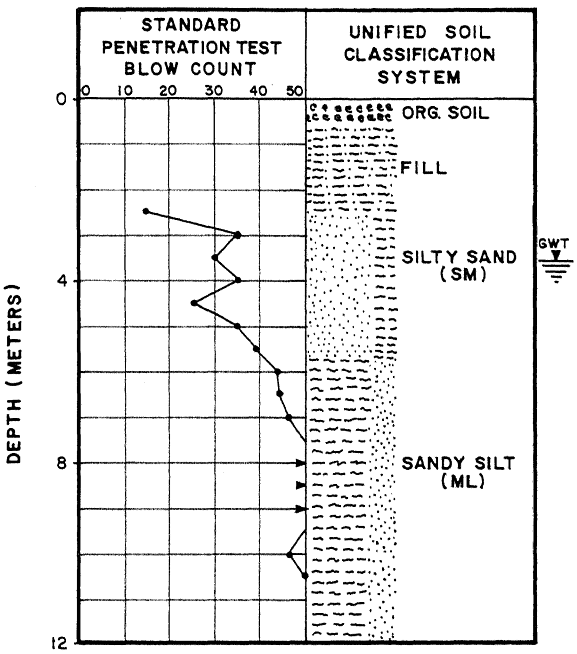


Fig. 6 Typical Soil Profile

Index tests showed the following results:

Natural water content	19-42 %	
Void ratio	0.84-1.87	
Specific gravity, Ss	2.31	
Bulk unit weight	900-1500	kg/cm^3

Strength parameters were found to be as follows (Padilla 1988):

	Internal angle of Friction Ø	Cohesion kN / m^2
Quick triaxial test	20°-36°	29-140
Standard penetration	27°-40°	

Because of the above, it emits that throughout the tunnel, the subsoil was formed by pyroclastic deposits of vitreous and pumice nature, which materials show a resilent behavior and have a high absorption and friction. These characteristics make them highly erodibles due to the presence and flowing of the water.

Up to this level, the study showed that the tunnel was located in a zone of pumice materials deposits, with high underground pluvial water accumulations, which original morphology, included a series of canyons and due to urban works, the fillings covered and rubbed out the old riverbeds, whose marks were founded during the construction of the work, and the soils exploration.

In relation with subsequents borings in Fig.7, are presented the standard penetration tests, performed in the surrounding soils of the tunnel, to analyze the grade of compaction of the fillings. The graphic study, showed that the relative density is very heterogeneous with low values in some zones, where the measured resistance in these tests, tended to zero, being more critical the east side of the structure.

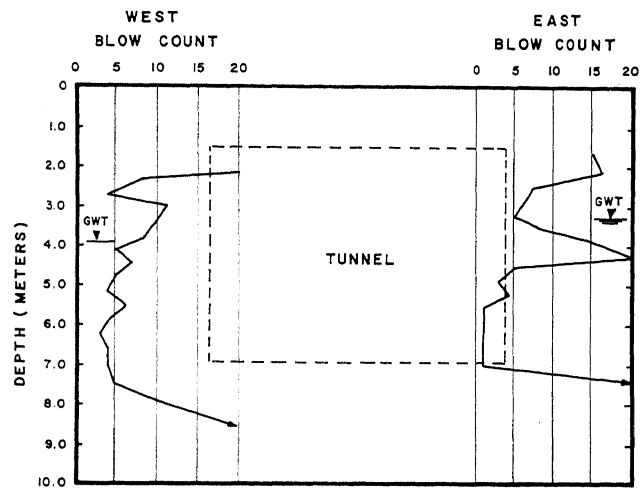


Fig. 7 S.P.T. Results on Tunnel Surrounding Fills

To analyze if above results were due to deficient placing of the fillings or for erosion effects due to the seepage, the concept of critical gradient of Terzaghi (1967) was used together with the criterion of Van Zyl and Harr (1981) in account not only of the sumerged soil weight, but as to the friction forces developed between the solid particles to define the failure gradient, i_f:

Where:

i_f = Ns i_c
i_c = Critical gradient
Ns = a correction factor to account for soil characteristics

So, the factor of safety, with respect to the seepage erosion is define by:

$$FS = \frac{if}{ie}$$

Where: ie = exit gradient

For the surrounding soils to the tunnel with the data of the realized tests and considering a piezometric height of 3.50 m on the floor level, the estimate factor of safety, FS, varied from 0.54 to 1.59 with a medium value of 1.02, this indicates that in some zones there was dragging of solid particles.

Even if the compacted fillings remained up to its maximum density, this would not be sufficient to avoid the hydric erosion, so in this case, it should be very convenient to make the fillings of the tunnel with a soil-cement mix.

Due to the above, the conclusión is that the water streams toward the interior of the tunnel, caused the dragging of solid particles of the surrounding soils to the structure, this began in the discontinuity that formed the border between a rigid medium (concrete walls and floor) and the soil, which fine particles begin to displace within the soil matrix toward fissures, cracks or coarser layers, that if it continue progressing could collapsed the structure.

Also analysis of the uplift pressures was made, giving nonencouraging results, because in the zone of the ramp the factor of safety against flotation was less than 1.0, for which if the hydraulic pressures weren't overthrow, would have stability problems.

HYDROLOGICS STUDIES

The works consisted in the cuadricule of 40 piezometers, as pumping tests in 3 places of the zone.

With the piezometrics levels the equipotentials lines were traced, the stream lines and axles were defined. The piezometric surface was not regular as it showed a complex morphology, principal due to the presence of the tunnel. The depth of the phreatic line in relation to the ground surface changed from 2.20 to 4.20 m. The general direction stream SW-ENE wasn't uniform and the important and well watered reliefs of Los Colomos, feed the aquifer.

The depresion profiles were affected by hydraulic gradients that varied from 0.0067 to 0.0388 implicated some artesianism, the estimated of the factor of safety, against dragging of solid particles gave bigger values to 20, which means that the natural stream of subterrain water --- would not produce solids dragging.

With the results of the pumping tests, the coefficients of the permeability of the aquifer were calculated obtaining values between 8.05 x 10^{-3} and 7.00 x 10^{-4} cm/sec. The estimate predictions due to the hydrocompaction varied between 0.09 and 0.12 m while the hydric erosion analysis produced by the pumping throw factors of safety, from the order of 0.65, which indicated that the pumping will produce dragging of solid particles with the respectively consequences in relation to pipings, settlements, etc.

The conclusion of these analysis was that a disorderly water stream existed toward the tunnel due to the fact that the construction of the structure, intercepted subterrain water flows creating sinous stream lines. Have to point out that the subterrain water volumes increase remarkable during the rainy season.

IMPLEMENTATION AND BEHAVIOR OF THE CORRECTIVES MEASURES

According to the exposed, it was necessary to solve the following situations: the freatic water pressure against the structure, the entrance of non-controlled water toward the box, the dragging of solid particles and the lack of compactation of the surroundings fills to the tunnel.

The first implemented solution was taking advantage of the ballast bed (0.50 m), that covers the floor slab of the box, to install two lines of verticals drains connected to the longitudinals pipe lines, that discharged in the pumping deposits, where the water dislodges to be used in the irrigation of gardens. (Fig.8)

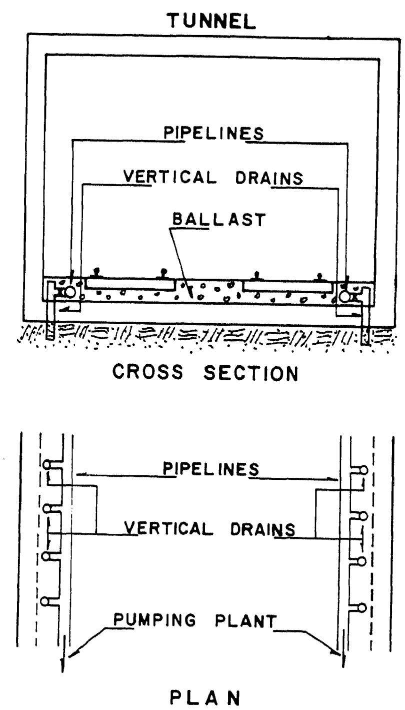


Fig. 8 Drainage System

The drain consists in a vertical perforation through the floor slab down to a depth of 1.0 m. In which is inserted a perforated steel galvanized pipe of 0.025 m, diameter and wrapped in geosynthetic to avoid the migration of solid particles as the prompt obstruction of the pipe.

To verify the kindness of the drainage system, tests, consisting in closing the system, were made and it caused that in less of 5 minutes the water started to penetrate through the structure cracks and orifices; after the valves were open, and the system was putting to work, approximately in 15 minutes the water stopped entering the box; the entrance water quantity to the system of the drains was of the order of 0.006 m^3/sec

After these proofs, with the drain system working, the complete box was impermeabilized, the joints cracks and orifices, etc. were sealed to preserve dry the interior of the tunnel, as to oblige the water to flow through the drainage system.

Unfortunately, because of economy and appearance motives the stabilization works of the surrounding fills to the tunnel were not made.

The tunnel has been functioned for four years and the operation of the urban electric train have not been interrupted (Fig.1) but there are problems that have been solved in the best possible way, as some settlements on the pavement of Calzada del Federalismo, due to displacements of the fillings that are being repaired with asphaltic mixture. Other situations were presented when the drainage system had to be suspended temporaly, due to failures in the pumping deposits, because water begins to flow inmediately to the interior of the box, as shown on Fig.9.

Fig. 9 Water Inflows Into the Access Ramp

CONCLUSIONS

Undoubtedly, the problem that have been presented, in this as in other cases, are due to projects supported on superficial studies that did not permit to detect unfavorable geohydraulics conditions.

Nevertheless, the obtained experiences in these works, permit now to obtain the necessary resources to realize more precise and complete studies that minimized the problems of the subterrain works that are in process, where there have been using for example, diaphragm walls of plastic concrete, impermeabilization groutings, massive use of geosynthetics, etc.

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