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"JET GROUTING" IN TUNNELLING : CONSOLIDATION IN THE "EL SILENCIO" MANOUVERING SECTION OF THE SECOND LINE CARACAS SUBWAY

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ABSTRACT

After a review on the jet grouting technology and Caracas subway, the arch lining underpinning carried out in a critical area of the tunnel in the "El Silencio" manouvering section of Line 2, is described. The geometrical layout of this intervention, the equipment employed, the different phases and main characteristics of the jet grouting implementation are also described, as well as the reults obtained.

INTRODUCTION

The construction of the Caracas subway has meant, among other achievements, a remarkable qualitative step forward for the Venezuelan engeneering practice when constituting a strong driving element acting as a constant encouraging factor on the country´s engeneering, facing it with the permanent challenge of dealing with and solving its non ordinary and always not simple problems. Obviously, as it always happens in such circumstances, experiences get frequently extrapolated, which causes them to leave their natural path thus later being applied to other enviroments to eventually belong to the technological patrimony of the engeneering community of the country.

A clear and precise example of what has been previously said is constituted by the "CCP" technology (jet grouting tecnology) introduced in Venezuela in 1979 aiming at the specific goal of solving a contingent problem related to the excavation of the Caracas subway´s twin tunnels in a section of Line 1.

It was a tecnology that besides being completely unknown in the country, was also new and still in its semiexperimental phase as it had only been introduced in the engeneering practice a few years before early in the seventies by a japanese company called konoike Construction Co. after its invention by Wataru Nakanishi and its later presentation to the scientific world by proffesor G. Miki of the University of Tokio (International Conference on Soil Mechanics and Foundation Engeneering in Moscow, 1973).

CCP stands for "Chemical Churning Pile" and represents a technique for ground consolidation which consits of projecting on the ground to be treated, by means of an inhector located at the rising end of a pipe and with a very high pressure, a stabilizing mixture in such a way that the ground and the mixture is stirred and mixed, resulting, once cementation is completed, in a constant column structure of very high mechanical characreristics.

Obviously, we are dealing with a new injection technique which, due to the peculiar capacity of disaggregation of the natural ground contemporarily mixing it with the injected fluid, allows the treatment of any kind of ground requiring mechanical improvement, thus avoiding the problems that come with penetrability related to granulometry of the ground and also preventing, on grounds of very heterogeneal composition, that the substance being injected following preferential paths thus ineficiently arranging on veins or layers.

Additionally, and opposed to traditional injection tecniques on grounds, with the jet grouting, thanks to its capacity to optimise the injection energy and guarantee uniform result on the sector treated producing a remarkable increase in the resistance of the shaft on the natural ground, condenser or reduced volumes of treatment can be effectively and selectively used oriented in space.

Right after the first application of jet grouting in Venezuela, in the works of the Caracas subway the examples have been spreading and diversifying along the two lines constructed so far, and its use has been widely forseen for the construction of the third line to be shortly started.

The sample of the use of jet grouting presented in this work is nevertheless of great interest as it constitutes the first application directly carried out in Venezuela from the under ground up, from the inner side of a partially excavated tunnel.

CARACAS AND ITS SUBWAY

Caracas is located in the homonymous valley, constituted by a long and narrow depression crossed from West to East by the Guaire river. Both extremes, Petare at the East and Catia at the West, are about 25 Km far from each other, its maximum width reaches scarcely 4 Km from North to South, and the average height of the valley is about 900 m above the sea level. The sea is at the North and it is separated from the valley by the imposing but narrow mountain chain called "Sierra del Avila", which elevates at 2640 m above sea level.

The valley was probably originated as an indirect consequence of an important fault system located, from East to West, in all the South side of the Avila. From it, a great number of seasonal torrents, that mold deep and narrow furrows, come down towards the South. Besides, there are many alluvial cones at the bottom of the mountain, some of them reach the valley mixing up gradually with the alluvial deposits of the Guaire.

At the South, the valley´s delimitation is less clear. There is a minor relief, from which sides affluents that cut their own alluvial sediments, drop towards the Guaire.

The rocks that constitute the reliefs of the region are pretertiary. They are exposed to an intensive thermodynamic metamorphism and transformed into micaceous, calcareous and graphitic schists and sometimes they are changed in gneiss and amphibolites. All the superficial and subsuperficial horizons show an intense influence of atmospheric phenomena on the soil, wich frequently causes the transformation of the original rock in a residual soil.

The mantle of lands that cover the valley mainly originates from adjacent reliefs and in less degree from the alluvial sedimentation that comes from the Guaire and its affluents. They are lenticular deposits generally discontinuos and extremely variable in the dimension of the components which can reach, in isolation, the decimeter dimensions. This is a direct consequence of the differences that exist in the transportation characteristics: length, load and pendent of the affluents.

In relation to the underground water, the general gradient follows the valley's pendent: West to East. But locally, it is capriciously modified by many circumstantial factors, that go from superficial and subsuperficial transversal waters coming from the mountain, to the existence of natural underground water reserves in bags, isolated by the intercalation of permeable and impermeable soils. Generally, there are underground waters rarely more than 10 m deep, and always variables with the seasons' wather.

Caracas subway projet was initiated in 1968 and its building started in 1972 in an elevated structure sector, and in 1976 the first tunnels were excavated.

The basic network of Caracas subway is formed by three main lines:

Line 1 goes from the East to the West of the valley, almost parallele to the Guaire river. It has 22 stations, in a lenght of more than 20 Km. It is completely built and in use. Approximately the 80% of the line is underground.

Line 2 goes from the South West to the center of city, where it joins with Line 1. It is less than 20 Km long and it has 13 stations. This line is also in use, and 30% of its is underground.

Line 3 which goes almost parallele to Line 2 and joins in the South with Line 1, will be about 20 km long and will have 14 stations. It is already projected and its building is starting. Approximately 70% of it will be underground.

As a whole, more than half of the underground lines are in twin tunnels of circular sections, with an internal radious of 2.63 m and an external one of 2.85 m. They were excavated by "shell" disposed for the continual assembling of the lining which is constituted by precasting segments of reinforced concrete. The tunnels average depth is about 15 m, varying from a minimum of 5-6 m, to a maximum of 25-30 m.

On the other hand, Line 2 is characterized by the fact that a large sector of the underground run, is in a double way tunnel, built with a partial section excavation in two phases and aproximately 2500 m long between the stations "Maternidad" and "El Silencio", including manouvering section in the North extreme of the line, after joining Line 1.

JET GROUTING TECHNOLOGY

The procedure, represented in fig.1, can be coprised as follows:

. A pipe of aproximately 50 mm in diameter is introduced on the ground up to the required depth.

. During this operation a valve that is openned and closed automatically by means of difference in pressure allows, from an injector axially located at the base of the pipe, the out flow of water under pressure coming from a pump, which helps the pipe penetration as happens in ordinary drilling tecniques.

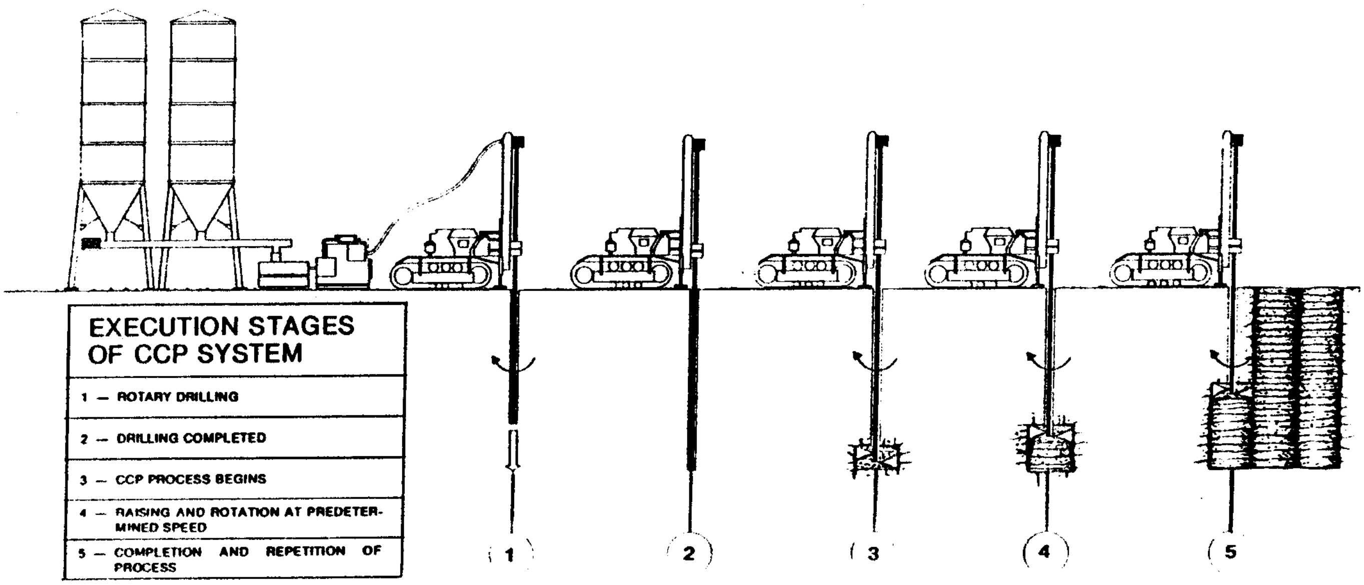

FIGURE 1

. After the complete penetration of the pipe, the stabilizing mixture is injected instead of water, from the same base of the pipe but in a direction perpendicularly to the axis, and under very high pressure and by means of special injectors.

. Due to the fact that the pipe rotates, this process of injection afects the whole surrounding and up to a radius that esentially depends on the ground conditions, injection pressure and nature of the mixture. Around this radius the original structure of the ground is destroyed and which is separated, stirred and intimately mixed with the substance injected.

. Finally, due to the fact that during the injection process, the pipe is gradually raised also, the treatment afects without an ongoing solution, higher levels thus a cohesive structure in the form of column being formed under ground around the drilling.

By repeating the indicated operations in several drillings and according to requirements, both an ongoing treatment by means of adyacent columns and eventually compenetrating each other, and also as an optional treatment for any required distribution can be carried out.

In normal applications the pressure of injection range is (250-350) Kg/cm², the diameter of the injector's tewels is (2-4) mm, the velocity of rotation is 20 revolution per minute, the elevation velocity is 15 cm per minute and the ammount of mixture injected is about 30 litres per minute of mixture water cement in a proportion of (0.5-1.0) to 1.

By means of the method above described, and according to the specific case, changing the several percentages in the stabilizing mixture and considering the nature of the ground a final product of (40-80) cm in diameter, average resistence to free preesure of (10-200) Kg/cm² (fig.2) and with a permeability coeeficient of (10^{-7}-10^{-9}) cm/s.

The column, aproximately cylindrical is formed from the bottom up due to the action of the jet of cement mixture injected from one or more holes in slow rotation and at extremely high pressure. The primary effect is the instant desgregation of the surrounding ground and the

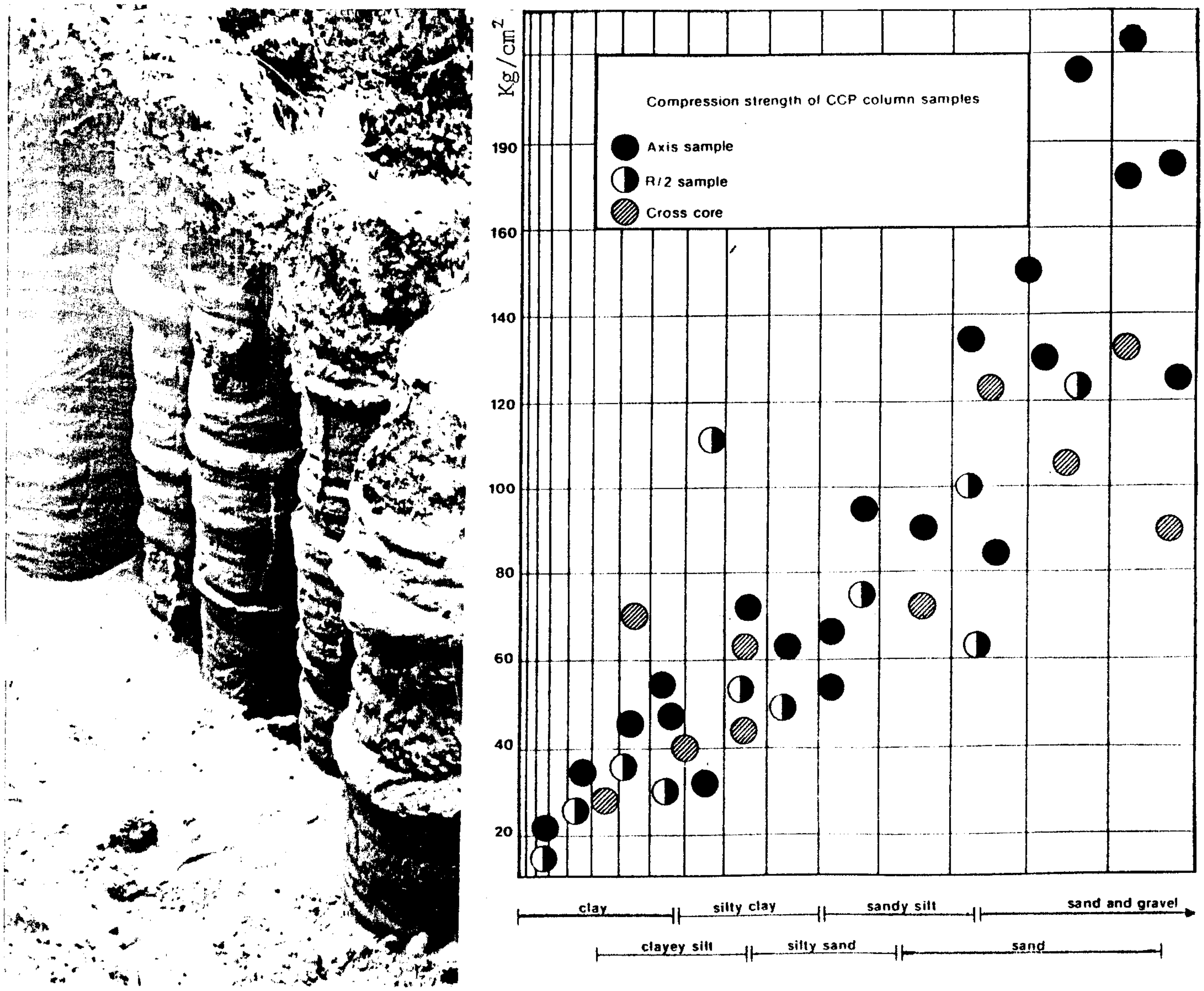

FIGURE 2

second effect is constituted by the intimate mixing of the particles of the desgregated ground with the cementing element injected.

One of the most interesting physical aspects of the techique described is the total exhaustion of the extremely high pressure of the jet being injected, within a limited radius at few centimeters, eliminating all possibilities of unwanted side effects on the grounds or adjacent structures.

Evidently the above can be explained by observing that despite the extremely high pressures of injection (over 400 Kg/cm²) along the drilling bar during the injection a reflux of the mixture is produced thus allowing for the total volume of the fluid that constitutes the nucleus of the CCP column in formation, to keep at hydrostatic pressure, except for the dynamic effect of the jet's impact strictly limited to the portion of the ground directely affected.

Additionally and exactly due to the previously mentioned concentrated dynamic action and limited to time adn space, a compression "claquage" effect is produced and dynamic densification that turns out to be of benefit as it produces a geomechanical improvement of the affected ground proportion which could spread to a radius of up to three times the diameter of the column itself.

On the other hand, the applications that forsee the constitution of adjacent and compenetrated columns, the result is surprisingly possitive in the sence that the continuation of the conforming structure, due to the "wall effect" with which if a jet is projected against a wall with enough force it is not reflected but it slides along the surface of the wall itself. Such an effect, when the jet is projected against a columnal body, makes the jet surround the cylindrical surface by an arc of over 180° before retreaving.

From the opperational and practical standpoint, the jet grouting technology as it has been described, includes three well defined and differenciated phases: drilling, injection and the eventual mounting of the column.

About the drilling,its diameter has been defined of two inches and its technology should be selected in every case, based on the nature of the ground to be drilled, and taking into account the specific requirimens for the application, as far as lengh and inclination is concerned.

The rotating drillig technique is recommended on ground with medium or fine granulometry because of the fact that in these cases light equipment and the use of a rotating header with a bolt pin chuck on a mast (4-5) m are enough, allowing them to operate with only one train of rods (16-18) m deep and with very high prodctions.

On grounds with thick granulometry and in the presence of rock blocks and large stones, the rotopercussion can turn out to be more convenient in terms of production and at times necessary, resulting in a need for heavier equipment making the use of trains with large rods impossible and finally with a productivity necessarily reduced.

As for the drilling geometry, for the case of verticals the reachable lengths are noticeable up to (30-40) m with ordinary equipment, while the possibility of inclination becomes strictly conditioned by the versatility of the equipment.

Ordinary equipment allow 45° inclination without major inconveniences, while for inclination closes to, more specialy prepared equipment must be used.

Drilling equipment of reduced dimensions are also ordinarily used which operate in reduced areas and even inside normal constructions, obviously at the expense of lower productivity in the layout of the works.

The injection, in ordinary applications, uses the same drilling equipment and its tecnlogical peculiarities are directly related to the acting high pressures.

As far as pomp systems and transmission of mixture is concerned it´s all related to sophisticated technology. The equipment is very large and is installed at due, and some times long, distances from the site where the drilling and injection takes place making the use of an efficient and very safe transmission hose system necesary.

Likewise, the system for preparation of the mixture must be of adequate technology to the high quality required by the product to be injected, in relation to the accuracy and constancy of the quantities of elements to be mixed, and also to the constancy, purity and physical quality of the injection product, which will finally be injected through holes of up to a minimun of 1 mm in diameter.

THE ARCH LINING UNDERPINNING

At the northern end of Line 2, to the north of the terminal station, the rail road is extended by a manouvering section of aproximately 200 m long.

The section of such an underground structure is that of double horseshoe way tunnel, and its excavation had been planned in two phases: first the top arch including its final lining, and then the remaining section with only one new casting to complete the lining.

Due to the relatively moderate depth, of about 40 m, and in consideration to the geotechnical nature of the ground in susch sector (alluvial soils: clay and clayey sand with gravel, over residual and weak roks: micaceous and calcareous schists), a consolidation of the ground from the surface, prior to the excavation had been forseen and carried out by means of silicate injections.

Such a treatment had systematically been applied with moderate results but eventually been accepted along a vast area of the same line simultaneously in the presence of tunnel in double horseshoe way with similar characteristics to that of the manouvering section and practically adyacent to the latter, from which it is separated by the structure of the "El Silencio" terminal station.

During the phase following the excavation of the top arch and construction of its final lining, when proceeding with the second phase of the excavation, important and non aceptable setting formations on the susface were observed, due to the excessive decrease in the arch lining at a range of (20-30) cm.

After evaluating different alternatives, within the techniques and economically possible, it was decided that jet grouting be used as foundation for the arch lining, prior to the second phase of the tunnel´s excavation.

Due to geometric limitations imposed by limited space available, the scheme represented in fig.3 was designed and specially small drilling machine, normally used to drill the inside of edifices in all structure layout operatios with stability under critical situation, was used.

The work was carried out with medium performance which generally reached a production of 20 m, for every daily shift of 10 hours, distributed in (6-7) columns.

The total section of the tunnel treated was 40 m long, and the total work was carried out in about 50 days, with a total of 850 m of jet grouting distributed in 300 coulumns, nearly.

The longitudinal separation between each point treated (6 columns) along the tunel´s axis, was about 1.5 m along the arch lining and on both sides of this.

The injection pressure was 350 Kg/cm², and the cement consumption was 4 bags of 42 Kg each every lineal meter of the jet grouting coulumn carried out with a resulting diameter of aproximately 50 cm, varying in more or less 20% according to the competence of the ground treated.

The excavation works for the whole section of the tunnel and casting of the remaining lining, were carried out after an interval of 30 days after the jet grouting treatment and the results obtained were very satisfactory as settings on the ground´s surface adyacent to the

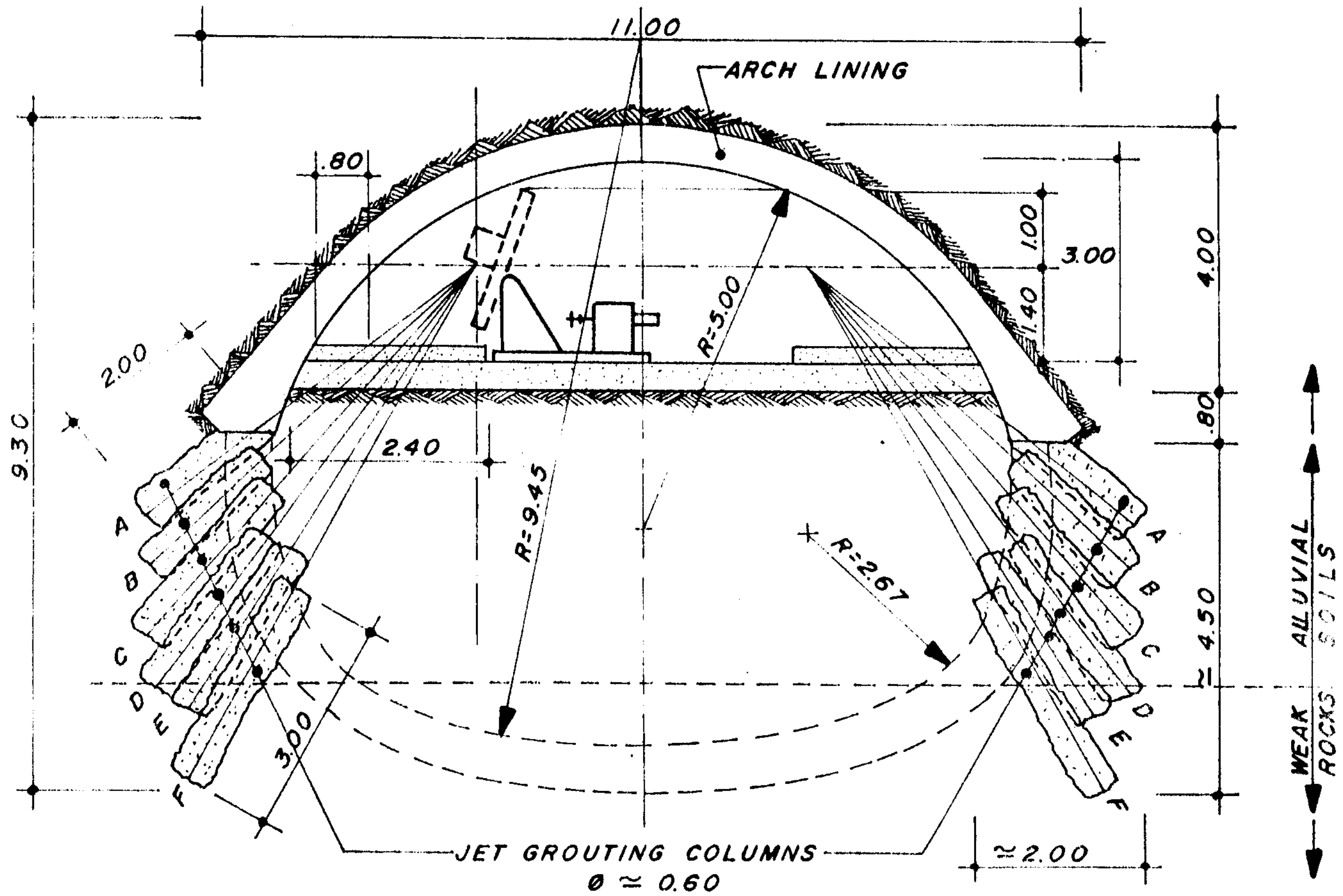

FIGURE 3

excavation were considerably reduced as a consequence of the sharp reduction of descent in underground of arch lining at moment of the excavations: the maximum value registerred do not surpase the 0.5 cm range.

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RESUMEN

Después de una panorámica sobre la tecnología Jet Grouting y el Metro de Caracas, se describe la intervención de subcimentación del arco de revestimiento de la Cola de Maniobras del Silencio de la Línea 2 del Metro de Caracas. En particular se describen los esquemas geométricos, los equipos empleados, las diferentes fases constructivas y las principales caracteristicas del Jet Grouting, asi como finalmente los resultados obtenidos.

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After a review on the jet grouting technology and Caracas subway, the arch lining underpinning carried out in a critical area of the tunnel in the "El Silencio" manouvering section of Line 2, is described. The geometrical layout of this intervention, the equipment employed, the different phases and main characteristics of the jet grouting implementation are also described, as well as the reults obtained.

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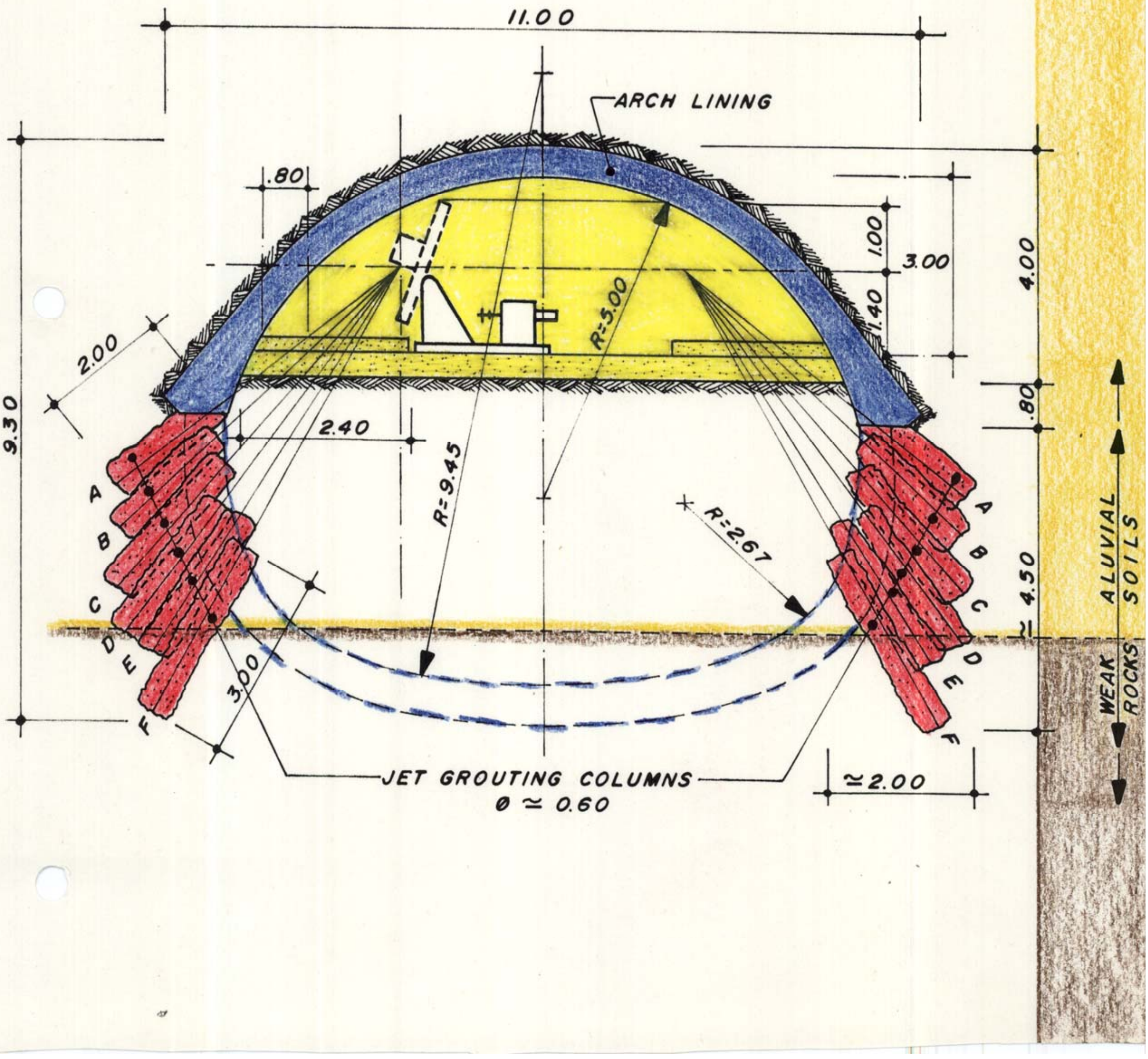

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