ISRM, International Symposium Eurock 93. Lisboa - Portugal, 21 al 24 Junio 1993

Analisys and prevention of the damages that could be causes by the future excavation of hydraulic tunnel very close to Caracas subway twin tunnels

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ABSTRACT: A numerical analysis by finite element model is carried out to optimize the design of a consolidation rock mass scheme to be ejecuted prior to excavate a hydraulic tunnel very close (1.5 m under) to the subway twin tunnels. The objetive of this rock treatement is to avoid the damages that could be cause due to asymetrical settlements of the lining subway tunnels. The rock mass treatment finally designed, allows to reduce from 1.5 cm to 0.5 cm the theoretical settlements calculated by numerical simulations.

At the present moment, two twin tunnels of aproximetly 6 m in diameter, along a kilometer of the Line III of the Metro of Caracas, are in final phase of construction. With the use of TBM, in a rock formation of schistose and metheorized rock mass.

The future development of the urban aqueduct anticipates the construction of a tunnel of 5 m in diameter (INOS tunnel) whose alignment will intercept, with a deviation of aproximately 40°, the twin tunnels under them atdistance of only 1.5 m.

Anticipating the possibility that such future excavation could affect the continuity of the transportation in the above tunnels, a numerical analysis was carried out to simulate the damaging effects of the future excavation and later, the beneficial effects of a possible improvement of the rock mass, prior to the new hydraulic tunnel construction.

Finally the analisys permits to optimize the design of the works to be executed prior to the beginning of the subway transit: by grouting to fill the joints of the rocks mass and consequently increase the global stiffness so as to reach acceptable figures of deformations that will develop with future excavations.

The excavations found at aproximatley 70 m depth in a rock mass of schistose graphitose and metheorized formation, hard and very jointed. The geomechanics parameters for the rock mass are: RQD = 15 % and RMR = 25; in consecuence it is posible to estimate by Bieniawski correlation:

$$E=10^{(RMR-10)/40}$$

a global deformational modulus of E=2500 MPa. This value has been confirmed by a plate load test carried out in a nearby rock formation with lithology, structure and general fisical state very similar to the mass in reference; and also by laboratory test where has been obtained a elastic modulus of El=30000 MPa for the intact rock (E/El=0.08).

The twin tunnels of the Caracas subway with a 6 m diameter and 11 m beetween each oter, has been excavated by TBM and lined with a prefabricated concrete rings of 22 cm in maximun thickeness and a

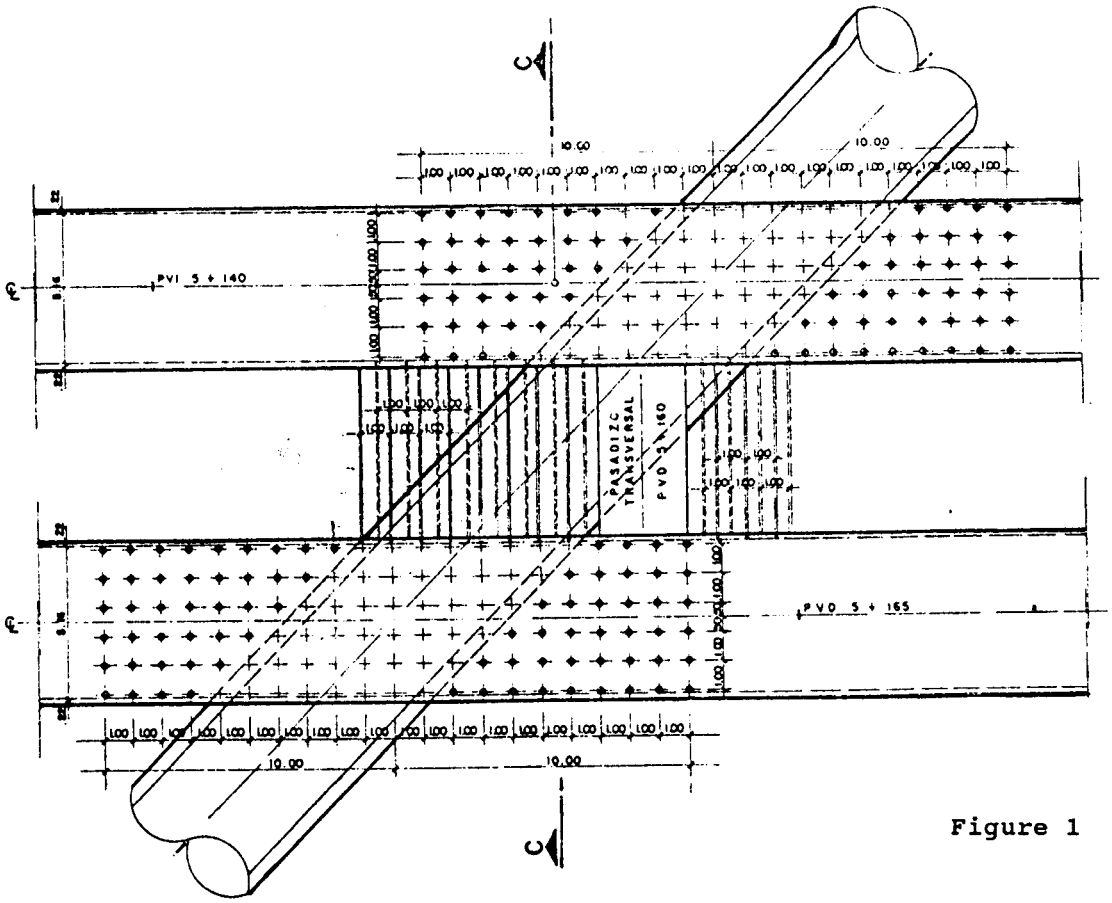

Figure 1

global deformation modulus of Er=32000 MPa. The INOS tunnel of aproximatly 5 m in diameter will be built with a minimun separation of 1.50 m from its ceilins and the bases of the subway tunneles, with an angle of intersection of aproximately 40° (figure 1).

The numerical simulation process was carried out with a plane model of ishoparametric quadrangular finite elements (372 nodules and 312 elements) simulating an elastoplastic behavior for rock mass and an elastic behavior for lining ring of the subway tunnels.

The finite element model was elaborated geometrically to allow the continues simulation of at least three relative positions INOS tunnel-subway tunnels, corresponding to equal numbers of excavation sections (element groups "25-36-47-60-77-98"; "128-129-146-159-172-189" y "210-220-241-258-271-298"), according to what can be observed in figure 2.

The above was achieved assigning null deformational parameters to the three groups of elements that in each case, represent the section of excavation of the INOS tunnel.

In such matter it is simulating the critical conditions corresponding to the construction stage in winch there in not support for that tunnel.

For each one of the three geometrical situations analized, the conditions corresponding to the rock mass without treatment were simulated, and later, conditions that include a consolidation tretament were simulated. Such a consolidation of the rock mass has the objetive of reducing the subway tunnels deformation as a consecuence of the INOS tunnel excavation by means of an adequated stiffness of the surrounding rock of the future excavation.

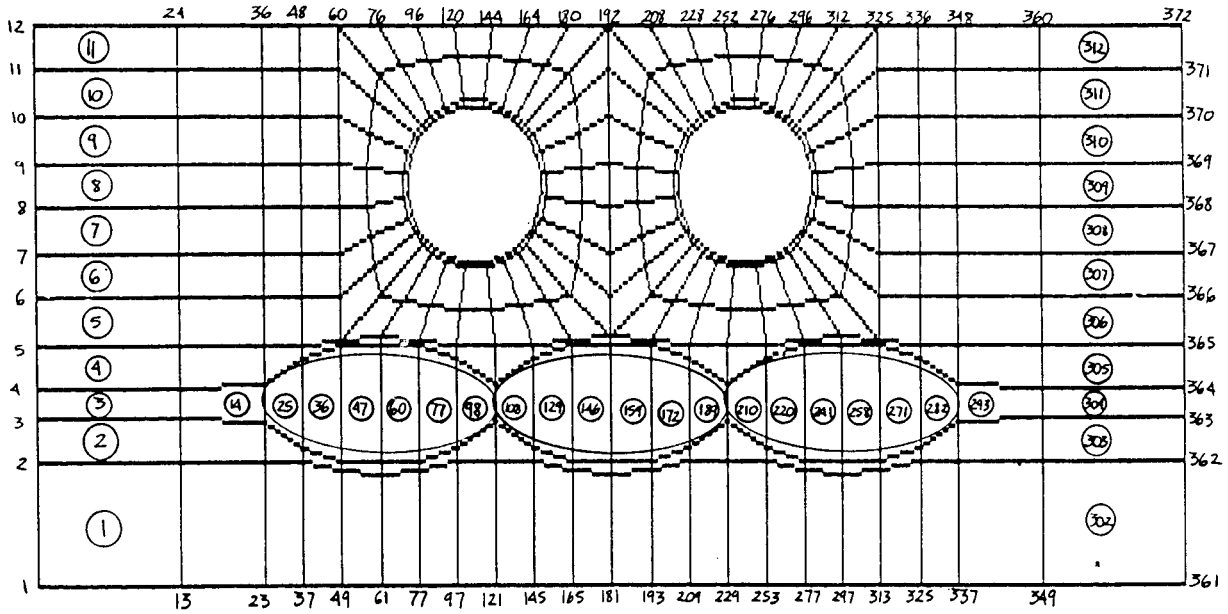

Figure 2

In the figure 3 the calculus models are indicated with the consolidated volumes of the rock mass for each one of the three relative geometries, analyzed simulating in the calculus a global deformation modulus of E'=18500 MPa (E'/El=0.62 equivalen to a RQD=85% and RMR=60) for the consolidated rock mass sector by means of a water-cement mixture injection (the diameters of the perforations are 9 cm and the inyection pressure is of 0.5 MPa according to the geometrical scheme of the figure 4, with a mean value of aproximatly 4 m of inyection perforations each m3 of treated rock mass).

It has been planned to prepar a test site to carry out in situ tests, and also it is planned to carry out laboratory tests with the purpouse of confirm the assigned values and, eventually to optimize the predesigned consolidation scheme until reaching the necessary rock mass stiffness.

The results of the numerical simulation indicate that, independently of the three relative geometric positions INOS tunnel-subway tunnels, and considering the rock in natural conditions (without consolidation), it is expected that the absolute settlements of the lining of the twin tunnels will take place of an aproximate 1.5 cm (figure 5).

Even though that magnitud of settlements will not affect in considerable way the lining structure of the twin tunnels because of the related angular distortions are minimal, that could affect in a more or less degree the functioning of the trains due to the settlments tend to be asymetrical in the subway tunnels.

The results obtened considering the new geomechanical conditions of the rock mass, product of its consolidation, indicate that the absolute settlements that will be produced in the lining of the twin tunnels, are of an aproximated magnitud of 0.50 cm, wich can be considered as minimal.

The above mentioned, indicate that the proposed consolidation scheme allows to guarantee that the INOS tunnel excavation can be executed without the rock deformation affecting apreciatively the subway

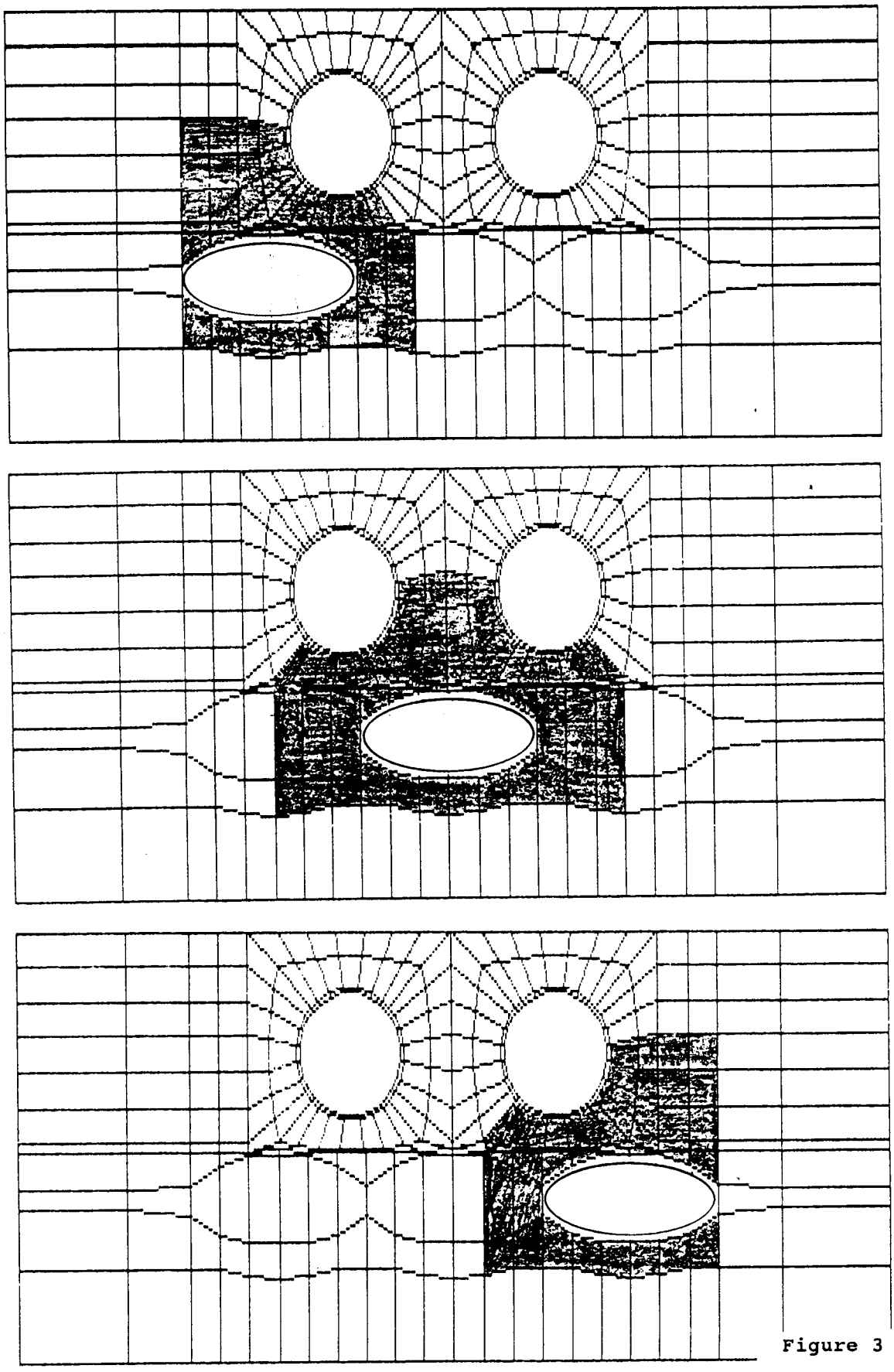

Figure 3

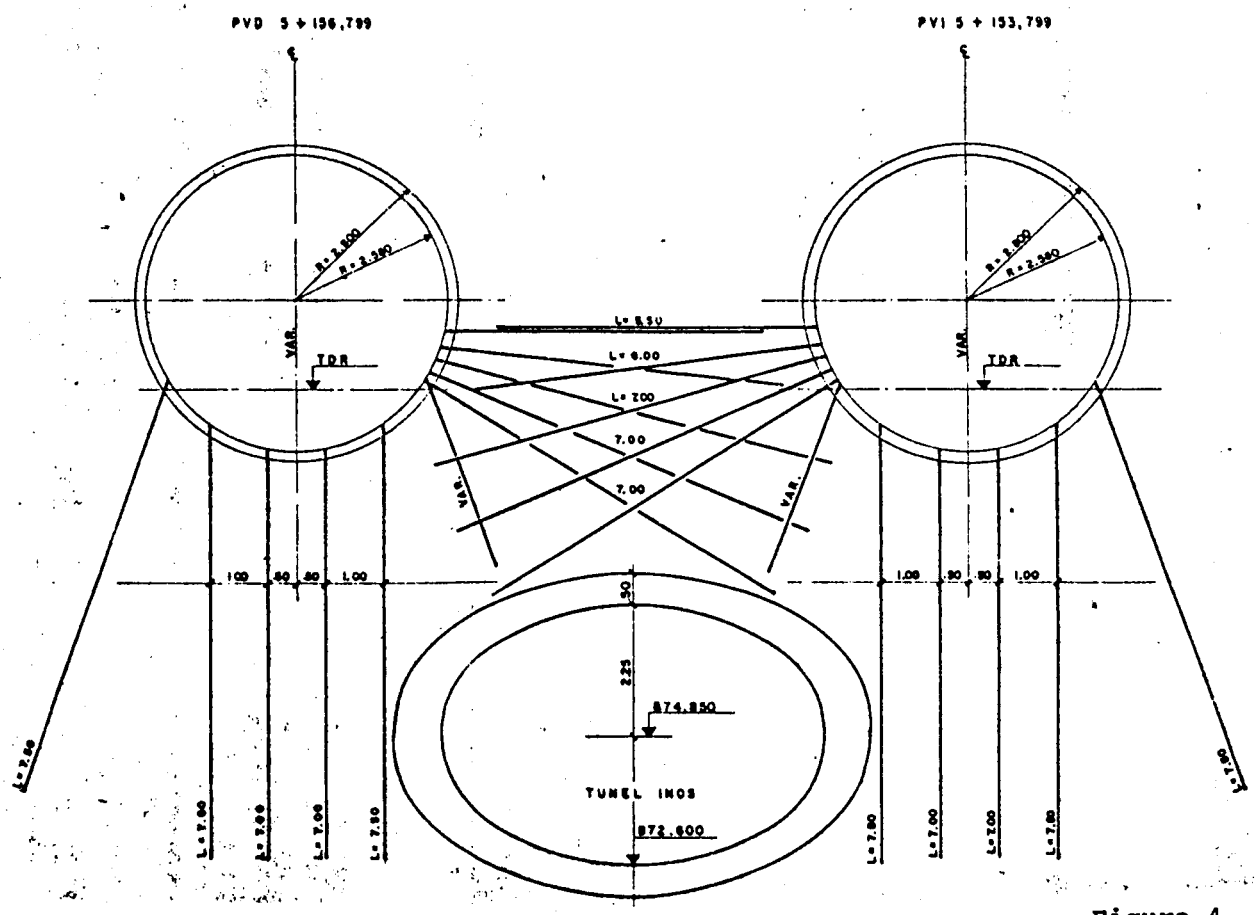

Figure 4

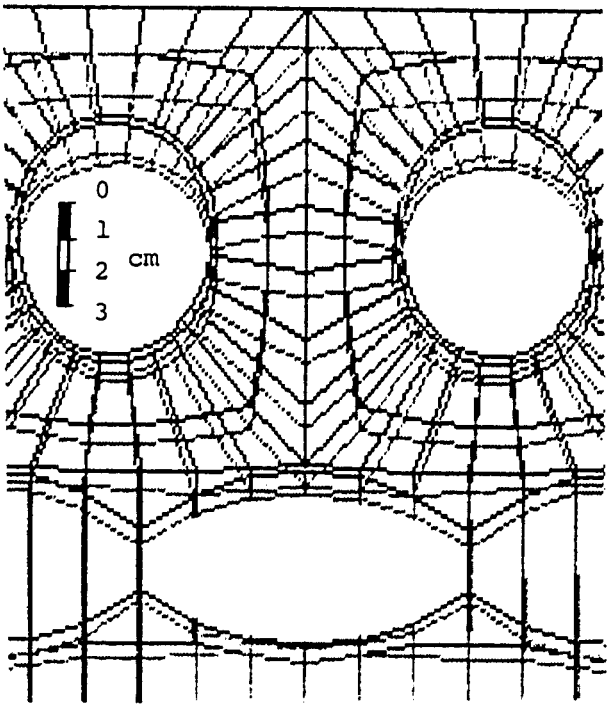

Figure 5

tunnels structure and the functioning of the trains.