IDENTIFICATION OF FRESSURES AND MAINTAINANCE IN RAILWAY TUNNELS

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1. INTRODUCTION

As is well known one of the most interesting matters which Railway Administration has to face is the maintainance of old tunnels. Generally, these were built under difficult conditions in places not always optimally chosen due to political decisions or to the stringent technical requirements of that transportation mode as well.

The control of liner's deformation has been until now the only manner to estimate the safety of the tunnel, and has been usually done in a random manner by personnel not always well qualified. This is especially dangerous in countries with a huge proportion of tunnels on their network.

On the other hand it is necessary to maintain the shape and dimensions of the opening to guarantee the undisturbed passage of the cars and, sometimes, of the special cargo transported by rail. As strength limits are generally broader than the functional ones it has been usual to try to control first the geometrical properties of the section and this is why several mechanical and optical devices were developed to establish the section's shape.

The enormous precision acquired with the development of laser-based experimental facilities and its combination with the powerful new digital computers suggests the use of geometrical measurements not only for the checking of shapes but as input to evaluate the stress state in the liner as well.

This paper describes the first move that our group has begun in that direction.

2. OUTLINE OF THE PLAN

As was said above the idea is to use the measurements of liner displacements as a means of analysing the stress state in it as well as in the surrounding media. If this can be fully achieved the procedure will provide a rational basis for analysing the consequences of reinforcements, anchor bolting, etc. which can be used to increment the working capacity of the tunnel.

2.1. Experimental facilities

The main tool to be used in a sistematic fashion is a railway-car specially designed to measure distances while forming part of the normal train. It has been described elsewhere (Diaz del Rio, 1982) and so we shall only cite its main features.

As a structure it is essentially a hollow beam of great stiffness supported in a truck which can be incorporated into a standard train. At one of its ends there is a laser focus which sends a ray to the liner and can analyse the distance with a computer facility which is placed at the other end of the beam. The ray sweeps around the section at a great speed and so it is possible to take a huge amount of data to adjust the shape of the section.

The computer set includes a mini-computer with several storing devices, plotter, etc. The main procedure is to take the data while the train is in motion and after reaching selected spots, to stop and study the results obtained in order to repeat the measurement or to continue with it. The personnel in the vehicle can, of course, make this study "on line" if this is needed because the chosen computer has enough capacity and speed to simultaneously fulfil several jobs.

The output of interest to us is a series of measurements of distances which, differing from previous ones, allows the computation of displacements during the time elapsed.

When the displacements show an increasing activity it is time to analyse what is happening in the liner structure and in the surrounding media.

2.2. Computational methods

The analysis of continuous media is routinely done at present using both powerful computers and new computational methods. The problem we are faced with has, nevertheless, two special characteristics: first it is generally a three-dimensional problem, although in some cases it can be reduced to a plane-strain case, and secondly it is nearly impossible to know fully the true stress-state in the media which subsumes the structure. The computational methods used to complement the experimental ones tried to face those two challenges.

2.2.1. Three-dimensional computer program

The routine tool used lately to analyse continuum problems is the finite element method (F.E.M.). Nevertheless its possibilities are greatly reduced in 3-D problems due to the huge amount of unknowns that it is necessary to manage. This is especially discouraging in our particular problem where the interesting results are confined to the soil-liner interface. This is why we have decided to use the technique known as Boundary Integral Equation Method (B.I.E.M.) or Boundary Element Method (B.E.M.). Only the discretization of the boundaries and interfaces is needed and so the dimensionality of the problem is reduced by one, that is, the elements are two-dimensional which reduces the discretization labour. The developed code has been described elsewhere (Doblaré and Alarcón, 1981) and includes the possibility of treating piecewise heterogeneous materials, anchor forces, gravity loads, etc. Presently it is limited to elastic media but a simpler code has been put to work for elastoplastic materials (García Benítez, 1982) and is currently being incorporated into the large one.

The main objective of that program is to analyse the stress-state in the soil media using geological and geotechnical results and the stresses at the liner-soil interface.

It is clear that this step is the most difficult and - generally a huge amount of work is necessary to reasonably adjust the "initial" state of stress in the media. This is where an efficient computational tool like the B.I.E.M. is essential to minimize the cost - of the parametric and repetitive analysis.

<u>2.2.2. Identification of pressures</u> The second difficulty, and certainly a key one, is the reliable determination of the pressures acting at the soil-structure interface. If they can be assessed with some - degree of accuracy the analysis of the liner can be done with precision and that of the media established based on the previously described method.

The most promising attempt at the moment is the method proposed by GIODA (Gioda and Jurina, 1981). The set of equations to establish is formed by the equilibrium equation and the usual constraints in the liner structure, plus any available data. In our case these are the displacements calculated as in article 2.1. as well as several stress measurements (see 3.3. below), or any other data that might be collected. The distribution of pressures is then discretized in the function of several selected values - which are the unknowns of the problem. As there are more equations than unknowns the minimization of an error norm, for instance, by a least squares method, allows the establishment of the set of equations to - be solved. There are several improvements that it - is possible to incorporate in the main ideas set out by GIODA in order to reduce the parameter sensitivity of his method, (of course the main one is sound engineering judgement)and to increase its effectiveness.

3. A CASE STUDY

We have recently had the opportunity of starting the study of a tunnel that shows hints of having undergone a process of increasing deformations. As was said before the first task is to analyse the actual stress-state and then by successive measurements to follow the history of these. What we can present at the moment is the first part of the study which has required a lot of "computational methods and experimental measurements" interaction.

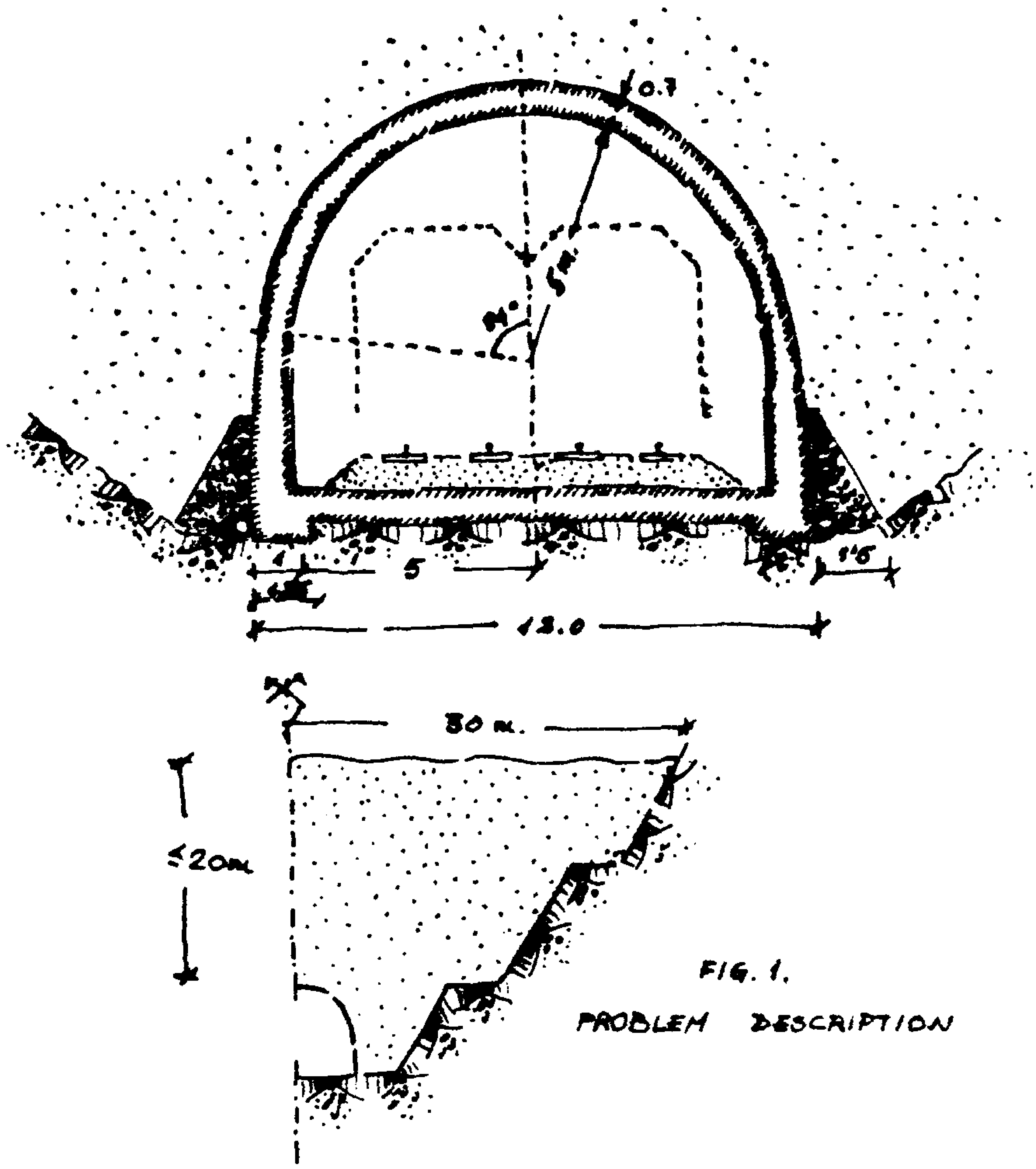


FIG. 1.
PROBLEM DESCRIPTION

3.1. Description of the problem

The tunnel is for a double-track line and was built in a "cut and cover" fashion. The general geometry is displayed in Fig.1. In Fig.1a the dimensions of the reinforced concrete liner can be seen, while in Fig.1b, we present the general arrangement of the trench excavated in the natural soil and the relative proportion between the tunnel-liner and the filling material. The height above the vault crown varies reaching nearly 20m. The natural soil is a kind of argillite offering values of the undrained shear strength of about 20 kg/cm^2 and a large effective angle of internal friction. There were also some hints of potential expansivity in spite of which the products of excavation were used to fill the trench.

In order to assess the order of magnitude of the

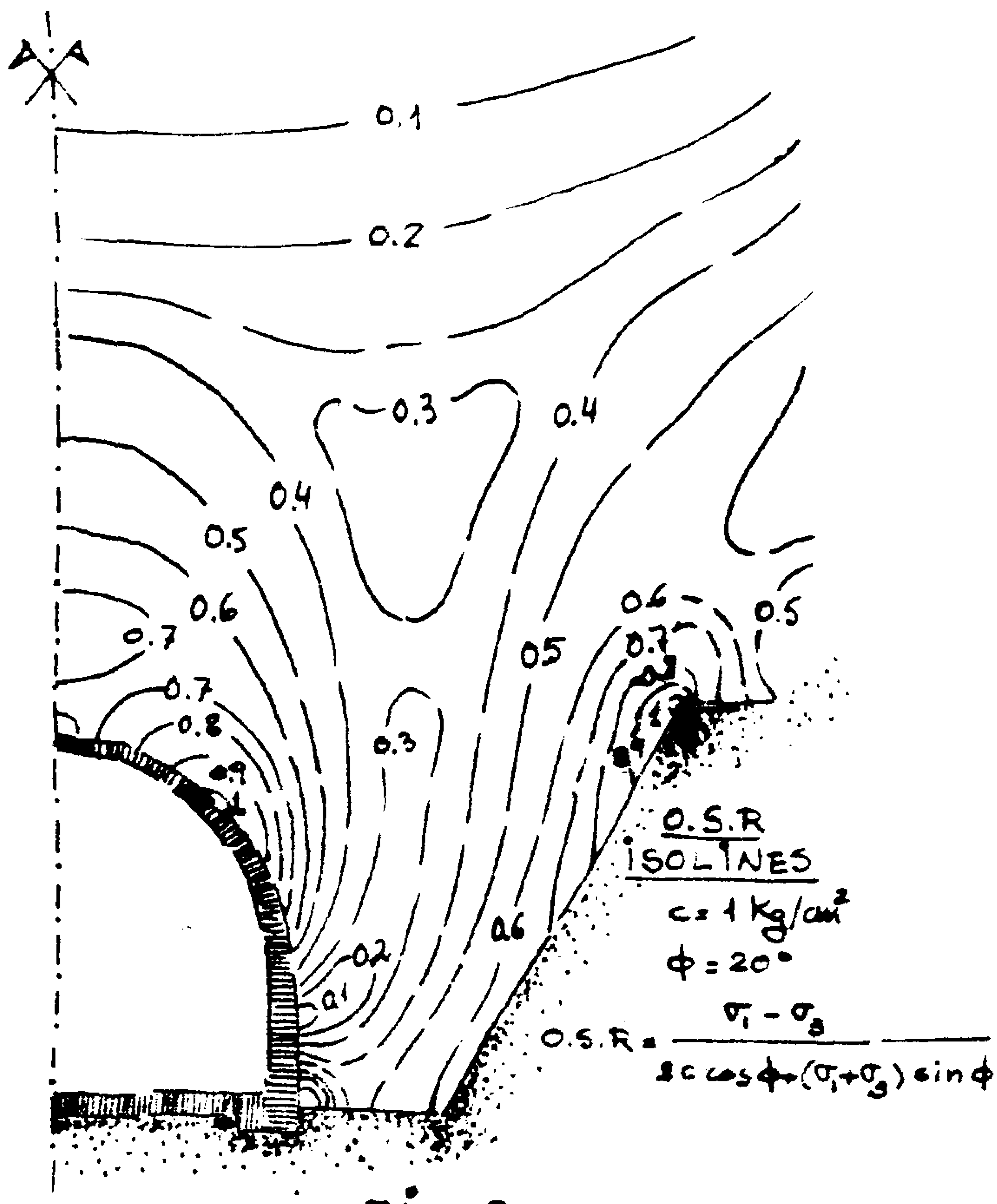
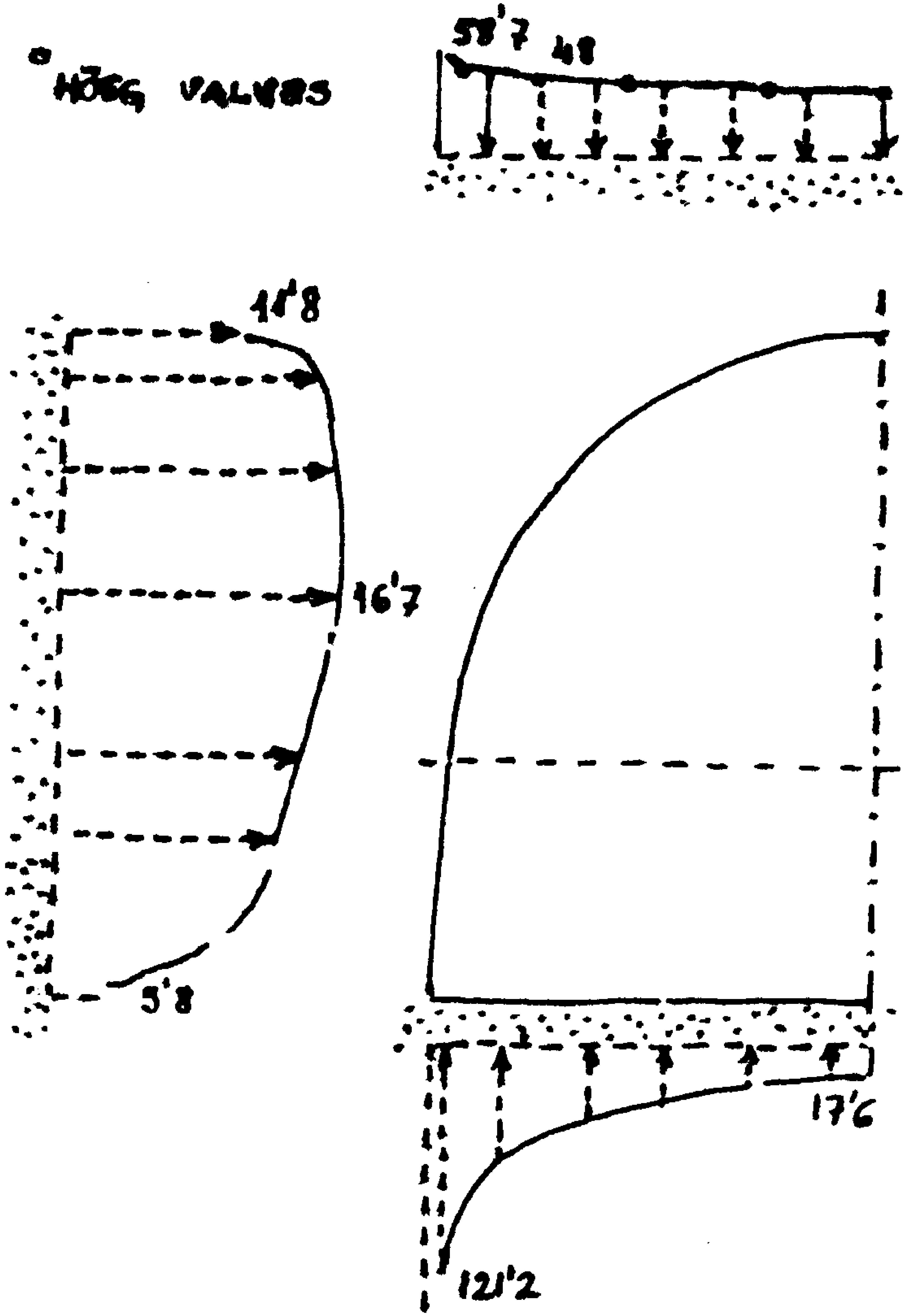
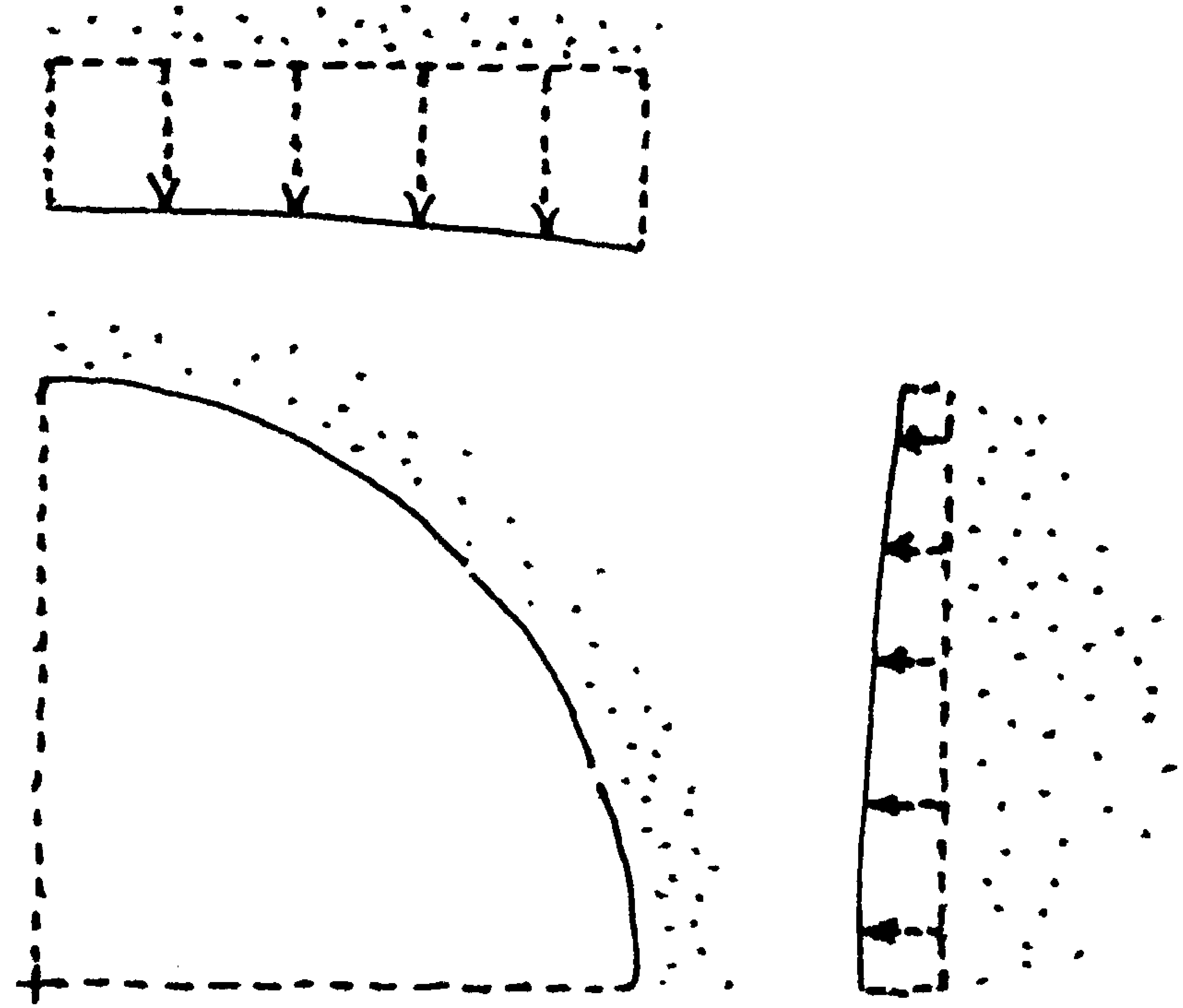


FIG. 2.

loads several studies were conducted. One of them was an F.E. analysis of the model which tried to establish whether or not the acting loads fitted the classical hypothesis for this class of problem. The analysis was done on the elastic range and with the "switch-on" of the self-weight after some tests for the significance of the representation of successive filling. Then the isolines of over-stress ratio (Naylor, 1981) were plotted (Fig.2). Values of OSR

° HÖEG VALUES





HÖEG FORMULA

FIG. 3

greater than 1 represent potential areas of plastification. As can be seen the rigidity of the structure is so great that there is a concentration of load on the vault and an arching effect on the vertical walls. For the indicated values of the angle of internal friction and cohesion it can be seen that the medium remains elastic everywhere and only in the midpoint of the vault and at the low end of the vertical wall there are stress concentrations. There are some high values of the O.S.R. near the sharp edge of the berms in the natural soil but this is clearly not a real situation and, in any case, it has no effect on the interface stresses.

To clarify the situation Fig.3 collects the pressure distribution on the interface. As can be seen the crown pressure is nearly 1.5 times the geostatic value, which agrees with the old rules of MARSTON. In Fig.3b we have also represented the results of Hoegh's formula (Hoegh, 1968) which show a remarkable agreement with our results.

3.2. Parametric studies

Once the numerical model was accepted several parametric studies were conducted varying the relative properties of natural and filling, the cover depth, the possible influence of the drainage etc. Fig.4 for instance represents the values taken by the ben-

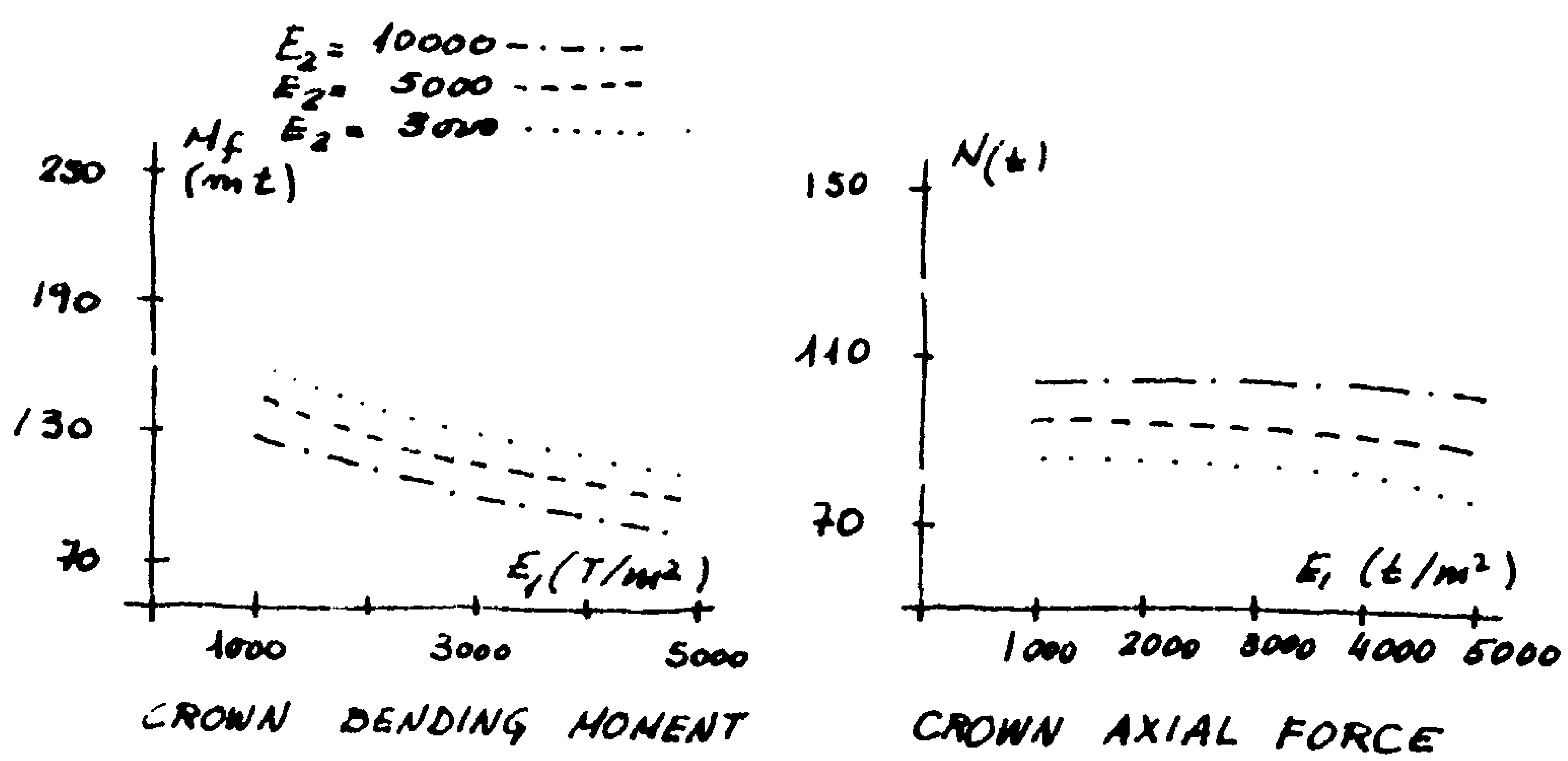


FIG. 4

ding moment and axial force in the crown for different YOUNG moduli of the natural soil (E2) and filling one (E3). Also interesting is Fig.5 where we compare the bending moment diagrams for two very different values of the YOUNG moduli in the natural soil. Here we can see the change in sign at the end of the mat which reflects the fact that the wall is much more "built-in" when the soil is harder.

3.3. Establishment of the actual situation: experiment versus theory

In order to establish the actual stress-state in the liner several measures were taken including measurements of displacements as well as measurements of

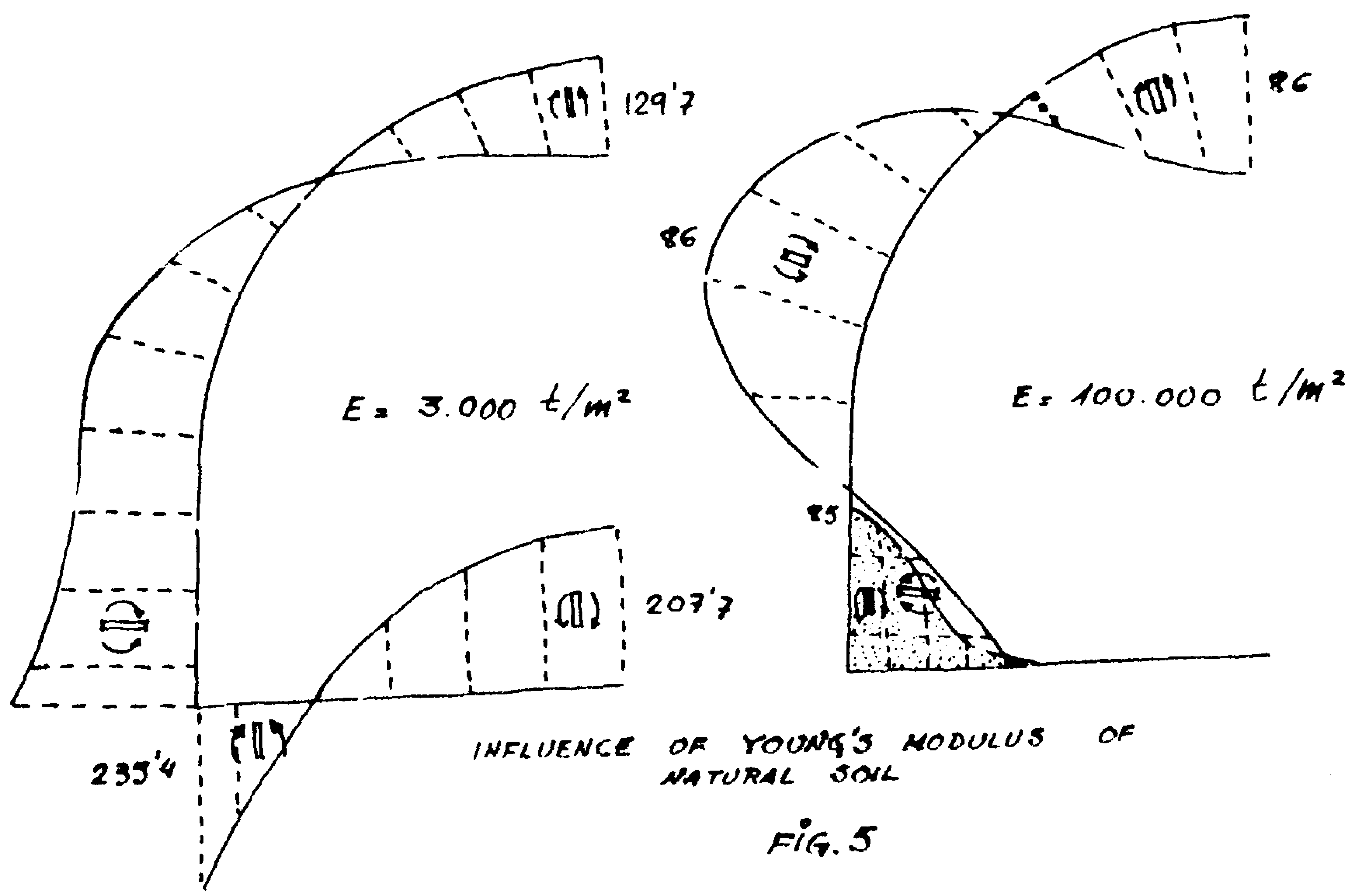


FIG. 5

the stress values in the reinforcement. These last ones were taken by cutting the reinforcement at selected places and looking at its contraction. The comparison of measured deflections and stresses with the computed ones (see previous article) served to fix the parameters of the problem. For instance, in Fig.6 we present the evolution of several interesting quantities with YOUNG's modulus of the natural soil. The most sensitive parameter is the ben-

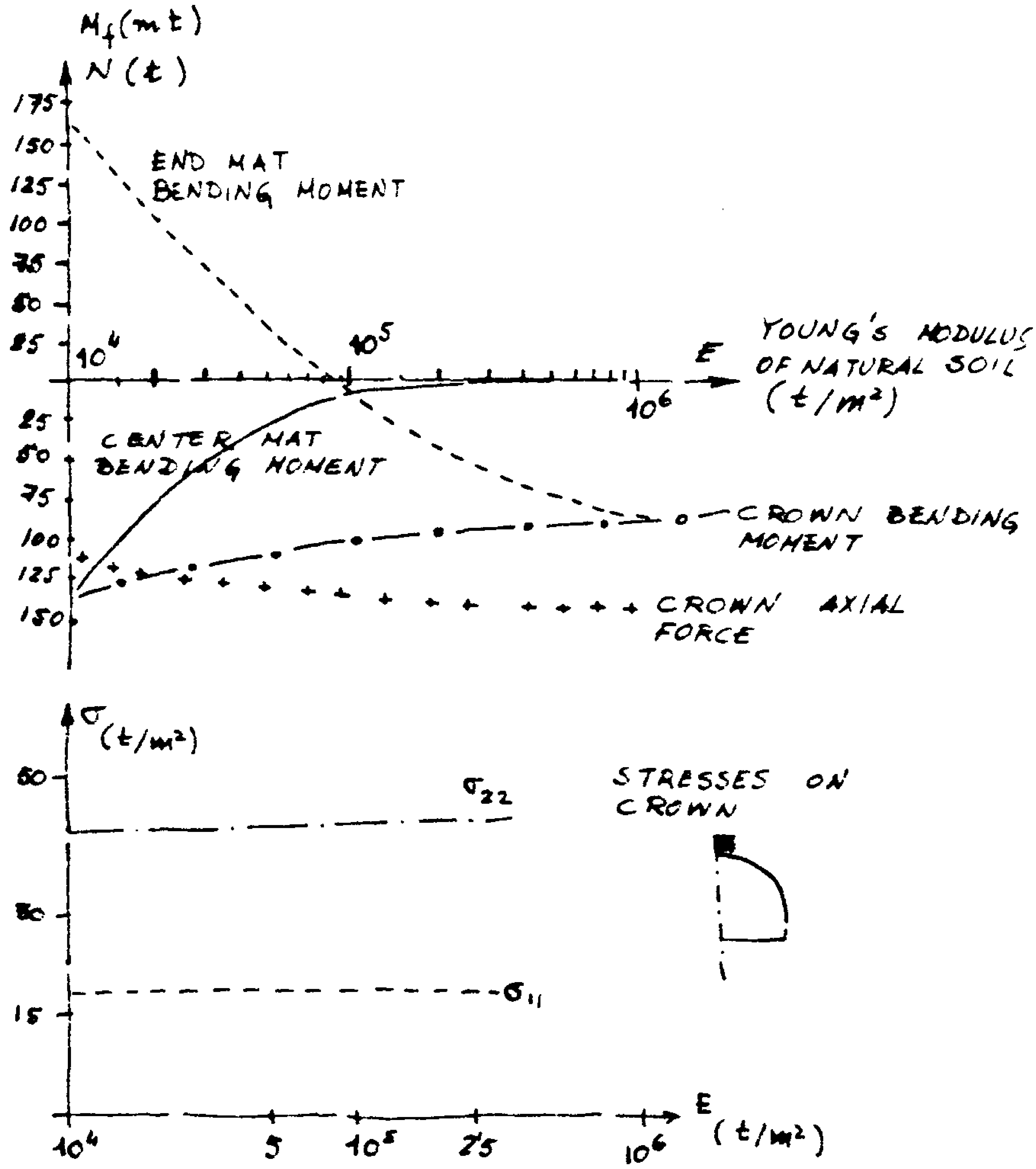


FIG. 6

ding moment at the end of the mat foundation. So by comparing the stress in the reinforcement at several tunnel sections it is possible to adjust this one. As can be seen the interface pressures are not affected much by this value and the increasing stiffness shown by Fig.5 is due to the contribution of the soil.

3.4. Future work

With the initial stress state fixed, it is possible to start the maintainance plan, A continuous surveying with the special car described in 2.1. will allow the computation of the stresses at regular time intervals and to at least assess the order of magnitude of the factor of safety in the tunnel.

4. CONCLUSIONS

In the above lines we have broadly described an interactive set of tools used to determine the safety of tunnels and to provide data for the decision making of its maintainance. Although, no doubt, there are still several drawbacks in the difficult procedures in use it is clear that the way is promising and future improvements both in experimental and analytical methods will increase our understanding of this matter.

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