THE DETERMINATION OF THE TRANSMISSIVITY OF COASTAL AQUIFERS BASED ON THE OBSERVATION OF SINUSOIDAL, ONDULATORY, TRANSITORY REGIMES INDUCED BY TIDAL OSCILLATIONS

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ABSTRACT : It is not infrequent to find that work to be carried out in harbours and shipyards demands large-scale excavation in dry conditions below sea level. The pumping operations required in the course of the execution or development of the work often dictate the nature of the constructional process and its typology. In this paper, an attempt is made to develop a method for ascertaining the transmissivity of the terrain affected by the excavation, on the basis of the damping effects or time-lag with which the oscillation of the tide is transmitted through the filtering media. This method, which was initially developped by FERRIS for one-way propagation in homogeneous terrain, is here extended to cover more frequent, irregular situations where such propagation is bi-directional.

RESUME : Les chantiers qui sont réalisés dans les ports et les arsenaux, exigent fréquemment l'exécution de grandes excavations à sec, au-dessous du niveau de l'eau. Les épuisements nécessaires en phase d'exécution ou d'exploitation du chantier conditionnent fréquemment le processus constructif ou même la typologie de celui-ci. Dans cette communication on développe une méthode pour estimer la transmissivité des terrains, affectés par l'excavation, à partir de l'adoucissement et du retard avec lesquels l'oscillation de la marée se transmet à travers un milieu filtrant. Cette méthode, développée par FERRIS pour la propagation à une direction en terrain homogène, s'étend aux cas plus fréquents d'irrégularités, et de propagation à double direction.

RESUMEN : Las obras que se realizan en puertos y astilleros precisan, con frecuencia, la ejecución de grandes excavaciones en seco, bajo el nivel del mar. Los agotamientos precisos, en fase de ejecución o explotación de la obra, condicionan frecuentemente el proceso constructivo o incluso la tipología de la misma. En la comunicación se desarrolla un método para estimar la transmisividad de los terrenos, afectados por la excavación, en base a la amortiguación y al desfase con que la oscilación de la marea se transmite a través de un medio filtrante. Este método, desarrollado por FERRIS para propagación unidireccional en terreno homogéneo, se extiende a los casos más frecuentes de irregularidades, y a propagación bidireccional.

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1. Introduction

In relation with harbour works, ship building and repair facilities, it is frequent to be confronted with the problems arising from the - need to dewater excavations at depths of up to 15 m. below sea-level.

This occurs in the case of large-sized dry docks. Here, the dewatering operations during the execution of the work and remaining water flows during actual exploitation, if the dry dock is of a "drained" type, may constitute one of the fundamental conditioning factors when selecting the structural typology of the work and the methods of construction. Before such problems can be solved, the transmissivity of - the terrain affected by the excavation work must be known with the -- greatest possible degree of accuracy.

We were faced with a particularly difficult case of this type when - making and analysis of the problems which might arise during the construction and maintenance of the dry dock for ship repairs which Diatlansa intends establishing on the island of Tenerife. This involved - the performance of large-scale excavation works in volcanic terrain - lying along the Atlantic coast, where the soil consisted of a layer - of highly pervious slag lying on top of a relatively impervious basaltic "coulée".

In pervious soils, the oscillations produced by the ocean waves are - transmitted inland to a considerable distance, with the resultant damping effects and time-lag which are a function of the hydrogeological characteristics of the terrain involved.

Consequently, it was felt that a quick, economical way of estimating these parameters might be to analyse the oscillations of the water table level in a grid of borings which had been carried out in the area for the geological investigations. For interpreting the results obtained, we resorted initially to the method developed by FERRIS in 1941. But the limitations of this method, soon became quite clear, since it refers exclusively to the unidirectional propagation of a pure sinusoidal wave in homogeneous, isotropic, indefinite terrain.

This paper is a summary of the principal results of the studies which, taking the original idea as their point of departure, were carried out in an attempt to find solutions for the greatest possible number of - practical cases. It should be pointed out that other methods must even tually be employed in order to estimate the effective porosity of the terrain over a period equal to the half-life of the tidal wave.

2. Working hypotheses and the range of application of the study

Apart from those mentioned specifically in each section, the following are some of the more general hypotheses adopted for this work:

- Newtonian fluid.
- The absence of incoming flows of water from the terrain.
- The absence of surface recharge.
- An aquifer of homogeneous thickness and a horizontal bottom.
- No account is taken of phenomena such as evapo-transpiration, capillarity or the effects of air dillution in the water.

Furthermore, in order to be able to apply the Dupuit approach, which is indispensable for the validation of the results, it is vital that the extension of the aquifer be at least twice its thickness. Moreover, if the flow is to be laminar, the thickness of the aquifer must be at least four times the amplitude of the tidal oscillation (if the transmissivity is less than 2,000 m2/hour, the effective porosity is 30% and the average diameter of the grains is 1 cm.)Lesser thicknesses may be tolerated for smaller values of these characteristics.

3. Unidirectional

3.1. General equation

Bearing in mind the Dupuit approximation and the fact that the free - surface is sufficiently flat, if the thickness of the aquifer is relatively large with respect to the oscillation, then the equation representing movement may be written as follows:

$$\frac{\partial^2 h}{\partial x^2} = \frac{n}{c} \frac{\partial h}{\partial t}$$

where:

c is the transmissivity of the aquifer.
h is the height of the free surface or the piezometric head, as the case may be.
n is the effective porosity.

This equation is really exact in the case of an artesian aquifer, and is sufficiently close in the case of a water table whose only variations are the result of tidal oscillations.

For x = O (with, pure sine oscillation on the coast), the general - boundary condition will be:

$$H = H_o \sin \frac{2\pi t}{T}$$

where H_o is the semi-amplitude of the tidal oscillation and T is its duration. Further on, an analysis will be made of the influence of - the fact that such oscillations may not be purely sinoidal.

3.2. Homogeneous, indefinite aquifer

In the case investigated by FERRIS, the following is the equation - which here defines the oscillation of the water at a point at distance x from the coast:

$$h = H_o \ e^{-x\sqrt{\frac{\pi n}{TC}}} \ \sin \left(\frac{2\pi t}{T} - x\sqrt{\frac{\pi n}{TC}}\right)$$

The damping coefficient (that is, the ratio between the semi-amplitude of the oscillation of the water at that point, h_o, and that of - the oscillation of the sea) would be:

$$\frac{h_o}{H_o} = e^{-x\sqrt{\frac{\pi n}{TC}}}$$

and the value of the time-lag in hours, t_α, between the oscillation at that point and that of the sea, would be:

$$t_\alpha = \frac{x}{2}\sqrt{\frac{T}{\pi C}}$$

Figure 1 shows the values of the damping coefficiente (more easily - observed that those of the time-lag) for n = O.1, T = 12.67 hours - and different values of C. It should be stressed that the curves are valid as long as the value $\frac{n}{TC}$ remains unchanged.

UNLIMITED HOMOGENEOUS AQUIFER: DAMPIG OF THE TIDAL WAVE

n = 0.1

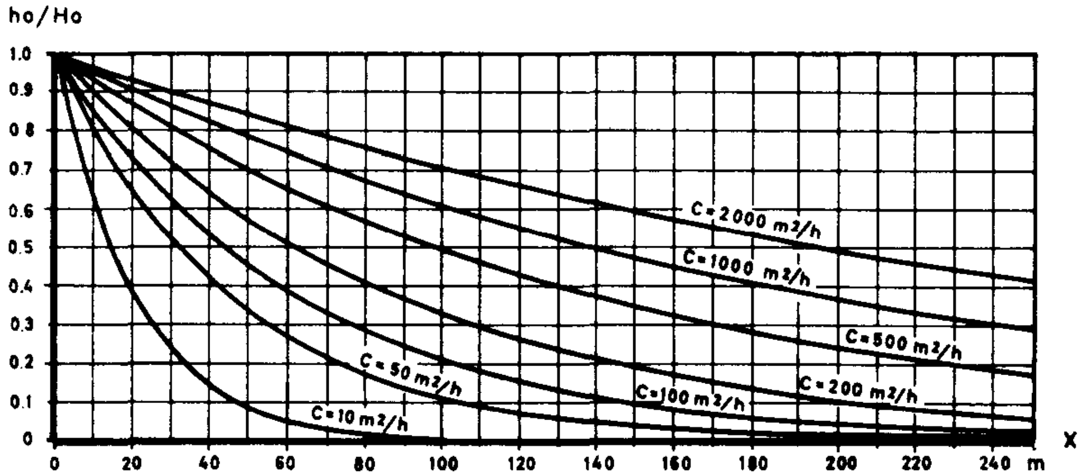

Fig. 1

3.3. <u>An aquifer formed by two consecutive homogeneous media</u>

This is the case when the terrain reveals certain n_1 and c_1 characteristics up to a distance L from the coast, and other different n_2 and c_2 characteristcs theareafter. Two different approaches may be used - to analyse such a system:

a) The approximate method. Il is assumed that the oscillations in the first medium are not affected by the existence of the second, and that, in this latter medium, the movements are as if this imaginary boundary were actually a coastline, where the damping effects - and time-lag of the tide were the result of their transmission -- through the first. In these conditions, the damping coefficiente - would be:

In the first medium : $$\frac{h_{10}}{H_o} = e^{-x\sqrt{\frac{\pi n_1}{TC_1}}}$$

In the second medium : $$\frac{h_{20}}{H_o} = e^{-L\left(\sqrt{\frac{\pi n_1}{TC_1}}-\sqrt{\frac{\pi n_2}{TC_2}}\right)-x\sqrt{\frac{\pi n_2}{TC_2}}}$$

where the origin of the coordinates is the coast.

b) The exact method. The differential equations for both media are integrated, with their respective boundary conditions and flow continuity condition at the boundary. Calling $u_1 = x\sqrt{\frac{\pi n_1}{TC_1}}$, $u_2 = x\sqrt{\frac{\pi n_2}{TC_2}}$,

$p = L\sqrt{\frac{\pi n_1}{TC_1}}$ and $\nu = \sqrt{\frac{c_1\, n_1}{c_2\, n_2}}$, and adopting the boundary line as the origin of the coordinates for both media, the damping coefficient has the following values:

In the first medium: $\frac{h_{10}}{H_o} = \sqrt{\frac{\sin^2 u_1(\nu \operatorname{Sh} u_1 + \operatorname{Ch} u_1)^2 + \cos^2 u_1(\operatorname{Sh} u_1 + \nu \operatorname{Ch} u_1)^2}{\sin^2 p(\nu \operatorname{Sh} p + \operatorname{Ch} p)^2 + \cos^2 p(\operatorname{Sh} p + \nu \operatorname{Ch} p)^2}}$

In the second medium: $\frac{h_{20}}{H_o} = \frac{\nu}{\sqrt{\sin^2 p(\nu \operatorname{Sh} p + \operatorname{Ch} p)^2 + \cos^2 p(\operatorname{Sh} p + \nu \operatorname{Ch} p)^2}}\, e^{-u_2}$

Figure 2 is a graphical representation of these coefficients, where a comparison is drawn between the two ways of solving the problem for $\mu_1 = \sqrt{\frac{\pi n_1}{TC_1}} = 0.0035\ m^{-1}$ and $\mu_2 = \sqrt{\frac{\pi n_2}{TC_2}} = 0.0100\ m^{-1}$ (and $\mu_1 = 0.0100\ m^{-1}$ and $\mu_2 = 0.0035\ m^{-1}$, in the inverse case). The distances from the boundary to the coast are 20;40 and 100 m.

AQUIFER CONSISTING OF TWO HOMOGENEOUS ZONES: WAVE DAMPING

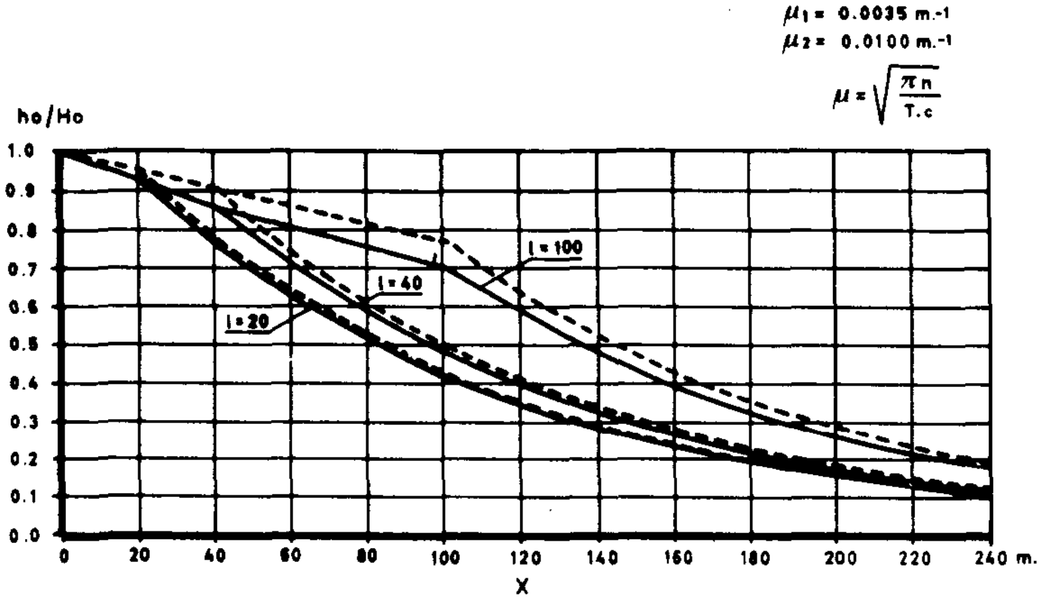

Fig 2 —— APROXIMATIVE SOLUTION
----- EXACT SOLUTION
l = DISTANCE FROM SEA TO BOUNDARY

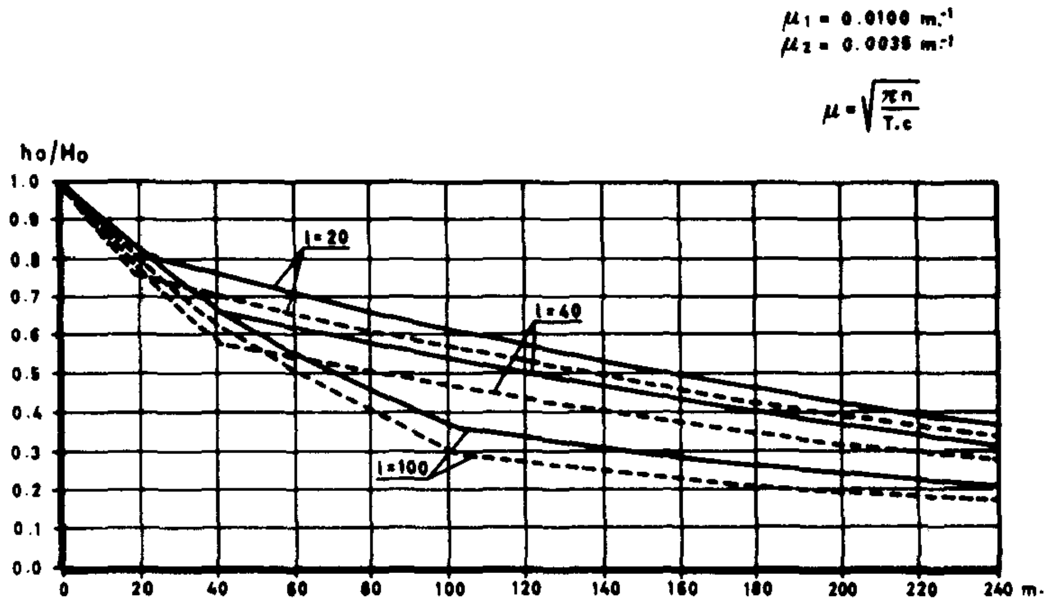

Fig. 2'

The approximate method, which is simpler and quicker, may be used in a first analysis if the following is the case:

- The observation point is not near the boundary.
- The diffusivity $\frac{C_1}{n_1}$ of the first medium is greater than that of the second.
- The value of $P < 0.2$

3.4. <u>The case of preferential ways</u>

This is the case when, in a homogeneous medium, there is a path whose conditions are much more favourable for the passage of water. It may be analysed in an approximate manner, by assimilating it to the case mentioned above (see Figure 3), provided that:

- The distance, d, from the analysed point to the preferential path is much shorter than the distance D from this point to the coast.

- The dimensions of this path are such that they do not impose any important restriction on the expected flow.

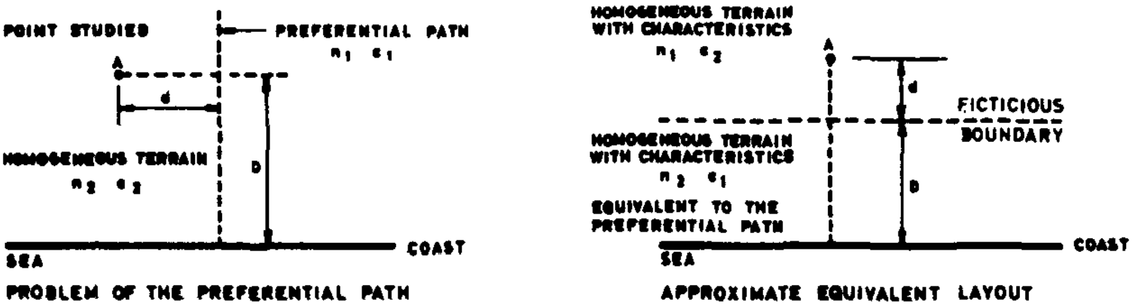

Fig. 3

Consequently, if the characteristics of the media are known, it is possible to deduce the distance d from this point to any preferential path, as is shown in Figure 4 for two cases of D, μ_2.

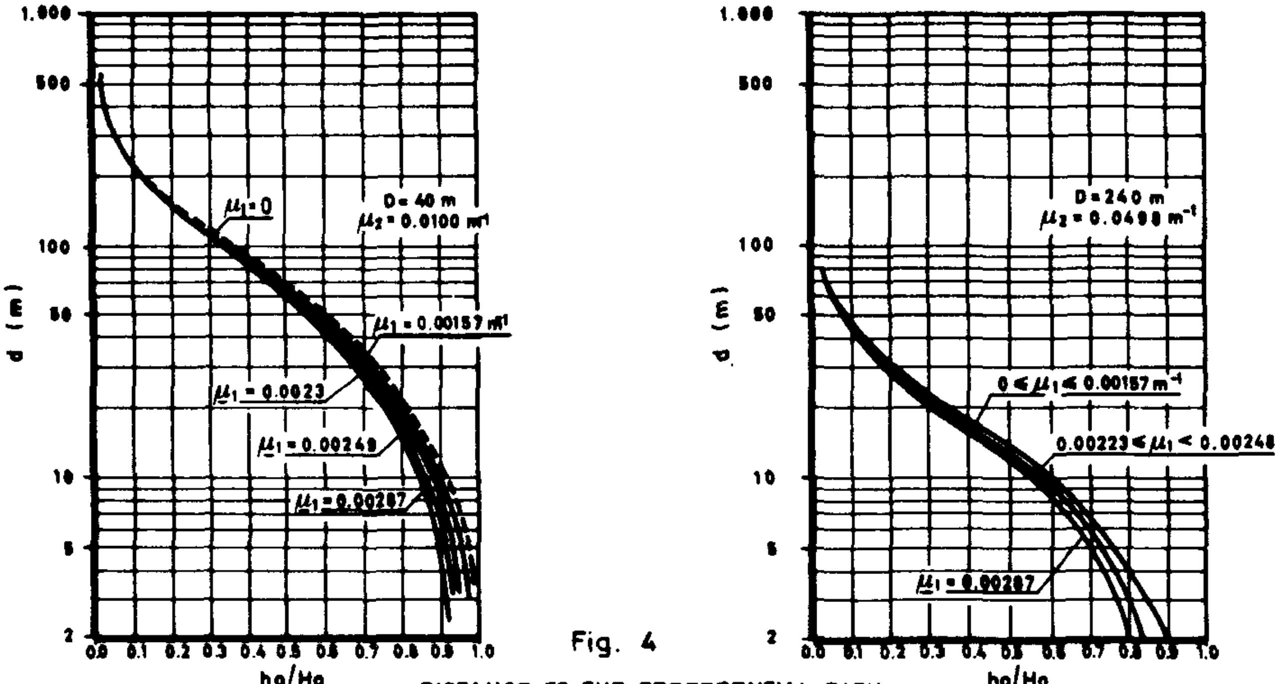

Fig. 4

DISTANCE TO THE PREFERENTIAL PATH

As will be observed, the characteristics of a preferential way - provided that the diffusivity is very high - are of little importance and the damping effects at any one point tend to be similar to those which would be present if the preferential path were a coastline.

3.5. An aquifer limited by an impervious barrier

This is the case of an aquifer which is limited by an impervious barrier at a distance L from the coast. The linear nature of the differential equation makes it possible to use the image method to satisfy the boundary cobdition which the existence of the barrier represents, since the movement of the water will be the same as if, at a distance of 2L, there were another imaginary coast with synchronous oscillation. Consequently, this solution may also be applied in the case of an isthmus.

So, taking this barrier as the origin, it appears that the damping coefficient will be:

$$\frac{h_o}{H_o} = \sqrt{\frac{\cos 2u + Ch\,2u}{\cos 2p + Ch\,2p}}$$

and the angular displacement will be:

$$\alpha = \arctan \frac{\tan p\ th\ p - \tan u\ th\ u}{1 + \tan p\ th\ u\ \tan p\ th\ p}$$

Figure 5 represents both functions for different values of $\mu = \sqrt{\frac{\pi n}{TC}}$ and L = 50 m.

HOMOGENEOUS AQUIFER LIMITED BY AN IMPERVIOUS BARRIER
BARRIER AT 50 m.

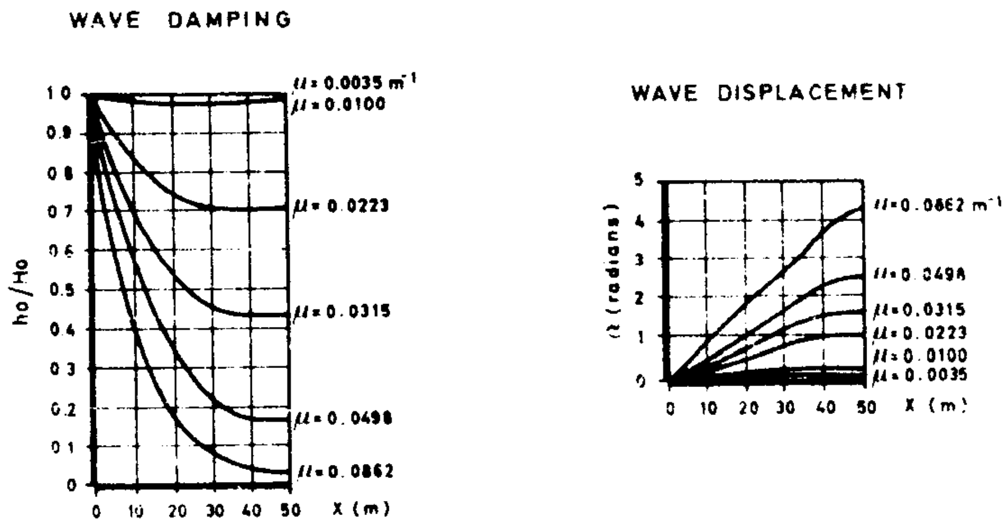

Fig 5

In order to know the extent to which the existence of a barrier affects the results, Figure 6 shows cases without any barrier, or with one at a distance of 250 m.

COMPARISON BETWEEN THE DAMPING COEFFICIENTS OBTAINED WITH OR WITHOUT AN IMPERVIOUS BARRIER

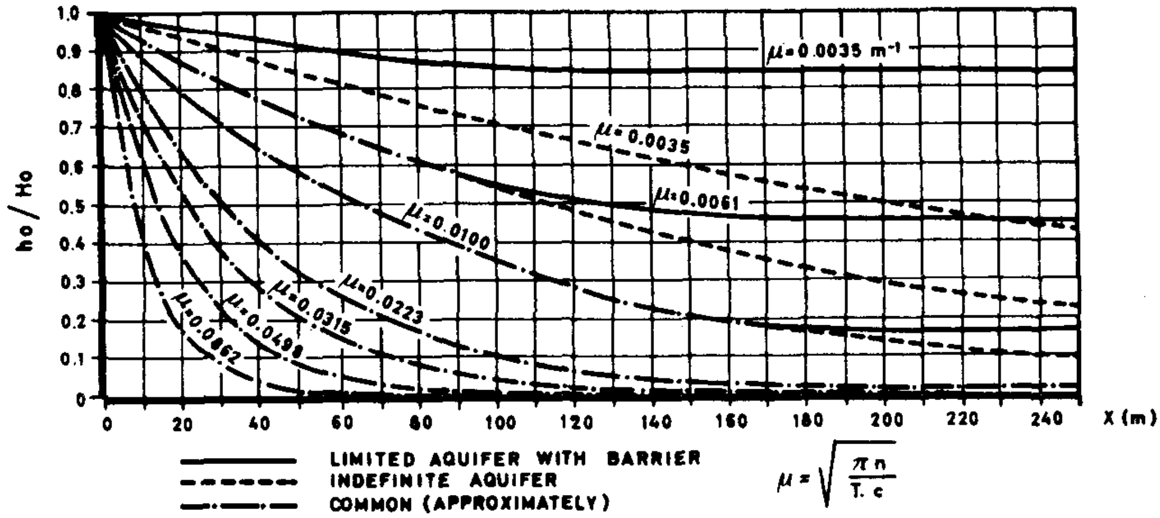

Fig. 6

Consequently, it may be observed that, if the diffusivity is not excessively high and the barrier lies at a considerable distance, then the analysis may be carried out without having to take these effects into consideration.

3.6. The influence of variations in the amplitude of the oscillations

All the foregoing analyses were based on the assumption that the tidal wave is a continuously pure sinoid. The amplitude of the tide is not constant, however, and actually undergoes a series of daily, fortnightly, monthly, biannual and annual variations. Here, returning once again to the basic case of a semi-indefinite, homogeneous medium, let us investigate the effects which each of these variations (considered separately) may have. In other words, let us analyse what actually happens if the amplitude follows a sinoidal law; that is, if the wave, in the sea, are of the following type:

$$H = H_1 \left(1 + \xi \cos \frac{2\pi t}{T_2}\right) \sin \frac{2\pi t}{T_1}$$

where T_1 is the basic oscillation and T_2 is the superimposed variation in the amplitud.

If we make $\frac{1}{T'_1} = \frac{1}{T_1} + \frac{1}{T_2}$ and $\frac{1}{T'_2} = \frac{1}{T_1} - \frac{1}{T_2}$ then, by integrating - the differential equation of the movement, the oscillation at any one point is griven by:

$$h = H_1 \left\{ e^{-x\sqrt{\frac{\pi n}{T_1 c}}} \sin\left(\frac{2\pi t}{T_1} - x\sqrt{\frac{\pi n}{T_1 c}}\right) + \frac{\xi}{2}\left[e^{-x\sqrt{\frac{\pi n}{T'_1 c}}} \sin\left(\frac{2\pi t}{T'_1} - x\sqrt{\frac{\pi n}{T'_1 c}}\right) + e^{-x\sqrt{\frac{\pi n}{T'_2 c}}} \sin\left(\frac{2\pi t}{T'_2} - x\sqrt{\frac{\pi n}{T'_2 c}}\right)\right]\right\}$$

It is demonstrated that, when T_2 $30T_1$, (that is, fortnightly variations or greater) the assumption that, when analysing a period, the amplitude is constant throughout and equal to that measured during - the period, such an assumption does not give rise to errors greater than 0.16 . In actual practice, therefore, the effects of such an - assumption are negligible.

Nor will there be any excessive degree of error, if no allowance is made for daily variations, provided that the point is near the coast (displacement of less than one period) and variations in the amplitude with respect to the mean are no greater than 10%. Figure 7 gives us an idea of the order of magnitude of the errors committed, through excess, when ξ = 0,1. 0.2 and 0.4. This is done by means of curves - obtained from the logarithmic and exponential adjustment of a series of values adopted as maximum limits of error.

VARIATION IN THE ERROR AS A FUNCTION OF THE u COEFFICIENT OF A POINT WHEN CONSIDERING THE SEA LEVEL TO BE CONSTANT AND EQUAL TO THE MEAN

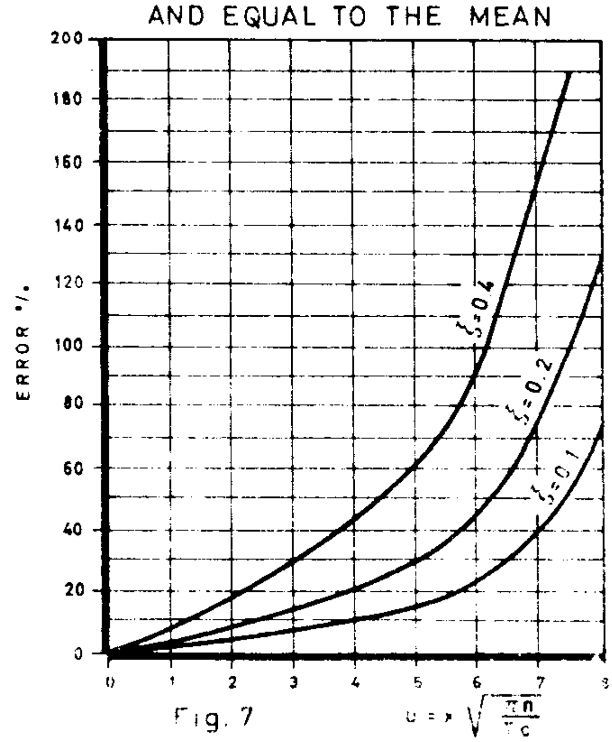

Fig. 7

Although, at a first glance, this graph might give rise to some alarm, in actual practice it is most unusual to find ξ or u values greater than 0.1 or 5 respectively. In other words, errors will be less than 15%.

4. Biaxial current

4.1. General equation

Under the same conditions and using the same notation as in section 3.1., the following is the equation which governs the movement of a two-dimensional wave through a homogeneous, isotropic medium:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{n}{c} \frac{\partial h}{\partial t}$$

where the boundary condition, as in the above-mentioned section, is the sinoidal oscillation of the tide all along the coast.

4.2. Solution by numerical calculation

The above equation may be solved by means of finite differences and subsequently calculated numerically on a computer. PRICKETT and LONNQUIST have developed a solution to the equation together with the corresponding programme, on the basis of an iterative system using files and columns. The programme operates with any coherent system of units and, in principle, is valid for confined aquifers although, as already indicated, in our case this solution is sufficiently approximate to be applied to unconfined aquifers. The programme boundary conditions may be either impervious barriers, constant-head recharges or constant-flow recharges. The expected time increments increase in a uniform way at a rate of 1:2. What this means is that the programme cannot be directly applied to the case in question unless these elements are subject to some modification.

4.3. Application to the case of an indefinite, homogeneous aquifer, limited by two orthogonal coasts

The programme was adjusted by means of the following modifications:

- The time delays were taken as being constant and equal to 0.1.T.
- For each time delay, we assumed a constant-head recharge along the edges of the coasts (using values given by the sinoidal function of the tide) and along another two edges which are parallel to the coasts and lie sufficiently far in to nullify the effects of other edges, according to the movement equation defined in section 3.2.

For calculation purposes, we adopted a mean sea level of 1.35 m. a tidal semi-amplitude of H = 1.20 m. and T = 12.67 h.

At the moment when t = 0, it was assumed that, at all points on the 20 x 20 m. grid, h = 1.35. Operations then continued until the observed heads at one point, at an equivalent instant in two consecutive periods, were markedly similar (differences of less than 10%). This was generally achieved for the third period.

On the basis of the numerical data obtained, it was possible:

a) To draw the variation of the damping coefficient in lines orthogonal to the coast, as may be seen in Figure 8 where n = 0.2 and C = 500 m^2/hour.

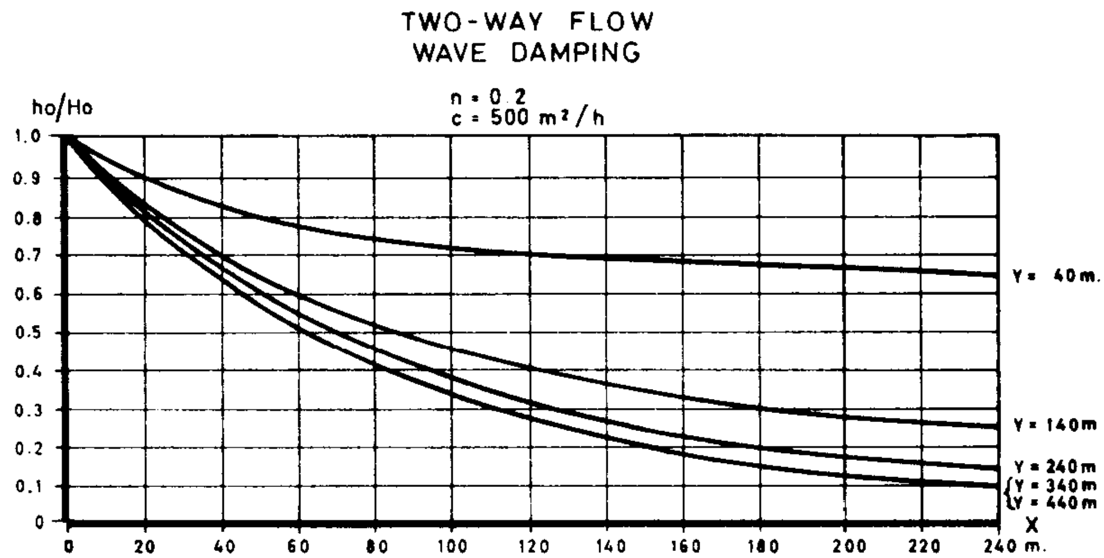

Fig. 8

b) To draw a ground plan of the lines of equal damping for the above case, as will be seen in Figure 9.

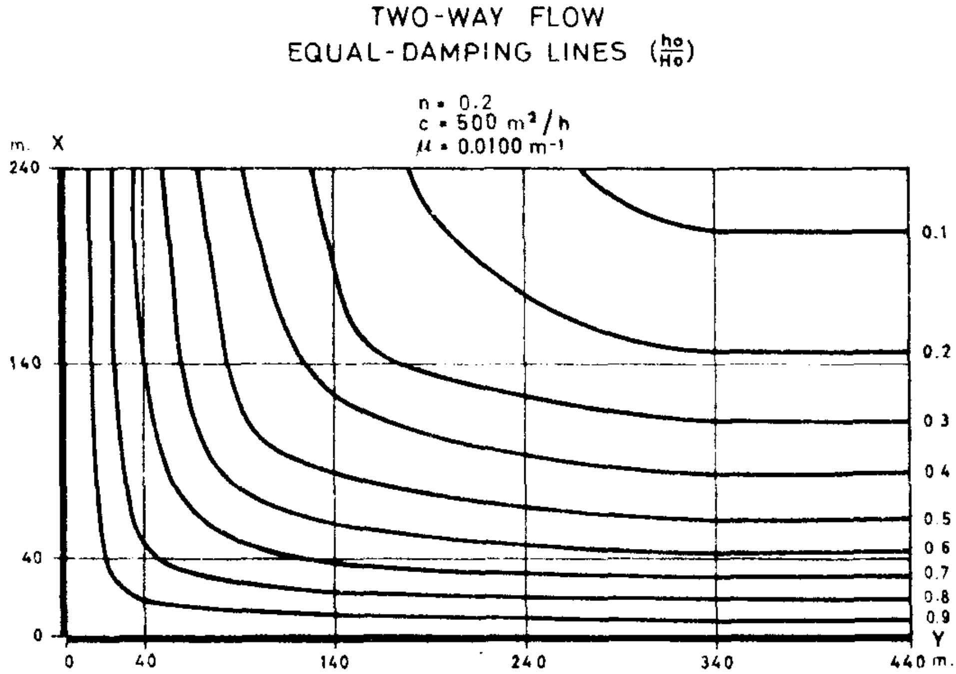

Fig. 9

c) Taking the data obtained from the different calculations as a point of departure, to try and find (for each point on the main grid in Figure 9) some correlation between the damping coefficient and the value of $\mu = \sqrt{\frac{\pi n}{TC}}$, which is characteristic of the medium and the oscillation. The results appear in Figure 10 which may be inmediately and directly applied to cases which often arise in actual practice, if the damping is measured at any point on the grid.

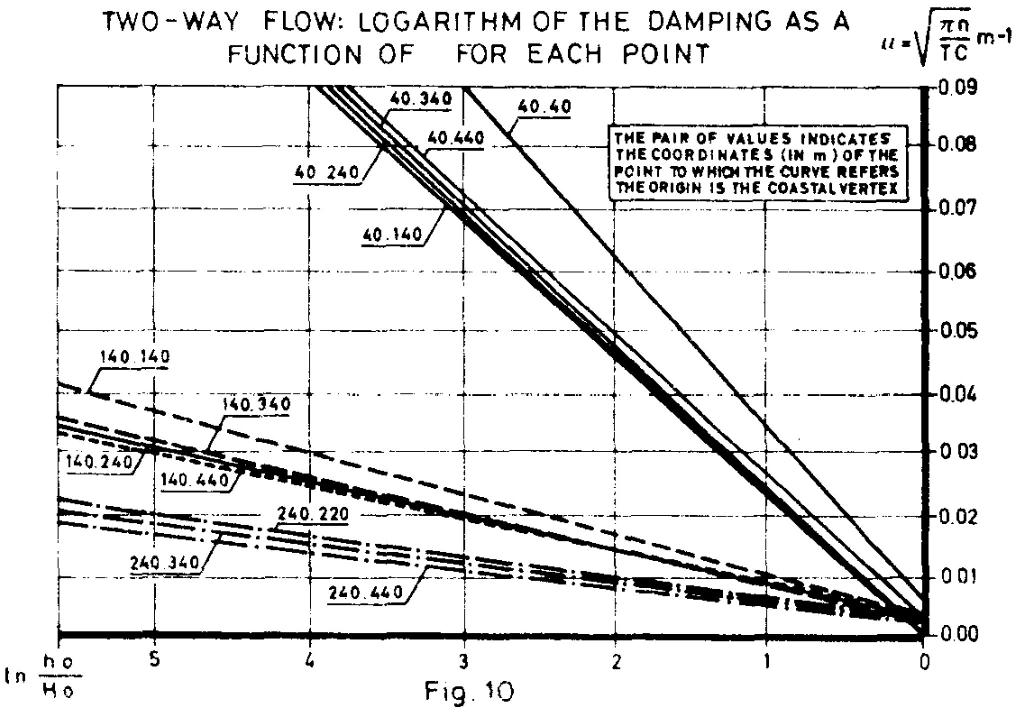

Fig. 10

Similarly, displacement could be treated in the same way, although, in view of the fact that it is rather more difficult to calculate in actual practice, it is felt that it need not be included in this context.

d) It is demonstrated that, at a specified distance from one of the coasts (a variable as a function of μ), the behaviour of the water table is practically unaffected by its existence. Therefore, it is unnecessaty to make a two-way analysis. These values are:

$\mu < 0.0045\ m^{-1}$	$D > 500$ m
0.0065	400
0.0090	300
0.0200	200
0.0500	100

4.4. <u>The simultaneous equations method</u>

This is a simple, approximate method for determining the characteristics of the terrain, making allowance for a lack of homogeneity and isotropy and with no particularly defined contour lines. Here, we rely on the characteristics of the oscillations observed in a network of points.

For this purpose, we assume a discretizated medium such that the water which enters or leaves a point O must do so through a system of orthogonal tubes; in other words, the flow is broken down vectorially in accordance with directions x and y.

Consequently, we take point O in the network, together with another four adjacent points. Thus, the oscillation at O will take the following form:

$$h = M \sin \frac{2\pi t}{T} + N \cos \frac{2\pi t}{T}$$

and at one of the four adjacent points:

$$h_i = M_i \sin \frac{2\pi t}{T} + N_i \cos \frac{2\pi t}{T}$$

Since all along the flow line i, O the one-way current differential equation must be satisfied, this equation may be integrated throughout the length of the flow tube, under the previously mentioned conditions taking into account the continuity at point O. If we assume that, along each path, the transmissivity, c, and the effective porosity, n, are constant, then we obtain:

$$M = U\ (p) \sum_i M_i + V\ (p) \sum_i N_i$$
$$N = -\ V\ (p) \sum_i M_i + U\ (p) \sum_i N_i$$

where U (p) and V (p) are highly complex functions of $p = L\mu$. L is the side of the network of observation points and μ retains the same significance as before, $\sqrt{\frac{\pi n}{TC}}$. Figure 11 summarises the variations in these expressions as a function of p.

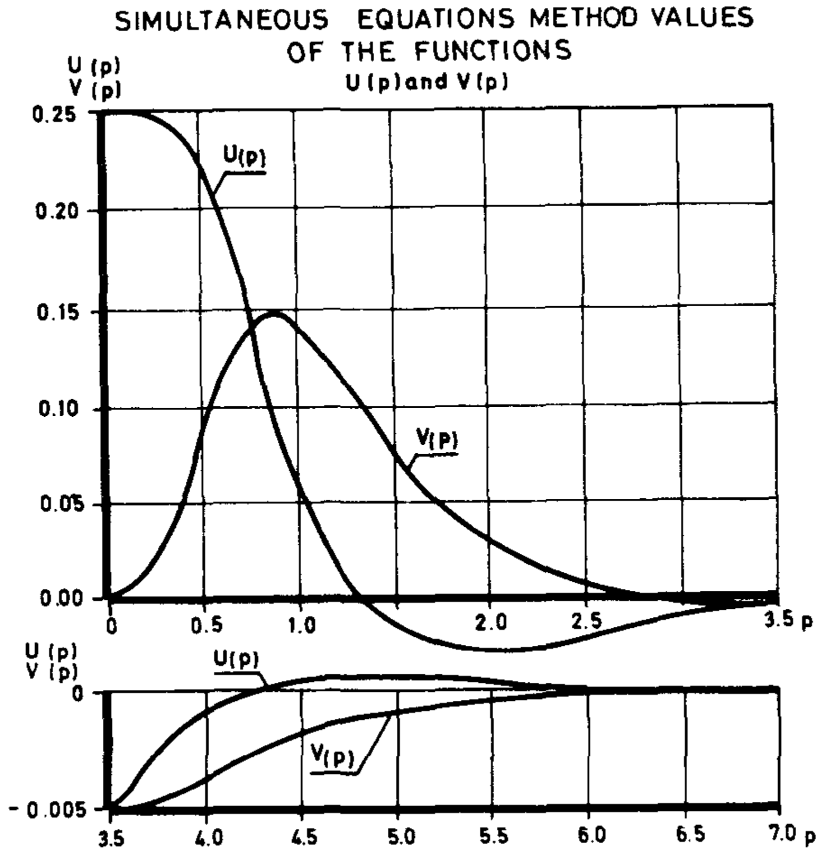

Fig. 11

Therefore, if we know the characteristics of the terrain and the oscillations at these four extreme points, we can use the above expressions to arrive at those of the centre point. Moreover, since

$$U(p) = \frac{M\Sigma M_i + N\Sigma N_i}{(\Sigma M_i)^2 + (\Sigma N_i)^2}$$

$$V(p) = \frac{M\Sigma N_i - N\Sigma M_i}{(\Sigma M_i)^2 + (\Sigma N_i)^2}$$

If it is true that c and n are constant throughout the space under - consideration, then we can obtain the transmissivity of the terrain using the oscillations measured at a central point and another four adjacent points.

On the basis of this method, the operative process for finding the - transmissivity of any terrain whatsoever, would be as follows:

a) The terrain is divided up into a square grid whose sides are made shorter as the heterogeneity increases. Using the piezometers at each of the vertices, we can find the values of M and N which define tidal oscillation at these points.

b) The points are taken in groups of five: one in the centre and four immediately adjacent points following the lines of the grid. Using the M and N values observed at these points, we find U(p) and V (p) which, when inserted in Figure 11, give us the values of p. These values should not differ from one another by more than the permitted degree of error (in the region of 20%, bearing in mind the - characteristics of the method used). The mean of p will provide a transmissivity value. If, however, the difference between the p values is excessive, the grid must then be sub-divided into smaller stretches, since this reveals the characteristics of the terrain - change too brusquely with respect to the initial dimensions of the grid. If $U(p) > 0.25$, this means that the centre point is not fed - from the sides. In consequence, the grid must be rotated until the preferential paths are located. A swing of 45º, which allows the - same square grid to be used, is normally sufficient.

c) In this way, we finally obtain for each stretch of grid two transmissivity values, depending on how either one end or the other was considered as being the centre point. The mean of the two may be taken as being the definitive value of the zone.

5. Conclusion

We feel that, using the procedures indicated, we have been able to generalize FERRIS, method in such a way that it may be applied to a large variety of situations. It must be remembered that the methods for measuring the elevation of the water in a piezometer may, of themselves, give rise to some margin of error. Consequently, the simultaneous equation method may, in practice, be applied as a method for obtaining, with some degree of accuracy, the characteristics of zones where there is some heterogeneity. Once the combined variation of the transmissivity is known, that will be the moment to apply some of the other, more exact systems which are normally used in cases of well-defined morphology to arrive at a more precise adjustment of this characteristic --

which is so decisive when planning not only the means of execution of the works but also the definitive morphology.

6. Analysis applied in the Granadilla dry dock, in Tenerife

To obtain data concerning the permeability of the ground at a large number of points in the area, intention was made to use the geological borings grid in order to measure the tidal oscillations at these points and compare them with oscillations at the sea. To this purpose all the borings were used as piezometers in order to observe variations in the level of the water in their inside. For illustrative purposes, figure 12 shows the measurements taken one day along a line of borings.

It was found that, in all borings, water level oscillation was very - important, even at the furthest points to the shoreline

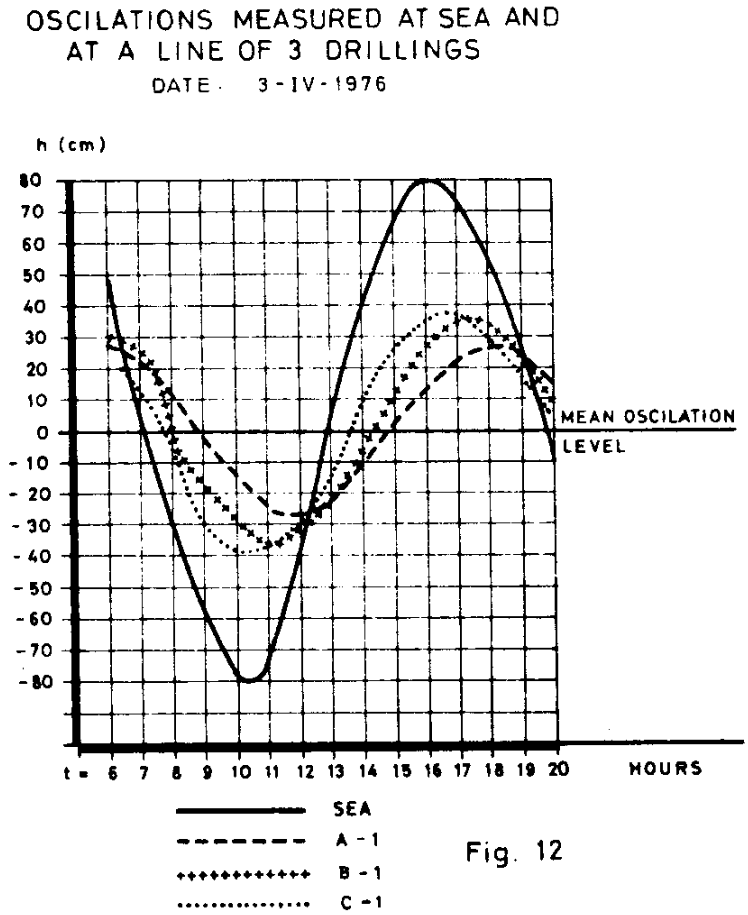

Fig. 12

and that the damping coefficient (oscillation amplitude at the boring divided by oscillation amplitude at the sea) ranged between 0,22 and 0,64.

The interpretation of the data provided by these observations tend to be very different, depending on the hydrogeological morphology assigned to the sub-soil and the estimates made for the free parameters. As far as morphological aspects are concerned, it should be pointed - out that the Ferris method assumes a totally homogeneous aquifer and monodirectional propagation of the perturbance, and with this assumption there exists no satisfactory adjustment for any pair of n, C - values. In consequence it was necessary to analyze a certain number of additional hypothesis. In this way the following additional interpretations were made:

a) The transmissibility along coast is less than in the rest of the area.

   In this way it turns out that the hypothesis which best adjusts - to the observed variations in the water levels is that the width of the less pervious zone lies between only a few meters and 25 m. with an average transmissibility from 25 to 250 m2/hour; for the remainder of the aquifer the transmissibility would be in the region of 4000 to 6000 m2/hour (n=0,1).

b) An analysis was also made of the influence which might result from the form of the coast (an angle of practically 90º) since this implies that water may be enterring on two sides and that the problem is therefore, two-directional.

   The result was too precarious and did not give a satisfactory - explanation for the observed oscillations.

c) The last hypothesis taken into consideration was the existence of preferential ways in the ground where resistance to the water circulation was either nil or very slight. In this case, if these preferential ways are sufficiently near to each other, even if the - transmissibility of the ground is low, the damping effect can be - adjusted to the observed values. On making these calculations the results show that, if such a preferential way does exist at 25 m. from the point of observation (n = 0.1, as always) the transmissibility wich corresponds to the observed damping effect would be - between 19 and 30 m2/hour, whereas if such a preferential way lays 50 m. away, the transmissibility must be supposed higher, from 28 to 45 m2/hour.

The analysis just described, give a picture of the hydrogeological - problem raised by the future construction of the dry dock which, in principle, may be considered as uncertain. The interpretation of these tests and their results may very greatly depending on the values assigned to the parameters involved, concerning which there exists - no real certainty (for exemple, concerning the value of n).

Needless to say, when evaluating the results several different interpretations may be made. Amongst these here is this one which, in our opinion, may lead to the maximum degree of compatibility between the observations made:

i) There exists, between the sea and the land, a moderate transmissibility coastal barrier due to a smaller thickness of surface slag in this zone, or to a lesser degree of fissuration in the volcanic strata or even to minor openings of the fissures as resul of sediments.

ii) The inner zone has a medium-to-high transmissibility.

iii) The entire zone described above may be crossed by high transmissibility preferential ways represented by much more transmissible zones within the slag, or by fissuration in the basalt, or by both.

As a result, we think now, that any risks caused by hydrogeological problems during construction may be technically overcome. The same applies also to the risks which arise concerning the exploitation, which may need the adaptation of the design to the real conditions of the ground.

With regard to the real development of events and dewatering problems in the course of construction and exploitation (the accepted solution includes a drained slab), we must wait to the results of the works.

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