Coastal Soils Permeability Based on Tidal Damping

Calcul de la Transmisivité par la Onde de la Marée

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SYNOPSIS In this paper, an attempt is made to develop a method for ascertaining the transmissivity of the terrain affected by large-scale excavations near the shore line, on the basis of the damping - effects with which the oscillation of the tide is transmitted through the porous media.

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.

We were faced with a particulary difficult case of this type when making an 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.

It was felt that a quick, economical way of estimating the hydrogeological characteristics 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.

2. UNIDIRECTIONAL

2.1. General equation

The equation representing movement may be written as follows:

$$\frac{\partial^2 h}{\partial x^2} = \frac{n}{c}\,\frac{\partial h}{\partial t} \qquad (1)$$

where: c is the transmissivity of the aquifer, h is the height of the free surface or the piezometric head, and 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 = 0, the general boundary condition will be:

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

where H_o is the semi-amplitude of the tidal oscillation and T is its duration.

2.2. Homogeneous, indefinite aquifer

This case was investigated by FERRIS (1951), and therefore we do not develope it here.

2.3. An aquifer formed by two consecutive homogeneous media

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 theareafter.

The differential equations for both media are integrated, with their respective boundary conditions and flow continuity condition at the - boundary. Calling $u_1 = x\mu_1 = x\sqrt{\frac{\pi n_1}{TC_1}}$, $u_2 = x\mu_2 = x\sqrt{\frac{\pi n_2}{TC_2}}$, $p = L\sqrt{\frac{\pi n_1}{TC_1}}$ and $\nu = \sqrt{\frac{c_1\ n_1}{c_2\ n_2}}$, and adopting the boundary line as the origin of the coördinates for both media, the damping coefficient has the following values:

In the first medium:

$$\frac{h_{10}}{H_o} = \sqrt{\frac{\sin^2 u_1(\nu h \sin u_1 + h\cos u_1)^2 + \cos^2 u_1(h \sin u_1 + \nu h \cos u_1)^2}{\sin^2 p\,(\nu h \sin p + h\cos p)^2 + \cos^2 p\,(h \sin p + \nu h \cos p)^2}} \qquad (3)$$

In the second medium:

$$\frac{h_{20}}{H_o} = \frac{\nu\, e^{-u_2}}{\sqrt{\sin^2 p(\nu h \sin p + h\cos p) + \cos^2 p(h \sin p + \nu h\cos p)^2}} \qquad (4)$$

Figure 1 is a graphical representation of these coefficients, for $\mu_1 = 0.0035\ m^{-1}$ and $\mu_2 = 0.0100\ m^{-1}$

2.4. The case of preferential ways

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.

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 2.

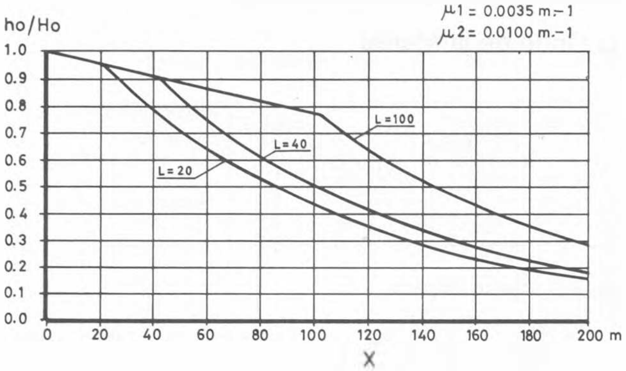

Fig. 1. AQUIFER CONSISTING OF TWO HOMOGENEOUS ZONES: WAVE DAMPING.

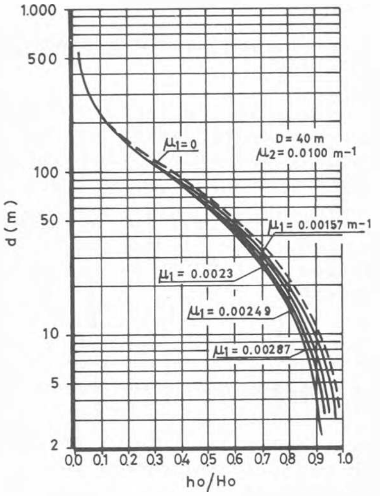

Fig. 2. DISTANCE TO THE PREFERENTIAL PATH

As will be observed, the characteristics of a - preferential way - provided that the diffusivity is very high - are of little importance.

2.5. 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. Taking this barrier as the origin, it appears that the damping coefficient will be:

$$\frac{h_o}{H_o} = \sqrt{\frac{\cos 2\ u + \text{hcos}^2\ u}{\cos 2\ p + \text{hcos}^2\ p}} \qquad (5)$$

It may be notted 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. BIAXIAL CURRENT

3.1. General equation

The equation which governs the movement of a - two-dimensional wave through a homogeneous, isotropic medium, is:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{n}{c}\frac{\partial h}{\partial t} \qquad (6)$$

where the boundary condition, is the sinoidal - oscillation of the tide all along the coast.

3.2. Solution by numerical calculation and aplication to the case of an indefinite, homogeneous aquifer, limited by two orthogonal - coasts

PRICKETT and LONNQUIST (1971) have developed a numerical solution to the equation together with the corresponding programme. The programme boundary conditions and time increments were adjus-- ted 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 and -- along another two edges which are parallel to the coasts and lie sufficiently far in to nullify the effects of other edges.

On the basis of the numerical data obtained, it was possible to try and find some correlation - between the damping coefficient and the value - of μ.
The results appear in Figure 3.

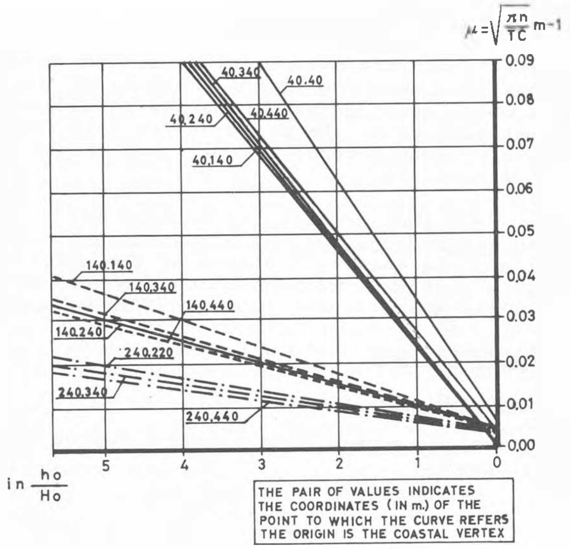

Fig. 3. TWO-WAY FLOW: LOGARITHM OF THE DAMPING AS A FUNCTION OF μ FOR EACH POINT

It is demonstrated that, at a specified distance from one of the coasts it is unnecessary to make a two-way analysis. These values varie from 100 to 500 m., for values of μ from 0,05 to -- 0,0045 m^{-1}.

3.3. The simultaneous equations method

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 particulary defined contour lines.

Here, we rely on the characteristics of the oscillations observed in a network of points.

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. (Fig.4)

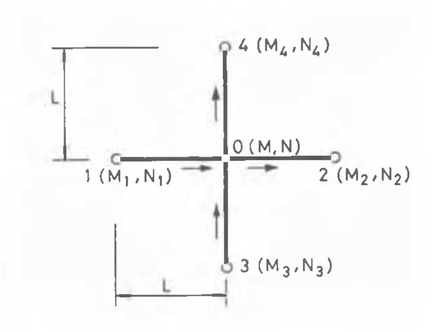

Fig. 4. ELEMENT OF NETWORK

We take point O in the network, together with another four adjacent points. The oscillation at O will be:

$$h = M \sin \frac{2\pi t}{T} + N \cos \frac{2\pi t}{T} \qquad (7)$$

and similar, with coefficients M_i, N_i in the four adjacent points.

If we assume that, along each path, c, and n, are constant, then we obtain:

$$M = U(p) \Sigma M_i + V(p) \Sigma N_i$$

$$N = - V(p) \Sigma M_i + U(p) \Sigma N_i \qquad (8)$$

Where U (p) and V (p) are highly complex functions of p = Lμ. L is the side of the network of observation points. Figure 5 summarises the variations in these expressions as a function of p.

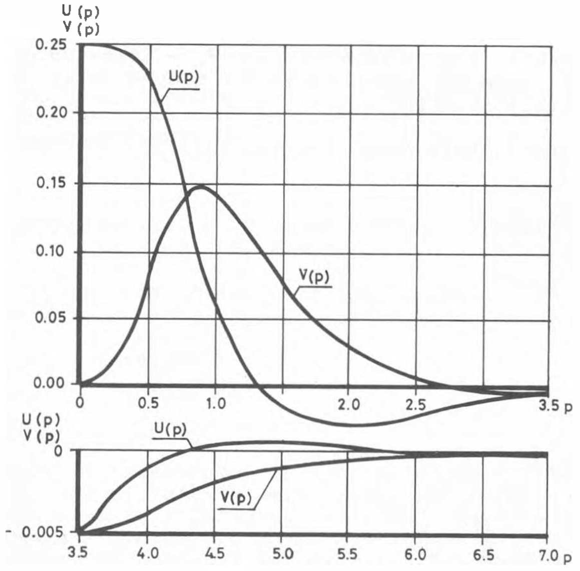

Fig. 5. SIMULTANEOUS EQUATIONS METHOD. VALUES OF THE FUNCTIONS U (p), V (p).

Moreover, since

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

$$(9)$$

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

if it is true that c and n are constant throughout the space under consideration, then we can obtain the transmissivity of the terrain.

The operative process for finding the transmissivity of any terrain, would be as follows:

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

b) The points are taken in groups of five: one in the centre and four inmediately adjacent. Using the M and N values observed at these points, we find U (p) and V (p) which, when inserted in Figure 5, give us the values of p. These values should not differ from one another by more than the permitted degree of error. If, however, the difference between the p values is excessive, the grid must then be sub-divided into smaller stretches. If U (p) > 0.25, this means that the centre point is not fed from the sides. In consequence, the grid must be rotated.

c) In this way, we finally obtain for each stretch of grid two transmissivity values. The mean of the two may be taken as being the definitive value of the zone.

4. CONCLUSION

We feel that, we have been able to generalize FERRIS method in such a way that it may be applied to a large variety of situations. The simultaneous equation method may be applied for obtaining with some degree of accuracy, the characteristics of zones where there is some heterogeneity. Once the variation of the transmissivity is known, that will be the moment to apply some of the other, more exact systems.

5. 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.

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

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.

Assuming a totally homogeneous aquifer and monodirectional propagation of the perturbance, there exists no sctisfactory adjustment for any pair of n, C values. In consequence it was necessary to analyze additional hypothesis:

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 400 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 m^2/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 depend on the values assigned to the parameters involved, concerning which there exists no real certaintly (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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