ABOUT THE ATTENUATION OF THE AMPLITUDE OF THE PIEZOMETRIC FLUCTUATIONS BY MEANS OF AN HORIZONTAL DRAIN

A cura di L.Colombo, D.Cremonesi, V.Francani

Indice

1. INTRODUCTION

The use of horizontal drain to avoid the effects of the groundwater rise both for the slope stability and for the foundations of the buildings safeguard have been examined by many researchers which stated some relationships that describe the interrelations between hydrogeological parameters and the area involved in the piezometric depression related to drainage.

This paper deals with the efficacy of horizontal drainage on the attenuation of a continuous series of rising and lowering of the groundwater head of the rivers. The repetition of these events can indeed produce underground erosion and subsidence of the soil. The horizontal drains arrangement is parallel to river, and the effectiveness of the drainage depends over all by their distance and by their depth respect to watercourse.

2. DEFINITION OF THE PROBLEM AND ACTUALLY KNOWLEDGE

In order to design the horizontal wells, it has been considered the drainage system represented in Fig. 1, and the effects of the river fluctuations have been calculated according to Pinder's method (1969). Figure 2 represents the hydrograph of a river during a flood and the piezometric heads of the groundwater linked to the river computed with the method of Pinder et al. (1969).

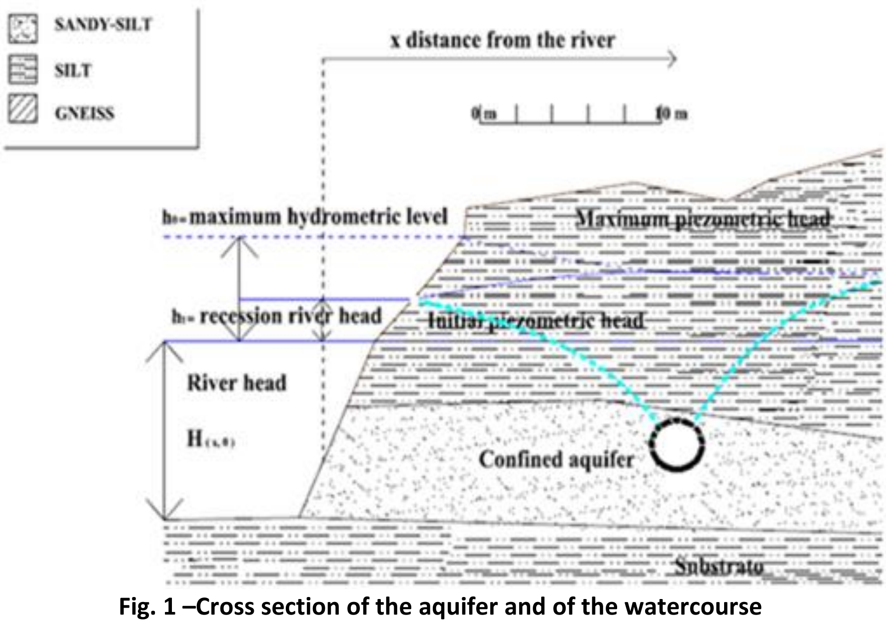

Fig. 1 –Cross section of the aquifer and of the watercourse

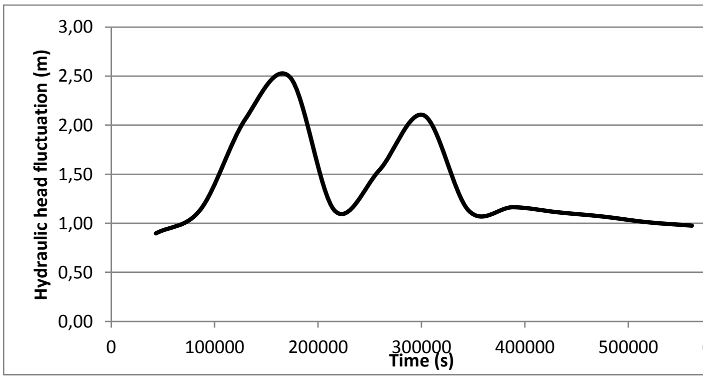

Fig. 2 Variations of the hydraulic head measured at different distances to the riverbed after a flood and during recession

The Pinder et al. relationship (1959) allows calculating correctly the effects of the floods on piezometric fluctuations, at a distance x from the river, using the following relation (2.1):

$$h_p = \sum_{m=1}^{p} \Delta H_m \left\{ erfc \frac{u}{2\sqrt{p-m}} \right\} \tag{2.1}$$

where h_p *[m]* represents the variation of the hydraulic head at a distance *x* from the river, ΔH_m is the change of hydraulic head of the surface during the period of time *(p-m)t*, being *p* the number of the intervals, *m* an integer and *u* is the parameter defined as

$$u = \frac{x}{2\sqrt{\alpha t}} \tag{2.1b}$$

The domain of the function is limited, imposing a constant head condition 100 meter far from the river, because the function *erfc* tends to infinite as *x* becomes greater.
Colombo et al. (2011), revising the Pinder and Cooper's relation (1959), obtained the piezometric gradient depending from the hydraulic head variations and the distance *x [m]* from the river:

$$J(x,t) = \frac{\Delta h_p}{x_0} = \frac{\Delta h_p + H_i erf(u_i)}{x} \tag{2.2}$$

Considering the Darcy's Law function of gradient defined by previous (2.2), of the section of well P_i (circular section with *r [m]* radius) it is possible to obtain the relation (2.3), substituting the value of the flood *Q* with the value of the mean hydraulic gradient. The (2.3) considers not only the variations of the gradient, but also the fluctuations of the river as shown by the (2.1)

$$s(x_i) = \frac{\Delta h_p n}{4 b_o x_0} r^2_{dreno} \left\{ \ln\left(\frac{4\alpha t}{\gamma r^2}\right) + \ln\left[\frac{(4\alpha t)^{n-1}}{2 x_i^2 \gamma^{n-1}}\right] \right\} \tag{2.3}$$

Where *n [-]* is the number of wells simulating the drainage trench, *r [m]* is the radius of the well, x_i *[m]* is the distance between the well and the middle of the drain; the distance, applying the superposition principle, is equal to *349*n*a*. The (2.3), modified as described above in order to consider piezometric fluctuations during floods, give the piezometric fluctuations lowering due to drainage system. It allows calculating the hydraulic gradient and in particular, to evaluate when it can reach critical values for piping.

To estimate the suitability of the analytical solution obtained by (2.3) a numerical model with the software GWVistas – Modflow (EMS – Environmental Modeling System, McDonald, Harbaugh, 1984) has been developed.

The numerical model has been designed to represent, in detail, what was studied using the analytical method. The grid is homogeneous around 5 meter sides. The choice to set small size cells, even if it makes the model heavier, is necessary in order to give a correct representation of drains and their influence on piezometric heads.

There is a large number of solutions for a partially drainage system in transient state but all presented works concern a constant flux along the open interval not considering groundwater table fluctuation; for the present note, moreover, the Goode and Thambynayagam formulation (1987) can be considered as a theoretical basis

$$s = \frac{Q}{2\pi T}\ln\left[\frac{1.5\sqrt{\frac{Tt}{S}}}{x}\right] + \frac{Q}{2\pi LK}(\sigma_z + \sigma) \tag{2.4}$$

where b [m] is the thickness of the aquifer, S [-] is the storage coefficient, L [m] is the drain length, K [m/s] is the hydraulic conductivity, Q [m3/s] is the flow rate, T [m2/s] is the aquifer trasmissivity, σ [-] is the skin factor which takes in account all changes of the hydraulic conductivity nearby the well. It approaches zero in the (2.4), σz [-] is the skin factor due to the vertical flux in horizontal well; it can be determined as follows:

$$\sigma_z = \ln\left[\frac{b}{2\pi r}\frac{1}{\sin(\frac{\pi z_w}{b})}\right] \tag{2.5}$$

In the studied case, using values of parameters in Table 1, the skin factor is equal to 2.45.

Tab. 1 Modeling parameters for the horizontal drainage design

MODELLING PARAMETERS	VALUE
Drain length L [m]	100
Aquifer thickness b [m]	10
Drain radius r [m]	2.5
Z_w [m]	Variable
Q drain [m^3/s]	Variable

Eq. (2.4) allows evaluating the drawdown function of the drain position zw with reference to the bedrock, and can consider anisotropic aquifers with different horizontal and vertical hydraulic conductivity. The relation, however, is applicable only for a steady state with a constant flow rate Q [m^3/s]. The domain of the function is also undefined, because it cannot consider the presence of a river and the effects on the piezometric heads during floods. This theoretical formula has been adapted to practical use, considering a constant radius of the drain sufficient to prevent critical velocities around the well, in order to evaluate the fluctuations of head when the drain is 10 meter far from the river and located at different depths above the bedrock. The distance x [m] between the drain parallel to the river and the river itself, following the indication of Milojevic (1963) has been considered in order to obtain a semi-infinite domain considering the presence of river; furthermore, the method of image has been applied, considering a symmetric drain with respect to the river. The following relation is able to give the superposition of drawdown:

$$s - s' = y' - y + \frac{Q}{2\pi T}\left[\ln(x') - \ln(x)\right] \qquad (2.6)$$

The formulation of Pinder et al. (1956) allows to calculate correctly the effects of the floods on piezometric.

Eq. 2.1 allows evaluating drawdown on the horizontal drain depending on the piezometric fluctuations due to the river located at a distance of x [m] from the drain. The computed drawdown depends (eq.2.4) on the length L [m]of the drain and on its elevations relatively to the bedrock. These results have been verified by means of numerical simulations using Modflow (Mac Donald-Harbaugh, 1988).

3. RESULTS OF THE COMPUTATIONS

By means of the relationships 2.1 and 2.4, have been calculated the piezometric changes (Fig. 3) during the flood described in Fig.1 in three different depth of the horizontal drain.

Fig. 3 – Analytical drawdown 10 meter far from the river, with the drain arranged to different elevation with respect to the bedrock

The results demonstrate that higher the elevation of the drain corresponds to higher amplitude of the hydrograph fluctuation, described by the red line in fig.3.

The change of the diameter of the drain can influence the attenuation of the flood effects, as demonstrate the results of the calculations synthetized in Fig. 4, where are represented two different drains, the 1 m representing the smallest size tested and the 2.5 m size representing the maximum one. The results clearly indicate that the enlargement of diameter and the vicinity of drain to the groundwater surface increase the efficiency of drain.

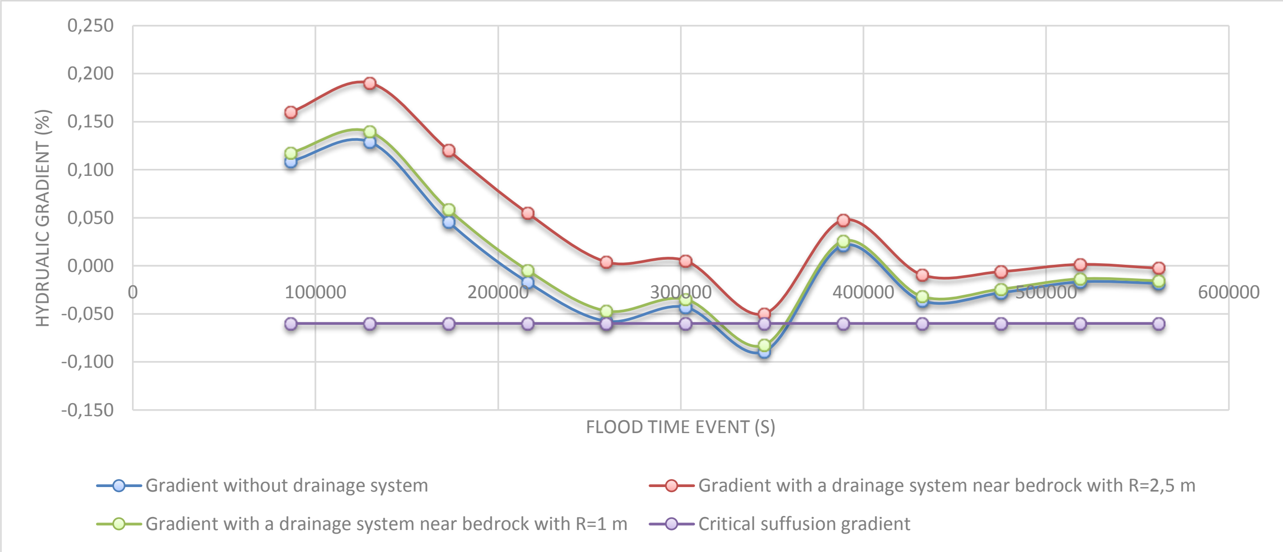

Fig. 4– Drainage system positioned near surface of aquifer (9 m from the bedrock) with different radius. The red line describes the hydrograph of the fig.2 and 3.

At the end, the simulations of the changes of the effectiveness of the drains with the distance from the river confirm that the attenuation of the amplitude of the piezometric fluctuations decreases with the distance from the river. In the fig.4 the value of the piezometric gradient beyond whom the aquifer can be affected by subterranean erosion (suffosion) has been indicated.

4. HORIZONTAL DRAIN RADIUS OF INFLUENCE COMPUTATION

Using the Pinder's relationship, the amplitude of the piezometric fluctuations due to river can be calculated at the distance x from the watercourse, and its attenuation can be evaluated by means of Goode relation. The radius of influence R of the horizontal drain corresponds to value of x minimizing the attenuation; the value of R allows designing other horizontal wells widening the piezometric depression.

5. CONCLUSIONS

The study demonstrates that the horizontal drains can attenuate the piezometric fluctuations, and that the location of the drain has a fundamental influence on the value of the diminution of the piezometric wave amplitude. The simulations made both with analytic and numerical approach confirm that the drain higher effectiveness have been reached for the drains located near the river and for form the bedrock. Using the Pinder's relationship, the amplitude of the piezometric fluctuations due to river can be calculated at the distance x from the watercourse, and its attenuation can be evaluated by means of Goode relation. The radius of influence R of the horizontal drain corresponds to value of x minimizing the attenuation; the value of R allows designing other horizontal wells widening the piezometric depression.

6. REFERENCES

Colombo L., Cremonesi D, Francani V. Hydrogeological critical settings for stability of river-banks: the case of the Pioverna river (Valsassina, Lecco), IJGE Università La Sapienza, Italy, vol. 2, Issue 1, Pages 23-38, 2011.

Cooper H. H. & Jacob C. E., A generalized graphical method of evaluating formation constants and summarizing well – field history. American Geophysical Union, vol. 27, issue 4, pp 526-535, 1946.

Dupuit J., Etudes theoretiques et pratiques sur le mouvement des eaux. Dunon, Paris, 1863.

Gattinoni P. & Scesi L., An empirical equation for tunnel inflow assessment: application to sedimentary rock masses, Hydrogeology Journal, Italy, vol. 18, issue 8, pp 1797-1810, 2007.

Goode P.A & Thambynayagam R.K.M., Pressure drawdown and buildup analysis of horizontal wells in anisotropic media, SPEFE2 (4), Texas, pp. 683-697, 1987.

Hutchinson J.N, Assessment of the effectiveness of corrective methods in relation to geological conditions and types of slope movements. Bulletin of International Association of Engineering Geology, vol. 16, pp. 131-155, 1977.

Jacob C.E., A generalized graphical method for evaluating formation constants and summarizing well field history, Am Geophys, Union Trans., vol. 27., pp. 526-534, 1946.

McDonald M. G, Harbaugh A.W., A modular three dimensional finite difference ground water flow model. U.S. Geological Survey Open File Report, pp. 83-875, 1984.

Milojevic M., Radial collector wells adjacent to the riverbank, J Hydraulics DIV ASCE Vol. 89, pp 133-151, 1963.

Moench, A. F., Computation of type curves for flow to partially penetrating wells in water-table aquifers. Ground Water, vol. 31, issue 6, pp. 966-971, 1993.

Muskat M., The flow of fluids through porous media, Journal of Applied Physics, 1937.

Odeh A.S. & Babu D.K., Transient flow behavior of horizontal wells: Pressure drawdown and buildup analysis, Texas, SPE Formation Evaluation,1990

Pinder F.G., Bredehoeft J.D & Cooper H.H., Determination of aquifer diffusivity from aquifer response to fluctuations in river stage, Water Resources Program, Department of Civil Engineering, Princeton University New Jersey, Water Resources Research, vol. 5, issue 4, 1969.

Schneebeli G., Hydraulique souterraine, Eyrolles, Collection du centre de recherches et d'essais de chatou, 1966.

Zaslavsky I. & Kassiff G., Theoretical formulation of piping mechanism in cohesive soils. Gèotechnique, vol. 15, pp. 305-314, 1965.