GROUNDWATER FLOW AROUND DEEP FOUNDATIONS

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Indice

1 ABSTRACT

In urban areas, the impermeable foundations of buildings and underground tunnels are often submerged in the groundwater. In particularly unfavorable geological settings ,the water flow is modified by these obstructions which can produce faults as well as cracks and tears in foundations. Sometimes, the buildings can collapse because of submerged foundations.

In order to describe and classify the most probable geological settings which may cause these problems, some typical cases of Italian floodplains conditions have been examined in this paper.
As it is well known, the alluvial plains area are characterized by sediments with a variable permeability and lenticular texture, slightly dipping downwards. The frequency of lenses of different dimensions and thickness, the occurrence of buried riverbeds and the presence of aquicludes, can produce heavy changes both in pressure and in flow directions locally, influencing the distribution of preferential groundwater flow and its direction.
This paper deals with the consequences on foundations stability arising from the most common geological settings in order to suggest a suitable monitoring approach useful to avoid buildings damages.

2 THE ALLUVIAL DEPOSITS OF THE MILAN AREA

The detailed analysis of hydrogeological setting in Milan area demonstrates that the foundations lie in a gravel sandy aquifer, with a permeability variable from 10^{-3} to $5{\cdot}10^{-5}$ m/s. The groundwater, according to the previous studies (Nordio, 1947; Desio, 1953; R. Pozzi e V. Francani, 1981), has an average velocity between 1 to 6 m/day, depending not only by the local variability of hydrogeological parameters (like hydraulic conductivity , transmissivity) but also by pumping well (extraction due to water supply stations for example).

Several silty clayey lenses often occur determining local changes in the direction of water flow.
A similar setting cannot produce any noticeable effect on the building stability, but several settlements have been noticed under specific conditions, whose analysis requires some theoretical detail.

In fact, where some lenses of less permeability are interbedded in gravelly aquifer, if the thickness of silty sediments reaches significant values (within some meters), an appreciable change in flow lines occurs, diverting the majority of the water flow around the lower permeable lens.

3 THE RELATIONSHIPS CONTROLLING THE WATER MOVEMENT

The governing equation for the pressure distribution is the Laplace formulation in spherical coordinates if the lens assumes a spherical shape

$$\frac{d[r^2 \sin\theta * (dh/dr))]}{dr} + \frac{d[(\sin\theta \frac{dh}{d\theta})]}{d\theta} = 0$$

where *h* (m) is the piezometric head , *r* (m) the distance from the mass-center of the lens and ϑ the dip angle of the flow line.

When the lens has a spherical shape, Phillips (1991) proposed a simple formulation between the specific discharge outside and inside the lens as follow:

$$Q_o / Q_i = G$$

Where *G*, named convergence factor, is

$$G = 3K_o / (K_i + K_o)$$

Therefore , according to Phillips (1991), when the lens is impermeable G = 3.

This simple relation allows to understand that the flow lines can be affected by strong changes when the silty lenses lie nearby impermeable foundations: the flow sections in these cases are strongly reduced, and the flow velocity is proportionally increased. The velocity is an important factor of subterranean erosion, and piping can be triggered in consequence of high velocity values.

In order to facilitate the understanding of the ways in which occurs the water circulation around the geological bodies similar to elongated lenses, they should be assimilated to prism-shaped bodies , having the same section as to the average of real lenses.

In fact, the lenticular shape of these geological bodies, is almost always distinctly recognizable only in peripheral parts of the lenses.

The water movement occurs according to equilibrium equation between the inflow and outflow of the prismatic shaped body; if it is the central cell of a system, consisting of other six lateral cells, from the equilibrium equation you get the value of the piezometric head at the midpoint of the prism using the expression (fig.1a):

$$h_0 = (h_1 N_1 + h_2 N_2 + h_3 N_3 + H_4 N_4 + h_u N_u + h_s N_s) / N$$

Where *h* is the piezometric heads , *N* the weighted average of the transmissivities of the prism and of the aquifer in which the prism is interbedded.

Therefore the value of each N can be computed as :

$$N_{ij} = \frac{Q}{(h_j - h_i)} = \frac{2bwk_i k}{L(k_i + k_j)}_j$$

Q (m^3/s) is the water flow passing from the cell *i* to the cell *j* , *b* (m) and *w* (m) are the values of the length sides of the flow section, *L* (m) is the distance of central point of each cell to flow section.

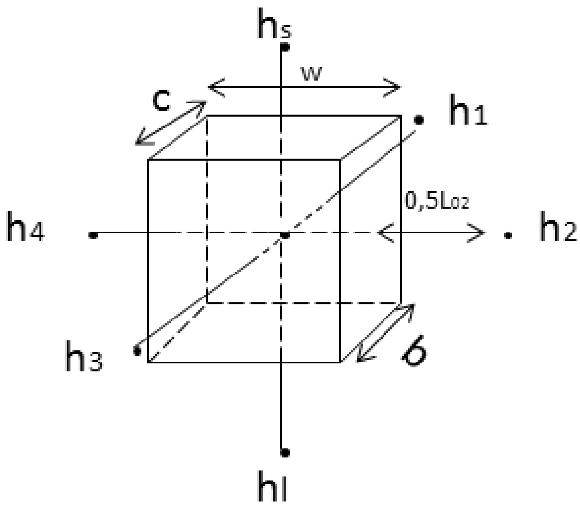

Fig.1a: Geometry of the central cell of the aquifer, when it is divided into equidimensional cells

Since the upper and lower surfaces (whose values of *N* are indicated by N_u and N_l respectively) have dimensions of the sides (*b* and *w*) much higher than the other surfaces of the prism (Fig. 1b), the water balance is strongly influenced by width of the lower and upper surfaces of the prism.

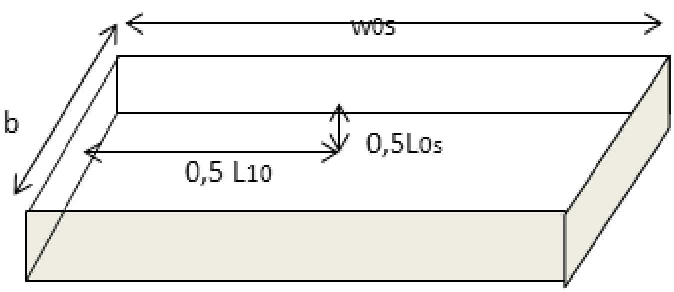

Fig.1b: The prism-shaped geologic body and the respective letters indicating the main geometric parameters of the central cell

In effect, the thickness of the lenses is very small and the water enters the lenses almost exclusively from upper and lower contact with the aquifer.

4 CASE HISTORY AND CONCLUSION

When the aquifer is silty , and the foundations of a building are located a few meters over a gravelly lens, the reduction of the flow section due to building impermeable foundations can have a very remarkable effect on the piezometric head h_0 , because (as well known from Bernoulli's theorem) the reduction of thickness of flow section, in the silty aquifer, generates the lowering of the piezometric head .

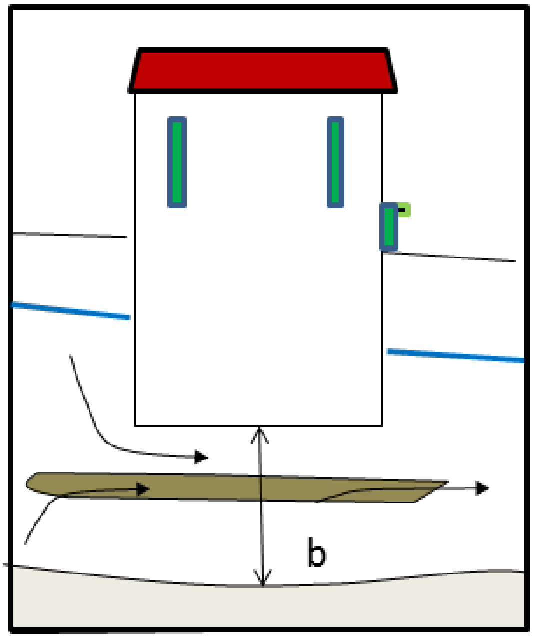

Fig.2 : Decrease of flow section thickness (b) due to foundations of the building

both in silts and in gravelly lens. In these conditions, the velocity of groundwater increases , and this fact can cause subterranean erosion of silt and the consequent settlement of building.

Figure 2 describes the reduction of flow section due to the impermeable foundations of the building.

Many buildings have been affected by similar problems, in particular when the operational measures for the drainage of the groundwater, led to the excavations which have affected the lens of gravel underneath the building.

The decrease of flow section under the building causes a pressure loss in the silty aquifer, and as the upper and lower surfaces have dimensions of the sides (*b* and *w*) much higher than the other surfaces of the prism (Fig. 1b), h_0 in the gravelly lens can be noteworthy reduced.

From the equation (1) the flow rate toward the gravelly lens can be also inferred , as it can increase proportionally to hydraulic gradient, by the change of h_0. The greater becomes the flow to the more permeable lens, the greater are the instability problems.

In fact , in several cases, serious failures occurred as a consequence of reduction of h_0 in the more permeable lenses interbedded in silty aquifers, in particular where, for the purpose of the drainage, the excavations affected the more permeable lenses.

These excavations in fact, to achieve the goal of reducing h_0, have led to an excessive lowering of the piezometric head in silty aquifer, and paved the way for the soil subsidence. For this reason, the excavation can compromise the stability of the foundations.

Other geological settings can cause similar problems, in particular when the foundations have been excavated in thin aquifer, which lies on impermeable bedrock. This aquifer is very exposed to increases of velocity and subterranean erosion.

Moreover, often foundations damages can occur when the permeable or impermeable lenses are located very close to each other, generating a global effect similar to the case described before.

The prevention of these problems involves the detailed analysis of hydrogeological setting, in particular of the permeability and the groundwater velocity field, during the design of the buildings, highlighting the water table fluctuations and the piezometric head reached in past time and trying to forecast the future piezometric setting.

5 A NUMERICAL EXAMPLE

A numerical example is presented in order to fix the theoretical developments done previously. The foundations of an hypothetical building go through groundwater, (Figure 2) , reducing the flow section . It must be calculated the change in pressure head h_0 in the center of the gravelly prism, due to head lowering in the sandy aquifer that surrounds it. In this theoretical case, for the small size of the building, the foundations don't cause any noteworthy change in the piezometric head at the extremes of the prismatic body, that are (m a.s.l.) : h4 = 17,10 m, h1 = 17 m, h2 = 16,90 m, h3 = 17 m.

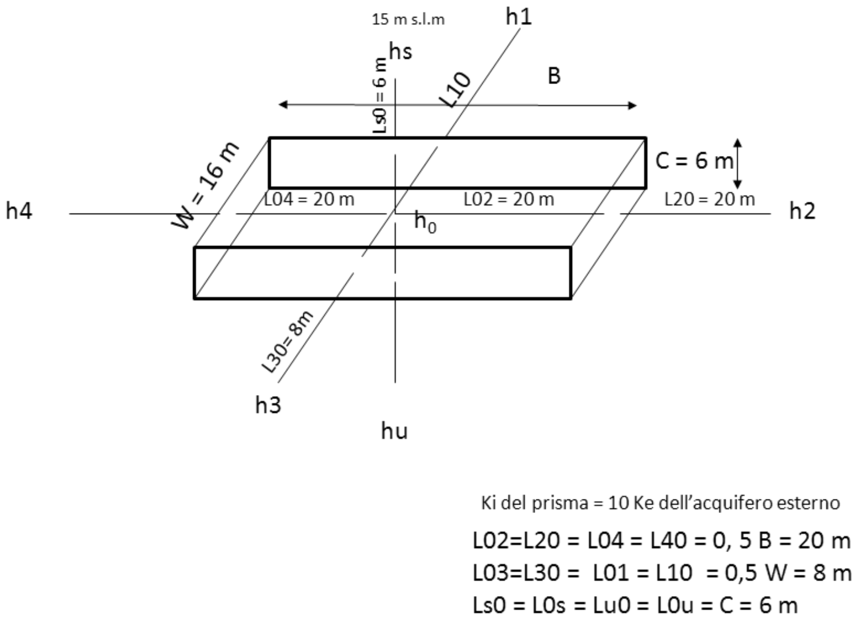

Fig.3 : A numerical example

The prism-shaped body with a permeability of 10^{-3} m/s is interbedded in the sandy aquifer with a permeability of 10^{-4} m/s. The dimensions of the more permeable portion of the aquifer have been indicated in the Figure 3.
The foundations entering the groundwater table cause the lowering of the piezometric head of the sandy aquifer in the middle of the flow section (i.e. hu and hs)., which are (m a.s.l.) : h4 = 17,10 m, h 1 = 17 m, h 2 = 16,90 m, h3 = 17 m.
Introducing the values of N_{iJ} and h_{ij} in the relationship 1),it can be calculate h_0. Taking into account that (according with 1), N_{ij} have to be calculated with the 2.

In this specific case it can be obtained:

$$N_{01} = N_{03} = \frac{Q}{(h_j - h_i)} = \frac{2 \cdot 6 \cdot 40 \cdot 10^{-7}}{8 \cdot 1{,}1 \cdot 10^{-3}} = 2{,}1 \cdot 10^{-2}$$

$$N_{02} = N_{04} = \frac{Q}{(h_j - h_i)} = \frac{2 \cdot 6 \cdot 16 \cdot 10^{-7}}{20 \cdot 1{,}1 \cdot 10^{-3}} = 8{,}7 \cdot 10^{-4}$$

$$N_{u0} = N_{s0} = \frac{Q}{(h_j - h_i)} = \frac{2 \cdot 40 \cdot 16 \cdot 10^{-7}}{6 \cdot 1,1 \cdot 10^{-3}} = 1,9 \cdot 10^{-2}$$

By substituting these values in the (1), the value of h0 is 15,28 m a. s. l.
Using the same relationships can be computed the value of h_0 when a drain lowers the piezometric heads along the building foundations, and the consequent increase of the flow rate both in the sandy aquifer and in prism-shaped body.

6 REFERENCES

Desio A. (1953): Sulla composizione geologica del sottosuolo di Milano in relazione col rifornimento idrico della città. L' acqua, n. 5-6, pp. 60-63, Milano.

Nordio E. (1957): Il sottosuolo di Milano. Comune di Milano, Servizio Acqua Potabile

Phillips G.V.(1991) – Geological fluid movement and reactions. Ed. McGrow-Hills, New York

Pozzi R., Francani V.(1981): Condizioni di alimentazione delle riserve idriche del territorio milanese. La Rivista della Strada, n. 303, Milano.