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THE PHENOMENON OF SOIL SUFFUSIONABILITY IN THE AREA OF THE CENTRAL WATER INTAKE IN ZAWADA NEAR ZIELONA GÓRA

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The paper addresses hydro-geological conditions of the Central Water Intake in Zawada. A possibility of suffusion being developed there has been analyzed.

Key words: suffusion, hydraulic conductivity, wells, grain-size distribution.

1. INTRODUCTION

The difficulties in obtaining water for economic purposes which many cities struggle with have made it necessary to study the factors affecting a decrease in the efficiency of a well, and thus affecting the operation time of a well

It is known that the choice of localization for an underground water intake shall be preceded by an exhaustive hydro-geological research. The research shall be carried out focusing not only on the volume of water uptake and its quality, but also on the possibilities of using the intake for many years

2. LOCALIZATION OF THE WATER INTAKE

The water intake is situated in the meander of the Odra river, in the left-bank valley, 8 km east of Zielona Góra, approximately 2 km east of the locality of Zawada, about 4 km north of the locality of Jany. The area of the water intake on the North and East is limited by the river-bed of the Odra river, whereas on the South by the edge of the Odra river valley which goes along the route Zawada – Jany, and on the West by the route Zielona Góra – Zawada – Cigacice. Its relative height does not exceed 51 m above the sea level. The area is flat with minimum differences in elevation, cut with numerous rift trenches and water-courses, of which the biggest called Zimna Woda, flows in the middle of the Odra river valley, east of the water intake. The total width of the valley amounts to 6 km and the area is free of forests. The area is consisted of floodland of the Odra river of the erosive and accumulative character [Chrzan, Hudak 2000].

The intake area begins approximately 350 m from the Zielona Góra – Cigacice road and stretches eastwards for 4200 m deep into the valley.

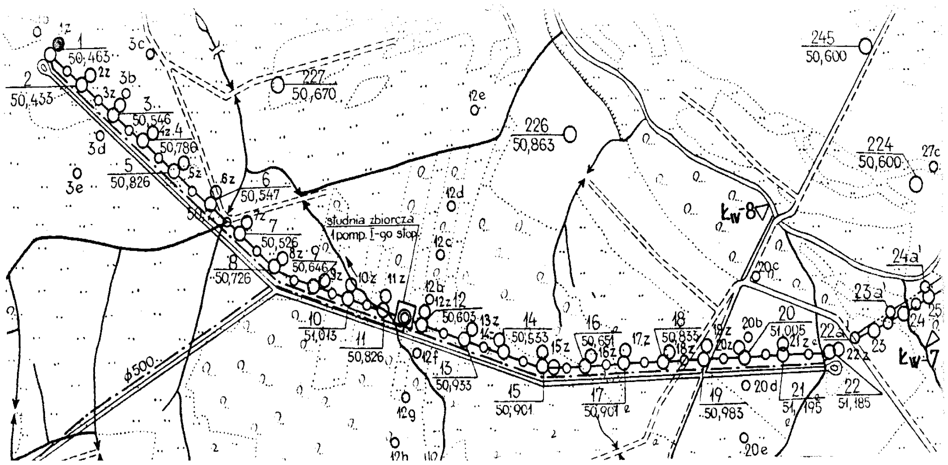

Fig. 1. Situational plan of the Central Water Intake in Zawadza [Kraiński 1993]

3. GEOLOGICAL AND HYDROLOGICAL CONDITIONS

The area of the intake is built up with neogen (the Holocene and Pleistocene) lying on thick tertiary formations, which are locally considerably distorted glacitectonically. The Tertiary formations are mainly Miocene silts with interlayers of sands, usually finely- grained, of small thickness and brown coal.

The Poznan silts – the Pliocene appear sporadically. The thickness of the Tertiary formations is not known, presumably it amounts to about 300 m.

The Quaternary formations of the intake area are made up of mainly the Pleistocene sands of various grain sizes, from medium-grained to coarse-grained, frequently with an additive of gravel and cobbles of North rocks. The gravels create inserts and interbeddings in the sands. Below the layers of sand and gravel there lie boulder clays, silt formations and interlayers of finely grained and medium grained sands in the form of inserts and lenticles among the clays. The main sand layer usually lies directly below the surface of the terrain or under the Holocene formations and its thickness ranges from a dozen of up to 25 m. The Holocene formations also lie close to the surface and they consist of fen soils, finely and medium-grained sands and silt formations. Their thickness does not exceed several meters, and there is a complete lack of them along the line of the water intake. The thickness of all the Quaternary formations totals approximately 50 m.

The main aquifer in the area under consideration consists mainly of sands of various grain sizes which appear almost on the very surface of the terrain. Their thickness ranges form approximately 16 to 25 m. It is a stratum quite well washed and sorted. The groundwater table is situated near the surface, shallowly at the depth of 0,5 - 1,0 m under the terrain. It depends on the land configuration. The aquifer is bedded with impermeable formations or weakly permeable ones, mainly with boulder clays. These formations do not constitute a uniformly formed stratum, but are characterized by variability in the formation both vertically and horizontally. The variations include the occurrence of interlayers or inserts, or lenticles of sandy formations, in which water stabilizes at the same depth as the water of the principal aquifer . This proves the existence of a hydraulic connection between all the Quaternary formations. The general direction of flow of groundwater determined by levelling of the water table in the bore-holes and test wells goes parallel to the axis of the valley, i.e., from south-east to north-west [Chudowski 1962].

4. CURVES OF SOIL GRAIN-SIZE DISTRIBUTION

The curves of soil grain-size distribution were made for each well beginning at the depth at which preliminary filtration of the well starts, every two meters and were included in the hydrologic documentation.

On this basis the values d_{10}, d_{50} and d_{60} were read, which were later used for the determination of the conditions in which the phenomenon of suffusion develops, understood as the process of washing out from the subsoil the finest particles of the soil by the stream of groundwater flowing at a given velocity. This phenomenon can occur when i_{kr} for a given type of soil is exceeded. The displacement of the soil grains due to suffusion results in local increase in porosity which in turn favours the intensity of filtration [Grabowski, Pisarczyk, Obrycki 1999].

5. HYDRAULIC CONDUCTIVITY IN THE SOIL

Hydraulic conductivity „k" were calculated for the aquifer in 1971 when the 2nd gallery was started up and in 1978 while the 3rd gallery of the well started operation by means of the Dupuit formula for water table layers with one observation well:

$$k = \frac{0{,}733 Q \lg \frac{x}{r}}{h_1^2 - h^2} \qquad [m/s]$$

where:

Q – capacity obtained while pumping the well, [m^3/h];
x – distance of the sight-hole from the well being pumped, [m];
r – radius of the well including the surrounding gravel, [m];
h_1 – thickness of the aquifer in the region of the sigh-hole, [m];
h – thickness of the aquifer in the region of the hole being pumped minus the value of depression, [m].

Hydraulic conductivity thus calculated are presented in Figure 2.

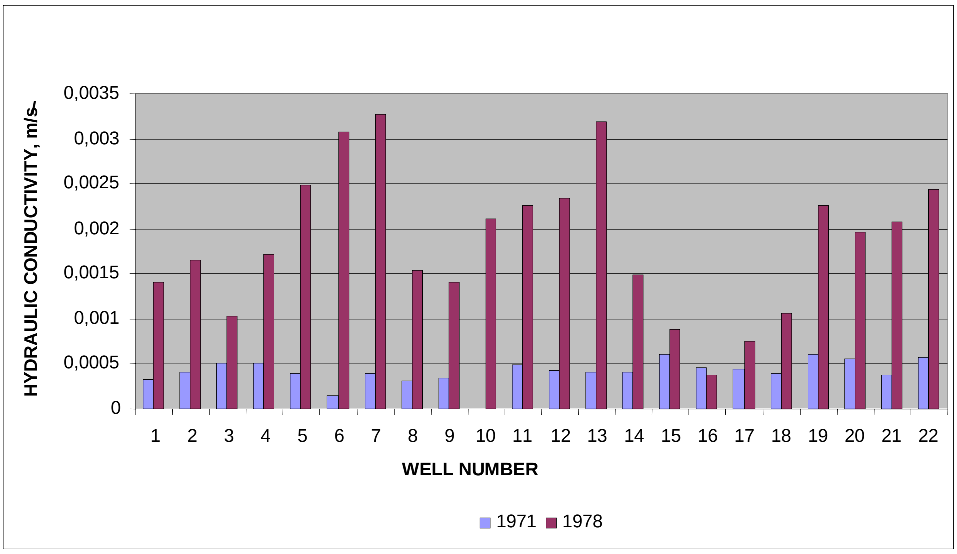

Fig 2. Coefficients of hydraulic conductivity in the soil in the years 1971-1978

On the basis of Fig. 2 it can be noticed that within a couple of years of operation the coefficients of hydraulic conductivity in the soil with new wells (1978) being constructed have increased considerably for individual wells, from 150%, for the well No. 17Z and up to 2100% for the well No. 6Z. An average increase in the value of filtration coefficients for the remaining wells is approximately four times greater in comparison with the coefficients in 1971. However, the method for calculating the coefficients of water filtration in the soil seems to be controversial. The Dupuit formula which was employed can be used for a single ideal well, whereas in the case under consideration we have incomplete wells. Moreover, a great number of bore-holes made should have been used and the formula with two sight-holes should have been applied. Thus there may be some doubts about the correctness of the results, nevertheless both in 1971 and in 1978 the same method was employed.

6. ANALYSIS OF SUFFUSION DEVELOPMENT POSSIBILITIES

On the basis of criteria of soil suffusion development and the data in Table 1 it was determined that according to W. S. Istomina suffusion develops when:

a) hydraulic conductivity k > (0,002 ÷ 0,00025) [m/s]:
   - hydraulic conductivity of 1971 ranges from k=0,000144m/s –well No. 6Z, to k=0,000611m/s – well No. 19Z,
   - hydraulic conductivity of 1978 ranges from k=0,00038m/s– well No. 16Z', to k=0,00327m/s– well 7Z'.

   This condition was satisfied for the wells of the 3rd gallery , except for the well No. 7Z', and also for the wells of the II/2nd gallery, except for the well No. 6Z;

b) the soil grain-size distribution is:

$$U = \frac{d_{60}}{d_{10}} = 10 \div 20$$

This condition was not satisfied either. In all the wells the soil grain-size distribution is less than 10, and that means that the soil is not liable for suffusion. Only in the well No. 17 it exceeds 20 and is 23,33.

c) hydraulic conductivity exceeds the critical for a given type of soil, value of hydraulic drop.

Busch and Luckner differentiated the following criteria for the development of suffusion:

a) geometrical criterion – the largest soil grains diameter which can undergo suffusion is :

$$d_s = 0{,}27\sqrt[6]{U} \cdot e \cdot d_{17}$$

where:
U – coefficient of graining non-uniformity,
e – void ratio,
d_{17} – diameter for which 17% of weight grains have a smaller diameter and a 83% larger, [mm];

b) hydraulic criterion:

$$i_{kryt} = \varphi_0 \sqrt{\frac{n \cdot d_s^2}{K}}$$

$$\varphi_0 = 0{,}6\left(\frac{\gamma_g}{\gamma_w} - 1\right)\mu * \sin(30^\circ + \alpha/8)$$

$$\mu^* = 0{,}82 - 1{,}8n + 0{,}0062(U - 5)$$

where:

n – soil porosity,
γg – soil weight by volume, [g/cm3],
γw – water weight by volume, [g/cm3],
U – coefficient of graining non-uniformity,
φ0 – angle of internal soil friction,
 - angle between water flow direction and direction of the force of gravity,
ds – the largest diameter of grains that can be washed [Busch, Luckner 1972].

Be for incidents marking the conditions of formation suffusion in prime paint critical falls the critical speeds of flow of water we can count, with example W. Sichardt:

$$v_{kr} = \frac{\sqrt{k}}{15} [m/s]$$

$$i_{kr} = \frac{1}{15\sqrt{k}}$$

Table 1. Values required for determining soil suffusion criteria [soil grain-size distribution charts]

Well number	U	Critical hydraulic gradient by formula:		
		Busch	Sichardt	
		1971	1971	1978
1	1,83	0,75	3,66	1,78
2	2,00	1,00	3,33	1,64
3	2,00	0,93	2,96	2,08
4	3,50	5,19	2,96	1,61
5	2,80	3,03	3,33	1,34
6	2,80	6,05	5,55	1,20
7	6,67	18,81	3,40	1,17
8	2,50	2,55	3,79	1,70
9	2,40	2,54	3,57	1,78
10	2,40	-	-	1,45
11	2,80	3,30	3,03	1,40
12	2,67	4,19	3,25	1,38
13	2,33	2,49	3,30	1,18
14	3,33	5,21	3,28	1,73
15	2,80	2,48	2,73	2,23
16	5,00	8,26	3,13	3,42
17	23,33	87,38	3,20	2,43
18	3,50	3,92	3,36	2,04
19	2,67	5,22	2,70	1,40
20	2,40	1,68	2,83	1,51
21	6,00	11,66	3,40	1,47
22	2,00	1,24	2,77	1,35

Assuming that the value of the critical hydraulic gradient equals more or less 1, it follows that for the wells drilled in 1971 the critical drops calculated according to Sichardt are greater and range from 2,70÷5,55 – Table 1; whereas for the wells drilled in 1978 they are smaller an are in the range of 1,17÷3,42. The critical drops calculated according to the formula given by Busch and Luckner are in the range of 0,75÷87,38. The minimum value was observed in the well No. 1Z and the maximum in the well No. 17Z.

7. CONCLUSION

Upon consideration of the above mentioned criteria of suffusion development in the soil, it can be said that this phenomenon could not occur in the soil under examination, the exceptions being the wells Nos. 7Z, 17Z and 21Z, where the critical hydraulic gradient exceeded considerably the value of 1.

From this exception it follows that the possibility of suffusion development cannot be in an absolutely explicit way excluded. Moreover, it seems that the linear location of the wells and what follows the linear arrangement of water filtration coefficients in the soil does not provide a full hydrologic characteristic of the area in question.

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