

## **Confined Groundwater at No. 52, Hollywood Road, Hong Kong**

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### **Synopsis**

Two standpipes were installed for site investigation purposes at No. 52, Hollywood Road, Hong Kong. Groundwater was observed to overflow continuously from the standpipes. After pipes were added to the top of the standpipes, the water level in the standpipes rose up to 0.6 and 3.7 m above the ground surface, respectively. This indicates that the groundwater in this site is well confined. Chemical analysis of the water samples from the standpipes confirms that the water was from deep groundwater. A further examination of the borehole and piezometric information collected from various sources indicates that the overflow phenomenon is quite common in Sheung Wan and Mid-Levels areas. This observation provides convincing field evidence for the conceptual model proposed by Jiao and Nandy [1] concerning a confined groundwater zone in slopes of weathered igneous rocks in Hong Kong. It is suggested that overflow is an important hydrogeological feature and deserves careful investigation since it may have adverse impact on slope stability and foundation design.

### **Keywords:**

Confined groundwater; artesian condition; hydrogeology; high hydraulic conductivity zone

### **1. Introduction**

Generally in groundwater studies for slope stability investigation in Hong Kong, the saprolite has been treated as an aquifer with perching horizons within it or at its base whilst a notional bedrock is assumed and treated as an impermeable boundary [2, 3, 4]. However, our studies have demonstrated that, at least in some places, a more permeable zone may exist at depth, either in the lower saprolite or at rockhead [1,5]. The groundwater flow regime in such a relatively high permeability zone may be confined, resulting in higher water pressure rise in response to rainfall than might otherwise be expected. We had been looking for more evidence for such a confined groundwater zone.

In September 2002, site investigation was carried out at No 52, Hollywood Road, Sheung Wan (Figure 1). Two standpipes (BH1 and BH3) installed at the site were reported by contractor showing overflow: groundwater running out of the standpipes continuously. After pipes were added to the top of the standpipes on 3<sup>rd</sup> October 2002, it was found that water level in the boreholes rose up to up to several meters above ground level. This indicates that the pore pressure at that site is high and the groundwater at this site is significantly confined.

In this paper, attempts are made to investigate this overflow phenomenon and a conceptual model is proposed to explain the occurrence of the artesian groundwater.

## 2. Site Background

The site is located at the lower part of the north-facing slopes of Victoria Peak on Hong Kong Island. The slopes consist of volcanic rocks with a granite intrusion [3]. A long history of engineering activities has resulted in hundreds of boreholes in this area (Figure 1). Using these borehole data, the authors have constructed a three-dimensional geological model (not shown here) in this area. Figure 2 shows a geological cross-section passing through the site. The slopes are covered by colluvium, which was derived mostly from volcanic and granite on the higher slopes. The thickness of colluvium varies considerably from zero to 5-20m in mid-slope. The depth of weathering in the granite below the colluvium cover varies from 2-3 m in the upper slopes to depths of over 50 m in the lower slopes.



Figure 1: Location of BH1 and BH3 at No. 52, Hollywood Road, Sheung Wan, Hong Kong. Hundreds of boreholes (black dots) were installed in this area based on which 3D geological models can be constructed.

The focus of this study is two boreholes located at No. 52, Hollywood Road (see inset of Figure 1). Both boreholes have a diameter of 19 mm and ground elevation of 33 mPD. The horizontal distance between them is only 7.6 m. The boreholes are about 58 m deep. As shown by the borehole records (see inset of Figure 2), the first few meters (3-5 m) near the surface consist of fill, old foundation materials, and colluvium. Below that are about 40 and 10 m of completely and highly decomposed medium grained granite (Grades V and IV), respectively. The boreholes did not reach the bedrock (Grade III). After the boreholes were drilled, the holes were filled with river sands to a certain depth. Standpipes of length of 15 m and 20 m were installed in BH1 and BH3, respectively.

## 3. Hydrogeological study of the site

### 3.1 Field study of overflow in BH1 and BH3

After pipes were added to the top of BH1 and BH3, the final static water level was measured as 0.64 and 3.73 m, respectively. The overflow rate in BH1 and BH3 was measured to be

47.2 and 2.1 mL/s, respectively. Falling-head tests, or slug tests, were conducted in the standpipes. The water level was increased to be about 1 m above the static water level after some water was instantaneously added to the standpipe. The time for the head to fall to 80% of the initial height was only a few minutes. Manual measurements of the water level of such a quick response can be very difficult and erroneous. A computer operated automatic transducer was used to measure the water level at interval of 1 second. The Hvorslev method was used to estimate the hydraulic conductivities. The hydraulic conductivities for BH1 and BH3 were found to be  $1.1 \times 10^{-6}$  and  $2.4 \times 10^{-7}$  m/s, respectively.

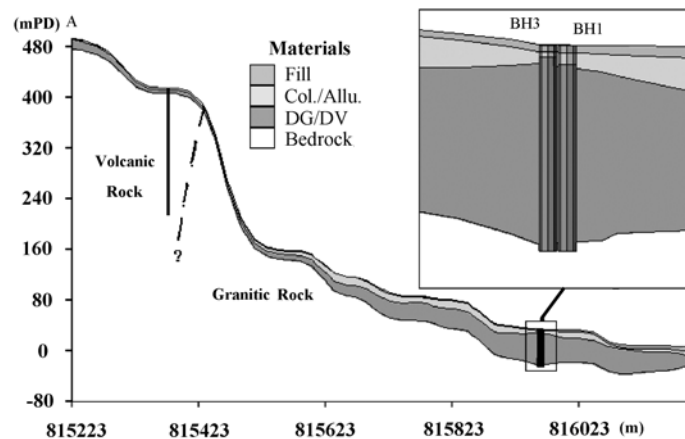


Figure 2: Simplified geological cross section through the site (see Figure 1 for location of the section)

It is believed that the final water level could be much higher if piezometers with opening only at the bottom were used. High pore pressure must have been dissipated when the groundwater originated from the deep aquifer seeps into the shallow soils along the borehole. The horizontal distance between the two boreholes is very short, but the two boreholes have significant different water levels, flow rates, and hydraulic conductivities. This indicates that the underground system is extremely heterogeneous.

### 3.2 Chemical analysis of water samples from the standpipes

It may be argued that water from BH1 and BH3 may not be groundwater but leakage from water service pipes around the site. Samples of water from the boreholes were collected for laboratory chemical analysis for major ions and trace elements. The chemical content of the waters can provide reliable information of the source of the water. Table 1 summarizes the chemical contents of water samples from the boreholes, together with the corresponding values of seawater and tap water collected from service pipes nearby. Water from BH1 and BH3 is of Na-Ca-Cl type with total dissolved solute (TDS) of 299 and 223 mg/l, respectively, which is categorized as “fresh water” according to the classification by Robinove et al [6].

Table 1 shows that overall water chemical contents of water samples collected from BH1 and BH3 are very close to each other, except for a few items. The contents, however, are distinctly different from those of seawater and tap water. Therefore, it is unlikely that the water from BH1 and BH3 was leakage from service pipes transporting seawater or tap water.

## 4. Overflow in Sheung Wan and Mid-Levels Areas

It is further suspected that overflow may not be a localized phenomenon. In light of this, various site investigation reports and piezometric records in the Mid-Levels area available

from the library of the Civil Engineering Department of the HKSAR and private companies were examined for any site with overflow. Totally, 24 sites with overflow were identified. Figure 3 shows the distribution of overflow in and around the Mid-Levels area. It seems that the overflow phenomenon is quite common in this region.

Parameter	BH1	BH3	Seawater	Tap water
Na <sup>+</sup> (mg/l)	60.40	37.19	10500	11
Mg <sup>2+</sup> (mg/l)	6.89	3.62	1350	1.61
K <sup>+</sup> (mg/l)	15.42	11.74	380	2.82
Ca <sup>2+</sup> (mg/l)	22.43	16.56	400	20.39
SiO <sub>2</sub> (mg/l)	16.73	16.41	1.22	1.99
F <sup>-</sup> (mg/l)	0.11	0.14	1.3	0.48
Cl <sup>-</sup> (mg/l)	141.10	94.44	19000	21.07
NO <sub>2</sub> <sup>-</sup> (mg/l)	0.00	2.6	0.13	0
Br <sup>-</sup> (mg/l)	1.21	0.93	65	0
NO <sub>3</sub> <sup>-</sup> (mg/l)	19.28	6.52	0.76	6.76
SO <sub>4</sub> <sup>2-</sup> (mg/l)	1.99	1.9	2650	15.57
HCO <sub>3</sub> <sup>-</sup> (mg/l)	13.69	28.28	150	42.87
Total Fe (µg/l)	2.54	2755	10	92.27
Sr <sup>2+</sup> (µg/l)	195.6	126.1	9334	38.55
Li <sup>+</sup> (µg/l)	6.62	5.26	168	6.09
Ionic balance (%)	+1.63	-2.01	+0.32	-0.86
TDS (mg/l)	299.2	223.1	~34500	124.57

Table 1: Chemical parameters of water samples from BH1 and BH3, seawater and tap water.

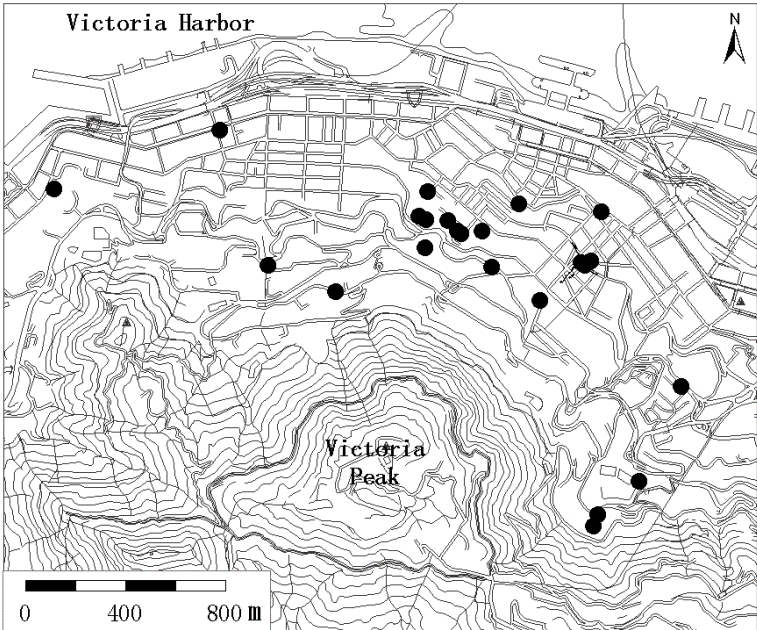


Figure 3: Sites with overflow (black dots) in the Sheung Wan and Mid-Levels Areas.

As have been seen in a number of site investigation reports, the importance of the overflow phenomenon has been largely ignored by local engineers. For a typical piezometer or standpipe with water level below ground surface, the geotechnical engineers usually conduct falling head or constant head tests to estimate hydraulic conductivity and may also monitor the water level for few days to weeks, as required by Geoguide 2 [7]. However, when overflow occurs, engineers would simply mark “overflow” or “water level = ground surface” in their reports without any further investigation. It is suggested that the final static water level should be obtained by adding pipes to the top of the piezometer or standpipe and permeability tests should be carried out, as what we did for BH1 and BH3. Overflow may

represent high pore pressure and great uplift forces and is more important than typical water level situation. Such a phenomenon deserves more careful investigation since it may have adverse impact on foundation design and slope stability.

**5. Conceptual hydrogeological model**

The observation of artesian groundwater condition in this site with head several meters above the ground surface confirms the conceptual model presented by Jiao and Nandy [1] that includes a confined high permeability zone along the rockhead in the weathered igneous rock profiles in Hong Kong. Figure 4 presents the possible conceptual model for groundwater flow in the study area. The colluvium consists mainly of coarse or fine sands. This material is permeable and can become perched aquifer during rainfall seasons, but may dry during other seasons. The highly decomposed rock or saprolite (Grades V and IV) below the colluvium can be regarded as aquitard due to its clay-rich content. As demonstrated by Campbell and Parry [8], kaolin concentrations commonly occur in relict discontinuities in saprolite (Grades V and IV material) in weathered rocks in Hong Kong.

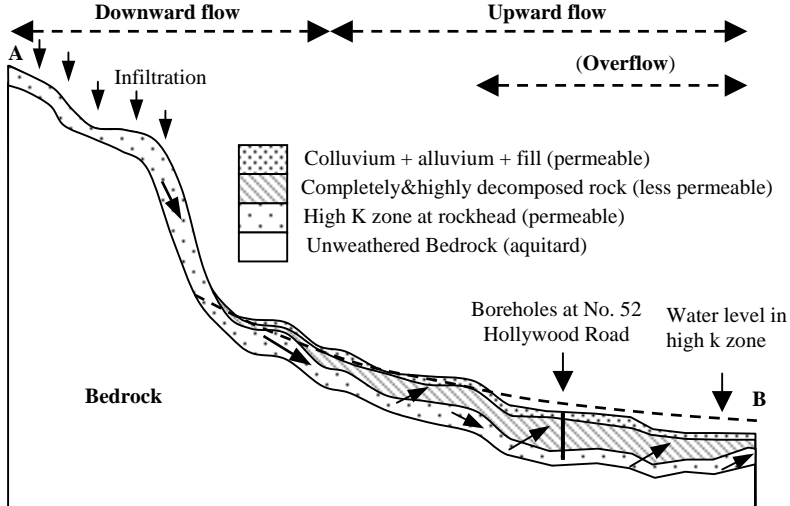


Figure 4: Conceptual model illustrating the occurrence of overflow. Groundwater with recharge from uphill flows downhill along the more permeable zone near rockhead.

The rockhead zone below the saprolite can be relatively more permeable due to well-connected fractures. This zone outcrops at the upper part of the slope and receives rainfall infiltration in wet seasons. The infiltrated water moves downhill roughly along the high permeability zone and recharges to the sea. Part of the groundwater will leak upwards into the saprolite. The rockhead zone is a permanent confined aquifer. It is believed that the head in such a zone may be increased and the zone becomes more confined progressively in the process of urbanization since urbanization usually retards the natural groundwater upward and lateral discharge. For example, piers of the building foundation are usually anchored at least 5 m below the rockhead and the foundation replaces the natural soils with concrete and other construction materials; land reclamation will not only increase the groundwater flow path to the sea but also consolidate the marine mud and consequently decrease its permeability.

**6. Conclusion**

This paper reports the overflow phenomenon observed at No. 52 Hollywood Road, Hong Kong. Field studies and laboratory chemical analysis are carried out to investigate the

overflow phenomenon. A further examination of the site investigation reports and piezometric records collected from various sources indicates that overflow is a common phenomenon in the Sheung Wan and Mid-Levels areas. This observation provides field evidence for the conceptual model presented by Jiao and Nandy [1] that proposed a confined high permeability zone along the rock head in the weathering profile of igneous rocks in Hong Kong. The common geotechnical practice for local site investigation tends to ignore the overflow phenomenon. It is suggested that overflow is more important than typical water level situation and deserves more careful investigation since it may have adverse impact on foundation design and slope stability.

### **Acknowledgement**

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