Comments on

Review of Landslides at cut slope 8SW-C/CR175 at Pak Kong Treatment Works, Near O Long Village Sai Kung

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1. Introduction

The slope to the northeast of the Pak Kong Water Treatment Works failed in 1989, 1992, and 1997. A report was presented to summarize the findings of a detailed study of the landslide incidents.

I was contacted by Maunsell Geotechnical Services Limited to review the above report because they told me that “GEO have discussed with us to find assistance to review the hydrogeological conditions of a major landslide in Pak Kong”.

My review was conducted entirely based on the draft report provided by Maunsell, although I occasionally used some information such as previous GEO reports, topography maps and rainfall data available in my office. No site visit was made for the review purpose. No discussion was held with the engineers who conducted the field study.

2. Overall comments about the report

The investigation carried out in this report has been quite comprehensive. The report presents the conclusions of the investigation, and reaches a logical conclusion about the factors which contributed to the failure of the slope.

In additional to routine investigations which can be found in similar GEO reports, this report has much more detailed discussion on groundwater flow and hydrogeological conditions. This report has a careful examination about the change of hydraulic conductivity with depth, including particle size analysis and permeability studies. As far as I know, this is the first landslide investigation report which points out clearly the possible existence of a highly permeable zone along the rock head and confined groundwater in such a zone.

I agree with the report that the failure in 1989 was probably caused by over-steepened cut slope, while the failures in 1992 and 1997 are typical deep-seated slides caused by a complex hydrogeological regime, although such a regime is not yet fully understood.

3. Suggestion to improve this report

3.1: A big-picture view of the hydrogeology of the site

As a hydrogeologist, I always feel much more comfortable to start a hydrogeological study from a large (regional) scale first because groundwater at any specific site belongs to a regional flow system. Groundwater flow at a regional scale controls the overall flow direction at a specific site and the recharge and discharge zones of the regional system determine the average water level in a specific site. Impact of the regional flow system on a site is especially more important when a confined groundwater zone exists.

Local engineers, however, may feel that the boundaries of such a regional system are far from the specific site and may have no direct impact on the flow at the site. I understand
that it is hard to conduct any detailed study over such a large scale but it may help to add one or two paragraphs to describe the system and a figure to include the boundaries of the system.

The hydrogeology around the failure site can be divided into three scales: regional scale, local scale, and site scale. The report gave a good description about the groundwater flow system at the site scale (from the toe to the crest of the slope), and have some discussion about the local scale but there is no discussion on the regional scale.

The regional hydrogeological system is bounded to the west by the mountain ridge between the Ma On Shan and the Buffalo Hill and to the east by the Sai Kung coast. Such boundaries result in an overall southeast groundwater flow in this area. The stream systems running in the NW-trending flat elongated Sha Kok Mei valley and Pak Kong valley consist the north and south boundaries of the regional system, respectively.

The small hill ridge running from Tai Shui Tseng to Huang Fa Tsuen divides the regional scale system into two local scale systems: the northeast one between the ridge and Sha Kok Mei valley and the southwest one between the ridge and the stream in the Pak Kong valley.

In natural environment, groundwater in this local system between Tan Cheung Road and the Pak Kong valley can flow southeast and drain to the Sai Kong bay or southwest and drain to the streams in the Pak Kong valley. The mean sea level is the “base level” to which the groundwater system drains. The so-called base level can be loosely defined as the lowest groundwater discharge level. Such a level controls the overall hydraulic gradient and flow pattern in a groundwater flow system.

The stream at about 10 to 20 mPD? in the Pak Kong valley serves as the base level of the local flow system. Most of the areas below the elevation of 60 mPD in the Par Kong valley were marked as cultivations in the “Hong Kong Guide 2001” (Survey and Mapping Office Lands Department, 2001), “which indicates the abundance of water on the hill slopes”, as pointed out in the report. It is believed that there areas are largely the seepage zones of the regional and local groundwater flow systems, especially in the wet seasons.

If the flow to the stream is significantly impeded by WTW, the ground level (30 mPD) of the WTW becomes the base level of the local flow system. A structure such as WTW which elevates the base level of a groundwater flow system by over 10 m is believed to have significant impact on the water level and flow pattern in the groundwater flow system.

3.2: Anthropogenic modification of the flow system

I feel that groundwater flow in this area has been modified by various anthropogenic activities. Most of the activities seem to increase the water level.

The water treatment works (WTW) was located at “the northern flanks of the Pak Kong valley, close to the bottom of the valley”. WTW was constructed between 1982-1992. The construction of the water treatment facilities started with the tunnel portal work in 1982, but main construction of the facilities seems to be in 1989. WTW is areally extensive structure, with a total area of about 70,000 m². Figure 10 shows that the clarifier tanks of the WTW cut about 7 m below the ground level. The foundation of the tanks must be deeper.
The impact of the WTW on the flow system is two fold: Firstly, it’s large base area sits on the otherwise seepage zone or groundwater discharge zone and blocks the upward seepage of the flow system; secondly, the impermeable concrete barrier tanks, together with their foundation, block the southwest flow of the groundwater. The second effect was discussed in the report.

The timings of the construction of WTW and the slope failures indicate that there may be a close relation between them. I believe the impact of the WTW on the flow system may be greater than what was discussed in the report. If the groundwater system is an unconfined one, the buildup of groundwater level caused by WTW may occur only in the immediate area to the northeast of WTW because groundwater can discharge in the slope in the form of springs. Figures 10 and 11 show, however, that the clarifier tank and its foundation may intercept the confined groundwater zone along the rock head. In this case, WTW may cause an increase in the groundwater level all the way from the toe of the slope to the groundwater recharge area near Po Lo Che Road.

Large-scale land reclamation was carried out in the Sai Kung Bay in the early 1990’s (?) and commercial and residential buildings (such as Lakeside Garden) were constructed. The original coastal line seems to be located immediately below the Hirams Highway, now the coastal line has been extended eastward by several hundreds of meters, which increases the groundwater flow path to the sea and reduces the seaward discharge of shallow groundwater. The deep foundations and diaphragm walls of these buildings may cut into the bedrock and impedes the submarine groundwater discharge through the deep fracture network near the rockhead.

In addition to the WTW tanks and the deep foundations of the commercial and residential buildings, there are other structures such as service reservoirs around the site. The modification of any single one of the structures on the flow system may not be significant or even negligible, but the accumulative effect of all these structures may lead to a considerable change to the flow system.

In addition, bare soil around structures and vegetation removal and may increase rainfall infiltration.

I would like to suggest adding some background information about structures or engineering activities which may modify the flow system around site, including a) the foundation of WTW, b) the timing of the constructions of the foundation and the clarifier tank wall, c) timing of the major land reclamation in the coast and construction of the building foundation in the reclaimed areas. A map showing the old topography (before WTW was constructed) may also help.

If there is a close relation between the failures and the construction of WTW, this should be included in the conclusion part of the report.

3.3: Possible temporal change of the groundwater system since 1984

It was observed in 1984 (Note the Stage I site formation works of WTW started in 1985. WTW was mainly constructed in 1989) that the piezometric readings show groundwater level was 1 to 4 m below ground surface (Page 19). “Based on the piezometer readings at the four boreholes, the groundwater level was generally 6 to 11 m below ground surface during the wet season of 1985 (P19)”. “The maximum rise in the groundwater level
measured during the wet season of 1985 was only about 2.5 m at BH2”. Figure 21 shows that the water level in the slope was fairly flat and the water level is not quite sensitive to rainfall in 1985.

However, after WTW was completed in 1989, “clarifier’s surface was heavily eroded and there were existence of soil pipes with continuous water running out from the pores. The largest pipe has a maximum diameter of about 500 mm.” (Note the annual rainfall in 1989 is below average.) “Piezometers BH2 and G1 indicated 8 m and 6 m rise … during the wet season of 1992 (P20)”. “Highest groundwater levels recorded were in early Aug 1994 following heavy rainfall on 22 July 1994, when the groundwater table was 4 m below the surface (at DH213), close the slope crest.

The above observation may indicate that the water level in this site has been increased and the response of the water level to rainfall in the groundwater system has become more sensitive since 1984. Such a change may be induced by the construction of WTW. More conclusive discussion can be made only after a more careful examination of the piezometric response and rainfall. I suggest that more water level data and rainfall data should be collected and analyzed carefully to see if there is any connection between the increases in water level and its sensitivity to rainfall and the construction of WTW.

It does not make much sense to discuss groundwater level without knowing the rainfall first. The report only provided rainfall information after 1990. I suggest to include rainfall data (even yearly rainfall may help) in all the years when the water level information is discussed.

3.4: Size of the groundwater catchment at the site

It was mentioned on Page 7 that “the catchment above the site has an area of 6,000 m² directing surface runoff to the ephemeral drainage channel” (on P18 it is 4,000 m²). Some piezometric response to rainfall shows that the groundwater catchment may be much greater than that.

DH213, which is close to the crest, shows that “the groundwater level appears to respond relatively quickly to rainfall with a distinct rapid rise in the water pressure noticed within about 24 hours of rainfall…and … reached a maximum in about 3 to 12 days period”.

The above observation shows that the quick rise may be caused by the recharge in the immediate catchment of 4,000 to 6,000 m², but such a small catchment may not be able to sustain the slow rise in water level in a period of 3 to 12 days. The gradual increase in water level may be due to a much larger groundwater catchment at the local scale rather than that at the site scale. I should have a better idea about the catchment if I had a field trip.

3.5: Review of previous research

I would like to suggest that the authors of the report should place their work in the context of the existing local literature. Landslides have been extensively studied and many landslide investigation reports have been published in Hong Kong. There were landslide sites with complicated hydrogeological conditions similar to the Pak Kong landslides. I can think of a few: Siu Sai Wan (Ho and Evens, 1993), Lai Ping Road (Sun and Campbell,
1998), Sham Shui Kok (GEO, 1998) etc. It would be nice to review briefly these reports, compare the hydrogeological phenomena with those in the previous studies, and point out some groundwater features which have been presented at other sites.

I do not wish to appear to be promoting my own works, but here I would like to point out that I have quite a few publications regarding high hydraulic conductivity zone in igneous rock profiles, confined groundwater along rock head, etc. These previous publications are entirely uncited here.

If we do not cite previous works properly, we may mislead uninformed readers, get lost in the local landslide research history, and in some cases, reinvent wheels which are already there.

3.6: Other minor or more specific comments

1) I would suggest that the “tunnel portal” should be clearly marked on the map. More information such as size and depth of the tunnel should be provided. Any information about groundwater ingress during tunneling?
2) Page 7: second paragraph from bottom: “High level seepage” was noted that “horizontal drains appear to be largely ineffective”. Any details about the drains? How deep?
3) Ph 3, Page 13: It should be useful if the discharge rate of the spring was measured. Such a rate should provide some information on the size of the catchment.
4) Ph 3, Page 14: I feel the soil nailing and soil compaction may only increase the confinement of the surface soil to the confined groundwater in the fracture zone.
5) On the same page: Two rows of 20 m drains were installed. They should have intercepted the rock head as can be see from Fig 11. Any information or measurement about the groundwater discharge from these drains?
6) Page 14: about geomorphology etc: Is it possible to add a map showing the topography before WTW was constructed?
7) Ph4, P18 and Figure 20: It is hard to follow the discussion and description about permeability values. It may help if you specify Figure 20a, b, or c. I cannot see the “increasing trend with depth” or “the permeability within the rock mass is higher closer to the rockhead”. Is “depth below rockhead” in the last figure correct? It may be hard to compare the permeability values obtained from different methods.
8) Ph 2 from the bottom, P18: I estimated the catchment above WTW to be about 280,000 m².
9) In the same paragraph: “Piping was also observed…” I suggest when a pipe or spring is found, more detailed description should be provided. For example, the elevation of a piping/spring should be recorded. This can provide information on the range of water level fluctuation.
10) Ph3, P19: It was observed in 1984 that the piezometric readings show groundwater (level) is 1 to 4 m below ground surface. Where were the piezometers? Were the cut-off drains really constructed as suggested? Are the piezometric readings available?
11) Ph 4, P19: “According to his observation, the slopes appear to be quite dry during excavation”… I doubt if the excavation has reached the rock head. Any information groundwater ingress during the whole excavation process?
12) Ph 2 from bottom, P19: Figure 21: What is the frequency of the piezometric measurements? Measurement points should be marked on the curves. It will be much helpful if rainfall is also added to the figure.
13) Ph4, P20: All the piezometers are installed above rock head except DH213 which is at or immediately above the rockhead. I suggest that piezometers should be installed in or below rockhead to intercept the flow from the high permeability zone?

14) P23: The discussion in the “theoretical seepage analyses” regarding the damming effect of the clarifier tank wall is interesting. I speculate that not only the wall, but also the areally extensive base of WTW, have impact on the flow system. I also speculated the impact would be greater than that discussed in this section.

15) I cannot comment about the modeling because details (boundary conditions, aquifer structures, rainfall added to the model, etc) are not given.

16) Last sentence, P28: “saprolite layers acting as an aquaclude in the short term”. This is awkward. An aquaclude is an aquaclude. It should not change with time.

17) Why was the effect of WTW not mentioned in the conclusion?

18) Figure 1: the location of the site in the inset is wrong

19) It would be nice to have a map including the regional system (Ma On Shan and coastal along Sai Kung)

20) Figure 5: The first legend: 1998-1989?

21) Figure 6: It helps if scale is added.

22) Figure 10: it gave me a hard time to find the location of A-A, which turns out to be shown in Fig 12, too late!

23) Figure 11: is the horizontal scale as same as vertical one?

24) It is easier to read if all the maps (Figures 2, 4, 5, etc) have the same orientation.

25) Figure 15, 16: Too many points. Hard to read

26) Figure 23 (or 22): It is more convenient to relate water level with rainfall if both water level and rainfall are drawn in the same figure.

27) I hope there is a table which summaries some of the details (ground level, tip location or response zone) of all the piezometers.

28) Plate 17: arrows showing locations with oil and grease strains will help

29) Plate 18: arrows showing one of the seepage locations will help

4. Recommendation for further studies

4.1 More detailed study on hydraulic conductivity profile and confined groundwater zone

By comparing clay-rich CDG shown in Plates 13 and 14 with well-fractured rock shown in Plate 15, one can speculate intuitively that the rockhead could be much more permeable than the CDG. I feel that the hydraulic conductivity contrast between clay-rich CDG and fracture zone near the rockhead may be greater than that discussed on Page 18.

The discussion on Page 18 is based on average hydraulic conductivity values. The simple mathematical average of the measured hydraulic conductivity data tends to underestimate the overall hydraulic conductivity of the rock mass (Jiao et al., 2004). A fracture zone will have the greatest effect on groundwater movement, however due to low fracture density, the possibility that a borehole will intercept a fracture zone is very low. The averaged hydraulic conductivity value cannot be representative of overall hydraulic conductivity of the mass weathered rock without giving more weight to large measured hydraulic conductivity values, such as those associated with fracture zones.

As I discussed in various occasions since 2000 (Jiao and Malone, 2000), such a high hydraulic conductivity zone along the rockhead may be quite common in Hong Kong.
However, there is a lack of direct hydraulic conductivity measurements about the existence of such a zone. I would like to suggest conducting some hydraulic conductivity test of high resolution along the vertical profile. This can be achieved by heat-pulse flow meter tests or tracer tests.

4.2 High-resolution monitoring of water level change in response to rainfall

As pointed out in the report, weekly or even daily measurement of the water level may not be able to catch the highest water level or determine accurately the delayed response to rainfall. I speculate that the water level along the fracture zone below the toe could be higher than the ground level sometimes in wet season as we observed in other places in Hong Kong (Jiao et al, 2003). I suggest to install automatic transducers in piezometer groups in three different locations (toe, crest and a location between them) to monitor water level changes at much smaller time interval. Each group should have piezometer tips at different vertical locations in CDG and the fracture zone near or below rock head. To intercept flow through enough fractures in the fracture zone, the response zone of a piezometer in the fracture zone should be longer than 1.3 m.

Such a high resolution measurement of water level will also cross check the possible existence of the high hydraulic conductivity zone along the rock head. Such a zone is expected to have a confined groundwater flow, which will show distinctly different piezometric response to rainfall compared to an unconfined system (Pop et al., 1982; Jiao and Nandy, 2001, p33).

4.3 More comprehensive study on the anthropogenic modification of the flow system

As discussed on the report, the clarifier tanks of WTW form a 220 long impermeable concrete barrier along the toe of the slope and may impede the natural groundwater flow further downhill.

I feel that the impact of the WTW on the flow system may be even greater because, in addition to the above effect mentioned in the report, the large base area (70,000 m²) of the WTW sits on the otherwise seepage zone or groundwater discharge zone and blocks the upward seepage of the flow system.

If the groundwater system is an unconfined one, the buildup of groundwater level caused by WTW may occur only in the immediate area to the northeast of WTW because groundwater can discharge in the slope in the form of springs. However, if WTW blocks the confined groundwater zone along the rock head, WTW may cause an increase in the groundwater level all the way from the toe of the slope to the recharge area. I have discussed such a scenario in previous papers (Jiao, 2000, p33).

This study can be best achieved using a three-dimensional numerical model, but such a modeling study is not trivial. The model should simulate the temporal and spatial changes (water level, sensitivity to rainfall) of the groundwater flow system in the process of WTW construction.
4.4 Post-mortem study for the real mechanisms and causes of the failure

I feel that the hydrogeology at this site is typical for deep-seated landslides in Hong Kong. Lots of previous slope failures (Jiao and Nandy, 2001, Figure 5) may have been caused by similar hydrogeological conditions. All the landslide investigation reports propose various hypotheses about groundwater conditions and slope failure models. After the investigation is completed and the report is submitted, there is no further study to confirm or verify these hypotheses. The mechanism and cause of a failure may never be fully understood.

I strongly support a proper post-mortem study to have a sound understanding about the hydrogeology and the real mechanisms and causes of the slope failure. This includes long-term monitoring, careful examination of the piezometric response in piezometers installed in various locations of the slope, and comprehensive numerical modeling.

5. Lessons to be learnt

5.1 Importance of comprehensive hydrogeological study at typical hill slopes

Slope failure in weathered igneous rocks has long been the subject of local research, but the impact of hydrogeological conditions on slope stability in Hong Kong is still relatively poorly understood (Hencher et al, 1984; Hencher, 2004).

So-called slope failure problem in many cases is essentially a groundwater problem. If a complicated hydrogeological regime is presented in a slope, traditional remedial measures such as soil nailing and cutting slope back very often may not help or even lessen stability. This is because cutting back reduces the soil weight required to balance the pore pressure at the confined zone, and soil compaction and grouting from soil nailing may make the groundwater more confined.

Unfortunately, some basic hydrogeological issues such as the typical hydraulic conductivity profile in igneous rock slopes and whether the groundwater in such a slope is confined or unconfined are still not well addressed. Some hydrogeological studies are carried out only as part of the slope stability study. Such a study is site specific and very often incomplete.

The Government should identify a few slopes with typical hydrogeological conditions and conduct comprehensive studies to investigate systematically the hydrogeological characterizations in Hong Kong. The study area should include an entire flow system.

5.2 Study on impact of engineering structure and activities on groundwater flow system

Few places in the world have experienced such intense urban growth as Hong Kong has over the last half century. The natural groundwater flow system has been modified by various anthropogenic activities and most of the activities seem to increase the water level.

Many major engineering projects require environmental and risk assessment. I feel that the impact of some projects on groundwater systems and the engineering and environmental consequence when the flow system is modified should be included as part of the
assessment. For example, large-scale coastal land reclamation, construction of areally extensive structures such as WTW or elongated structure such as MTR and tunnel may impede groundwater flow and cause adverse effect in slope stability. A groundwater monitoring programme should be implemented to examine long term change of the water level around the sites. If a structure is to increase water level significantly, measures should be taken to reduce the water level to the background level.

References


Jiao, J. J. and A. Malone, 2000, A hypothesis concerning a confined groundwater zone in slopes of weathered igneous rocks, in Symposium on Slope Hazards and Their Prevention, 8-10 May, 2000, Hong Kong, P. R. China, p165-170.


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