Implementation of Comprehensive Geotechnical Monitoring Programme Against Ground Displacement Before and During Construction of the HATS Project in Hong Kong

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ABSTRACT

Many tunnelling infrastructure works are on-going in Hong Kong recently, including the construction of 21 km of deep sewage tunnels under the Harbour Area Treatment Scheme Stage 2A project. Although water ingress has been tightly controlled by comprehensive pre-excavation grouting, any drawdown of the groundwater level during construction of the sewage tunnels may cause ground settlement which can subsequently affect existing buildings or structures in the vicinity. In recognition of this potential risk, an extensive geotechnical monitoring programme is implemented to monitor the ground conditions against possible displacement impact to existing structures and utilities. It can also provide forewarning for carrying out necessary protective measures to existing buildings and structures, particularly to those with historical or archaeological values.

This paper presents the types of the geotechnical monitoring stations including ground settlement markers (GSM), piezometers, automatic groundwater monitoring devices (AGMD), utility monitoring points (UMP), structure settlement markers (SSM), extensometers and vibration monitoring point (VMP) as well as the special monitoring on sensitive building with historical value nature using visual survey and thermographic imaging survey. The difficulties and constraints to implement the monitoring scheme and additional monitoring identified during the construction stage are also reviewed.

1. INTRODUCTION

The Harbour Area Treatment Scheme (HATS) aims at improving the water quality in the Victoria Harbour by collecting sewage from urban areas on both sides of the harbour for centralized treatment at Stonecutters Island Sewage Treatment Works (SCISTW). HATS Stage 1 covering urban Kowloon, Kwai Chung, Tsing Yi, Tseung Kwan O and eastern part of Hong Kong Island was commissioned in December 2001. Since then, the water quality of the Harbour has substantially been improved. Construction of HATS Stage 2A, which includes 21 km of sewage conveyance system (SCS) collecting sewage from the northern and south-eastern part of the Hong Kong Island, commenced in July 2009 and is in progress. The method of rock excavation is by means of the drill and blast method.

For the construction of the SCS, the Drainage Services Department (DSD) has implemented a comprehensive monitoring programme to monitor ground conditions, existing structures and other possible impacts which may arise as a result of the works. The monitoring programme includes the installation and monitoring of Ground Settlement Markers (GSM), Structure Settlement Markers (SSM), Utility Monitoring Points (UMP), Vibration Monitoring Points (VMP), Extensometers and Piezometers equipped with Automatic Groundwater Monitoring Device (AGMD).

The monitoring stations are in general so located to extensively cover an area within a distance of 400m from both sides of the SCS alignment which is shown in Figure 1.

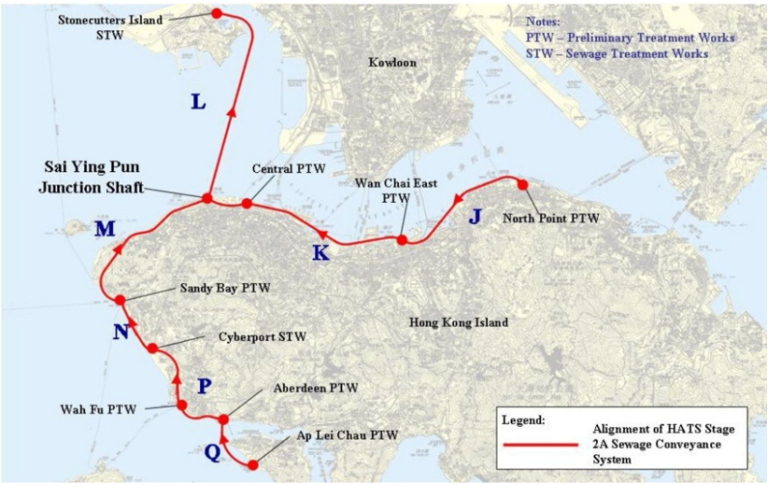


Figure 1: Plan of HATS2A Sewage Conveyance System

2. TYPICAL INSTRUMENTATION

2.1 Ground Settlement Marker (GSM)

Ground Settlement marker (See Figure 2) is used to monitor ground surface movement. The ground settlement marker type 1 is installed at ground surface for measurement of soil surface settlement. It comprises a 50 mm long x 15 mm diameter surveying nail with a plastic collar top and epoxy bottom.

The ground settlement marker type 2 is installed at concrete paved or artificial hard surface. It consists of a 25mm outer diameter steel rod whose lower end is welded to 250 x 250 x 12mm steel plate that is firmly embedded in crushed stones. The upper end of the rod is hemispherical in shape from which vertical displacement could be measured. The steel rod is protected by 75mm diameter PVC pipe and installed 0.4m below concrete pavement.

2.2 Utility Monitoring Points (UMP)

Ground settlement may lead to settlement of buried utilities and inflexible pipes are particularly susceptible to damage. Hence, Utility Monitoring Point (UMP) (See Figure 2) is proposed to be installed at gas mains and water mains which are less flexible. For utilities within zones susceptible to high settlement risk, the UMPs were installed at 50m spacing along the tunnel alignment.

The UMP basically consists of a steel pipe flange with a vertical section of steel riser pipe, which is installed on top of existing utilities pipe in a 125mm diameter borehole. Centralisers are placed at 3m intervals within the steel riser pipe. A PVC sleeve is used to isolate the steel riser pipe from the soil and the space in between the PVC sleeve and the riser pipe will be filled with bentonite slurry. The UMPs are also placed at the existing gate valve chamber, the cap of gate valve or any fixed point on the gate valve for monitoring of any settlement of the existing pipe.

2.3 Structure Settlement Markers (SSM)

Structure settlement marker is used to monitor the movement of the existing buildings/ structures which may be affected by the works. Featuring a spherical head and a plated body that minimize damage to the building, the wall-mounted marker is installed around the external facade of the building.

To adequately monitor the settlement of Existing Building Structure (EBS) (See Figure 2), the markers were proposed based on the condition survey conducted in pre-contract stage such that any differential settlement of the EBS and hence the orientation of the deformation, could be recorded. For highway structures, the markers were installed at the two ends (mainly at the abutment which is normally rested on footing) with one in the middle to record the settlement. Some SSMs were proposed at the approach ramps to the Cross-Harbour Tunnel at Causeway Bay and Western Harbour Crossing at Sai Ying Pun. Tilting markers have been also installed on some buildings adjacent to the shaft.

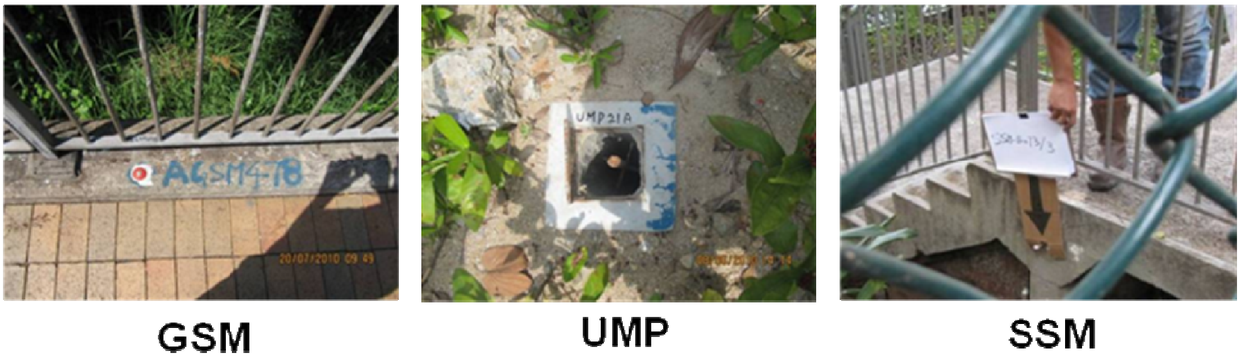


Figure 2 : Examples of Ground Settlement Marker (GSM), Utility Monitoring Point (UMP) and Structure Settlement Marker (SSM)

2.4 Piezometer/AGMD

Multi-level piezometers containing up to three tips with tips installed at a minimum depth of 10m into bedrock, in saprolitic soil and in the superficial deposit layers to detect any change in pore water pressure in various strata. The piezometers are equipped with automatic groundwater monitoring devices (AGMD) which measure the piezometric data electronically. The data obtained are transmitted off-site to a remote computer system by a Wireless Data Transmission Unit (WDTU). During tunnel excavation, it is necessary to continue monitoring potential drawdown of the groundwater table over an influence zone of approximately 400m in radius from the tunnel face. Although more costly than a conventional manual measurement by a dipmeter, the AGMD can record pore water pressure in a preset time interval with instant wireless data transmission. The typical details and schedule of installations are shown in Figure 3.

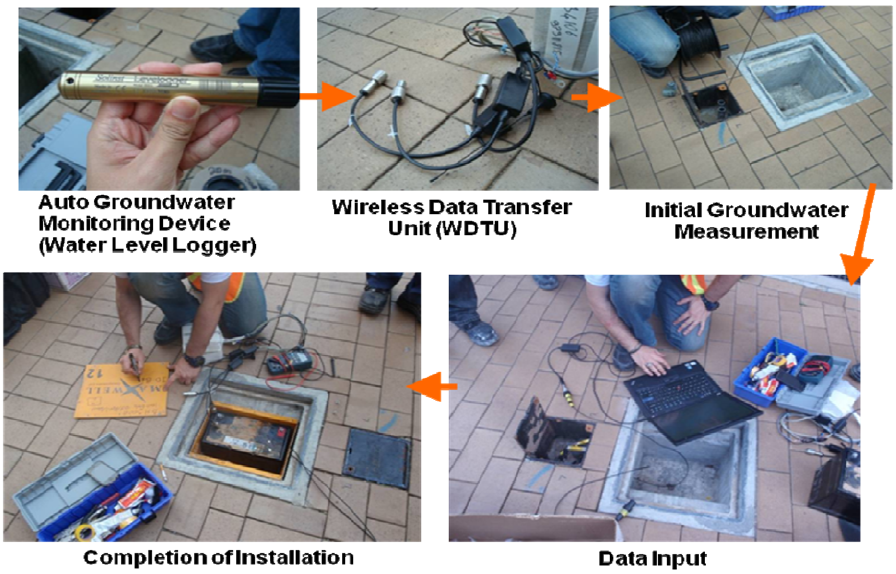


Figure 3 : Installation procedure of AGMD and WDTU

2.5 Vibration Monitoring Point (VMP)

Excessive blasting vibration may cause damage to buildings, structures, utilities, slopes, retaining walls, natural terrain and even boulder fields. Hence, the blasting is required to be monitored such that it is executed within the limit set by the regulatory authority. In fact, the blasting vibration recording is a requirement of the blasting permit. The seismograph used is required to have 3 directions channels for vibration monitoring and a fourth channel for air overpressure measurement. The contractor is required to locate the seismograph vibration sensors and air overpressure sensors at locations of sensitive receivers as determined in the Blasting Assessment Report or as directed. A set up of the seismograph is shown in Plate 1. In addition, real time vibration monitoring has been installed inside the MTRC Tsuen Wan Line Tunnel as shown in Plate 2.

Plate 1 : Set-up of Seismograph Vibration Sensors and Air Overpressure Sensors

Plate 2 :Set-up of seismograph for real time vibration monitoring inside MTRC Tsuen Wan Line Tunnel

2.6 Extensometer

Subsurface deformation monitoring is being carried out in the Cyberport Waterfront Park area to determine any settlement occurring in the compressible fill, marine deposit and alluvium layers. This was done through the installation of rod-type extensometers in two boreholes in the area. To ensure good anchorage in the soil layers, borros type anchors were used. The borros type anchor has 3 prongs that can protrude approximately 150mm from the body with applied hydraulic pressure. These anchors are connected to the surface mounted reference head by measurement rods which are protected from the grout by PVC sleevings to ensure their free movement. The magnitude of deformation is determined by measuring the movement of the rods attached to the anchors relative to the head of the extensometer anchored at the top of the borehole. Installation of the extensometer is shown in Plates 3 and 4.

Plate 3 : Connect Borros type anchor to Rod Extensometer

Plate 4 : Installation of Rod Extensometer

3. PROPOSED ALERT, ACTION AND ALARM (AAA) LEVELS

Under the construction contracts, the contractors are responsible for proposing the Alert, Action and Alarm (AAA) trigger levels for monitoring purpose. For monitoring of groundwater drawdown which is the primary cause for possible ground movement, it is specified that the changes in piezometric pressure head and groundwater table should not be greater than a serviceability limit equivalent to one metre head of water below the baseline. In this connection, the contractor is required to avoid any undue settlement by controlling groundwater inflow to the tunnel such that the maximum ground settlement recorded by any GSM or UMP is not greater than 50mm and that recorded by any SSM is not greater than 25mm under normal situation. The Alert, Action and Alarm levels being 50%, 80% and 100% of the total allowable limits. As for blasting, the vibration limit for existing buildings and structures constructed up to current standard is 25mm/s while the maximum allowable air overpressure is 120dBL. More stringent requirements for vibration limit are stipulated for more sensitive structures such as power stations, water retaining structures and even significant monument structures. The Alert, Action and Alarm levels for vibration and air overpressure measurements are 90%, 95% and 98% of the allowable limits.

Geotechnical monitoring for the different instruments consists of standard and active monitoring at different frequencies depending on the location of the tunnel face from the monitoring stations.

4. GEOTECHNICAL MONITORING DATABASE

The monitoring data for each type of instrument described above are available for viewing 24 hours a day during construction. This is made possible because of the use of a web-based geotechnical instrumentation database (See Figure 4) which can store, analyze and present the data obtained both on screen and in report formats. All instrumentation data collected manually are uploaded into the database no later than one day after survey while piezometric pressure data collected by AGMD are transmitted every half an hour through WDTU. The database have the capacity of auto notification once AAA level is exceeded.

Graphical plots or tabulated monitoring data of any monitoring device can be easily generated from the database. The user-interface also allows data from different instruments of interests to be overlain for analysis purpose. Such functions allow the user to easily interpret if the ground settlement is caused by changes in piezometric head which indicate changes in groundwater condition.

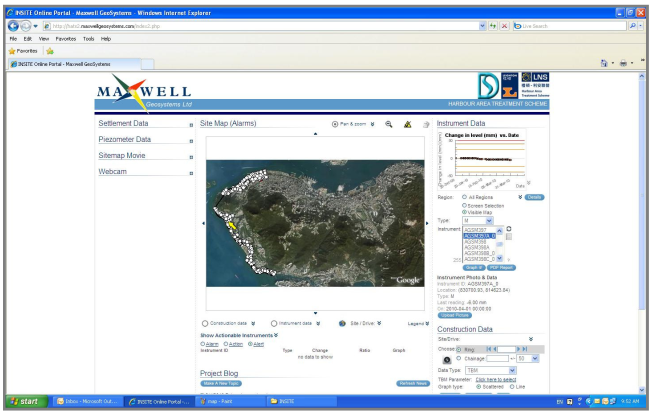


Figure 4 : Geotechnical Instrumentation Database

5. IMPACT ON EXISTING BUILDING STRUCTURE (EBS) AND PROTECTION AGAINST DAMAGE TO EBS

5.1 Visual Survey

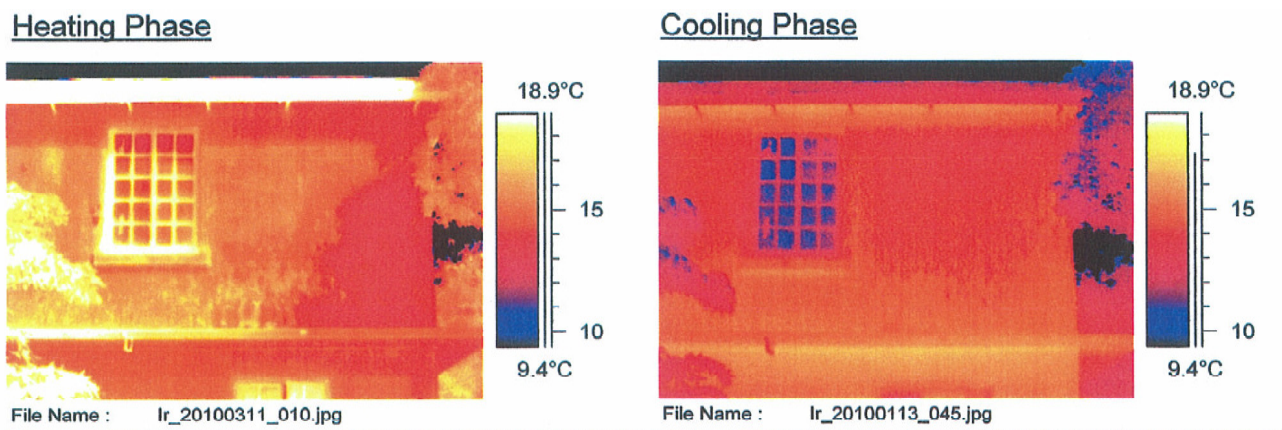
The EBS along the alignment of the sewage tunnels are divided into 4 different categories, namely Category A, B and C and heritage resources for surveillance purpose under the condition survey. However, the list of existing buildings and structures all involved a pre-condition visual survey prior to the commencement of tunnel excavation. Vibration monitoring points for blasting near heritage resources was set at suitable locations with agreement from Antiquities and Monuments Office. The visual survey record (See Plate 5) provides an assessment of the physical conditions of the affected property by identifying its defects and deficiencies. The pre-condition survey is considered absolutely essential so as to protect all parties involved in the construction works against future claims.

Plate 5 : Condition of an existing crack recorded during the visual inspection survey

5.2 Thermographic Imaging Survey

For Category A EBS, which is highly sensitive existing building structure adjacent to the tunnel alignment, thermographic imaging survey is required in addition to the conventional visual survey. The thermographic survey is a quick and non-destructive testing to examine old building structures. It identifies the debonding of finishing and water leakage problem, and therefore can provide an efficient and effective evaluation about the building condition.

In general, areas with air voids in defective concrete have higher temperature than normal concrete under solar radiation. Thermograph image shows these slight temperature differences in locating the problematic area. Thermographic imaging survey has been carried out at a Category A EBS, namely the batteries adjacent to the Victoria Road, and the record is illustrated in Figure 5.



Area Reference	10
Result	No areas of suspected debonding

Figure 5 : Thermographic Imaging Survey at Category A EBS, Batteries near Victoria Road

6. DIFFICULTIES AND CONSTRUCTION CONSTRAINTS

As the piezometers used to monitor groundwater condition are installed deep below ground near the SCS whose alignment is in close proximity to the sea, the water in the piezometer tube is saline in nature. This variation in the density of the water in the tube warrants the need of regular calibration to correlate the pressure recorded by the transducer of the AGMD against the true depth of the water column to ensure correctness of water level data.

During the construction of the two deep diaphragm wall shafts in the Sai Ying Pun area, it was noted that the piezometers/AGMD installed deep into the bedrock nearby reacted by showing a drop in piezometric pressure through real time transmission. The observed piezometric pressure head drop was interpreted to be caused by the presence of voids in the rockhead allowing water seepage into the shafts. This led to the instruction of extensive toe grouting at rockhead level of about -80mPD in the course of construction of the shafts. The additional grouting proved to be critical in making the shafts watertight as supported by the presence of grouting material filling the joints and cracks in the rockhead in subsequent excavation of one of the shaft as shown in Plate 6.

Plate 6 : Exposed Rockhead showing Presence of Micro-fines Cement Grout in Joints and Cracks

The benefit of having real time monitoring as exemplified above is that decision for correction can be made at the first sign of problem.

It is noteworthy to mention that the piezometric head in the rock could be affected significantly even by drilling for pre-excavation grouting at a distance of 150m if packers were not applied immediately to stop the inflow from connected flowpaths. The observed problem was due to site constraint of limited working space thus restricting timely installation of packers. The piezometric head drop eventually recovered after the hindered drillholes were grouted.

During the construction of the HATS2A project, a number of other projects including the MTRC West Island Line, Hong Kong West Drainage Tunnel (HKWDT) and Laying of Western Cross Harbour Main and Associated Land Mains from West Kowloon to Sai Ying Pun projects were in progress in different areas along the SCS alignment. As such, regular meetings with these parties were needed to exchange monitoring data and construction programmes. Joint surveys were also carried out with Western Harbour Crossing and Stonecutter Island site.

As regards vibration monitoring, the Contract states that the influence zone is 132m based on attenuation of blast vibration to 5mm/sec on the use of 6kg maximum instantaneous charge (MIC). However, AMO requires that vibration monitoring should be carried out whenever the proposed blasting is within 200m from a target buildings or structure. The influence zone for buildings and structures with historical and archeological values identified along the alignment of the SCS was later extended to meet AMO’s requirement. These liaison works and on-going monitoring works are crucial to the project progress and stakeholders.

7. CONCLUSION

In support of the construction of deep seated sewage tunnels under the HATS 2A project, a comprehensive monitoring programme has been implemented according to Contract requirement. Monitoring of disturbance to ground, utilities and building structures at greenfield locations along the tunnel alignment before commencement of excavation works provides a baseline from which the effect of ground movement due to tunnelling can be assessed. The installed piezometers equipped with AGMD provide first hand information of the piezometric pressure through real time transmission to guard against potential effect of surface settlement due to consolidation of the underlying soil strata. The deep piezometers installed in the bedrock are most sensitive to change of piezometric pressure in the pore spaces of the rock and considered instrumental in monitoring groundwater inflow to tunnels during their construction. The condition survey protects the interest of all parties involved in the construction in the event of a third party claim. In this connection, both visual inspection and thermographic imaging survey were applied depending on the categories of the EBS. The use of a web-based database greatly enhances the application use of the geotechnical instrumentation.

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