Building Monitoring

Monitoring Solution Providers Pte Ltd (MSP) was engaged by Taisei Corporation for monitoring the movement of surrounding buildings near their project site for Circle Line Stage 3 Contract 853, Construction and Completion of Marymount Station Including Tunnels.

There were two (2) total stations deployed for this project with one located on the roof of Lip Hing Industrial Building and another on the roof of Bishan 8 Condominium Tower A. Refer to Fig 1 for the monitoring zone.

The Automated Monitoring System located at Lip Hing Industrial Building was for the structural monitoring of terrace houses along the tunnel route for LTA project C853. The terrace houses are situated along the proposed C853 Marymount MRT tunnel, in particular, the **Pemimpin Place** area and along **Pemimpin Terrace**. The total station for monitoring these houses was located on the roof of Lip Hing Industrial Building. The list of houses being monitored in the above-mentioned area is listed as follows:

<table>
<thead>
<tr>
<th>Pemimpin Place 53</th>
<th>Pemimpin Place 68</th>
<th>Pemimpin Place 88</th>
<th>Pemimpin Place 102</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pemimpin Place 55</td>
<td>Pemimpin Place 82</td>
<td>Pemimpin Place 90</td>
<td>Pemimpin Place 104</td>
</tr>
<tr>
<td>Pemimpin Place 63</td>
<td>Pemimpin Place 84</td>
<td>Pemimpin Place 92</td>
<td>Pemimpin Place 118</td>
</tr>
<tr>
<td>Pemimpin Place 64</td>
<td>Pemimpin Place 85</td>
<td>Pemimpin Place 94</td>
<td>Pemimpin Terrace 52</td>
</tr>
<tr>
<td>Pemimpin Place 65</td>
<td>Pemimpin Place 86</td>
<td>Pemimpin Place 96</td>
<td>Pemimpin Terrace 66</td>
</tr>
<tr>
<td>Pemimpin Place 66</td>
<td>Pemimpin Place 87</td>
<td>Pemimpin Place 98</td>
<td>Pemimpin Terrace 68</td>
</tr>
</tbody>
</table>

The Automatic Monitoring System installed on the roof of Bishan 8 Condominium Tower A was for monitoring the displacement of existing terrace houses along the proposed Marymount tunnel during the construction.
The Automatic Monitoring System (AMS) officially commissioned on 1st April 2006.

Prior to actual monitoring of the surrounding buildings, a trial test was carried out to verify and determine the bandwidth of the fluctuation and accuracy of the system based on the customized scheme and site conditions. The test will also verify the stability of the monitoring system from effects of ‘Shimmering’ due to hot afternoon roofs and steep angular measurements, affecting the EDM and angular accuracy of the total station.

The test location was proposed to be at the roof of Lip Hing Industrial Building, which was also the first monitoring location. Prisms were installed with various types and distances and a total of 8 reference prisms spatially located to simulate the actual monitoring scheme. Below was the proposed location of these prisms for the total station on the roof of Lip Hing Industrial Building:

<table>
<thead>
<tr>
<th>Prism Location</th>
<th>Distance to total station</th>
<th>Type of Prism</th>
</tr>
</thead>
<tbody>
<tr>
<td>House No. 86 LTA 204</td>
<td>150m</td>
<td>25mm dia. (GB104)</td>
</tr>
<tr>
<td>House No. 79 LTA 213</td>
<td>120m</td>
<td>25mm dia. (GB104)</td>
</tr>
<tr>
<td>House No. 7 LTA 188</td>
<td>220m</td>
<td>60mm dia. (APS12)</td>
</tr>
<tr>
<td>House No. 9 LTA 159</td>
<td>290m</td>
<td>60mm dia. (APS12)</td>
</tr>
<tr>
<td>House No.107 LTA 144</td>
<td>390m</td>
<td>60mm dia. (APS12)</td>
</tr>
</tbody>
</table>

The test was carried out continuously over 3 days, with an initial 2 days to determine an arbitrary baseline prior to the commencement of the test. A report was to be submitted 3 days after the test completion to relate any finding from the test conducted.

A sequence of the entire installation is summarized below:
- Determine locations of all equipment to be installed (monitoring prism and Instrument);
- Approval of Plan and Particular Method Statement;
- Installation of instrument housing, brackets and prisms;
- Installation of Power Points from existing sources;
- Training’ of Prisms (Coordinate Transfer);
All the equipment installed for the trial test would be incorporated into the actual Automated Monitoring System. The equipment used is as follows:

i. Sokkia Net1-m total station;
ii. Instrument housing, brackets and shelter;
iii. Electrical fan and canvas sheet for cooling down the instrument;
iv. Power supply on top of the building;
v. Reference prisms and monitoring prisms installed.

The system adopted for this purpose is:

A total station would be located at the roof of Lip Hing Industrial Building. A small Instrument hut was built at the roof to protect the instrument from direct sunlight and rain. The Instrument would receive direct power supply from the building and will communicate with an on-site computer. It would start recording, transmitting, processing and output data at every 4 hour interval.

Monitoring prisms would be installed as follow:
- on each affected terrace house, where the tunneling route underlines these houses;
- on structures where suspected movement is to be expected.

Reference prisms would be fixed onto structures at 30m outside the Tunnel Route line (outside the zone of influence.)

A ‘Control Cabinet’ would be used to house the power supply, Uninterrupted Power Supply (UPS), Computer CPU, Wireless Modem, Instrument Power Adaptor, Communication Converter and Cooling Fan.

**Report on the influence of shimmering effects from road and clay roofing affecting the fluctuation of the Automated Monitoring System**

In the Automated Monitoring System, the proposal is to use 60mm diameter glass prism for distances above 150m. For distances below 150m, normal 25mm diameter glass prism was used. The proposed location was from the roof of a building where vertical angles and shimmering effects of a hot day were experienced. In a 230m distance and a 10-Storey building, the vertical angle is not more than 10 degrees and for 400m, the vertical angle is not more than 5 degrees, which will not influence much on the fluctuation of readings. Therefore,
the main concern is the effects of shimmering from low-rise rooftops.

To simulate the on-site testing, a location of the building was chosen to overlook the low rise roof. Due to constraints, the total station was located on the fifth storey with 2 prisms located someway on the ground level affix to a ‘Tripod’. The location of the 60mm diameter prism was located 230m and 400m away.

**SUMMARY OF RESULTS:** The raw reading results show that:

<table>
<thead>
<tr>
<th>Distance of prism from total station</th>
<th>Raw reading fluctuation</th>
<th>Raw slope distance measurement</th>
<th>Raw vertical angle measurement</th>
<th>Raw horizontal angle measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>230m</td>
<td>±1.0mm</td>
<td>±0.4mm</td>
<td>±1.2&quot;</td>
<td>±0.8&quot;</td>
</tr>
<tr>
<td>400m</td>
<td>±1.3mm</td>
<td>±0.4mm</td>
<td>±0.8&quot;</td>
<td>±0.7&quot;</td>
</tr>
</tbody>
</table>

The Mean Average of 3 reading coordinates shows that for both distances of 230m and 400m, the fluctuation in dx, dy and dz is within ±1mm.

The calculated readings or processed readings are based on the quality of raw readings and the ability to obtained quality raw readings. The system is based on repeated averages where a higher accuracy is obtained from processing. In the summary above, it has proven that using a 60mm diameter and the ‘Autolock’ function of the total station with the suggested environment, the processed readings would be within the stated fluctuation of ±1mm. The processed readings may be smaller than the fluctuation as the readings has to pass through the ‘Least Square’ adjustment.

**MAINTENANCE**

The system has to be kept well-maintained throughout the duration of monitoring to maintain a high quality of reliability. The maintenance activities carried out during the monitoring period are stated below:

i. Manual survey of all prisms on a monthly basis to determine any movement of the reference prism and to verify the monitoring prism’s coordinate against the automatic ones.

ii. Leveling of total station on the bracket, on a monthly basis during manual survey access, to reduce errors from collimation correction and to prevent any movement from station position exceeding the instrument’s collimation range (polynomial collimation errors).

iii. Conduct on-site calibration on a 3 monthly interval.

iv. Reboot on-site computer on a 2 monthly interval to reduce risk of ‘Hanging’ of programs and increase speed of processor.

Installation of the prisms and the total station started somewhere in early July 2005. Every precaution had been made to install the prism with “Full Facing” towards the total station position as each prism was targeted and recorded numerous before installing. Refraction from glass windows, swaying branches and passing vehicle/pedestrian was avoided whenever possible.

The Automated Monitoring System at Lip Hing Industrial Building was commissioned on 1st November 2005 and all displacement mentioned was historically related to this start date. According to the records, the total station at Lip Hing Industrial Building, (A) was calibrated and replaced on the 21st March 2006. The replacement of total station at that time was carried out as a precautionary action. However, in replacing the total station, the readings for the Automated System were still the same, proving that the system readings had no problems and thus eliminated the former total station as a fault. The ‘Open’ environment (rain, sunshine, refraction), and using the “Finelock” system, the angular spread from raw readings tends to be larger than other physical conditions or other monitoring situations. Fluctuation of cycles was expected due to numerous heavy downpour experienced in March and April 2006.
In explaining the “Finelock” system, the total station sends out an Infra-red signal to the prism and the reflection from the prism provides the total station information to shift and lock on to the highest returned strength, which was at the centroid of the prism, and the centre point of prism was measured. When a prism moves, the total station will still lock on to the highest returned signal strength, which will still be from the centroid. Thus, when comparing centroid readings, the difference is negligible (less than 1mm) as compared to a readjusted prism. When the prism rotates around its own axis, there is no difference in readings. It will require a substantial amount of tilt (more than 10 degrees, from experience) or movement from the prism to translate into a 5mm difference, for example. This tilt phenomenon was not found. Trend and resultant from the Automated System would be equivalent to any Manual 3-D survey when carried out.

Joint survey from the roof of Lip Hing building was carried out between MSP and Taisei’s Resident Surveyor. The investigation was carried out on 27th May 2006 between 9am to 12am in the morning. The aim of this investigation was to relate the pre-computation between the survey readings with Manual Precision Leveling and total station raw readings, as well as with the processed readings. This pre-computation allow a relationship of validating the processed readings from the Automated System, that they truly reflect the raw readings obtained from the site, as the entire survey cycle is processed as a whole.

Verification on Site
The investigation carried out on 27th May 2006 is explained in this passage. A separate total station (B) was mounted on a tripod at the roof of Lip Hing Industrial Building and the existing total station (A) was used as well. With a known settlement point GL9540 as Reference and targeting it with a mini prism, both prisms PT88 and PT86 and GL9540 was targeted and recorded in two (2) faces using total stations (A) & (B). This exercise was to correlate and compute the difference from prism to prism height and relate them to the processed readings or RL. This method also eliminates any suspicion of the existing instrument accuracy.

Results & Conclusion
The difference in height between PT88 and PT86 obtained from raw (A) instrument was h₁=6.739m.
The difference in height between PT88 and PT86 obtained from raw (B) instrument was h₂=6.739m.
The difference in height between PT88 and PT86 obtained from processed readings (B) instrument from the Real Time Monitoring System was h₂=6.739m.
The existing (B) instrument on top of Lip Hing Industrial Building has a bigger spread between F1 and F2 compared to (A) instrument sitting on top of Tripod, which was recently calibrated. This comparison is made to the Manual Targeting Mode only.

There is a constant 13mm difference in the Reduced Level from Precision Level with the Automated Monitoring System. This means that the initial Reduced Level of the Automated Monitoring System started with 13mm from the absolute Reduced Level. This difference has no bearing to the resultant displacement obtained from the Automated Monitoring results.

Settlement result from Taisei’s Resident Surveyor revealed a highest –9mm precision.
leveling obtained for the period from 20\textsuperscript{th} April 2006 to 27\textsuperscript{th} May 2006, which coincides exactly to the results obtained for the same structure and period as the Automated Monitoring System.

In the above findings, it was concluded that the reading obtained from the Automated Monitoring System correctly reflects the displacement of the monitored structure from the site. With a proven track record of robust and accuracy, and steps taken to check, replace, calibrate, recalculate and study the effects, the goal was to make sure that the current and future readings were to be reliable.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure1}
\caption{60mm DIA Prism}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure2}
\caption{25mm DIA Prism}
\end{figure}
PROJECT PHOTOGRAPHS

Lip Hong Industrial

Lip Hong Industrial

Junction 8 Condominium

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MONITORING SOLUTION PROVIDERS PTE LTD
33 Ubi Avenue 3, #05-31, VERTEX
Singapore 408868
Tel: +65 – 67479766
Fax: +65 – 6458 0824
E-mail: enquiry@mspsystem.com
Website: www.mspsystem.com
Co. Reg No: 200210421W