BREAKWATER STRUCTURAL MONITORING USING VRS-RTK TECHNIQUE

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Abstract

The geodetic and geotechnical technique have long history in deformation monitoring. However, the last few years, the GPS technique has been display that GPS sensor can be effectively deployed in structural health monitoring or deformation monitoring. With recent advance of GPS technology, structure monitoring can be conducted using modern RTK technique namely VRS-RTK. VRS-RTK is a virtual non-existing station created from a real observation of a multiple reference station network. The launched of Malaysia Real Time Kinematic GPS network (MyRTKnet) by Department Survey and Mapping Malaysia makes VRS-RTK technique available. This paper firstly focuses on the principle of VRS-RTK technique in structural monitoring. Further discussion include the significance of this technique based on a study case of breakwater structure in Kemaman, Terengganu.

Keywords: Global Positioning System, VRS-RTK, breakwater monitoring

1.0 INTRODUCTION

Deformation survey is an important area of engineering survey. It can be categorize into geotechnical, structural and geodetic technique. The geodetic technique of monitoring survey can be carried out using terrestrial positioning system and Global positioning system (GPS). However, this study only focus on latest approach of GPS for monitoring technique.

There is a great opportunity for receiver to be used as a sensor for structural monitoring. With the advance of GPS technology, the development of the full satellite constellation, continuous and automated monitoring using GPS becomes increasingly practical and cost-effective. In brief GPS can measure directly the position coordinates and even can detect the drift or displacement of object in high precision rate of 0.1s and higher using real-time mode. The sampling frequency of GPS receiver is about 0.05Hz, and the location precision can approach 5~10mm.

Currently, various studies have been made on the utilization of VRS-RTK through the establishment of network-RTK infrastructure or frequently denoted as continuously operating reference system (CORS) worldwide. It is noted that VRS-RTK in general resolves the limitation of distance-dependent error of classical GPS-RTK technique. Considering on the reliability of Malaysian network-RTK namely, MyRTKnet on providing a dependable positioning accuracy, it is suggested that VRS-RTK can be well-implemented in local high accuracy applications i.e. structural monitoring.

This study presents the methodology and findings of the GPS survey measurements at the South Breakwater of the Export Terminal, Tanjung Sulong, Kemaman, Terengganu Darul Iman (Figure 1). The South breakwater was constructed between 1981 and 1985 to facilitate entrance of ship and protect the

Export Terminal of the Plant Operation Division of PETRONAS Gas Berhad (PGB). The breakwater is of rubble mound type armoured with stone of igneous rock, weighing 5-10.5 tonnes. In order to monitor the performance of the structure due potential movements subsequently induced by wave action and seepage, the monitoring survey were carried out.

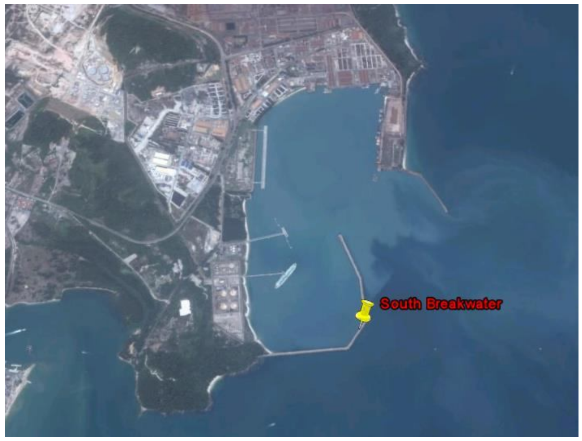


Figure 1: **South Breakwater at Export Terminal Tanjung Sulong, Kemaman, Terengganu**

2.0 METHODOLOGY

A set of GPS measurements were conducted throughout the observation campaign. As the result of measurement campaigns, the X, Y, Z cartesian coordinates was determined from the comparison of static survey and VRS-RTK survey measurements. The monitoring point (A, X, B, C, D and E) at breakwater is as shown in Figure 2.

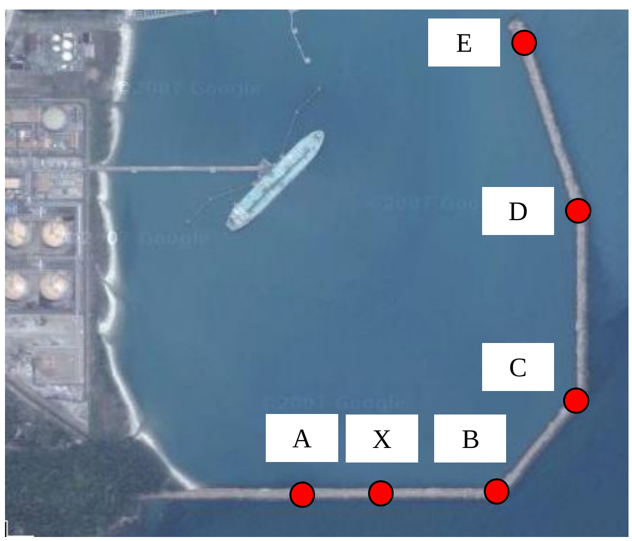


Figure 2: **Monitoring point at South breakwater**

The flow of GPS campaign is as ilustrated in Figure 3.

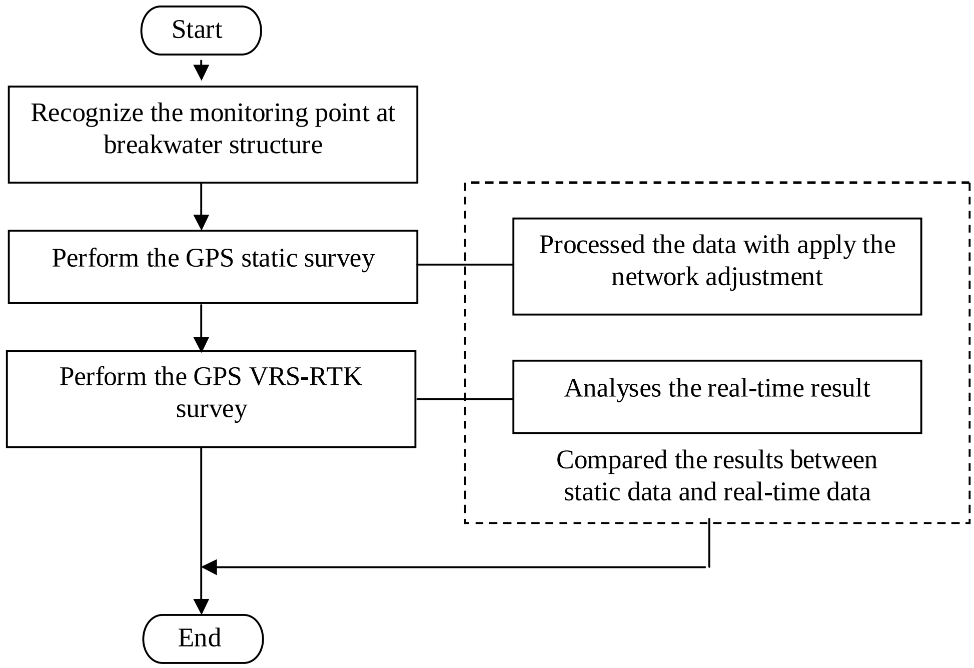


Figure 3: **Flow of GPS campaign**

Two GPS campaigns which include the static survey and VRS-RTK survey were performed. The system consists of a number of GPS receiver units (sensors) on the monitoring points, plus one or more reference receivers installed at fixed and known points. For the purposed of study, the static survey data will be used as a reference. The VRS-RTK on the other hand survey provided the real-time monitoring result.

Static surveying is a relative positioning method using carrier-phase measurements. Static GPS employs two or more stationary receivers to track the same satellite. In survey works, the used of static surveying includes the control survey, boundary survey and deformation survey. The concept of static survey is based on tracking the simultaneous measurements at both the base and rover receivers respectively. Figure 4 shows the concept of static GPS.

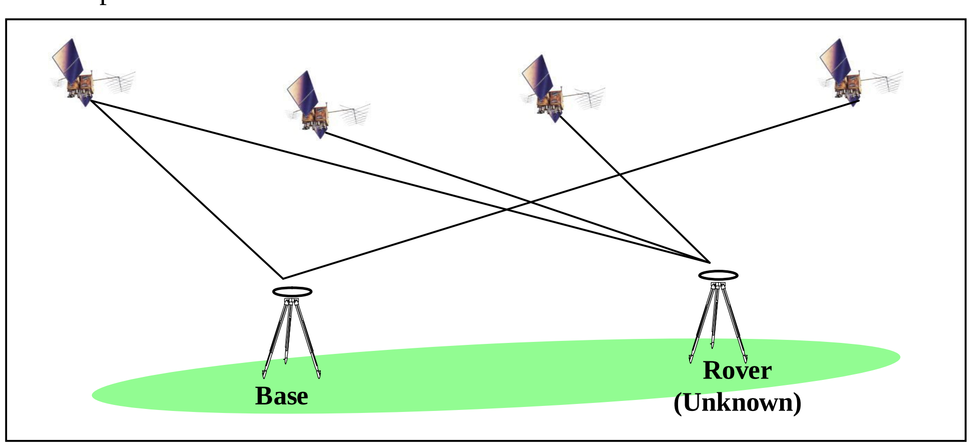


Figure 4: **The concept of static GPS**

One receiver is set up as base receiver at known point such as GPS monument (with precise coordinates), while the other receiver is set up as rover at any point (unknown point). Base receiver supports any number of rover receivers as long as both receivers track a minimum of four common satellites.

The network-RTK was a current worldwide trend. Malaysian Real-Time Kinematic Network (MyRTKnet) is a new nation-wide GPS network in Malaysia and this system infrastructure developed for GPS users to provide RTK and DGPS services with unmatched accuracy and coverage for positioning applications across the country. Our government push our country to developed this new generation of RTK to achieve her developed nation status for Real time survey and mapping infrastructure technology before year 2020. The VRS-RTK was perform to test the ability and reability performance of MyRTKnet. Currently, MyRTKnet have 65 RTK reference stations forming the network, covering the whole of Peninsular Malaysia and two major cities in Sabah and Sarawak. MyRTKnet provides high performance solution for real-time data collection needs of Malaysian users. Figure 5 shows the RTKnet stations in Malaysia.

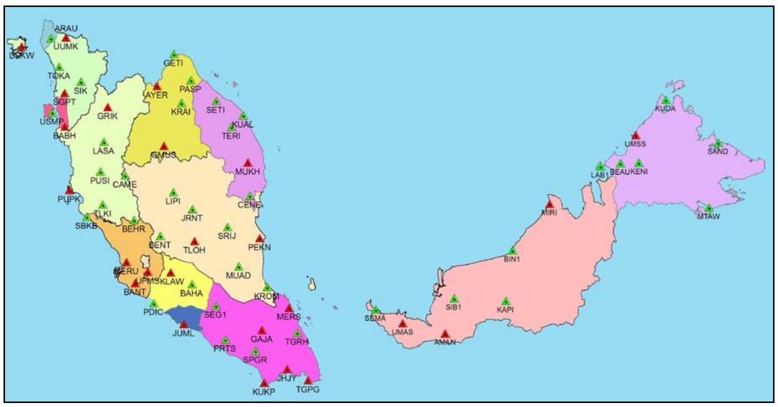


Figure 5: RTKnet Stations in Malaysia *(DSMM Geodesy, 2008)*

The rover receiver sends the approximate position in a standard NMEA position string called GGA to the control center using a mobile phone data link, such as GSM, 3G and GPRS. The control center will accept the position, and responds by sending RTCM correction data to the rover. As soon as it is received, the rover will compute a high quality DGPS solution, and update its position. The rover then sends its new position to the control center. The network server will calculate the new RTCM corrections so that they appear to be coming from a station right beside the rover. It sends them back out on the mobile phone data link. This VRS technique provides integrity monitoring with all users sharing the same common established coordinate frame. Figure 6 shows the concept of VRS-RTK technique.

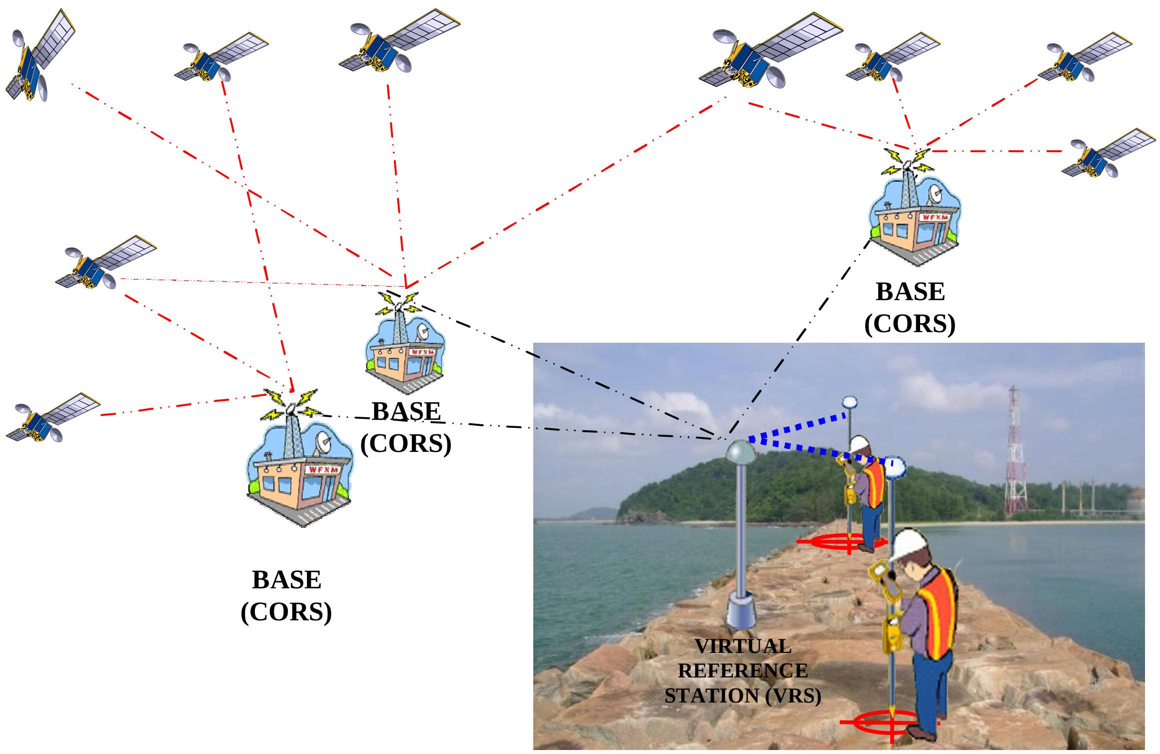


Figure 6: **Concept of VRS-RTK**

2.1 Instrumentation and Software

TRIMBLE 4800 and Topcon HiPer GA receivers were used throughout this project (Figure 7). It is a tightly integrated instrument in which all components (antenna, receiver and UHF radio link) are in one unit that sits atop a pole (which cleverly contains the batteries in its base) or a tripod. The TRIMBLE 4800 is a dual-frequency GPS receiver in which the electronic of GPS receiver and antenna can track and use data from both L1 and L2 signals from the GPS satellites. The advantages of dual-frequency receivers include, the ability to survey with higher accuracy for longer baselines and less occupation time spent at each survey (monitoring) points. The basic specification of both instruments are as shows in Table 1 and Table 2.

Figure 7: **TRIMBLE 4800 GPS Receiver and Topcon HiPer GA Receiver**

Table 1: **Accuracy of TRIMBLE 4800 Receiver**

Accuracy	
Horizontal accuracy	5 mm±0.5ppm
Vertical accuracy	10 mm±0.5ppm
Data storage of receiver	2 Mb

Table 2: **Accuracy of Topcon HiPer GA Receiver**

Accuracy	
Static, Fast Static L1+L2 L1	 H: 3mm+0.5ppm x D, V: 5mm+0.5ppm x D H: 3mm+0.8ppm x D, V: 4mm+1.0ppm x D"
Kinematic, RTK L1+L2/L1	 H: 10mm+1ppm x D, V: 15mm+1ppm x D"
DGPS	0.3m Post Processing, <0.5m Real-time

For data downloading the Trimble Geomatic Office (TGO) and Topcon Link software were used. The TGO software allows processing of raw GPS measurements in a single Microsoft Windows package. The main feature of the TGO software is the pull down menus that are user friendly and helpful with the provision of on-line help. As with other GPS software packages, the TGO provides the graphical display of the entire project with simple editing tool. Other features are such as the network adjustment, co-ordinate transformation and RINEX (Receiver Independent Exchange Format).

2.2 Field Work

The Department of Surveying and Mapping's GPS point (P227) was included in the network as a reference point for static survey. The following points were observed during the GPS campaign:

i. One reference station (P227).
ii. One control station (UTM01) near the Export Terminal. This point served as an additional reference station
iii. Six monitoring points (A, X, B, C, D and E) on the breakwater.

For the purpose of this study, two TRIMBLE 4800 receivers were used to make observations in static mode. For this implementation, one receiver was configured as reference station and the other as rover. The reference station located on P227 station 10.5 km from the monitoring point on the breakwater. This station was part of the JUPEM GPS network. Figure 8 shows the GPS set-up on the reference station and Figure 9 shows the set-up of rover station.

Figure 8: **Reference Station**

Figure 9: **Rover Station**

During the static survey, carrier phase observations were recorded every 15 second and on each day every station was observed for approximately half an hour. A minimum of four satellites were observed during the whole observation period. The static surveying technique have been conducted to establish the true positions (coordinates) of the monitoring points.

The P227 station is taken as a reference station for relative positioning in post-processing mode. The processing is done by invoking the PROCESS GPS BASELINES command. Network adjustment was performed using the TGO software. Output from this software consists of adjusted coordinates at two stations for each observation session, along with the associated covariance information. Since, the GPS positioning provides position in geocentric World Geodetic System 1984 (WGS84), the transformation of these coordinates to the local geodetic system is needed. In this case, the GPS data processing and reduction of the three dimensional WGS84 coordinates were performed to obtain Rectified Skew Orthomorphic (RSO) coordinates. The results of static GPS measurements for the six monitoring points were summarized in Table 3.

Table 3: **Coordinates of Static Monitoring**

Points	Latitude	Longitude	Height
A	4°14'20.33982"N	103°27'42.84803"E	9.608
X	4°14'20.33910"N	103°27'49.72737"E	9.703
B	4°14'20.32691"N	103°27'56.11772"E	9.645
C	4°14'25.88993"N	103°28'00.71422"E	6.887
D	4°14'35.74752"N	103°28'00.70558"E	6.728
E	4°14'46.22207"N	103°27'57.13856"E	7.100

Topcon HiPer GA receiver was used to perform the VRS-RTK technique. VRS-RTK measurement were perform at 1 epoch for every monitoring point. Every epoch include with 10 observations (no. of observation) and 1 observation was collected at an average of 5 second observation. VRS-RTK provide the position in real-time. The solution type of this observation was fixed solution. The example of the result for VRS-RTK observation mode is shows in the Table 4 and Table 5 shows the result of VRS-RTK survey.

Table 4: **Example result of VRS-RTK monitoring (Result of point A)**

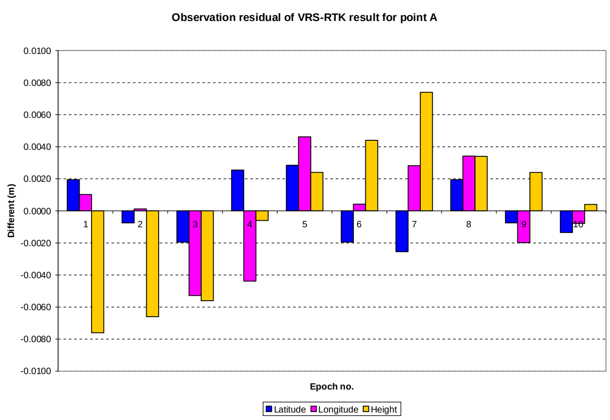
ANALYIS OF VRS-RTK										
Station no	A				Epoch				1	
No of observation	Latitude (U)				Longitude (T)				Ellipsoid height(m)	
	°	‘	″	v (m)	°	‘	″	v (m)	Observation	v (m)
1	4	14	20.33991	0.0019	103	27	42.84813	0.0010	9.606	-0.008
2	4	14	20.33982	-0.0008	103	27	42.8481	0.0001	9.607	-0.007
3	4	14	20.33978	-0.0019	103	27	42.84792	-0.0053	9.608	-0.006
4	4	14	20.33993	0.0025	103	27	42.84795	-0.0044	9.613	-0.001
5	4	14	20.33994	0.0028	103	27	42.84825	0.0046	9.616	0.002
6	4	14	20.33978	-0.0019	103	27	42.84811	0.0004	9.618	0.004
7	4	14	20.33976	-0.0026	103	27	42.84819	0.0028	9.621	0.007
8	4	14	20.33991	0.0019	103	27	42.84821	0.0034	9.617	0.003
9	4	14	20.33982	-0.0008	103	27	42.84803	-0.0020	9.616	0.002
10	4	14	20.33980	-0.0014	103	27	42.84807	-0.0008	9.614	0.000
Average	4	14	20.33985		103	27	42.84810		9.614	
Minimum	4	14	20.33976		103	27	42.84792		9.606	
Maximum	4	14	20.33994		103	27	42.84825		9.621	
RMS (m)	0.000				0.000				0.000	
Diff coordinate with true value	0.000				0.000				0.006	

Table 5: Coordinates of VRS-RTK Monitoring

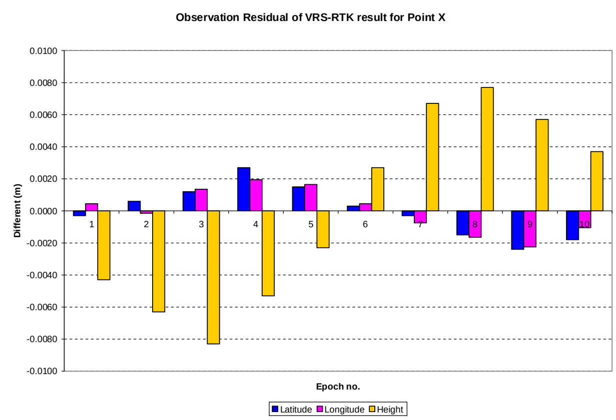
Points	Latitude	Longitude	Height
A	4°14'20.33985"N	103°27'42.84810"E	9.614
X	4°14'20.33914"N	103°27'49.72740"E	9.700
B	4°14'20.32692"N	103°27'56.11774"E	9.650
C	4°14'25.88997"N	103°28'00.71422"E	6.891
D	4°14'35.74749"N	103°28'00.70553"E	6.734
E	4°14'46.22208"N	103°27'57.13861"E	7.104

2.3 Data Analysis

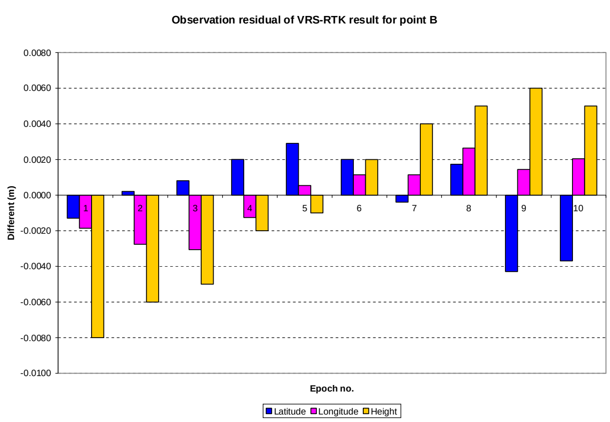
Statistical analysis was conducted using Root mean square (RMS) calculation. The mean of 10 VRS-RTK result for each point was compared with the static result. The different value of VRS-RTK result with the average coordinate for each point illustrated in Figure 10.



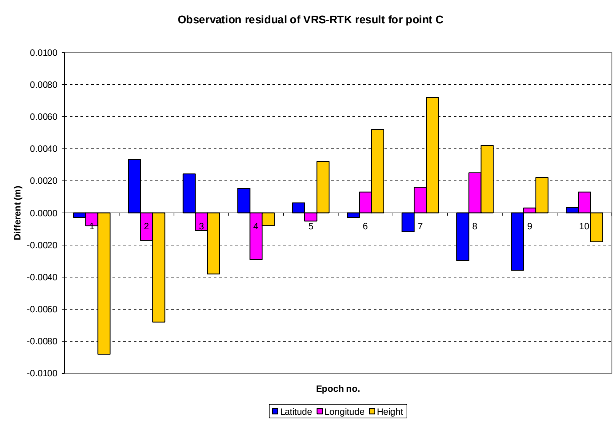
Point A



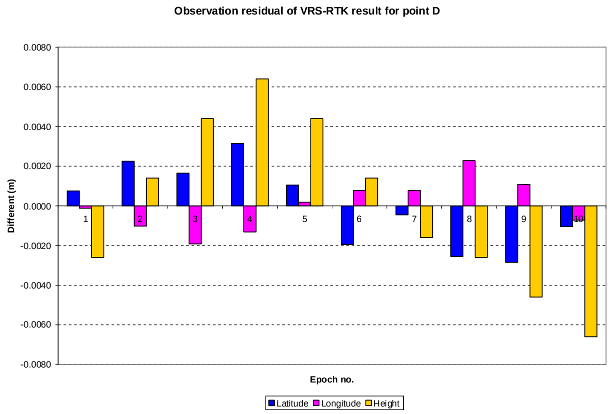
Point X



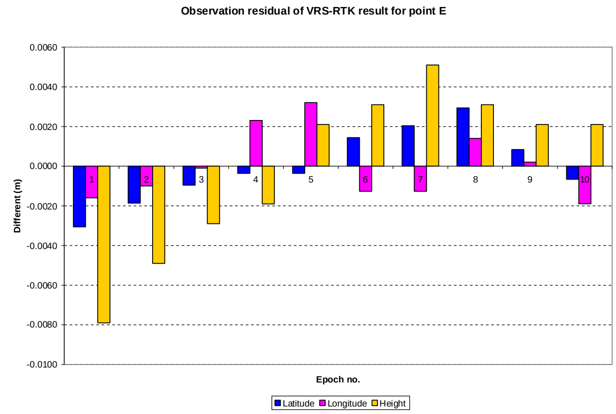
Point B



Point C



Point D



Point E

Figure 10: **Observation residual of VRS-RTK result for point A, X, B, C, D and E**

The graph shows that the horizontal component of VRS-RTK result gives a small residual (5mm) while the vertical component gives up to 1 cm residual. This result shows the VRS-RTK technique have a good potential for breakwater monitoring. In this monitoring case, it is suggest that the VRS-RTK can be used for structural monitoring. This VRS-RTK technique also suggest for monitoring work at in this country.

For the purpose of South Breakwater monitoring, observations campaign of static and VRS-RTK result were analyzed. The adjusted coordinates and reduced levels between two different campaigns (observation mode) were compared and investigated. Table 6 shows the adjusted coordinates (horizontal) of the monitoring points in the RSO coordinates system between two observation modes. Table 7 shows the difference coordinate for vertical component.

Table 6: **Difference Coordinates of Monitoring Points for Horizontal Component**

	Static		VRS-RTK		Differences (")	
Points	**Latitude**	**Longitude**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
A	4°14'20.33982"N	103°27'42.84803"E	4°14'20.33985"N	103°27'42.84810"E	-0.003	-0.007
X	4°14'20.33910"N	103°27'49.72737"E	4°14'20.33914"N	103°27'49.72740"E	-0.004	-0.003
B	4°14'20.32691"N	103°27'56.11772"E	4°14'20.32692"N	103°27'56.11774"E	-0.001	-0.002
C	4°14'25.88993"N	103°28'00.71422"E	4°14'25.88997"N	103°28'00.71422"E	-0.004	0.000
D	4°14'35.74752"N	103°28'00.70558"E	4°14'35.74749"N	103°28'00.70553"E	0.003	0.005
E	4°14'46.22207"N	103°27'57.13856"E	4°14'46.22208"N	103°27'57.13861"E	-0.001	-0.005

Table 7: **Height Differences for Vertical Component**

Points	Height of Static	Height of VRS-RTK	Differences
A	9.608	9.614	-0.006
X	9.703	9.700	-0.003
B	9.645	9.650	-0.005
C	6.887	6.891	-0.004
D	6.728	6.734	-0.006
E	7.100	7.104	-0.004

The coordinate difference for easting component is also about 7 mm. In regards to the vertical movement, the difference between these two observation mode is about 6mm. From Table 6 and 7, it can be concluded that the VRS-RTK gives good accuracy that shows the maximum settlement was about 7 mm. Figure 11 shows the difference of static and VRS-RTK in both horizontal and vertical component in detail.

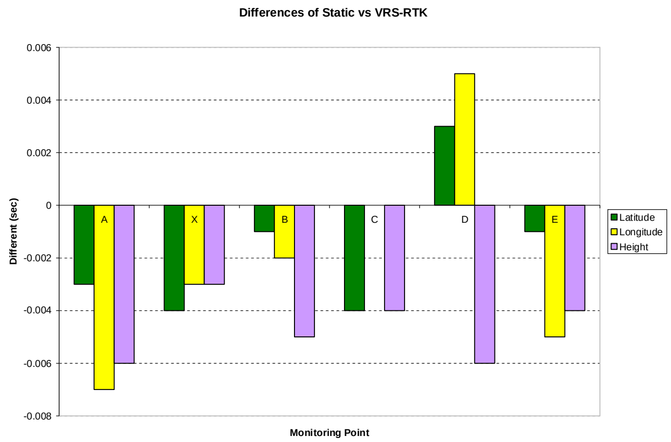


Figure 11: **Difference of Static vs VRS-RTK in Horizontal and Vertical Component**

3.0 CONCLUSION

The launched of Malaysian RTK GPS Network (MyRTKnet) by DSMM makes VRS-RTK technique available. VRS-RTK technique improves significantly the current single base GPS-RTK in terms of accuracy and reliability. Compared to other conventional method, GPS especially through the advent of VRS-RTK technique is capable to overcome the limitation of climate thus satisfying the demands of structural health monitoring for dynamically large engineering structures in Malaysia through the aspect of continuity, real-time and automation.

4.0 ACKNOWLEDGEMENT

The authors would like to acknowledge the Geodesy Section, Department of Surveying and Mapping Malaysia (DSMM) for providing the VRS data used in this study.

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