CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter expresses the final decisions made based on the results and findings of the study. The study was oriented to find solutions for the research problems whether it is beneficial to apply GPS surveys in building construction, what GPS survey techniques are applicable for vertical alignments in high-rise buildings, which one is the best suitable technique among them, and what problems or challenges are there in such GPS applications in high-rise buildings? This chapter explains in detail how it is concluded to accomplish the problems. It further presents the recommendations and suggestions towards the improvements of GPS surveys and future researches.

6.2 Conclusions

According to the results achieved through the analysis of the data gained through experts' comments, case studies and experiments, it can be concluded as follows on the suitability of GPS survey techniques for vertical alignments in high-rise buildings and the challenges or problems to be considered in such applications.

6.2.1 GPS survey techniques in high-rise buildings

The comparison between the GPS techniques and traditional survey methods shows that though the GPS techniques except RTK cannot be used for setting out works, the difficulties of surveying in high-rise buildings are extremely simplified by their great advantages such as better accuracy, efficiency, less time consuming, no need for inter-visibility, no need for references within a shorter visible range, day-night operation, weather independency etc.

Even though the traditional methods are used for surveying in high-rise buildings, it is necessary to have a proper system for cross-checking to ensure the quality.

Thereby, the RTK GPS with a proper system of cross-checking can be used for setting out tasks in high-rise buildings. Likewise, though the other GPS techniques cannot be used for setting out tasks, the applications of those GPS survey techniques with the combination of Total Station or other traditional survey methods for vertical alignments in high-rise buildings of any forms make surveying easier and more advantageous.

When considering the suitability of different GPS techniques for surveys in high-rise buildings, even though the setting out task which is the most important survey requirement in construction at the outset can be done by the RTK GPS, its questionable accuracy due to less redundancy drags it back in the order of the best suitability. Thus, the effectiveness and efficiency of GPS survey techniques on their standalone applications for vertical alignments in high-rise buildings are still lacking. Hence, it can be concluded that the GPS techniques can be applied for vertical alignments in high-rise buildings, but it should be combined with a proper system of cross-checks with traditional survey methods.

According to the literature, GPS techniques are not used as standalone survey techniques in high-rise buildings and they are applied with the combination of Total Station or other traditional survey methods. This situation is further supported and verified by the result gained in the preliminary data analysis on the methods of surveying applied in building construction projects in the industry. Thus suitability of GPS techniques for vertical alignments in high-rise buildings has to be considered with the combination of traditional survey methods.

According to the accuracy, efficiency, reliability and time consuming, both the experts' recommendations and the results of the case studies prove that Static GPS with the combination of Total Station or other traditional survey methods is the best suitable GPS survey technique for vertical alignments in high-rise buildings. Thereafter, Kinematic, RTK, Fast Static and Pseudo-Kinematic techniques take their places in the order given with the combination of traditional methods as above. It should be emphasized that the Kinematic technique was not recommended by the construction experts as an effective GPS technique for vertical alignments in building construction, but the final results express that Kinematic is the second best suitable GPS technique for the particular task. Core Wall Control Survey System is the best example for ensuring the suitability of GPS techniques in high-rise buildings. The combination of GPS techniques and Total Station simplifies the tasks of surveying for vertical alignments in buildings with different morphology and heights.

6.2.2 Challenges

Even though the GPS surveys eliminate some problems faced while applying the traditional surveys methods, such as greater efficiency, less time consuming, no need for inter-visibility, no need for references within a shorter visible range, around-the-clock operation, weather independency etc., still there are many challenges to be vigilant while applying the GPS surveys in building constructions.

Generally the operational and space related challenges are common for any kinds of GPS surveys. As per the comments of the related professionals and field experts, the relative importance indices express that the nature of environment, shape of the structure, construction interferences, distance from the reference stations, need of powerful communication link, necessity of CORS, building movement, safety, quality control and electro-magnetic signal interferences are the major challenges to be considered while applying the GPS techniques for vertical alignments in high-rise buildings. As explained in the previous Chapter, these findings are further supported and verified by cross-checking done in the case studies and experiments.

Although the other space related and operational challenges such as visibility to sufficient number of satellites, atmospheric disturbances, expensiveness, ambiguity resolution, data latency, cycle slip, ionospheric turbulences etc., are covered in the list of challenges, they are very common for all kinds GPS survey applications and do not particularly influence the task of vertical alignments in high-rise buildings only.

6.3 Recommendations

As per the direct observations, experience and results gained in the study, the followings can be suggested on the GPS survey applications for vertical alignments in high-rise buildings towards further improvements of the techniques and future researches on the subject.

- With a proper system of quality control or cross checks, GPS survey techniques can be applied without any hesitation for horizontal and vertical alignments in construction of buildings with different morphology and heights.

- As explained in the Core Wall Control Survey System, the combination of GPS techniques, Total Station and other necessary items such as clinometers can provide precise and reliable solutions for the challenging vertical alignment tasks in super high-rise buildings.

- Vertical alignment in high-rise buildings is a very important aspect and it should be performed very accurately. As per the results of the study, GPS survey techniques can be applied for this purpose as above. Thus it can be strongly recommended that there is no hesitation in using GPS surveys for other construction tasks also.

- Generally local Continuously Operated Reference Stations (CORS) are established for projects by spending large amount of money; this study emphasizes that the data and correction services of CORS network service providers can be utilized for precise survey tasks economically. But the reliability of the service should be ensured.

- Precise setting out with GPS is still a big challenge. Hence the future researches or inventors should focus on the improvement of GPS techniques to make possible the precise and reliable setting outs with GPS.

- Fast Static and Pseudo Kinematics GPS techniques are not widely used for surveys; but the accuracy of Fast Static technique is better than RTK GPS, and the Pseudo Kinematic GPS also provides the results very closer to RTK. This level of accuracy of the techniques emphasizes their applicability for precise surveys.

- It is necessary to take necessary precautions or be prepared to face the above challenges may arise when applying the GPS techniques for surveys in building constructions.

- Communication link is a serious problem in GPS surveying. Even though the master and user receivers function perfectly, there will be no use if there is no proper communication link between them. Thus it is a must to have a powerful communication link between the master and user receivers for better transmission of correction data. External radio and satellite data modem are recommended.

- In order to develop or further improve the GPS survey techniques, the future researchers and inventors can concentrate on finding solutions for the above problems or challenges.

- Providing solution for the above problems in GPS surveys will result a greater revolution in construction surveying.

- The control points established for the experiments in the buildings can be utilized for other purposes which deal with national grid system of Sri Lanka, SLD99.

- Since this report explains in detail the application of GPS surveys in building construction and related challenges, it will be a very good reference as a handbook for construction professionals who are looking to use GPS in their projects or find alternative solutions for traditional survey methods.

6.4 Future Researches

Based on this research approach and findings, future researchers can focus on the following facts or problems for further analysis towards the further developments of the GPS survey techniques and construction surveying.

- Effectiveness and efficiency of GPS survey techniques for vertical or elevation controls in high-rise buildings.

- A comparison study between the VRS network RTK and single base RTK GPS performances.

- Performances of different RTK communication links in construction environment.

- The economical impact of CORS network services on the construction industry of Sri Lanka.

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Appendix - A: Questionnaire

QUESTIONNAIRE

This questionnaire is issued to collect data for an academic research on the topic of IDENTIFYING THE TECHNIQUES AND CHALLENGES OF GPS SURVEYING FOR VERTICAL ALIGNMENT IN HIGH-RISE BUILDINGS.

It is brought to you to involve your honor to add more value to the research by sharing your expertise and experience to identify the techniques and challenges. The information given by your voluntary responses will be used only for the analysis of this academic research and it will be ever confidential.

Part I

Please tick **(✓)** and write in the spaces given as appropriate.

1. Designation/Status

Surveyor	
Engineer	
Architect	
Academic Professional	
Other ………………	

2. Workplace/ Country: …………………………………………………..........
3. Name (Optional): …………………………………………….…………………
4. Company/ Organization (Optional): …………………………………………

Part II

Please tick **(✓)** and write the most appropriate one and skip if not applicable.

1) Experience in Construction Surveying

Below 1 year	
1 to 3 years	
3 to 5 years	
5 to 10 years	
Above 10 years	

2) Experience in GPS Surveying

Below 01 year	
01 to 03 years	
03 to 5 years	
5 to 10 years	
Above 10 years	

3) Experience in Construction of High-Rise Buildings

Below 01 year	
01 to 03 years	
03 to 5 years	
5 to 10 years	
Above 10 years	

4) Maximum number of stories involved

Less than 4 Stories	
4 to 12 Stories	
13 to 40 Stories	
More than 40 Stories	

Name of the Project: - ……………………………………………………….

5) Which method do you use for Horizontal and Vertical alignments in High-Rise Building?

GPS	
Total Station/ Traditional Method	
Combination of both	

6) If GPS, which technique do you use?

Static	
Rapid Static	
Pseudo Kinematic	
Kinematic	
Real Time Kinematic (RTK)	

Part III

Please indicate (✓) your level of acceptance, and write in the spaces given if there is anything to add.

1. Problems in using traditional surveying methods for Horizontal and Vertical alignments in High-Rise Building

	Strongly Disagree	**Disagree**	**Slightly Agree**	**Agree**	**Strongly Agree**
	1	**2**	**3**	**4**	**5**
1. More time consuming					
2. Inter-visibility between stations					
3. Building movement					
4. Shape of the structure					
5. Safety					
6. Nature of environment					
7. Distance from reference stations					
8. Applicability in night times					
9. Transferring the control points to upper level					
10. Construction Interferences					
……………………….					

2. How do you assess the level of accuracy, efficiency, quality and cost implication of GPS application for vertical alignments in High-Rise building against traditional survey methods?

	Worst	**Worse**	**About the Same**	**Better**	**The Best**
	1	**2**	**3**	**4**	**5**
1. Accuracy					
2. Efficiency					
3. Quality					
4. Cost implication					
…………………					

Part IV

1. Please indicate **(✓)** your level of recommendation on GPS techniques applicable for controlling verticality in High-Rise building during construction.

	Strongly Not Recommended	**Not Recommended**	**Questionable**	**Recommended**	**Strongly Recommended**
	1	**2**	**3**	**4**	**5**
1. Static					
2. Rapid Static/Fast Static					
3. Pseudo Kinematic					
4. Kinematic					
5. Real Time Kinematic (RTK)					

2. How do you assess the level of accuracy of those GPS techniques?

	Poor	**Average**	**Good**	**Very Good**	**Excellent**
	1	**2**	**3**	**4**	**5**
1. Static					
2. Rapid Static/Fast Static					
3. Pseudo Kinematic					
4. Kinematic					
5. Real Time Kinematic (RTK)					

3. Are there any Challenges in using GPS for controlling Verticality in High-Rise Buildings?

YES		NO	

4. Some of the possible Challenges are given below. Please indicate **(✓)** your level of acceptance appropriately; and write in the spaces given if there are more apart from these.

	Strongly Disagree	**Disagree**	**Slightly Agree**	**Agree**	**Strongly Agree**
	1	**2**	**3**	**4**	**5**
I. Practical Challenges					
1. Building Movement					
2. Shape of the Structure					
3. Safety					
4. Nature of Environment					
5. Quality Control					
6. Electromagnetic Signal Interferences					
7. Construction Interferences					
………………………..					
………………………..					

	Strongly Disagree	Disagree	Slightly Agree	Agree	Strongly Agree
	1	**2**	**3**	**4**	**5**
II. Operational Challenges					
8. Operation of Reference Receivers/CORS					
9. Distance from Reference Receivers					
10. Data Latency					
11. Ambiguity Resolution (AR)					
12. Difficult to Determine the Observation Span for AR					
13. Need of Powerful Communication Link					
14. Expensiveness					
15. Cycle Slip					
16. Number of Visible Satellites and Selective Availability					
………………………..					
………………………..					
………………………..					
………………………..					

	Strongly Disagree	Disagree	Slighty Agree	Agree	Strongy Agree
	1	**2**	**3**	**4**	**5**
III. Space Related Challenges					
17. Ionospheric Turbulences					
18. Mesospheric, Stratospheric and Tropospheric Disturbances					
…………………					
…………………					

Part V

If you wish to give any important comments or advices, please write here.

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………….....

Appendix - B : Transformation Parameters (WGS84 to SLD99)

7 parameters to transform coordinates from WGS84 to SLD99,

- Translation ΔX = 0.2933 m
- Translation ΔY = -766.9499 m
- Translation ΔZ = -87.7131 m
- Rotation about X axis = 0.1957040”
- Rotation about Y axis = 1.6950677”
- Rotation about Z axis = 3.4730161”
- Scale factor = 1.0000000393

Appendix - C : Coordinate Transformation Matrices – 'The Element'

- **Matrix A**

$$\left|\begin{array}{cccc} 84.533 & 139.37 & 1 & 0 \\ 139.37 & -84.533 & 0 & 1 \\ 104.043 & 88.986 & 1 & 0 \\ 88.986 & -104.043 & 0 & 1 \\ 134.322 & 90.767 & 1 & 0 \\ 90.767 & -134.322 & 0 & 1 \end{array}\right|_{6 \text{ X } 4}$$

- **Matrix P**

$$\left|\begin{array}{cccccc} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right|_{6 \times 6}$$

- **Matrix L**

$$\left|\begin{array}{c} 404184.950 \\ 490102.872 \\ 404131.892 \\ 490092.693 \\ 404128.228 \\ 490062.578 \end{array}\right|_{6 \times 1}$$

- **$(A^TPA)^{-1} * A^TPL$**

$$\left|\begin{array}{c} -0.178883324 \\ 0.983877065 \\ 404062.9517 \\ 490210.9735 \end{array}\right|_{4 \times 1}$$

Appendix - D : Coordinate Transformation Matrices – ‘Clearpoint’

- **Matrix A**

$$\begin{vmatrix} 134.640 & 170.998 & 1 & 0 \\ 170.998 & -134.640 & 0 & 1 \\ 128.960 & 118.924 & 1 & 0 \\ 118.924 & -128.960 & 0 & 1 \\ 128.962 & 104.032 & 1 & 0 \\ 104.032 & -128.962 & 0 & 1 \end{vmatrix}_{6 \times 4}$$

- **Matrix P**

$$\begin{vmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix}_{6 \times 6}$$

- **Matrix L**

$$\begin{vmatrix} 403988.968 \\ 490194.664 \\ 403936.757 \\ 490198.911 \\ 403921.871 \\ 490198.500 \end{vmatrix}_{6 \times 1}$$

- **$(A^TPA)^{-1} * A^TPL$**

$$\begin{vmatrix} 0.0274759 \\ 0.99962844 \\ 403814.3341 \\ 490324.5556 \end{vmatrix}_{4 \times 1}$$