Korean Geodetic Datum 2002(KGD2002): Nationwide GPS Network Densification

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Key words: KGD2002, GPS, Network Densification, Adjustment Computation

SUMMARY

South Korea has adopted new geocentric geodetic datum (KGD2002) on the 1st January 2003. For this realization, both very long baseline interferometry(VLBI) and GPS technique were used to determine the coordinates of the 1st order national geodetic reference network consisting of 14 GPS CORSs (Continuous Operating Reference Stations). The coordinate determination was based on the International Terrestrial Reference Frame 2000 with the reference epoch of 2002.0. Subsequently, as the first phase of the geodetic network densification, the 2nd order network adjustment was performed in 2006.

Therefore, it is necessary to implement the second phase of the datum densification by adjusting the 3rd order geodetic network comprising about 11,000 points. This network has been observed by GPS from 1997 to 2007. This paper describes details of the network adjustment strategy and procedure adopted in the second phase of the KGD2002 densification. This is followed by presenting recent results of the 3rd order network adjustment, indicating that the accuracy of the adjusted coordinates is better than 1cm and 2cm in horizontal and vertical components, respectively.

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1. INTRODUCTION

According to the revision of the Survey ACT, the Korean geodetic datum was superseded by the new global geodetic datum, Korean Geodetic Datum 2002 - KGD2002, from 1st January 2003. This datum transition supports modern satellite positioning technologies and ensures that the national spatial data is compatible with the international standard. The KGD2002 is a global geocentric system in which coordinates are aligned to the International Terrestrial Reference Frame 2000(ITRF 2000) with reference epoch of 1st January 2002 (Epoch 2002.0).

This was achieved by determining the coordinates of the datum origin and the 1st order national geodetic control points consisting of 14 GPS Continuous Operating Stations(CORS) through very long baseline interferometry(VLBI) and GPS observations processing. The VLBI observation was conducted through Joint Geodetic Project of Korea and Japan in 1995, and the measurement was sent to NASA to connect to the IVS network on 14th November, 2000. The adjusted coordinates from this work is based on ITRF 2000 with reference epoch of 1997.0. From 17th to 26th January 2002, GPS baseline survey and five geodimeter observations were carried out from the VLBI stations to the datum origin marker. Through these procedures, the coordinates of origin of KGD 2002 was determined with the reference epoch of 2002.0. Hence, the origin coordinates were updated by including the vector of the crustal motion from 1997.0 to 2002.0.

The Korean geodetic network comprises three hierarchical levels, such as the 1st, 2nd and 3rd order control points. The 1st order network is comprised of 14 GPS CORSs, and all the points of the 2nd order network were re-surveyed by GPS from 1996 to 2000. On the other hand, the 3rd order control network is heterogeneous in that both of GPS and EDM were used in the observations. Figure 1-1 presents the adjusted 2nd order network with absolute confidence regions. As mentioned at the beginning of this section, the KGD2002 coordinates of the 1st order control points were made during the new datum realization. A nationwide network adjustment was carried out in 2006 so as to densifiy the KGD2002 by determine the KGD2002 coordinates of the 2nd and 3rd order control points (Lee, et al., 2006 & 2007).
After then, NGII(National Geographical Information Institute of Korea) had performed GPS campaign at the 2,123 points for homogenizing the 3rd order network from 2006 to 2007, which leads to adjust the 3rd order geodetic control network. Hence, the main purpose of this project is to adjust the 2nd and the 3rd order networks so as to determine the KGD2002 coordinates.

This paper focuses on describing issues related with the 3rd order GPS network adjustment for the densification of the new Korean geodetic datum. After presenting the overall adjustment procedure, a brief description of GPS observations and their baseline processing is given. As the main part of this paper, results of the 3rd order network adjustment are detailed in sequence. Special emphasis will be given to discuss on the quality control, stochastic modelling, and network accuracy.

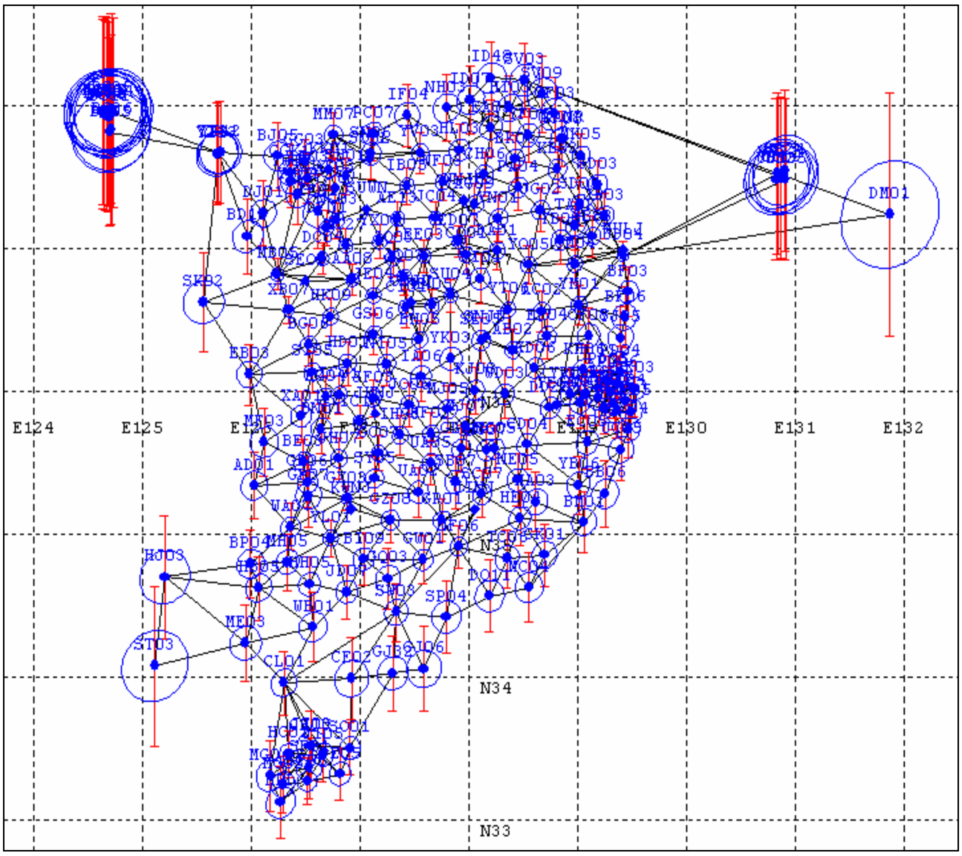

Figure 1-1. Adjusted network with absolute confidence regions (Lee et al., 2006 & 2007)

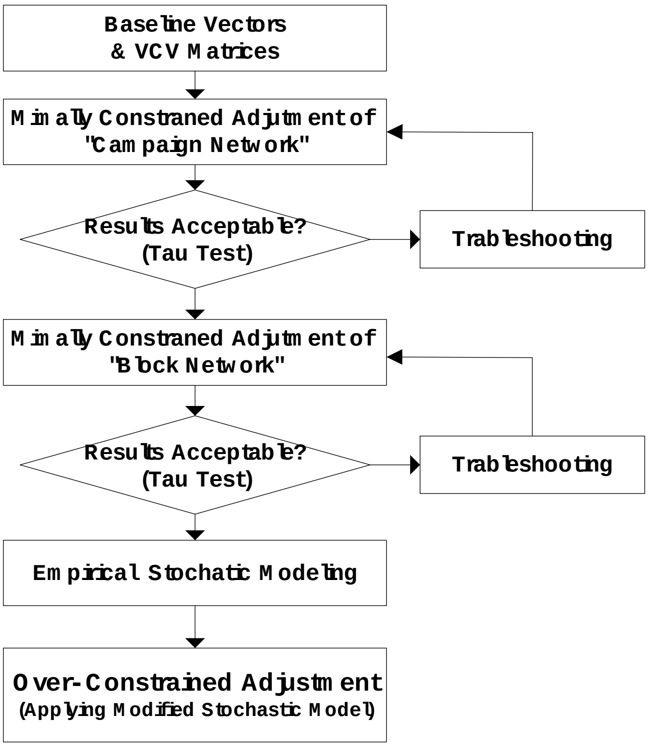

Figure 2-1. The 3rd order network adjustment flow

2. THE NETWORK ADJUSTMENT PROCEDURE

Figure 2-1 illustrates details on the procedure of the 3rd order network adjustment procedure. The adjustment began with minimally constrained adjustments with respect to each of the 81 campaign networks to detect outliers and ensure the quality of each network. After that, 20 block networks were constructed as shown in Figure 2-2 and each block network was successively adjusted with minimally constrained technique instead of considering a single nationwide network.

After detecting and removing outliers from the observation files, the empirical stochastic modelling techniques were applied to determine the magnitude of absolute and relative errors of the GPS baseline vectors. Finally, the over constrained adjustments were performed, in sequence, with respect to each of the block networks. In these block network adjustments, not only the 2nd order control points, but also the 3rd order control points, were overlapped by adjacent networks whose coordinates had been determined from preceding adjustments to avoid a dual coordinate estimation on the overlapped control points.

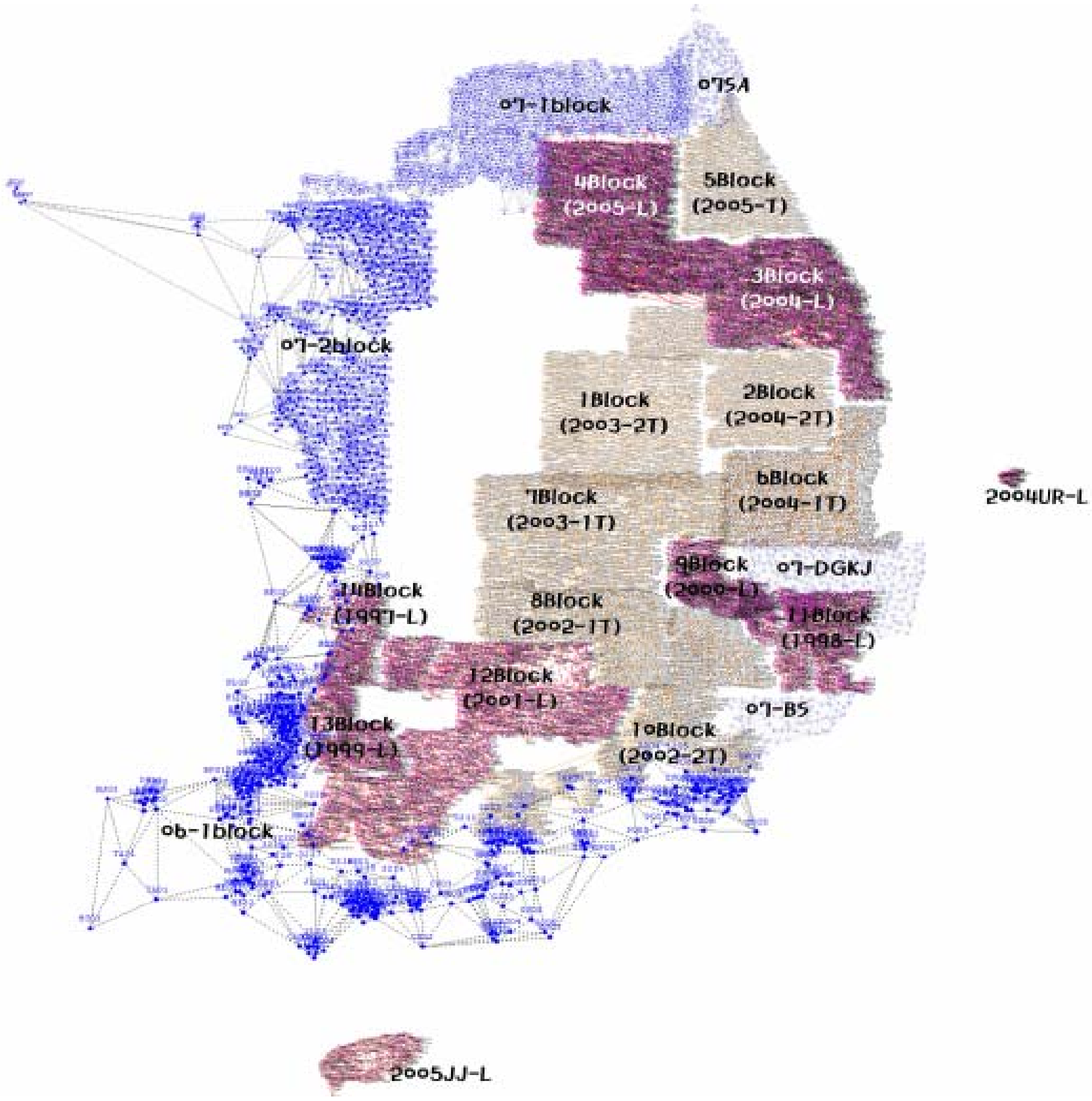

Figure 2-2. Composition of block networks

3. GPS OBSERVATIONS AND PROCESSING

The National Geographical Information Institute (NGII) of Korea together with a number of surveying contractors had held GPS observation campaign over the 3rd order geodetic network from 1997 to 2007. During these campaigns, about 10,000 points were observed. The Korean specification for GPS control surveying was applied for the observations so that the campaigns could achieve high levels of surveying efficiency and accuracy. The baseline length and GPS receiver occupation time was mostly 2 to 5km and 4 hours, respectively.

All the GPS data was initially processed by the surveying contractors, who made filed observations. Therefore, a number of different commercial software was used. However, in the case of GPS short baseline up to 10km, processing results are almost identical regardless which software is used. This is because applying the double-differencing technique to the GPS observation significantly reduce or even eliminate common error sources between a reference and a rover receiver. Hence, for this project, the processed baseline vectors, together with their variance-covariance (VCV) matrices, will be used in the subsequent adjustment unless significant problems (e.g., incorrect antenna heights and/or reference coordinates) exist.

Figure 3-1 shows an example of the adjusted block .

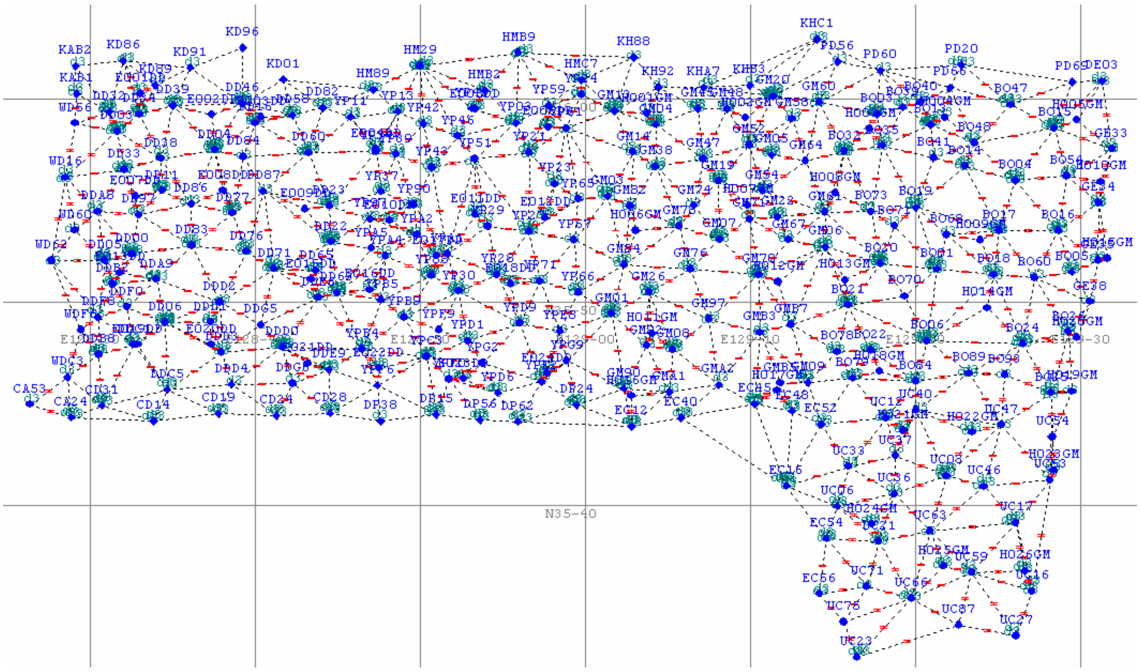

Figure 3-1. An example of the adjusted block Network (i.e., 2007-TG1, 180 points)

4. MINIMALLY CONSTRAINED ADJUSTMENT

Campaign network adjustments were carried out by fixing a single point of the 2nd order control point. They were performed with respect to all of the 81 campaign networks. After removing all the baselines identified as outliers, block adjustments were performed network by network. In these block adjustments a single 2nd order control point was held fixed. From the two different levels of the minimally constrained adjustments, a total of 108 baselines were detected as outliers and were removed from the input data files.

Table 4-1 shows the number of baselines detected and removed from the two levels of adjustments.

The empirical stochastic modelling scheme was applied to the selected campaign network in which GPS observations were processed by both LGO(Leica Geo Office) and TGO (Trimble Geomatics Office) static data processing modules. This process made it possible to determine that the magnitude of the absolute and relative error was 5mm + 0.5PPM and 10mm + 1PPM for the horizontal and vertical component, respectively.

Table 4-1. Results of outlier detection and identification procedure

Block Name	Num. of Points	Number of outlier			Block Name	Num. of Points	Number of outlier		
		Campaign	Block	Total			Campaign	Block	Total
1997-L	241	5	1	6	2004-2T	1,057	0	0	0
1998-L	435	4	2	6	2004-L	824	4	6	10
1999-L	292	1	1	3	2004UR-L	43	0	0	0
2000-L	430	12	0	12	2005-T	820	0	1	1
2001-L	1,117	5	10	15	2005-L	1,062	5	6	11
2002-1T	569	0	0	0	2005JJ-L	194	0	0	0
2002-2T	792	3	0	3	2006-1	400	6	3	9
2003-1T	702	1	2	3	2007-1	1,074	13	2	15
2003-2T	1,192	1	0	1	2007-2	469	4	2	6
2004-1T	1,004	3	5	8	2007-SA	180	4	0	0

Table 4-2. Summary of difference between the adjusted and predetermined 2nd order control points within the block network (unit: m)

Component	Mean	RMS	Maximum	Minimum
Horizontal	0.036	0.044	0.108	0.004
Vertical	0.038	0.048	0.148	0.001

After modifying all of the original VCV matrices using the determined values, all the block networks were readjusted by fixing a single point. In order to examine the block networks' overall accuracy, a comparison of the adjusted coordinates to the predetermined 2nd order control points was made and tabulated in Table 4-2. It was evaluated from these results that the absolute accuracy of the adjusted coordinates averaged 3.6cm in the horizontal and 3.8cm in the vertical component.

Relative confidences showing internal accuracy of 16 regions with respect to 95% probability were computed from the estimated parameters' VCV matrix and their statistical summaries are given in Table 4-3. It is found from the results that the average values were better than 1cm and 2cm in the horizontal and vertical components, respectively.

Table 4-3. Statistical summary of absolute confidence regions with 95% probability (unit: m)

Block	Comp.	Mean	Std.	Max.	Block	Comp.	Mean	Std	Max.
1997-L	Hor.	0.006	0.001	0.011	2004-2T	Hor.	0.006	0.001	0.011
	Ver.	0.014	0.003	0.026		Ver.	0.013	0.002	0.026
1998-L	Hor.	0.006	0.001	0.009	2004-L	Hor.	0.006	0.001	0.011
	Ver.	0.013	0.002	0.020		Ver.	0.014	0.002	0.026
1999-L	Hor.	0.006	0.001	0.009	2004UR-L	Hor.	0.006	0.001	0.008
	Ver.	0.013	0.002	0.021		Ver.	0.014	0.002	0.018
2000-L	Hor.	0.006	0.002	0.025	2005-T	Hor.	0.006	0.001	0.009
	Ver.	0.013	0.004	0.056		Ver.	0.014	0.002	0.020
2001-L	Hor.	0.006	0.002	0.028	2005-L	Hor.	0.006	0.001	0.009
	Ver.	0.014	0.003	0.064		Ver.	0.013	0.002	0.021
2002-1T	Hor.	0.006	0.001	0.010	2005JJ-L	Hor.	0.007	0.001	0.012
	Ver.	0.014	0.002	0.023		Ver.	0.015	0.002	0.027
2002-2T	Hor.	0.006	0.001	0.020	2006-1	Hor.	0.012	0.003	0.019
	Ver.	0.014	0.003	0.045		Ver.	0.027	0.006	0.043
2003-1T	Hor.	0.006	0.001	0.020	2007-1	Hor.	0.007	0.002	0.015
	Ver.	0.013	0.002	0.023		Ver.	0.016	0.004	0.034

5. OVER CONSTRAINED ADJUSTMENT

The final stage of the order network adjustment for determining the KGD2002 coordinate sets, over constrained adjustments were successively performed with respect to the 20 block networks. In these adjustments, all available 2nd order control points within the block network, and the 3rd order control points, overlapped with adjacent networks whose coordinates had been estimated from a preceding block network adjustment.

This approach avoids the repetitious estimation of the overlapped points between two adjacent block networks. The series of over constrained adjustments estimated KGD 2002 coordinate sets of 10,867 control points. Table 5-1 shows the order of the block network adjustment, the number of baselines and the points adjusted.

Table 5-2 shows the absolute confidence regions with respect to 95% probability from the final over constrained adjustments of 3rd order network. These results indicate that the absolute accuracy of the estimated coordinates of the 3rd order points averaged better than 1cm and 2cm in the horizontal and vertical components, respectively. However, it is important to note that this accuracy does not reflect the uncertainty of the 2nd order points fixed in the adjustments

Table 5-1. Summary of over constrained adjustments

Adjust. Order	Block	Number of points	Number of baselines	Adjust. Order	Block	Number of points	Number of baselines
1	2003-2T	1,292	5,055	11	1998-L	435	1,790
2	2004-2T	1,057	3,936	12	2001-L	1,116	4,024
3	2004-L	824	2,800	13	1999-L	291	1,139
4	2005-L	1,062	3,852	14	1997-L	240	1,657
5	2005-T	820	2,863	15	2004UR-L	32	83
6	2004-1T	1,004	3,893	16	2005JJ-L	188	606
7	2003-1T	902	3,527	17	2007-1	1,074	3,806
8	2002-1T	569	2,155	18	2007-2	469	1,475
9	2000-L	430	1,657	19	2006-1	400	1,284
10	2002-2T	794	2,816	20	2007-SA	180	447

Table 5-2. Statistical summary of absolute confidence regions (95%)

Block	Comp.	Mean	Std.	Max.	Block	Comp.	Mean	Std	Max.
1997-L	Hor.	0.006	0.001	0.011	2004-2T	Hor.	0.007	0.001	0.011
	Ver.	0.023	0.003	0.026		Ver.	0.015	0.003	0.026
1998-L	Hor.	0.007	0.002	0.009	2004-L	Hor.	0.006	0.001	0.011
	Ver.	0.016	0.004	0.020		Ver.	0.015	0.003	0.026
1999-L	Hor.	0.007	0.002	0.009	2004UR-L	Hor.	0.006	0.001	0.008
	Ver.	0.015	0.004	0.021		Ver.	0.015	0.003	0.018
2000-L	Hor.	0.008	0.003	0.025	2005-T	Hor.	0.006	0.001	0.009
	Ver.	0.017	0.007	0.056		Ver.	0.014	0.002	0.020
2001-L	Hor.	0.007	0.002	0.028	2005-L	Hor.	0.006	0.001	0.009
	Ver.	0.017	0.005	0.064		Ver.	0.015	0.003	0.021
2002-1T	Hor.	0.006	0.001	0.010	2005JJ-L	Hor.	0.007	0.004	0.012
	Ver.	0.015	0.003	0.023		Ver.	0.016	0.009	0.027
2002-2T	Hor.	0.007	0.002	0.020	2006-1	Hor.	0.009	0.002	0.020
	Ver.	0.016	0.004	0.045		Ver.	0.021	0.005	0.047
2003-1T	Hor.	0.006	0.001	0.020	2007-1	Hor.	0.006	0.002	0.019
	Ver.	0.014	0.003	0.023		Ver.	0.014	0.005	0.043
2003-2T	Hor.	0.006	0.001	0.015	2007-2	Hor.	0.004	0.001	0.010
	Ver.	0.014	0.003	0.024		Ver.	0.009	0.002	0.023
2004-1T	Hor.	0.006	0.001	0.012	2007-SA	Hor.	0.008	0.002	0.017
	Ver.	0.014	0.003	0.027		Ver.	0.019	0.005	0.039

6. CONCLUDING REMARKS

In order to keep in pace with international trend, to support modern space geodetic technologies and ensure that the national spatial data are compatible with the international standard, the Tokyo datum which had been used in Korea was superseded by the new geocentric datum (e.g., KGD2002) from 1st January 2003. The new datum was realized by determining the coordinates of the datum origin and the 1st order national geodetic control points consisting of 14 GPS Continuous Operating Stations (CORS) through very long baseline interferometry (VLBI) and GPS observations processing.

This paper describes issues related with nationwide GPS network adjustment for the 2nd phase of the densification of the new Korean geodetic datum (e.g., the 3rd order GPS network adjustment). First of all, general procedure of the GPS network adjustment was outlined. This was followed by giving a brief description of GPS observations and their baseline processing. Both of minimally and over constrained adjustment were performed to derive new KGD2002 coordinate sets for the 3rd order geodetic control points. It was possible from the results to conclude that the accuracy of the estimated coordinates is was better than 1cm and 2cm in horizontal and vertical component, respectively.

In order to re-establish homogenous geodetic network, NGII has continuously carried out GPS observations over about 1,000 control points since 2008(i.e., blank area in figure 2-2). Once the GPS observations are completed, it is planed to simultaneously perform the 3rd order network adjustment in year 2008/2009, which leads to supersede the old network established by traditional triangulation techniques.

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