GIP Ges. f. Industriephotogrammetrie mbH

Vorbemerkungen und Dank

1997 hat die Japanische Gesellschaft photogrammetrischer Firmen, Ass. of Precise Survey & Applied Technology (APA) einen Test initiiert um Einsatzbedingungen und Auswertemethoden von DGPS in der Bildflugpraxis zu erproben. Die Ergebnisse wurden 1998 bei einem Seminar in Tokyo vorgestellt. Aufgrund unserer besonders interessanten Ergebnisse waren auch Dr. Wübbena, Geo++ und ich zur Präsentation unserer Technologie und der Ergebnisse eingeladen.

Prof. Dr. Okamoto † von der Universität Kyoto hielt dabei einen Übersichtsvortrag über die erzielten Ergebnisse, der auch schriftlich in Japanisch vorliegt. Nach langer Zeit kann nun eine Übersetzung dieses Vortrages ins Englische vorgelegt werden.

Für den erheblichen Aufwand, diese Übersetzung durchzuführen und das Dokument in elektronisch gespeicherter Form bereitzustellen bedanke ich ganz herzlich bei Herrn Hiroyuki Hasegawa, GeoNet, meinem Vertriebspartner in Japan, der trotz seiner eng bemessenen Zeit diese Aufgabe angenommen hat.

Weiter bedanke ich mich bei der Ass. of Precise Survey & Applied Technology (APA), die die Teilnahme von GEO++ und GIP mit finanziert hat und so zum Erfolg der neuen Technologie in Japan beigetragen hat.

Besonders interessant ist ein Vergleich der Ergebnisse auf Seite 7. Zu vergleichen sind dabei z.B. die Spalten L5 und L6 gegen L7 und L8. Bei den Ergebnissen des Bildfluges mit der Zeiss-Kamera (Z1 - Z8) möchte ich besonders auf die Spalte Z8 hinweisen. Bei dieser Berechnung wurde nur ein Paßpunkt in der Blockmitte benutzt.

Dr. Erwin Kruck

Large Scale Aerial Photography and Triangulation Project in Toyonaka City Area

(Translated from Japanese Language)

Research Group selected Toyonaka city area as large scale aerial triangulation test site, for the second project area of GPS aerial triangulation test. Toyonaka city has already established precise ground controls as road management references, corresponding to 1/500 map sheets. At first an outlines of those control and check points is to be described briefly, and practical guidelines are derived from those precise ground controls for this test.

1 Flight Planning

Two different blocks, with different aerial camera systems, using GPS supported navigation / triangulation systems from Leica and Zeiss, were designed, corresponding to Toyonaka city 1/500 map sheet areas. Flight lines in two different blocks were identical to each other, expecting the so called pin point flight navigation, as described in the following planning map.

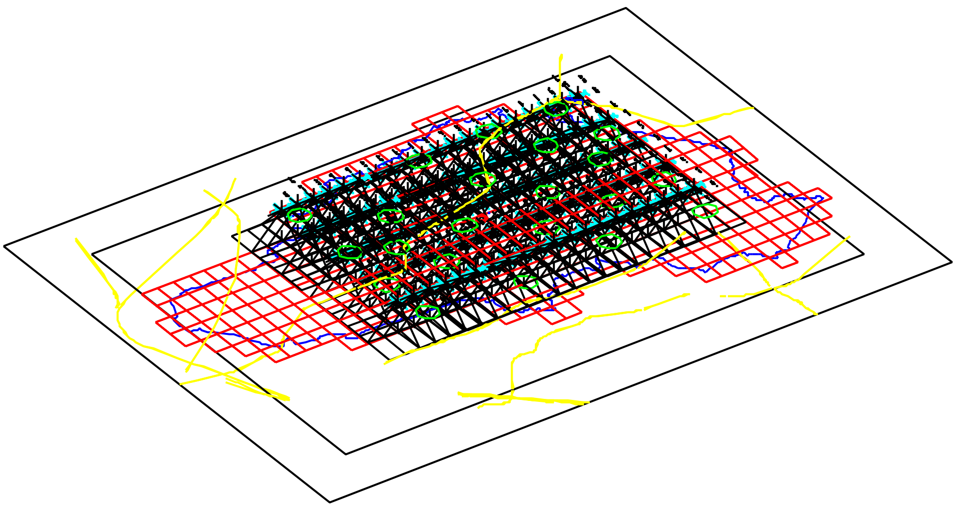

Fig. 1 GPS supported navigation and pin-point large scale photography

According to the current surveying regulation in Japan, 15% of flying height is the tolerance of exposure stations in the air, so GPS supported navigation system is highly recommended. There are some practical proprietary navigation systems in Japan, such as VEGA by Kyoritsu Aerial Photography, Inc..

To ensure the synchronized exposure time between GPS antenna phase center and perspective center of an aerial camera, the most advanced commercial systems, ASCOT from Leica and T-Flight from Zeiss were selected and planned.

Additionally, flight planning, exposure control and flight reporting softwares were expected to be the practical application and official flight record. The planned (Leica) and executed (Zeiss) flight lines are shown below.

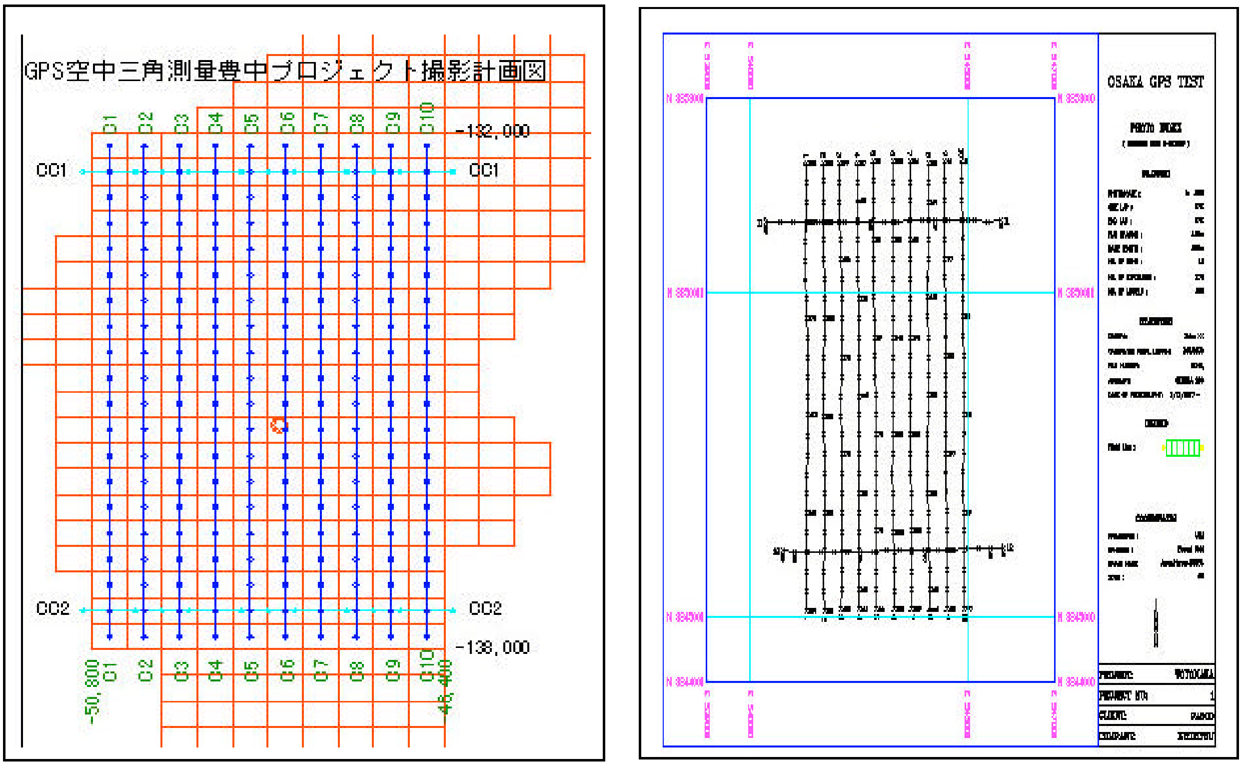

Fig. 2 Flight planning map (Leica) and flight reporting map (Zeiss)

As this flight planning was expected to coincide perspective centers with the centers of 1/500 map sheets of Toyonaka city, overlaps and sidelaps were much more than usual flight planning according to the surveying regulation. Representative items in flight planning are as follows:

PhotoScale	1/4,000			
Flying Height	600m	LEICA	1200m	ZEISS
Strips; No.	Parallel(N<>S)	10	20photos/strip	200 photos
Photos; No.	Cross(E<>W)	2	15photos/strip	30 photos
Exp. Interval	300m(Fix)	Ca.60%	designated	
Str. Interval	400m(Fix)	Ca.47%		
Camera	LEICA	RC-30	ZEISS	RMK-TOP
Focal Length	150mm	With FMC	W/o Gyro	300 mm
Navigation	LEICA	ASCOT	ZEISS	T-FLIGHT
Film	PANATOMIC-X	monochrome	Res. 250l/mm	PANATOMIC-X
Date / Aircraft	97.7.15	Cessna206	97.12.2	Caravan
Weather / Air	Cloudy / 24°C	7kt / 230°	H.Cl>Fine °C	30kt. 300°

Tab. 1 Flight planning and practice

2 GPS-Antenna-Baseline Surveying

GPS antenna phase centers were measured by baseline observations and adjusted with differenced and undifferenced solutions. At the airport, off-set measurement from projection center (fiducials) to GPS antenna phase center was done in advance before the flight. The following table shows technical items of the GPS baseline surveying before and during the flight.

Block	LEICA		ZEISS	
Ground Receiver	Trimble4000SS		Trimble4000SS	
Aircraft Receiver	LeicaGPS-Sys300		Trimble4000SS	
No. GCPs	Test site 2 Airport 1		Test site 2	
Frequency	L1		L1	L1,L2; not available
Time Interval	1Hz	1 session	2Hz	5 sessions
Navigation	ASCOT		T-FLIGHT	
Baseline GPS software	SKI-AERO	GEONAP	SKIP	GEONAP
GPS Antenna Offset	-1.83, -0.07, 0.73 (Unit in m)	Origin at perspective center	-0.02, 0.11, 1.48 (Unit in m)	X axis Flight direction

Tab. 2 GPS baseline surveying and offset measurement

3 Tie Point Selection, Pricking and Measurement on Analytical Plotter

With precisely calibrated analytical plotter, the most experienced operator did Tie point selection, Pricking and measurement on analytical plotter. He carefully selected control and check points out of 2000 existing ground controls. This process is described in the following table.

Block	Leica		Zeiss	
Pricking	PUG4		PUG4	
Tie point / photo	5pts / central line	Additional Tie points	5pts / central line	Additional Tie points
Measuring Instrument	Analytical plotter	C100	C130	Good calibration
No. of Tie-points	5364	Total no. 9986	5314	Total no.11330

Tab. 3 Tie point selection / Pricking / Measurement

4 Control / leveling / check points

In the entire area of Toyonaka city, more than 2,000 ground controls are established in square shaped concrete box of 40cm x 40cm size. In this test 500 points (averagely two points per photo) are used as check points.

3rd order ground surveying shows the accuracy of angular standard deviation (sigma 0) 5.5 arcsec., distance standard deviation 0.61cm and average reliability radius of new point 17.1mm. Leveling heights are given to 282 out of 484 check points (Leica block), and 248 out of 423 check points (Zeiss block), as direct leveled points.

Generally speaking, and from our experiences in the past projects, such as the previous research on middle/small photo scale GPS aerial triangulation tests, the presence of precise ground controls is quite an essential premise of this kind of research project.

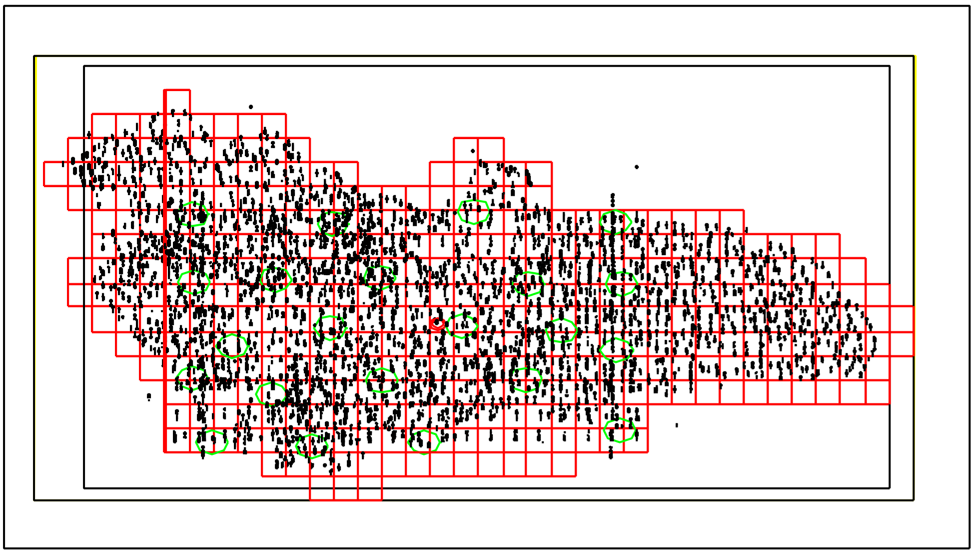

Fig. 3 Toyonaka map sheets (1/500) and ground controls: city area; 36.6 km^2

After the Kobe earthquake in 1995, offset from the center of the concrete box to the center of ground control metallic signal was measured for each ground control, and compensated to the official coordinate values of the ground control metallic signal, which was used as control / check point reference position.

Photo 1 Outlook of GCP box

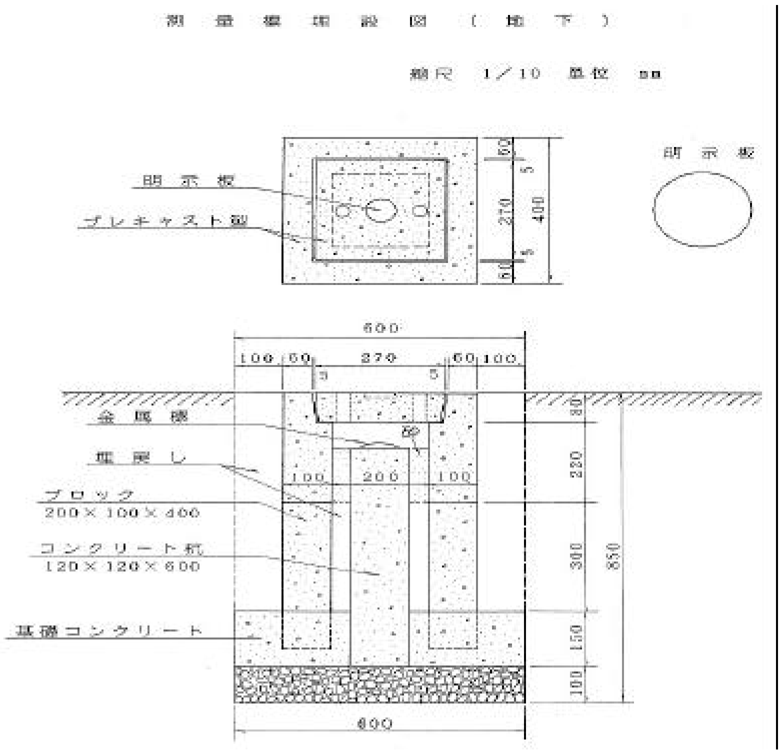

Fig. 4 Design of ground control box

5 Adjustments

After having completed measurement and orientations on an analytical plotter, block adjustments were done with PATB (INPHO), BINGO (GIP), and additionally KYOTO-B (Dr. Okamoto), ISBBA (Univ. of Melbourne Dr.Fraser).

Dr. Okamoto compared the results with his simulation data of this type. To investigate the accuracy indexes, such aspects as control type and location, observable weight, gross error detection and other error sources are discussed and classified. With those results and data, output figure and error ellipse presentation were prepared for the forthcoming practical projects.

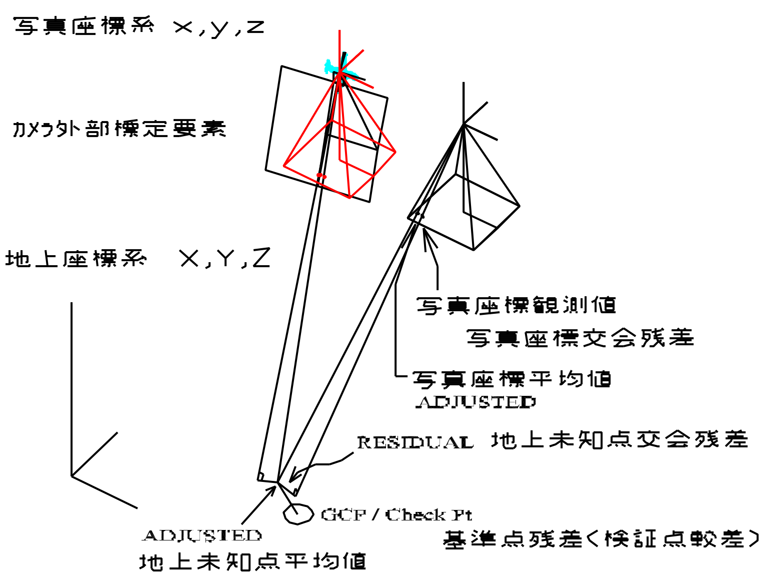

Fig. 5 Schema of accuracy index

6 Results and remarks

The current surveying regulation has such a tolerance value for the accuracy of aerial triangulation of 0.02% (in this flight 0.12m on the ground) of the flying height as RMS value of the adjusted GCPs. As our blocks have 22 GCPs, our RMS values are quite reasonably small according to the regulation, and not effective for the test purpose. In conclusion, accuracy indexes, such as external error of the check points,

σ_0 or Internal Error are used.

The results show high level accuracy of large scale aerial triangulation.

1) Superb accuracy at check points, according to the number rule of surveying regulation. (with 22 GCPs as controls)
2) Successful accuracy with only 4 corner controls and GPs antenna positions.
3) Non-linearity of GPS antenna position data and limit of Shift-Drift approach.
4) Un-neccesity of cross-strips, using Phase Ambiguity solution
5) Efficiency of self calibration

6.1 Achieved accuracy with 4 corner controls

When 4 corner controls were used, cases, L4,L5,L7,L8 show smaller external error at check points (Leica block; 0.12m --- flying height 600m), and cases, Z2, Z3, Z5, Z6, Z7 show smaller external error at check points (Zeiss block; 0.24m --- flying height 1200m).

As an extreme case, Z8, Bingo handled the block with only 1 point, showing the satisfactory accuracy according to the surveying regulation.

6.2 GPS baseline surveying softwares

To fix and compute phase ambiguity of mobile GPS antenna during the flight, some different solutions are available in production. Such differences in quality could be found in the previous table, such as the differences among the columns (L4/L5;L4/L8), using SKI-AERO and GEONAP. This test has also shown the importance of Undifferenced Observables as an additional product during the adjustments.

6.3 Necessity of Cross-strips

Starting from the initial stage of our tests in 1996, enforcement of a block with cross strips was regarded as inevitable requirement to tie the parallel strips over the area. The previous table, especially cases L8, Z6, Z7 show better σ_0 values and so forth, without any cross strips, on the contrary, cross strip cases show some influences from point pricking process.

As cases, L3, L6 and Z4 of Shift-Drift approach show bigger external error than (0.12, 0.24 respectively) without cross strips, cross strips are necessary for Shift-Drift approach.

6.4 For increase in accuracy in the future

As Dr. Okamoto indicated from the initial stage to realize the external error closer to internal error, GPS dual frequency/2Hz or more receiver, Phase ambiguity observable, Gyro- INS correction should be combined with GPS aerial triangulation software, and also better ground controls could let us discuss about check point accuracy within 1cm in the entire area for earthquake influenced country.

The following figures show the characteristics of the adjustments, shown in table 2.4, comparing some representative results.

Fig. 6 shows big residuals on the GPS antenna positions from the adjustment without GPS antenna positions. PATB of Shift-Drift approach shows big external errors at check points without cross strips.

Fig. 7 indicates small check point discrepancy of phase ambiguity approach (GEONAP/BINGO), without cross strips, as big residuals on the GPS antenna positions are eliminated.

Case No.		L1	L2	L3	L4	L5	L6	L7	L8	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8
		PATB						BINGO		PATB				BINGO			
No. of Self. Calib. Parameters		none	12	12	12	none	12	none	6+3	12	12	12	12	none	none	3+8	3+2
Cross Strips		yes	yes	NO	yes	yes	NO	yes	NO	yes	yes	yes	NO	yes	NO	NO	NO
GPS-Software		--	--	--	SKI	GEONAP		GEONAP		--	SKIP			GEONAP			
Weighting:																	
Photo Meas. [µm]		5	5	5	5	5	5	4.8	4.5	4/6	4/6	**4/6	4	4.4	4.4	4.4	4.4
Ground Controls [cm]		4	4	5	5	5	5	2,2	2,2	5	5	5	5	2,2	2,2	2,2	2,2
GPS [cm]		--	--	--	50	5	5	var	var	--	20	5	5	var	var	var	var
Results:																	
Adjusted GCPs		22	22	4	4	4	4	4	4	22	4	4	4	4	4	4	1
RMS Residuals of Control Points [cm]	in X	6	3,4	1,6	0,9	6,1	3,7	3,1	1,9	3,8	3,6	4,5	5,2	1,9	1,2	0,6	0
	in Y	6,2	4,5	1,6	0,5	4,4	2,4	1,3	1,6	3,6	4,6	4,2	5,9	2,7	1,6	0,7	0
	in Z	3,7	2,4	0,1	0,1	3,4	0,2	1,6	0,1	2,2	0,1	0,1	0,2	0,9	0,8	0,0	0
Sigma 0 [µm]		4.79	4.54	4.01	4.42	4.92	4.23	4.76	4.2	4.61	4.45	4.97	4.69	4.39	4.5	4.36	4.46
[cm]		1,9	1,8	1,6	1,8	2,0	1,7	1,9	1,7	1,9	1,8	2,0	1,9	1,8	1,8	1,7	1,8
Internal Error:																	
Std. Dev. of Adjusted Points [cm]	in X	3,2	3,0	4,5	4,5	4,0	4,0	3,1	3,1	3,4	5,2	5,6	5,6	3,8	3,9	3,9	5,8
	in Y	2,8	2,7	4,3	4,3	3,8	3,7	2,7	2,7	3,1	5,0	5,3	5,2	3,4	3,5	3,6	5,1
	in Z	6,9	6,5	18,5	11,6	5,3	15,7	5,7	5,7	13,5	15,6	13,6	34,8	11,3	12,1	11,9	16,4
No. of GPS / Photos					230	230	200	230	200		230	230	201	230	201	201	201
RMS Residuals of GPS Data [cm]	in X				11,1	4,3	3,6	4,4	4,0		13,1	2,8	2,9	4,8	4,8	4,6	4,6
	in Y				16,7	4,0	3,4	5,4	4,3		13,8	2,6	2,6	4,8	4,2	4,1	4,2
	in Z				55,7	7,3	4,9	6,2	6,0		6,7	4,3	4,2	4,5	4,4	4,4	4,6
External Errors:																	
No./Check Points		462	462	480	480	480	480	480	480	401	419	419	419	419	419	419	422
RMS Residuals of Check Points [cm]	in X	5,9	4,4	9,7	6,5	7,8	7,7	6,3	5,7	5,0	8,1	6,8	10,2	8,9	10,9	9,7	9,9
	in Y	8,1	6,2	10,9	8,5	8,0	6,2	6,3	4,8	4,5	8,7	7,2	9,1	8,5	11,4	10,6	7,0
	in Z	9,3	7,3	63,3	11,7	9,3	24,1	9,3	7,4	13,6	13,6	14,5	24,4	13,7	15,9	16,0	21,7
02% of Flying H [cm]		12	12	12	12	12	12	12	12	24	24	24	24	24	24	24	24
§ ¼ of § [cm] ContourInterval		25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25

Tab. 4 Accuracy Indexes in the adjustments (Leica/Zeiss camera blocks)

Fig. 8 shows small effect of tie point pricking from cross strips, even using GEONAP/BINGO, with cross strips.

Fig. 9 expresses the successful check point discrepancy which is far smaller than the tolerances of surveying regulation, using designated number of controls.

And the block with GEONAP/BINGO approach without cross strips has similar amount of check point discrepancy with 4 corner control points.

This is the ultimate goal of the test, to establish a new specification of GPS aerial triangulation projects.

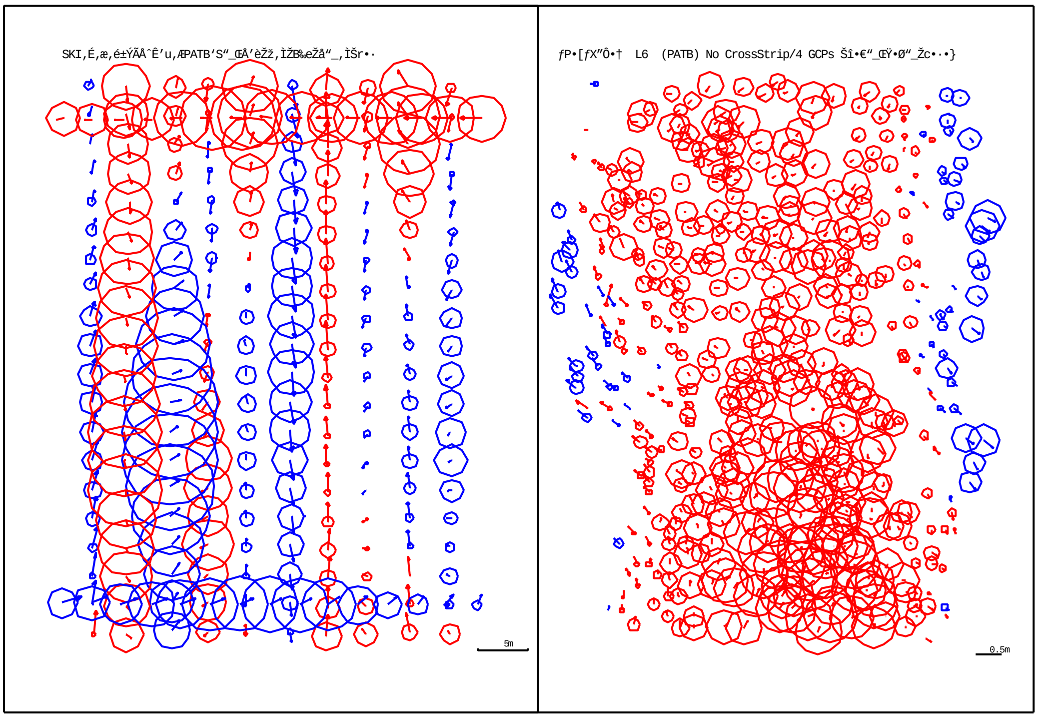

Fig. 6

Left: Discrepancy between GPS baseline surveying and PATB fully controlled block, and Non-linearity of GPS antenna phase center position

Right: (L5) Check point discrepancy of the four-corner control block without cross strips

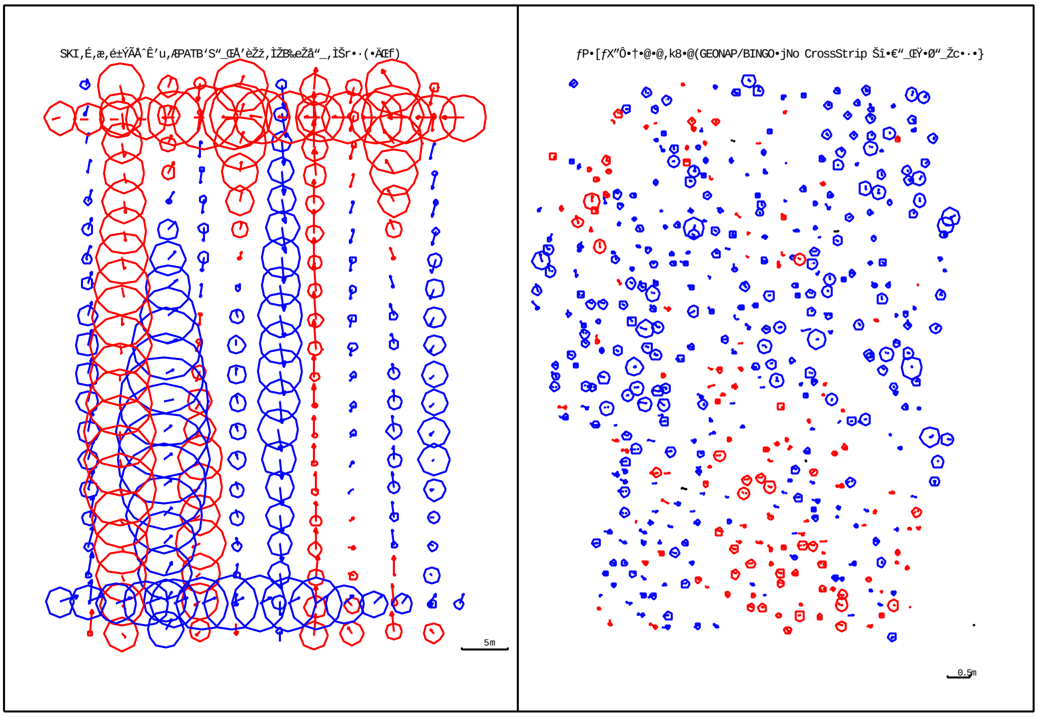

Fig. 7

Left: The same as above left (PATB)

Right: (L8) Four-corner control block with GEONAP/BINGO

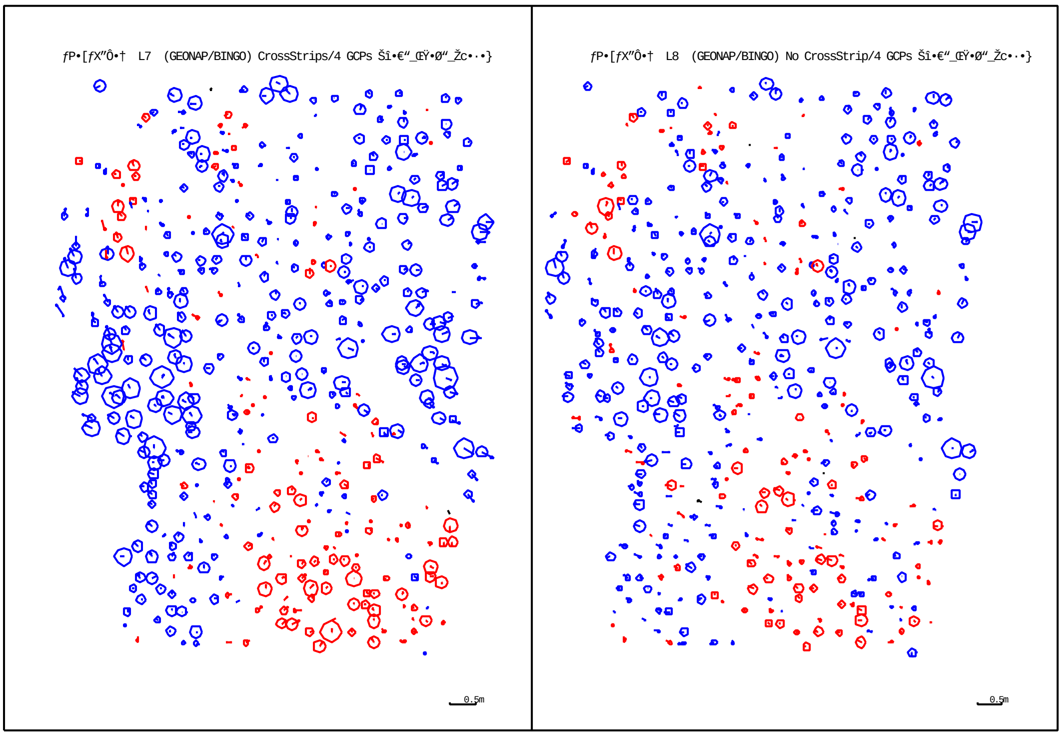

Fig. 8

Left: (L7) With cross strips using GEONAP/BINGO

Right: (L8) Without cross strips using GEONAP/BINGO

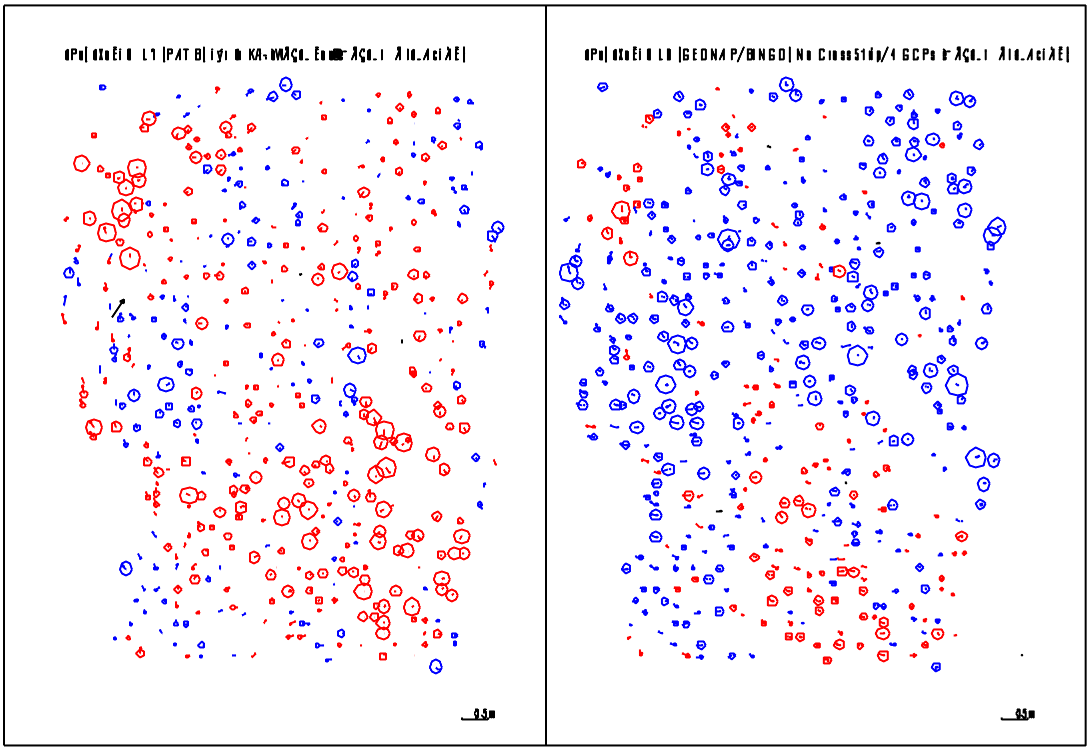

Fig. 9

Left (L1) Designated Number block with PATB (with cross strips)

Right (L8) Four-corner without cross strip block using GEONAP/BINGO