1. Introduction

The topographic mapping was conducted in the Southern Part of Ghana by the Japan International Cooperation Agency (JICA) in response to the request from the Government of the Republic of Ghana. The study was commenced in January 1996 and completed in March 2000. The study was conducted, in accordance with the Scope of Work (hereinafter referred to as "S/W") as agreed in March 1995 between the Survey Department of Ghana and the JICA preparation study team. .

The Study was carried out from August 1st 1996 as the study period of five years. However, aerial photography could not be carried out, therefore, the work plan had to be changed. Finally, the topographic mapping with a scale of 1/50,000 was carried out. The worldwide abnormal weather obstructed the aerial photography from the first year to the third year, which carried out four times. The achievement of aerial photography was 44% of the initial plan. Another reason why the work plan was changed is for the strong request to the Survey Department of Ghana at the time of the first end of the third year's Work. The Department requested the digital mapping from analogue mapping which was the initial plan. The request was discussed in JICA and the Advisory Committee was composed. The Advisory Committee discussed with the Ghana side and the following items were agreed.

(1) Aerial photography was not carried out.
(2) Change the analogue mapping to digital mapping, and the work schedule changed to digital method
(3) For the area where aerial photography could not be carried out, digital mapping was newly carried out to update the existing maps by using the existing SPOT satellite images.
(4) Transfer the technology of digital aping

According to the above agreement, the Study re-started from the latter half of the third year's Work.

The study area has the highest potential for future development because it is the central district of industrial production of Ghana and the world's third cocoa producing district and because the northern part of the study area is a gold producing center, a major source of acquisition of foreign currency. For planning various projects for these businesses, it is very effective to create the national topographic maps that reflect the actual circumstances correctly. The 1/50,000-scale topographic maps and digital data developed in this study by the request of the Government of Ghana will bring an enormous effect, contributing to the Economic Reconstruction Program of Ghana.

This report explains each step of 1/50,000-scale topographic mapping of the Southern Part and outlines products created in each step. The topographic maps, aerial photos and the results of surveys would be utilized for the development projects and environmental preservation of this area.

2. Outline of the Study

2-1 Ghana's Request and Study Items

2-1-1 Study Background

The Government of Ghana raised the request for technical cooperation and transfer of technology in the 1/50,000-scale topographic mapping to the Government of Japan, based on their policy that the national topographic mapping is an urgent need to promote the development of the social infrastructure for regional development and environmental conservation in the southern coastal areas where industrial, agricultural and fishing industries are concentrated and in the northwestern areas where the mining industries including gold are located.

The Government of Japan accepted the request of Ghana, and Japan International Cooperation Agency (hereinafter "JICA") that is the competent agency for technical cooperation dispatched a study team to confirm the contents of the request for the period of the middle of March, 1995 to early in April 1995. The study team held discussions with the Survey Department of Ghana (hereinafter "SDG") that is to be the counterpart of the Ghana side. As a result, the S/W for the above-mentioned study area of approximately 25,500 km^2 was agreed on March 17, 1995 between both Japan and Ghana

2-1-2 Request Items

In response to the request of the Government of Ghana, it was planned to create the 1/50,000-scale topographic maps as fundamental materials for use in various development programs and environmental plans in the southern part of the country.

Item	Specifications
1. Products	
a. Aerial photos and satellite images	Scale: 1:60,000 (super-wide angle camera) Approx. 11,100 km^2 Existing aerial photos (scale: 1:50,000, 1:20,000, 1:60,000) SPOT satellite images
b. National topographic maps	Others: Interim products Scale: 1:50,000 Area: Approx. 25,500 km^2 Printed maps: 40 maps in 5 colors, 1,003 sheets each Digital topographic map data: CD-ROM 10 sets each
2. Specifications of national topographic maps	
- Accuracy of ground control point survey	Relative position accuracy: 10 ppm
- Accuracy of Leveling	±5cm$\sqrt{S}$ (where S=km)
- Projection method	Transverse Mercator projection revised by Ghana

- Reference ellipsoid - Neatlines - Scale - Contour intervals - Print colors - Map symbol and application rules, and codes	Clarke 1880 Latitude 15' x longitude 15' 1 : 50,000 Intermediate contour 10 m 5 colors To be decided through discussions with SDG
3. Accuracy of topographic mapping	Planimetry: 0.5mm on the map Spot height: $\triangle h/3$ Contour line: $\triangle h/2$
4. Work rules	Overseas survey work rules (for topographic mapping) (draft) JICA (March 1994)

2-1-3 Objectives of the Study

The topographic mapping with a scale of 1/50,000 where the important developing area of southern Ghana shall be carried out in this Study by the survey of the present situation of the target area in response to the request of the Government of Ghana.

The target area is the high potential area of minerals and the central area of industry of Ghana. Moreover, this area is the central area of agricultural field. Therefore, this area has the highest potentiality of development. For the development the accurate topographic maps are necessary for various development of this area. The maps and the geographic data will be contributed to the economic development of Ghana.

2-1-4 Study Schedule

(1) Work Plan by Fiscal Year

The study plan by year as revised is shown below.

Fiscal Year	Study Items	
First Year (1995)	Work in Japan:	Preparatory work; Preparation of P/O; Report preparation
	Work in Ghana:	Aerial photo signalization; Aerial photography; Ground control point survey I
Second Year (1996)	Work in Japan:	Preparatory work; Preparation of P/O, Preparation of report
	Work in Ghana:	Aerial photography (continued); Ground control point survey II; Leveling; Pricking (I & II)
Third Year (1997)	Work in Japan:	Preparatory work; Preparation of P/O; Aerial triangulation; Digital plotting; Satellite image production; Preparation of report
	Work in Ghana: (First Phase)	Aerial photography (continued); Ground control point survey III; Pricking; Field verification.
	(Second Phase)	Field verification; Ground control point survey III; Pricking (III)

Fourth Year (1998)	Work in Japan:	Preparatory work; Preparation of P/O; SPOT image reconnaissance; Revision of existing topographic mapping data (including contour lines and secular changes); Partial plotting; Digital compilation; Preparation of report
	Work in Ghana:	Field verification (satellite image districts); Partial aerial photography
Fifth Year (1999)	Work in Japan:	Preparatory work; Preparation of P/O; Data revising; Mapping data output; Printing; Preparation of CD-ROM; Preparation of final report
	Work in Ghana:	Field completion; Transfer of technology in digital mapping data processing

(2) **Study Period**

The study period and the number of study members by year under revised plan are shown below.

Fiscal Year	Study Period and Study Members in Ghana	
First Year	Study period:	January 30 to March 28, 1996
	Study period in Ghana:	January 29, 1996 to March 25, 1996
	Study members:	21 JICA study team members 13 SDG counterparts
Second Year	Study period:	August 12, 1996 to March 25, 1997
	Study period in Ghana:	September 26, 1996 to January 24, 1997
	Study members:	22 JICA study team members 26 SDG counterparts
Third Year	Study period:	September 12, 1997 to March 25, 1998
	Study period in Ghana:	First Phase: September 28 to November 12, 1997 Second Phase: February 1, 1998 to March 20, 1998
	Study members:	17 JICA study team members 19 SDG counterparts
Fourth Year	Study period:	July 1, 1998 to March 15, 1999
	Study period in Ghana:	August 22, 1998 to October 23, 1998
	Study members:	14 JICA study team members 17 SDG counterparts
Fifth Year	Study period:	September 14, 1999 to March 16, 2000
	Study period in Ghana:	September 27, 1999 to November 12, 1999
	Study members:	15 JICA study team members 27 SDG counterparts

2-1-5 Study Plan and Implementation

(1) Work volume

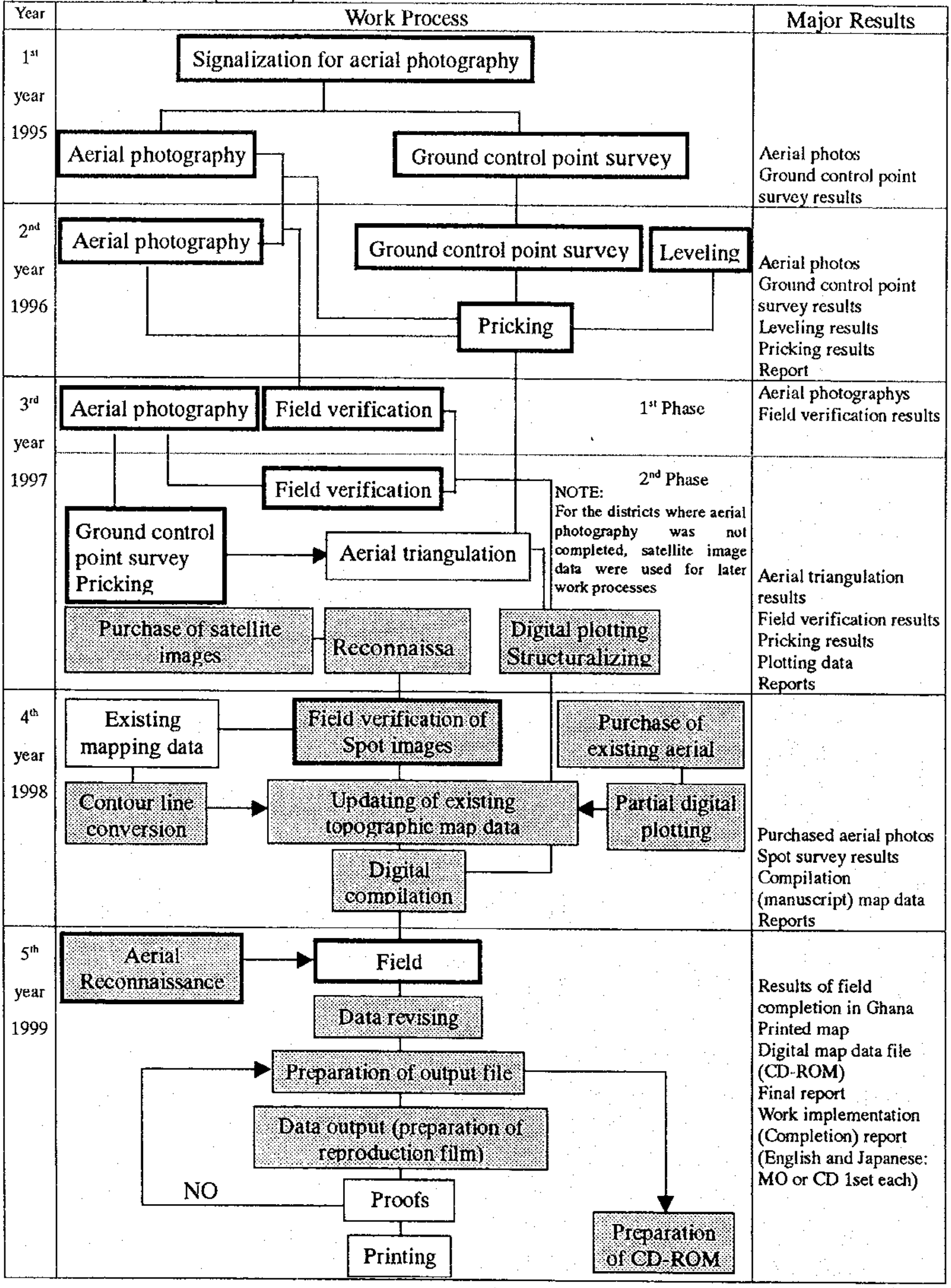
The work achievements for the first-year to fifth-year works are shown in the table below.

Year	Work Item	Planned Work Volume	Executed Work Volume	Remarks
1995 1st -Year	Signalization for aerial photography	0 point	One point	One point added
	Aerial Photography	Scale: 1/60,000 703 sheets (3,500L/km)	Scale: 1/60,000 140 sheets (700L/km)	Completed approx. 20% of all volume
	Ground control point survey (for positions and heights)	40 points	40 points	–
1996 2nd-Year	Aerial photography	Scale: 1/60,000 563 sheets (2,800L/km)	Scale: 1/60,000 74 sheets (346L/km)	Completed approx. 10% of all volume
	Ground control point survey (for heights)	34 points	34 points	–
	Leveling	1080 km	1,230 km	150 km over completed
	Pricking	Control points: 74 points Leveling: 1,080 km	Control point: 35 points Leveling: 580 km Bench marks: 102 points	· Photography for the 1st and 2nd years completed · Work volume is lower than the planned because of unfinished photography
	Report (English)	70 copies	70 copies	–
1997 3rd- Year - 1st Phase	Aerial photography	Scale: 1/60,000 489 sheets (2,454L/km)	Scale: 1/60,000 220 sheets (1,124L/km)	Completed approx. 32% of all volume. (Total 62% completed for the 3-years.)
	Field verification	4,270 km^2 (for 1st phase)	4,270 km^2	–
	Aerial triangulation	323 models	323 models	–
1997 3rd-Year - 2nd Phase	Ground control point survey (Additional)	4 points	4 points	–
	Field verification	6,830 km^2	6,830 km^2	–
	Pricking (points photographed in the 3rd year)	Control points: 20 points Leveling: 230 km	Control points: 20 points Leveling: 230 km	–
	Digital plotting	11,100 km^2 (20 sheets)	11,100 km^2 (20 sheets)	–
	Report (English)	35 copies	35 copies	–

1998 4th-Year	Field verification	14,400 km² (20 sheets)	14,400 km² (20 sheets)	–
	Partial photography	Scale: 1/10,000 100km²	–	Unfinished
	Purchase of existing aerial photos	–	Scale: 1/5,000 Area: approx. 100km²	Existing aerial photos purchased because partial photography was incomplete.
	Partial plotting	Scale: 1/50,000 100km²	Scale: 1/50,000 100km²	–
	Revision of secular data changes	14,400 km² (20 sheets)	14,400 km² (20 sheets)	–
	Contour line conversion	14,400 km² (20 sheets)	14,400 km² (20 sheets)	
	Map digitizing	–	–	Additional
	Digital compilation	25,500 km² (40 sheets)	25,500 km² (40 sheets)	–
	Report (English)	35 copies	35 copies	–
1999 5th-Year	Field completion	25,500 km² (40 sheets)	25,500 km² (40 sheets)	
	Transfer of technology in digital data processing	1 set	1 set Data revision for secular changes and digital compilation technologies	
	Data revising	25,500 km² (40 sheets)	25,500 km² (40 sheets)	
	Data output	40 map sheets	40 map sheets	
	Printing	1.003 copies per sheet	1,003 copies per sheet	5-color printing
	Preparation of CD-ROMs	10 sets	10 sets	Digital mapping data stored
	Preparation of Report	Work Report: 2 copies Final report: Japanese: 20 copies English: 50 copies Package of technical documents 40 copies	Work Report: 2 copies Final report: Japanese: 20 copies English: 50 copies	The specifications are as per the work instructions

(2) **Flowchart of the study**

The study flow (revised) is shown in the table below:



Year	Major Results
1st year 1995	Aerial photos Ground control point survey results
2nd year 1996	Aerial photos Ground control point survey results Leveling results Pricking results Report
3rd year 1997 (1st Phase)	Aerial photographys Field verification results
3rd year 1997 (2nd Phase)	Aerial triangulation results Field verification results Pricking results Plotting data Reports
4th year 1998	Purchased aerial photos Spot survey results Compilation (manuscript) map data Reports
5th year 1999	Results of field completion in Ghana Printed map Digital map data file (CD-ROM) Final report Work implementation (Completion) report (English and Japanese: MO or CD 1set each)

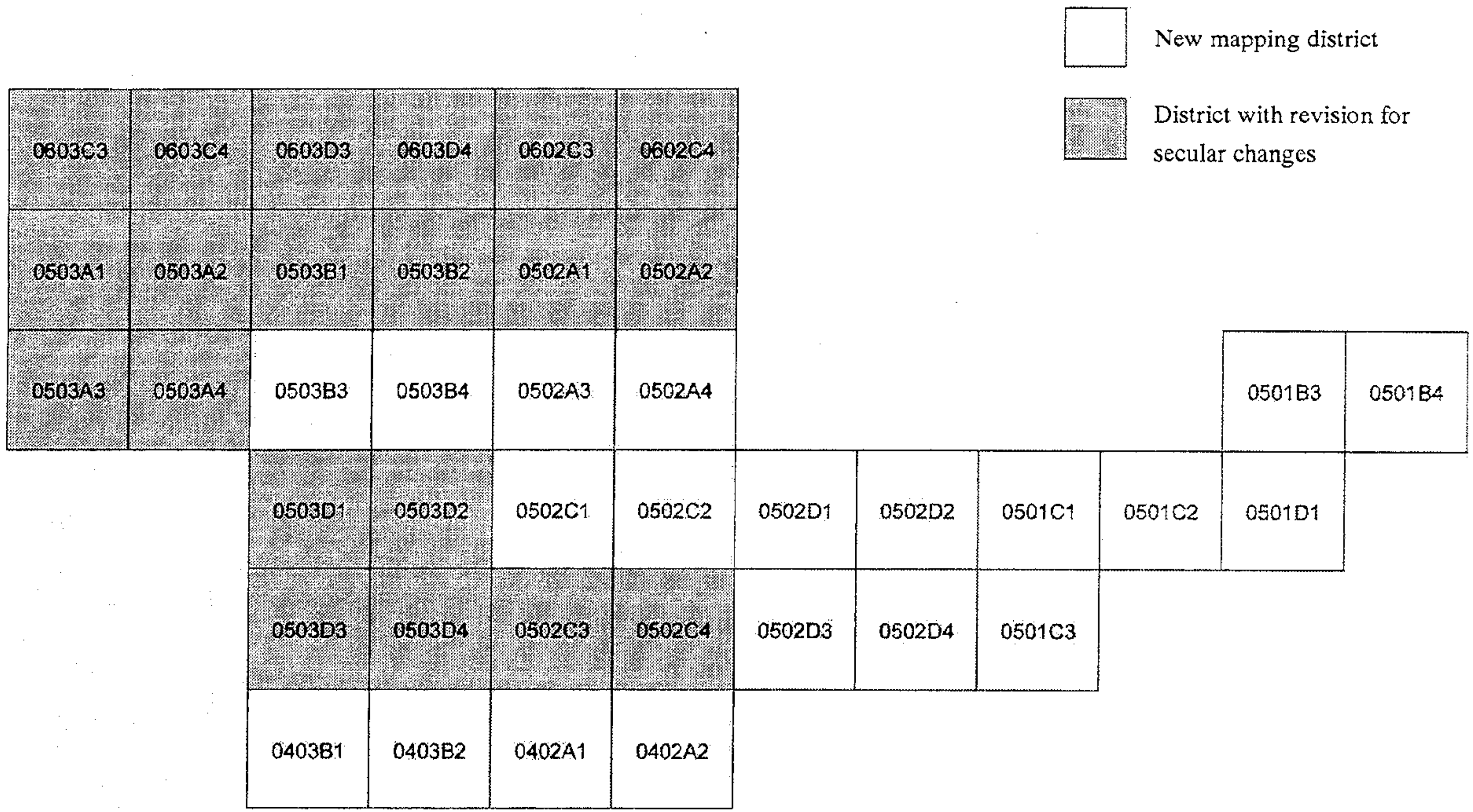
Note: [thick box] Work in Ghana [thin box] Work in Japan [shaded box] Modified or additional process

2-2 Change in the Study Plan

In the S/W, this study was originally planned for implementation using the analog system, and the work was scheduled to start in 1996 and complete in 1999. However, the topographic mapping method was changed into the digital system in 1997, the period of the study was extended for about 8 months, and the topographic maps were completed in March 2000 in Japan. The study was started in February 1996 and the work of aerial photography that is indispensable for topographic mapping was conducted twice in each year of 1996 and 1997, four times in total, in parallel with other ground survey works. However, the successful aerial photos that can be used for topographic mapping were for only about 44% of the entire study area because of bad weathers during each period of photographing in both years. Therefore, the photography of the entire study area could not be completed in this study. As a result, JICA reduced the study area and reviewed the entire plan of the study. On the other hand, the counterpart of Ghana made some requests to the study team at the end of 1997 that the analog mapping system be changed into the digital mapping system, that the printed maps be added to the final products, and that digital mapping data be provided.

It was very difficult to change the mapping system for the entire study area from analog to digital in the condition that the aerial photography was implemented for only about 44% of the entire study area. JICA studied the solutions to these requests. Then, JICA dispatched the study team to Ghana to discuss and coordinate the requests of the Ghana counterpart with the solutions by the Japanese side. This study team made the hearing of the contents of the request of the Ghana side, and explained about the method of revising the topographic mapping data using the satellite image data that the study team was examining. The study team explained also that this method was not fully established yet in the accuracy point of view even in the present time when technical innovation was making remarkable progress, and that if the digital topographic mapping data was created in this method, its accuracy would be lower than that of the data based on aerial photos because it would also depend upon the accuracy of the digital topographic mapping data possessed by Ghana. In response to these explanations, SDG argued that even if the accuracy was a little lower, the topographic maps should be created using the satellite image data for the study districts where aerial photography was not completed, because those districts are important for the environmental prevention and development programs. They requested JICA for providing the topographic maps and digital topographic mapping data. The study team brought the request to Japan. As the result of analysis and further study of the details of request of Ghana, JICA decided to accept Ghana's request because the study area covers the very important districts including Accra for Ghana. It was needed to change the original study plan to use the analog system, so that the study processes in and after the third year were also changed. In addition, the period of this study was also changed into a five-year plan starting in 1995. Thus, it was decided that the study would be continued. (See the topographic mapping district diagram.)

Topographic Mapping District Diagram



As a result of mutual discussions, the original plans were altered as described below.

① To change the topographic mapping system from analog to digital.

② To discontinue the aerial photography in 1997 because it is not expected that the aerial photography would be completed for the entire study area even if it was continued.

③ For the incomplete study districts for aerial photography, to utilize the existing topographic mapping data digitized from the 1/50,000 topographic maps that were implemented in the Ghana Environmental Resource Management Project that had been promoted by Ghana.

④ To conduct field surveys using the existing satellite images and to revise the secular changes in the digitized topographic maps because those are simply digitized from the existing topographic maps. As the topographic data are simply digitized in the foot unit for the contour lines and the heights, all the data would be converted into the metric unit.

⑤ To add the CD-ROMs storing the digital topographic map data as well as the printed maps to the final products as originally planned.

2-3 Transfer of Technology

During the implementation of the Study, the technology for the topographic mapping was transferred to the SDG counterparts through on-the-job training (OJT).

2-3-1 First Year: Ground Control Point Survey

(1) Actual Performance of OJT

The ground control point survey included the work stages such as the selection, observation and computation of the points necessary for the succeeding work stage of aerial triangulation.

Upon the point selection, the Study Team instructed the SDG counterparts that the effort should be made to place the points in the most favorable locations, such as;

- near the large buildings clearly identifiable on the aerial photos
- within the public facilities like schools, churches, etc. considering the protection of the points
- in the area having less difference of elevation comparing to the neighboring area

As for the observation, the instruction was given so as to follow the detailed technical specifications referring to the overhead clearance, time of observation, interval of receiving signals, etc.

(2) SDG Counterparts Accompanied the Study Team

From Great Accra Region:

Mr. Jones Ofori-Boadu

Mr. Johe Qnist

Mr. John C.Aequaah

Mr. Kofi Wemegah

Mr. Quarshie Quartey

Mr. Jeremiah Awabigo

Mr. C. R. K.Anyah

2-3-2 Second Year: Leveling and Discussions on Map Symbols

(1) Actual Performance of OJT

Among the counterparts dispatched from SDG, some of them were certainly experienced in leveling, but others were not.

Usually, the leveling is done by an observer (who reads the graduation of the level) together with two staff-men(who hold the leveling staff), and their good teamwork is most important to maintain the observing accuracy.

Considering the above, the Team appointed an experienced personnel as observer, and inexperienced ones as staff-men. Two members from the Team supported them and gave the following instructions;

- From the observer, the distance to the forward staff and the distance to the backward staff should be equal.
- Turning plate should be firmly fixed on the ground.
- The staff-men must watch the bubble very carefully so that the leveling staff may stand vertically throughout the work.
- The method of installing the level and the principle of leveling
- The importance of check survey for the existing benchmarks

(2) SDG Counterparts Accompanied the Study Team

From Central Region:

Mr. E. K. Nkebi

Mr. P. E. Attah

Mr. E. Abbah

Mr. D. Kumsenu

Mr. H. Mustaphd

Mr. G. K. Arhin

Mr. A. Gatsi

Mr. A. Abrefa
Mr. K. Sapong

From Western Region:
Mr. E. Djokoto
Mr. B. Gsutau
Mr. B. Doey
Mr. A. Robert
Mr. A. Godwin
Mr. A. Daniel
Mr. E. Paul
Mr. S. Francis

(3) Discussion on Map Symbols and Application Rules

It was the first experience for SDG to produce the middle scale topographic maps, and therefore the symbols for these maps had not formulated as yet. Under the circumstances, the meeting was held between SDG and JICA Study Team to discuss on the map symbols to be used in the Study.

At the beginning of the meeting, Director of Surveys demanded the application of unified African standard for map symbols. However, considering the fact that such new symbols as for roads, railroads and other important features quite differed from those being shown on the existing maps, the Team came to conclude the application of such symbols might bring confusion upon map users. Then the Team proposed SDL that the symbols presently shown on the existing maps should be basically used and any addition, correction and/or omission might be made, if required by any changes of the times. This proposal was finally approved by SDG after full consideration in their office.

The meeting was held again. Then the shape, size and other important details of existing symbols together with additional ones were determined (See the Minutes of Meeting, attached). After the meeting, the Team compiled a symbol list showing the specified symbols and their application rules. The list was submitted to SDG for reference. Besides, the symbols to be used for plotting the field results onto the aerial photos were also included in the above-mentioned list with code numbers (See the attachment).

The attendants of the meetings were as follows;
From Study Team:
Deputy Leader Mr. Koichi Miki

Mapping Planner	Mr. Kozo Okumura
Chief Surveyor	Mr. Hitoshi Yoshida
Surveyor	Mr. Masaru Terada

From SDG:

Director of Surveys	Mr. Na Al-haji Iddirisu Abu
Asst. Director	Mr. J. Dotse
Examiner	Mr. Marcus Tabil
Chief Cartographer	Mr. K. N. Arku Lawson
Chief Photogrammetrist	Mr. I. Andoh-Kesson
Chief Lithographer	Mr. E. R. Tetteh

2-3-3 Third Year: Field Verification Using Aerial Photos

(1) Actual Performance of OJT

As it was the first time for SDG to produce the middle scale topographic maps, the Study Team explained the outline of field verification work for these scale maps before accompanying the counterparts to the site.

The main items to be verified in the field were;

- the features which could not be identified on the aerial photos
- the classification of roads
- the names and locations of the features to be symbolized
- the village names, etc.

The Team instructed the counterparts that in case of the close existence of the features necessary for symbolization and/or annotation, the appropriate selection should be made taking their fame and landmark value into full consideration.

All the important names on the existing maps (like villages, mountains, rivers, etc.) should be confirmed to the local inhabitants. At that time, double-checking was necessary because it sometimes happened that the same feature had different names.

Special care should be taken to the village names, because some discrepancies between the names and relevant villages were found on the existing maps.

2-3-4 Forth Year: Field Verification Using Satellite Images

(1) Actual Performance of OJT

In this year, the field verification was carried out using the SPOT satellite images for the area where the aerial photos could not be obtained.

In principle, the field verification using the satellite images is basically same as that using the aerial photos. On the satellite images, however, it is difficult to interpret the narrow roads and small villages due to the inferiority in clearness. Therefore, the interpretation method specially applied to the satellite images was instructed to the counterparts.

As was expected, there found some changes of the roads, because the satellite images of this area were obtained 2 - 3 years ago. Therefore, the linear data of such roads were re-obtained by driving the motor car equipped with GPS instrument borrowed from JICA headquaraters. The operating manual and data processing method of this instrument were instructed to the counterparts for their own use.

(2) SDG Counterparts Accompanied the Study Team

From Digital Mapping Department:

Mr. J. Adu Baiden

From Western Region:

Mr. Paul Essiem

Mr. S. O. Koranteng

Mr. F. K. Sodokey

2-3-5 Fifth Year: Field Completion and Digital Compilation

(1) Field Completion

At the stage of field completion, it is specified that any important changes, if occurred after the field verification, may be incorporated. The final checking of the names and annotated details should be made for all the map sheets covering entire area of the Study.

Before starting the field completion, the Team requested SDG to examine the names and annotated details on the compiled manuscripts that were output from the digital map data. Upon alphabetizing a village name from its local pronunciation, the spelling sometimes differed from person to person because of the existence of various dialects in the country. So, the Team instructed the counterparts to inspect the alphabetical spelling very carefully and follow the opinion of responsible person, in case of any different views among the inspectors. At the same time, the Team advised the counterparts to make the name list per each map sheet so as to facilitate the inspection. The Team took the counterparts to the field and let them confirm the questionable names, which had been pointed out in the office. It is worth mentioning that the counterparts came to recognize the importance of inspection through the experience of this work..

The counterparts accompanied the Study Team are as follows;

From Great Accra Region:

Mr. E. S. Obodai
Mr. K. G. Sapong
Mr. P. Edison Attah
Mr. A. E. Lagosu-Gatsi

From Western Region:
Mr. Paul Essiem
Mr. Daniel Asiedu
Mr. G. Aye Bekoe
Mr. David Totimeh

(2) Digital Compilation

As previously mentioned in 2-2, the analog mapping system was changed into the digital mapping system from the third year of the Study. For this reason, SDG strongly desired the Study Team to transfer the digital mapping technology.

They have already produced the GIS basic data by digitizing the existing 1:50,000 scale maps in Ghana Environmental Resource Management Plan (GERMP), and therefore, they were quite skilled in dealing with the digital map data.

However, for lack of figure-processing software, they could not renew the digital map data for compilation.

Therefore, in the fifth year, the technologist of digital processing joined the Study Team as an instructor to perform the technology transfer. The seminar was attended by more than twenty persons not only from the digital mapping section but also from the various regions all over the country. It was a good surprise for the Team, as they have not expected such large attendants. For this reason, the Team had to change the instruction plan from man-to-man method to group method. All the attendants received the lecture at once, and after that they divided into groups of 4 - 5 persons to practice the technology in a computer given to each group. During the practice, the instructor walked round the groups to answer the questions, if any. The attendants were very eager in learning the technology. Some of them did not leave from computer even after the seminar.

In spite of the fact that the period was limited in ten days, the technical training in this stage had played a significant role for them to develop the technology in the near future.

(3) Results of OJT in Ghana

Many counterparts were dispatched not only from the SDL headquarters but also from the various regions throughout the period of OJT. For the SDG counterparts, it must be a good opportunities to learn and train the skills. While for the Study Team, it was very meaningful that they could maintain good relationship with the counterparts.

(4) Training in Japan

For the works implemented within Japan, the SDG officials were dispatched to Japan to participate in the training program for the most up-to-date technology in national topographic mapping. The various types of equipment brought from Japan for transfer of technology through OJT, including GPS receivers for ground control point survey, a computer for received data analysis, a computer for digital mapping data processing and software, were provided by JICA to the Ghana side on SDG's request after completion of the study.

During the period of implementation of the study, three (3) counterparts listed below were dispatched to Japan for technical training and visited the Geographical Survey Institute of Ministry of Construction and other survey-related institutions. They received the lectures on the topographic mapping processes and practiced various related technologies in order to acquire the most up-to-date professional knowledge and skills.

Technical training for counterparts in Japan

Name	Position	Period of Training
Mr. Mensah Christopher Ausustine	Chief Engineer, Digital Mapping Sec.	From November 2 to December 1, 1998
Mr. Jean Dotse	Assistant Manager, SDG	From August 11 to August 23, 1997
Mr. Awabigo Paul Jeremiah	Surveyor	From March 17 to April 17, 1997

2-4 Study Organization Members

JICA Study Team

Mr. Tokihiko KAMINISHI	Team Leader
Mr. Koichi MIKI	Deputy Team Leader
Mr. Kozo OKUMURA	Mapping Planner
Mr. Hitoshi YOSHIDA	Chief Surveyor
Mr. Yutaka KYAKUNO	Chief Surveyor
Mr. Tosio MIZUTANI	Mechanical. Eng.
Mr. Shinpei ISHIWATA	Mechanical. Eng.
Mr. Yotaka KOKUHU	Photographer
Mr. Shun TAKAGI	Photographer
Mr. Hideto HOSODA	Photographer
Mr. Daikichi NAKAJIMA	Photographer
Mr. Yasuo GOTO	Surveyor
Mr. Koichi WAKISAKA	Surveyor
Mr. Makoto TSUJIMOTO	Surveyor
Mr. Sadao MATUMOTO	Surveyor

Mr. Tomohiro MURAKAMI	Surveyor
Mr. Yuichi TABIKAWA	Surveyor
Mr. Kazutomo NAKANISHI	Surveyor
Mr. Koji FUKUZAWA	Surveyor
Mr. Kouzou ASANO	Surveyor
Mr. Shigeo ONO	Surveyor
Mr. Masahito OHASHI	Surveyor
Mr. Minori OHNAKAB	Surveyor
Mr. Tuyoshi YAMAZAKI	Surveyor
Mr. Michio SATOJI	Surveyor
Mr. Masaru TERADA	Surveyor
Mr. Masaaki MIZUOCHI	Surveyor
Mr. Takeshi NEMOTO	Surveyor
Mr. Masaya TOKITA	Surveyor
Mr. Kuniaki NOGUCHI	Surveyor
Mr. Kazushi ENDO	D.M. Planner
Mr. Kouzou YAMAYA	Digital mapping data processing
Mr. Fujio ITO	Coordinator/ D.M. Planner
Mr. Hideaki SAKAI	Coordinator
JICA Advisory Committee	
Mr. Hirishi UNE	Team Leader
Mr. Yoshimi TAKITA	Technical Staff, Geographical Survey institute
Mr. Toshihisa HASEGAWA	Staff JICA Headquarters
Mr. Hozumi KATSUTA	Study Planning
Mr. Tokihiko KAMINISHI	Consultant Team Leader
JICA Headquarter	
Mr. Takao KAIBARA	Director, 1st Development Study Division
Ms. Eri HONDA	Deputy Director, 1st Development Study Division
Mr. Tomoyuki KOSAWA	1st Development Study Division
Mr. Takahiro KASAI	1st Development Study Division
Embassy of Japan	
Mr. Akihisa TANAKA	Ambassador
Mr. Toshihiro KOJIMA	Ambassador
Mr. Shousuke ITO	Ambassador
Mr. Yuji OKADA	First Secretary
JICA Ghana Office	
Mr. Akio YATSUBAYASHI	Resident Representative
Mr. Shiro NABEYA	Resident Representative

Mr. Toshiharu KAI	Deputy Resident Representative
Mr. Osamu KOSEGAWA	Deputy Resident Representative
Mr. Fumio MIYAGAWA	Deputy Resident Representative
Mr. Akihito SANJO	Asst. Resident Representative
Mr. Christopher NUOYEL	Programme Officer

Ghana Counterparts

Na A1-haji Iddirisu Abu	Director of Surveys
Mr. E.S.Sai	Deputy Director
Mr. Ridwan Brimah	Asst. Director
Mr. J.Dotse	Asst. Director
Mr. J.A.Abossey	Staff Surveyor
Mr. E.R.Tetteh	Chief Lithographer
Mr. Marcus A.Tabil	Examiner
Mr. K.N.Arku-Lawson	Chief Cartographer
Mr. I.Andoh-Kesson	Chief Photogrammetrist
Mr. J.C.Acquaah	Staff Surveyor
Mr. J.Ofori Boadu	Asst. Staff Surveyor
Mr. S.Oppong-Antwi	Asst. Staff Surveyor
Mr. J.T.Odametey	Asst. Staff Surveyor
Mr. H.A.Kuffo	Asst. Staff Surveyor
Mr. E.Addo-Tawiah	D. M. Planner
Mr. E.A.Quaye	Asst. Chief Cartographer
Mr. F.Manu-Adabor	Asst. Staff Surveyor
Mr. George Frimpong	Asst. Staff Surveyor

Ghana Counterparts Field Work

Mr. J.Adu Baiden	Asst. Staff Surveyor
Mr. Paul Essiem	Survey Technician
Mr. S.O.Koranteng	Survey Technician
Mr. F.K.Sodokey	Survey Technician
Mr. J.Ofori-Boadu	Survey Technician
Mr. J.Qnist	Survey Technician
Mr. J.C.Aequaah	Survey Technician
Mr. K.Wemegah	Survey Technician
Mr. P.J.Awabigo	Survey Technician
Mr. N.Q.Quartey	Survey Technician
Mr. Daniel Asiedu	Survey Technician
Mr. Seth Kovangteng	Survey Technician
Mr. Francis Sodokey	Survey Technician

3. Technical Report

3-1 Outline of the Study and Work Schedule

The objective of the study was to create the topographic maps that can represent the present conditions of the southern part, the most important developing area of Ghana, and make available for multiple applications such as national development programs, environmental conservation plans and administrative plan. For this objective, aerial photography was newly conducted for the area of 11,100 km^2 (20 map sheets) of the entire study area of 25,500 km^2, and this work was started in January 1996 and completed in March 2000. For the remaining area of 14,400 km^2 (20 map sheets) where aerial photography was partially unfinished, it was planned to use existing satellite images. Therefore, the study was implemented by dividing the entire work period in phases for 5 years. The entire study area covers the most southern part of Ghana from 4°45' to 6°15' N Lat. and from 0°0' to 3°0' W Long., where the capital Accra and other major cities are located. The work schedule is shown in Form-5. (See "Ghana Topographic Mapping Work Schedule".)

The following study items were implemented to achieve the objective of the study:

(1) Signalization for aerial photography

Before aerial photography, aerial photo signals were installed to ensure the existing triangulation points to be clearly observed as ground control points on the aerial photos. In addition, the technology in signalization was transferred to the Ghana counterparts.

(2) Aerial photography

For aerial photography, an aerial camera with a super-wide angle lens of 90mm focal length was used. Aerial photos (panchromatic) of 1/60,000 scale were obtained only for the limited area of approx. 11,100 km^2 (20 map sheets) of the entire study area of 25,500 km^2. A jet airplane was adopted for photography to shorten the period of photography. Especially, for three mine districts with large secular topographic changes of the districts where photography was unfinished, it was planned to conduct 1/10,000-scale photography in flight at lower altitudes in which digital plotting might be very inefficient. During the test flight, however, it was confirmed that there were existing aerial photos covering those districts. The photography was stopped immediately and the existing aerial photos were purchased with JICA's approval to continue the further work.

(3) Ground control point survey

The ground control points for aerial triangulation and digital plotting were newly installed using the Global Positioning System (hereinafter "GPS"). These new ground control points were kept as temporarily buried stones for use in SDG's future survey.

(4) Leveling

Leveling was conducted to keep the height accuracy in the 1/50,000-scale topographic maps for the districts where the existing bench marks necessary for aerial triangulation and digital plotting are insufficient.

(5) Pricking

1) Pricking of ground control points

For aerial triangulation and digital plotting, the points that are clear on aerial photos were selected for new ground control points, which were pricked on the quadruple-enlarged photos. Eccentric observation of these points was also conducted to fit the eccentric points with their coordinates.

2) Pricking of bench marks

The vertical control points leveled and the existing bench marks were pricked on the double-enlarged aerial photos in order to maintain the height accuracy in aerial triangulation and digital plotting.

(6) Field verification

The field verification of the results of aerial photo interpretation necessary for digital plotting as well as the sampling of interpretation keys, selection of planimetric features and annotations were conducted for all study areas using the double-enlarged aerial photos and in accordance with the map symbols and application rules as agreed upon between SDG and the study team.

(7) Aerial triangulation

For the photographed areas, the block adjustment computations by the bundle method were executed.

(8) Digital plotting

Using the results of aerial triangulation, leveling, the existing bench marks and the results of field verification, digital plotting at the scale of 1/50,000 was performed for the area of approx. 11,100 km^2 (20 map sheets) in order to create digital topographic mapping data (hereinafter "new DM data"). They were converted into the Arc/Info coverage of the area of approx. 14,400 km^2 (20 map sheets), for 5 mining areas where topography was remarkably changed, performed digital mapping using existing aerial photos. The results were composed to the digital data of the existing topographic map (hereinafter "new DM data"). They were stracturalized the same as the new DM data and converted into the Arc/Info coverage.

(9) SPOT image processing

For the area of approx. 14,400 km^2 (20 map sheets) where aerial photos were not available, ortho images were produced using the SPOT satellite images.

(10) Revision of existing topographic map data

The contour data converted into the metric unit were displayed on the computer on an existing topographic map as the background and revised considering the topographic features.

(11) Digital compilation

For the new DM data (Arc/Info coverage) that was structuralized and the existing DM data (Arc/Info coverage) with the secular changes updated, mapping compilation was performed by the computer in accordance with the map symbols and application rules agreed between SDG and the study team.

(12) Field completion survey

The questions, uncertain points and secular changes on the digital plotting and data compilation were checked in the field completion survey.

(13) Field data revising

The new and existing DM data and mapping data were compiled based on the results of field completion survey.

(14) Plate-making film production

The mapping data in which data revising was completed were arranged in layers by color separation (of 5 colors) and plate-making films were produced by an image setter.

(15) Map printing

After inspection of the proof map sheets, the maps were printed in 5 colors by an offset printing machine.

(16) Preparation of CD-ROMs

The DM data and the mapping data were stored in CD-ROMs as the original data.

3-2 Signalization for Aerial Photography

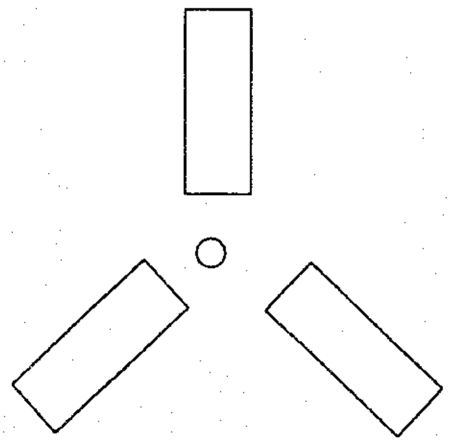
3-2-1 Outline

It was originally planned to use 4 existing control points, but another existing control point was added as a result of study. As there were no eccentric points such as clearly observable planimetric features, the aerial photo signal for this additional point was installed.

3-2-2 Shape of Aerial Photo Signal

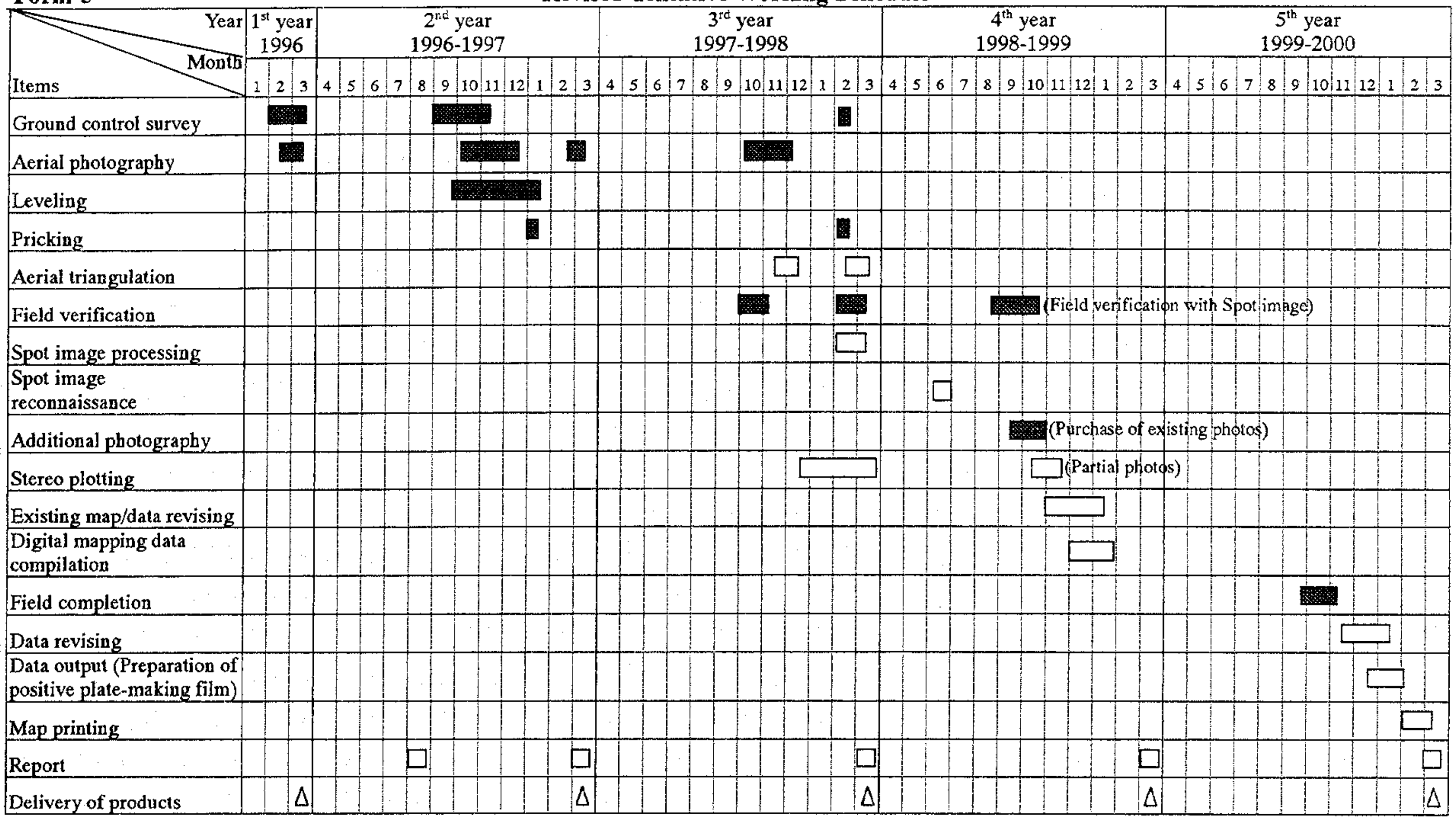
The aerial photo signal consists of three wings as a rule. One wing is formed as a 3m x 5m square and the material of the signal was a mold made of collected rock stones that were coated with white paint.

Shape of aerial photo signal



Form-5

Revised Tentative Working Schedule



Legend: —— Preparation ■ Work in Ghana □ Work in Japan Δ Explanation of reports ········ Other works

3-3 Aerial Photography

3-3-1 Outline

The aerial photography was planned for the southern part of Ghana of 25,500 km^2 located in the latitude 4° 45' to 6° 15' N and in the longitude 0° 0' to 3° 0' W. The scale of photography and the type of camera were the 1/60,000 scale and a super-wide angle camera as agreed upon in the S/W. The flight height was planned to be approximately 5,400 m. 20 photographic courses were planned from east to west, considering the shape of the entire study area. For the southern coastal area, 4 courses are added diagonally to cover the entire area. The photographic overlap and the side-lap were planned to be 60% and 30% respectively because there were relatively low height differences in the study area. (See the Aerial Photography Plan Diagram.)

However, bad weathers continued every day in this study area and it was not expected to complete the aerial photography in the first year. The aerial photography was continued until the third year. As a result, the aerial photography was suspended with the area of approximately 14,400 km^2 (20 map sheets) left not photographed of the entire area of 25,500 km^2 (40 map sheets). (See the Aerial Photography Orientation Maps and Photographing List.)

3-3-2 Subcontracting of aerial photography

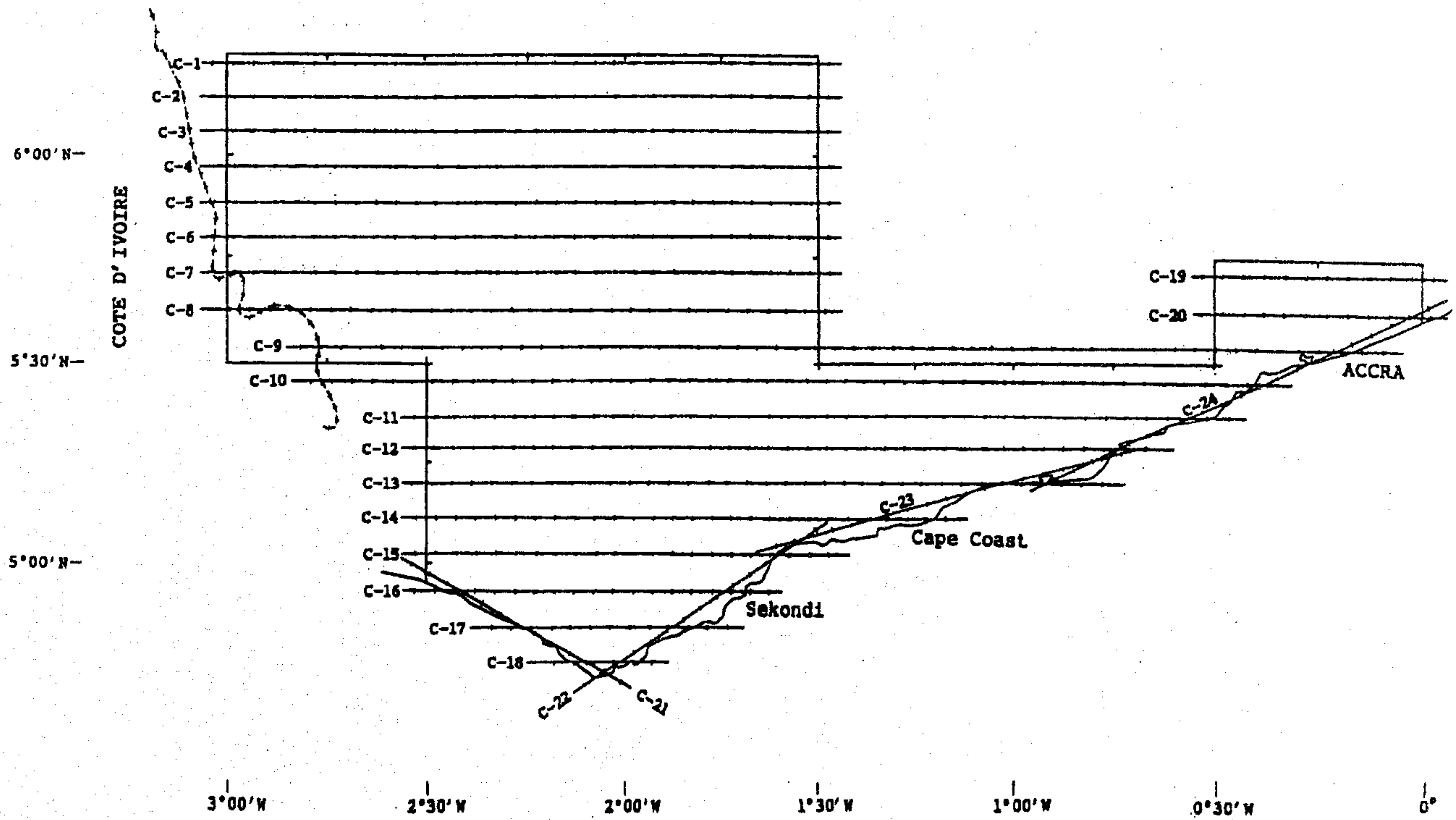
The subcontracts with Aircraft Operating Company (the Republic of South Africa, hereinafter called "AOC") and CTK-Network Aviation Ltd. (Ghana, hereinafter called "CTK") were made.

Item	Date of Contract (and Period of Photographing)
First Year	Feb.8, 1996 (Period of photo.: Feb. 23 to March 20, 1996 AOC)
Second Year	Sep. 20, 1996 (Period of photo.: Oct. 3 to Dec. 9, 1996 AOC) Feb. 22, 1997 (Period of photo.: Feb. 24 to Mar. 15, 1997 AOC)
Third Year	Sep. 26, 1997 (Period of photo.: Oct. 9 to Dec. 5, 1997 AOC)
Partial photography	Aug. 31, 1998 (Period of photo.: Sep. 11 to Oct. 25, 1998 CTK)

3-3-3 Base airport

Kotoba Airport (Accra) was used as a base airport for photographic flight. Weather information on the eastern part was obtained on a regular basis from the base airport and that on the western part from the Tokoradi airport and two meteorological observatories.

Aerial Photography Plan Diagram



PHOTOGRAPHING LIST

Course	Photo Date	(W) Photo No. (E)	(W) Com.No (E)	Adopted Photo No.	Remarks
1	24 Nov.'96	645 ~ 639	01 ~ 07	7	
2	24 Nov.'96	652 ~ 657	01 ~ 06	6	
3	24 Nov.'96	704 ~ 697	01 ~ 08	8	
4	2 Dec.'97	5560 ~ 5558	01 ~ 03	3	
5	2 Dec.'97	5552 ~ 5554	01 ~ 03	3	
6	2 Dec.'97	5541 ~ 5539	01 ~ 03	3	
7	26 Nov.'97	5489 ~ 5512	01 ~ 24	24	
8	26 Nov.'97	5475 ~ 5452	01 ~ 24	24	
9	18 Nov.'97	5256 ~ 5243	01 ~ 14	14	
'	13 Mar.'96	433 ~ 407	15 ~ 41	27	
'	25 Oct.'96	396 ~ 384	42 ~ 54	13	
'	13 Mar.'96	(443 ~ 441)	(02s ~ 04s)	(3)	Supplementation
'	13 Mar.'96	(438 ~ 435)	(07s ~ 10s)	(4)	Supplementation
'	30 Oct.'97	(4849 ~ 4857)	(32s ~ 40s)	(9)	Supplementation
10A	17 Nov.'97	5132 ~ 5124	01 ~ 09	9	
10B	17 Nov.'97	5116 ~ 5104	01 ~ 13	13	
'	20 Nov.'97	5287 ~ 5278	14 ~ 23	10	
'	24 Oct.'96	318 ~ 312	24 ~ 30	7	
'	7 Mar.'96	306 ~ 294	31 ~ 43	13	
'	24 Oct.'96	(311 ~ 307)	(34s ~ 38s)	(5)	Supplementation
11	17 Nov.'97	5139 ~ 5164	01 ~ 26	26	
'	3 Nov.'97	5062 ~ 5068	27 ~ 33	7	
'	7 Mar.'96	311 ~ 327	34 ~ 50	17	
12A	25 Nov.'97	5418 ~ 5422	01 ~ 05	5	
12B	17 Nov.'97	5190 ~ 5173	01 ~ 18	18	
'	7 Mar.'96	348 ~ 332	19 ~ 35	17	
13A	20 NOv.'97	5298 ~ 5293	01 ~ 06	6	
13B	7 Mar.'96	355 ~ 370	01 ~ 16	16	
14	22 Oct.'96	237 ~ 227	01 ~ 11	11	
'	8 Nov.'96	(543 ~ 533)	(01s ~ 11s)	(11)	Supplementation
15	25 Nov.'97	5403 ~ 5401	01 ~ 03	3	
'	3 Nov.'97	5051 ~ 5055	04 ~ 08	5	
16	20 Nov.'97	5334 ~ 5346	01 ~ 13	13	
17	20 Nov.'97	5326 ~ 5317	01 ~ 10	10	
18	30 Oct.'97	4887 ~ 4883	01 ~ 05	5	
19	13 Mar.'96	579 ~ 573	01 ~ 07	7	
'	7 Mar.'96	273 ~ 265	08 ~ 16	9	
20	13 Mar.'96	562 ~ 569	01 ~ 08	8	
'	7 Mar.'96	282 ~ 289	09 ~ 16	8	
21	20 Nov.'97	5302 ~ 5308	01 ~ 07	7	
'	21 Nov.'97	5384 ~ 5388	08 ~ 12	5	
'	20 Nov.'97	5310 ~ 5313	13 ~ 16	4	
22	30 Oct.'97	4890 ~ 4898	01 ~ 09	9	
'	22 Oct.'96	213 ~ 205	10 ~ 18	9	
23	13 Mar.'96	548 ~ 528	01 ~ 21	21	
24	22 Oct.'96	203 ~ 184	01 ~ 20	20	
'	13 Mar.'96	499 ~ 506	21 ~ 28	8	
Total				458 (32)	

3-3-4 Main photographic equipment

The following equipment was used for the aerial photography:

Item	Type
Aircraft	GATES, LEAR JET 24
Camera	CARL ZEISS RMK-A 8.5/23
Focal length	85.54 mm
Navigation system	GPS Navigation System 2000
Aerial film	AGFA AVIPHOTPAN 200PEI

3-3-5 Photographic results

The permit for aerial photographing was acquired on February 15, 1996. During the photographic period in the first year, cloudy days continued and the visibility was very unfavorable. The photographic period was extended until March 25, but it was only on three days of March 7, 13 and 17 when photography was possible. As a result of inspection, only the photos of the capital city of Accra and its environs in the eastern part of the study area could be adopted as usable. In the forest zone in the northwestern part, photographing was always conducted in the cloudy bad conditions due to the weather in the coastal district. Courses 1 to 4 were photographed continuously on March 17, but all the photos were covered with clouds and could not be adopted. The results of photographing are shown below.

Photographic results in the first year

	Plan	Result	Remarks
Photographic scale	1:60,000	1:60,000	–
Courses	24 courses	8 courses	Incl. re-photographed courses (C19, 20 and 23 finished previously.)
Extended photography	Approx. 3,500L/km	Approx. 700L/km	–
Number of photos	Approx. 703	140	–

The photographic work in the second year was continued from the results in the first year based on the same specifications. If the courses photographed in the previous year were interrupted, the overlapping point of three photos was a new start point of photographing. Although photographing was conducted in two phases for a period of October 11, 1996 to March 15, 1997, only 7 days were blessed with fair weather. A total of about 400 aerial photos were taken but only 74 photos could be adopted.

Photographic results in the second year

	Plan	Result	Remarks
Photographic scale	1:60,000	1:60,000	–
Courses	21 courses	7 courses	Incl. re-photographed courses (C19, 20 and 23 finished previously)
Extended photography	Approx. 2,800L/km	Approx. 346L/km	–
Number of photos	Approx. 563	74	–

The third-year photography was continued from the first and second years and based on the same specifications. Although photographing was started on October 11, 1997, the weather was not fair as ever. As a result, 56% of the entire study area was not photographed.

Photographic results in the third year

	Plan	Result	Remarks
Photographic scale	1:60,000	1:60,000	–
Courses	20 courses	16 courses	Incl. re-photographed courses (C19, 20, 23 and 24 finished previously)
Extended	Approx. 2,454L/km	Approx. 1,124L/km	–
Number of photos	Approx. 489	220	–

3-3-6 Photographic processing

After the photographing work, film development and printing for examination were made promptly. The development was made by rewinding development, so that the leader trailer was set enough to make no blurs.

3-3-7 Major equipment used

The main equipment used for photographic processing was shown in the table below.

Item	Type
Film developing machine	CARL ZEISS REWIND S/No. 111079
Contact printer	CARL ZEISS KG-30
Developing solution	AGFA ILFORD Q UNIVERSAL
Printing paper	AGFA RAPITONE PAPER, etc.
Dryer	CARL ZEISS TG-24 S/No. 20209

3-3-8 Aerial photo inspection

The items as mentioned below were inspected and the accuracy control tables were made up. Re-flight was also conducted for the courses the photos of which were improper.

(1) Overlap, side-lap and off-route photos

Inspection was made on the overlap of within 60±5% between adjacent-run photos, the side-lap of within 30±5% between course intervals and photographic flight routes.

(2) Tilt in aerial photo

The tilt in an aerial photo was checked on ψ-ω of 3 degrees or less and κ of 10 degrees or less relative to the vertical photo.

(3) Clouds, cloud shadow, halation and uneven development

The continued 5 photos were inspected on 3% or less of cloud, cloud shadow and halation effects except for the parts necessary for control point survey and digital plotting.

3-3-9 Photographic film compilation

Annotations, course numbers and photo numbers were recorded on each frame of film negative as agreed upon by the discussions between the study team and SDG. The details are as follows:

(1) Annotations

- District name, date of photography, course number, photo number and photographic scale
- Abbreviated name of Japan International Cooperation Agency (JICA)

The above annotations are indicated only on the first and last photos of each course, and only course number and photo number were indicated on other photos.

(2) Course number

East to west courses: C-1, C-2, C-3 --- in turn from north to south.

Slant courses: A series of numbers continued for the east to west courses is affixed in the order from west-side to east-side courses.

(3) Photo number

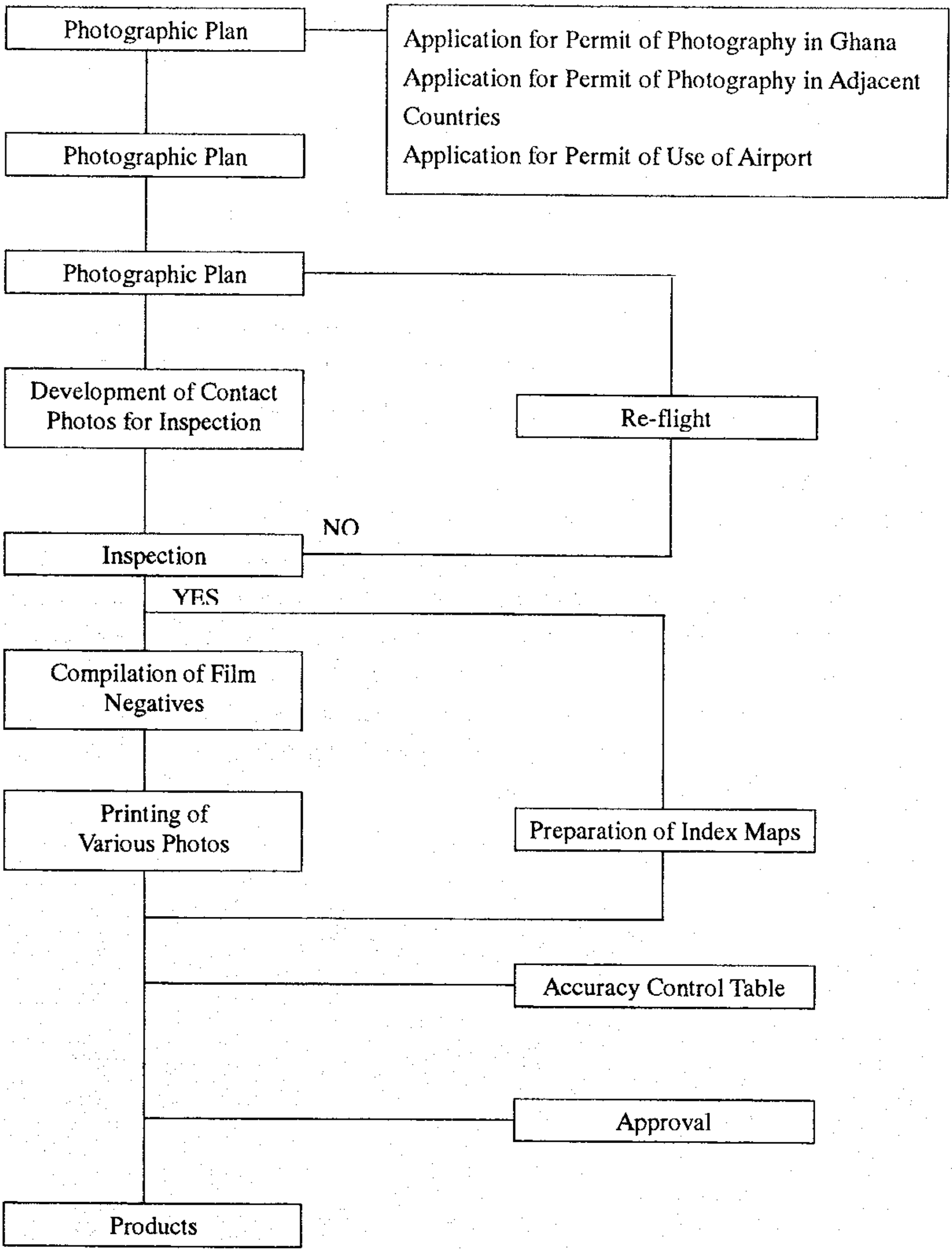
Numbered with 1, 2, 3, --- in turn from west to east for the east to west courses and the slant courses. A series of numbers is also affixed when the course is divided.

3-3-10 Districts pending for aerial photography

For some districts pending for aerial photography due to bad weathers, digital plotting was impossible. Therefore, it was decided to create digital topographic mapping data by using the digital topographic mapping data possessed by SDG and updating the secular changes. Then, ortho images were produced using SPOT satellite data. For 5 mine districts that had large secular topographic changes, the existing aerial photos were adopted.

3-3-11 Flowchart of aerial photography

The flowchart of aerial photography is shown below.



3-4 Ground Control Point Survey

3-4-1 Outline

In the first year, GPS survey (ground control point survey I) was made on 40 ground control points to determine their planimetry necessary for aerial triangulation and digital plotting and their heights.

In the second year, GPS survey (ground control point survey II) was carried out on 34 ground control points to determine only their heights in such districts where the heights were not available simply by leveling. In such districts, no existing bench marks were available or it is difficult to access from any existing leveling route.

In the third year, the GPS survey net was reviewed based on the results of aerial photography, 4 other ground control points necessary for aerial triangulation and digital plotting were added and GPS survey (the ground control point survey III) was conducted.

3-4-2 Point selection

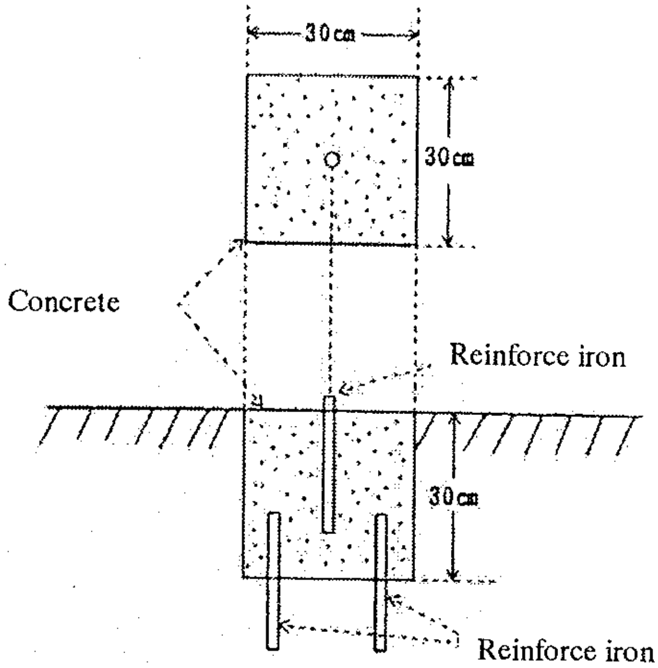
(1) Point selection in ground control point survey I (hereinafter "XYZ point")

Point selection was carried out according to the ground control point distribution plan to ensure that the ground control points to determine their planimetry and heights are positioned within public facilities as many as possible, taking into account of convenience for the later works and maintenance of signals. Originally, it was planned to use 4 existing control points, but 5 existing control points (one more than the original plan) were used as a result of review of the survey net before point selection. The new ground control points were 35 points.

Existing control points used

Control point	Latitude (N)	Longitude (W)	Height (m)
CFP245	5° 16' 31.7009"	1° 59' 02.6533"	95.798
GCS102	5° 16' 47.7497"	0° 44' 04.8751"	60.320
GCS112	5° 35' 33.2406"	0° 19' 39.6115"	195.011
GCS296	5° 48' 12.3594"	2° 26' 17.9711"	145.359
W3/34/28	6° 11' 49.7984"	2° 28' 44.9733"	313.081

For 35 XYZ points and 34 Z points that were newly selected, the marker stones as shown in the diagram below were installed.



(2) Point selection in ground control point survey II (hereinafter "Z point")
34 Z points were selected in accordance with the ground control point distribution plan for determining the heights of the control points. The point selection was made in the conditions that they were within the range of the control points set in the ground control point survey I and that they were suited to pricking, eccentric observation, GPS observation and conservation of monuments.

3-4-3 GPS observation of XYZ points

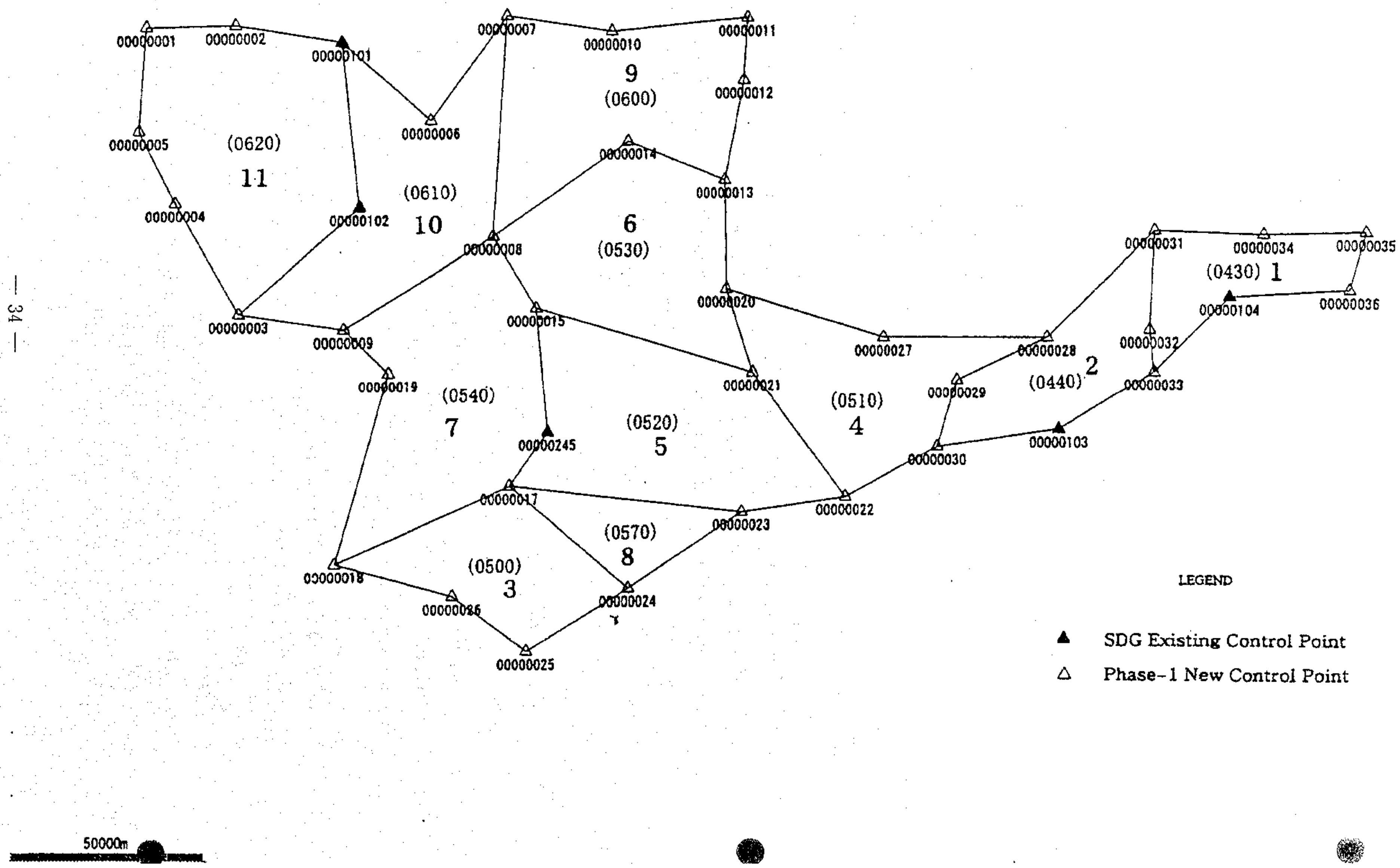
GPS observation was made on 40 XYZ points in the first year using 5 existing control points as given points. A total of 11 sessions of observation were conducted, in which simultaneous observation by 7 GPS receivers was made in each session. (See the diagram of GPS Observation Network on the next page.)

3-4-4 Major equipment used

The main equipment used in the GPS observation of the XYZ points is as follows:

Item	Type
GPS receiver	TRIMBLE 4000SSE, 7 units
Software	TRIMBLE, GPSURVEY, TRIMNET, and KENKYU-SHA KEN-Q, etc.
Computer	TOSHIBA DYNABOOK, 1 set
Compact GPS	TRIMBLE ENSIN, 7 units

GPS OBSERVATION NETWORK



3-4-5 Vector analysis of XYZ points

The GPS satellite data received in each session was subjected to vector analysis based on the WGS-84 spheroid. The maximum vector closure error in each session was 0.086 m (the tolerance is 1.55 m.), and the maximum closure error in combination of vectors in different sessions was 0.148 m (the tolerance is 3.094.). The analysis summary was so accurate that the average value of the redundant vector was approximately 5.7 cm.

In verification of the above vector analysis summary, it was confirmed that the ground control point survey in this study fully satisfied the accuracy requirement and that the control points also satisfied the accuracy for use as the given points for the Z point survey in the second year. (See the diagram of GPS Calculation Triangle Network on page 31 and the following pages.)

3-4-6 GPS observation of Z points

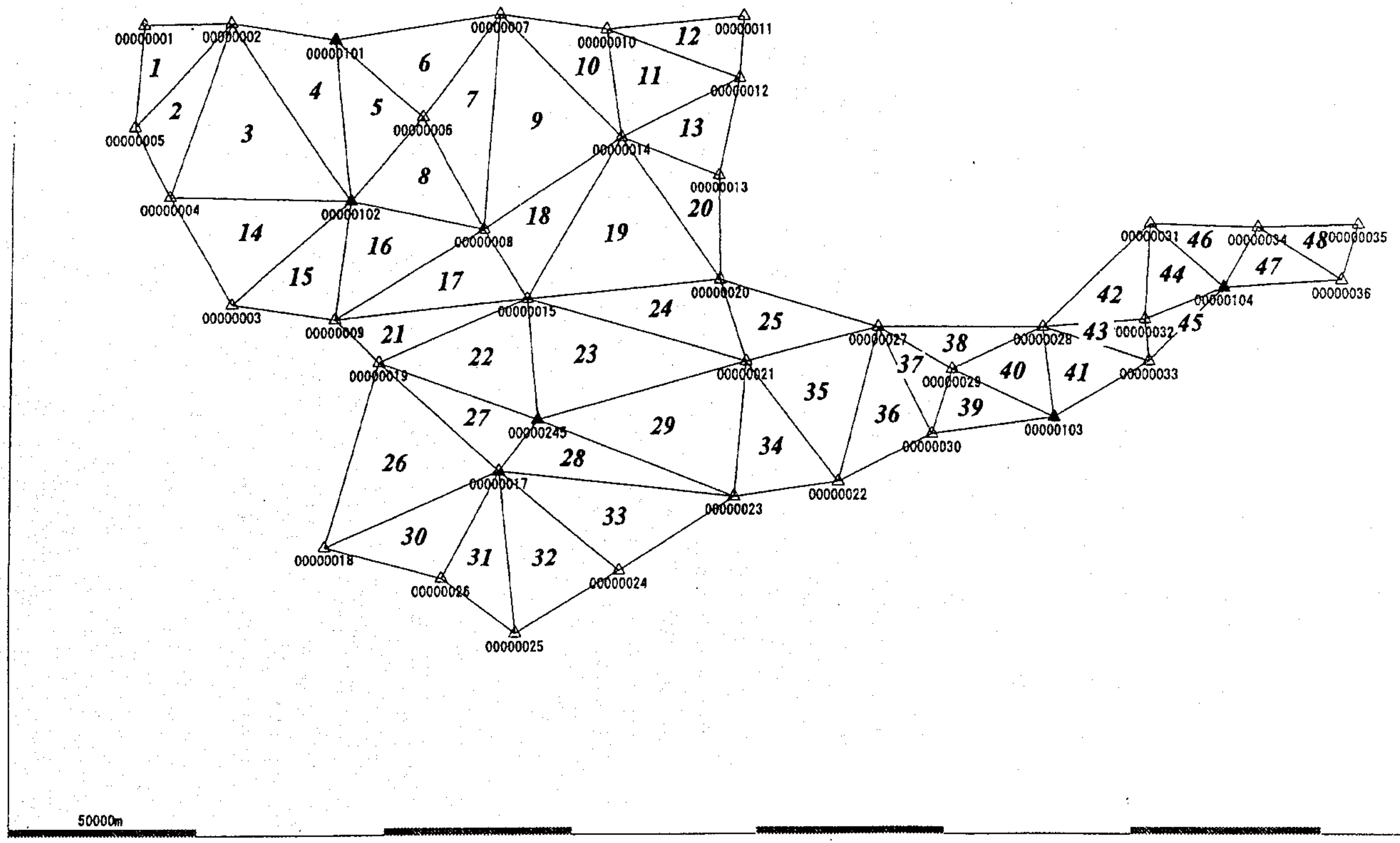
To determine the heights by the GPS survey, it is necessary to make corrective calculations using geoidal data. No geoidal height observation had been conducted around the study area in the past. Therefore, the heights of Z points were obtained by the interpolation method based on the heights directly obtained by leveling of the ground control points, and the relative heights to the geoidal heights calculated by the vector analysis summary in the GPS survey. The accuracy of the ground control point survey II ensured the very highly accurate observation and analytical values as the ground control point survey I. As a result of an interim review of the observation network, two of 34 points were used as the XYZ ground control points. A total of 29 sessions of observation were conducted, and simultaneous observation by 7 GPS receivers was made in each session. (See the diagrams of GPS Observation Network for GPS Leveling and Table of Comparison of Relative Geoidal Heights.)

3-4-7 Major equipment used

The main equipment used in the GPS observation of the Z points is as follows:

Item	Type
GPS receiver	TRIMBLE 4000SSE, 7 units
Software	TRIMBLE, GPSURVEY, TRIMNET, and Kenkyu-sha KEN-Q
Computer	TOSHIBA DYNABOOK, 1 set
Compact GPS	TRIMBLE ENSIN, 7 units

GPS CALCULATION TRIANGLE NETWORK



(1/2)

SUMMARY OF BASELINE COMPUTATION

Observation Group	Station combination for Baseline From	To	Computed Slope Distance	Accuracy
1 (0430)	34	35	26,600.185 m	
	35	36	15,512.779 m	Total Dist.= 166,603.102 m
	36	104	31,177.790 m	dx = 0.011 m
	104	33	28,028.344 m	dy = -0.007 m
	33	32	11,068.947 m	dz = 0.004 m
	32	31	25,809.307 m	Ratio = 0.0782 ppm
	31	34	28,405.750 m	
2 (0440)	31	32	25,809.304 m	
	32	33	11,068.958 m	Total Dist.= 183,334.081 m
	33	103	29,255.876 m	dx = -0.018 m
	103	30	32,792.588 m	dy = -0.019 m
	30	29	18,010.622 m	dz = 0.002 m
	29	28	26,505.573 m	Ratio= 0.1429 ppm
	28	31	39,891.160 m	
3 (0500)	17	24	42,266.566 m	Total Dist.= 182,170.103 m
	24	25	32,369.921 m	dx = -0.009 m
	25	26	24,612.179 m	dy = 0.003 m
	26	18	32,279.166 m	dz = -0.004 m
	18	17	50,642.271 m	Ratio = 0.0567 ppm
4 (0510)	27	28	44,017.974 m	
	28	29	26,505.606 m	Total Dist.= 224,501.634 m
	29	30	18,010.645 m	dx = -0.002 m
	30	22	28,176.363 m	dy = 0.001 m
	22	21	40,510.183 m	dz = -0.005 m
	21	20	22,923.419 m	Ratio = 0.0232 ppm
	20	27	44,357.443 m	
5 (0520)	21	22	40,510.152 m	
	22	23	28,127.394 m	Total Dist.= 243,342.822 m
	23	17	63,772.488 m	dx = 0.017 m
	17	245	17,072.295 m	dy = -0.020 m
	245	15	32,270.384 m	dz = 0.006 m
	15	21	61,590.110 m	Ratio = 0.1103 ppm
6 (0530)	14	13	28,514.502 m	
	13	20	28,382.440 m	Total Dist.= 208,046.851 m
	20	21	22,923.411 m	dx = 0.004 m
	21	15	61,590.050 m	dy = 0.000 m
	15	8	22,090.889 m	dz = 0.001 m
	8	14	44,545.559 m	Ratio = 0.0232 ppm
7 (0540)	9	8	46,201.235 m	
	8	15	22,090.894 m	Total Dist.= 236,040.313 m
	15	245	32,270.329 m	dx = -0.010 m
	245	17	17,072.287 m	dy = 0.000 m
	17	18	50,642.249 m	dz = 0.001 m
	18	19	51,350.558 m	Ratio = 0.0420 ppm
	19	9	16,412.763 m	

(2/2)

Observation Group	Station combination for Baseline From	To	Computed Slope Distance	Accuracy
8 (0570)				Total Dist.= 142,887.825 m
	17	23	26,600.185 m	dx = 0.001 m
	23	24	15,512.779 m	dy = -0.001 m
	24	17	31,177.790 m	dz = 0.005 m
				Ratio = 0.0367 ppm
9 (0600)	10	11	37,328.922 m	
	11	12	16,235.007 m	Total Dist.= 240,028.781 m
	12	13	26,701.445 m	dx = 0.059 m
	13	14	28,514.543 m	dy = -0.002 m
	14	8	44,545.587 m	dz = 0.009 m
	8	7	57,832.287 m	Ratio = 0.2502 ppm
	7	10	28,870.991 m	
10 (0610)	6	7	33,980.954 m	
	7	8	57,832.295 m	Total Dist.= 282,511.415 m
	8	9	46,201.298 m	dx = -0.029 m
	9	3	27,689.071 m	dy = 0.052 m
	3	102	41,839.133 m	dz = 0.000 m
	102	101	43,774.176 m	Ratio = 0.2113 ppm
	101	6	31,194.489 m	
11 (0620)	1	2	44,017.974 m	
	2	101	26,505.606 m	Total Dist.= 218,988.078 m
	101	102	18,010.645 m	dx = 0.002 m
	102	3	28,176.363 m	dy = 0.000 m
	3	4	40,510.183 m	dz = 0.002 m
	4	5	22,923.419 m	Ratio = 0.0127 ppm
	5	1	44,357.443 m	

GPS Data Examination Sheet

3-D Closure Error

Session No.	Station No.	Length (m)	Number of Station	Number of Side	DX (m)	DY (m)	DZ (m)	DS (m)	Allowable Error (m) -10ppm-
430, 440		276180.688	10	10	-0.047	-0.067	0.051	0.097	2.762
500, 570		240524.833	6	6	0.054	-0.026	0.030	0.067	2.405
510, 520		386824.067	11	11	-0.057	0.036	-0.012	0.068	3.868
530, 540		399905.382	11	11	0.045	0.004	0.017	0.048	3.999
600, 610		385985.440	11	11	-0.027	-0.078	0.010	0.083	3.860
610, 620		309382.802	9	9	0.109	-0.075	-0.067	0.148	3.094

Instrument
Trimble4000SSE
S/No. 3302A02377
S/No. 3348A04543
S/No. 3348A04545
S/No. 3348A04546
S/No. 3348A04548
S/No. 3348A04551
S/No. 3348A04542

Redundant Vectors

Session No.	Station No.	DX (m)			DY (m)			DZ (m)			DS (m)			Allowable Error (m) -10ppm-
		Length A	Length B	Diff.	Length A	Length B	Diff.	Length A	Length B	Diff.	Length A	Length B	Diff.	
620, 610	101, 102	4576.283	4576.357	0.074	4329.041	4329.065	0.024	-43318.492	-43318.526	-0.034	43774.133	43774.176	0.043	0.438
620, 610	102, 3	-1227.957	-1227.961	-0.004	31472.057	31472.100	0.043	27541.059	27541.098	0.039	41839.075	41839.133	0.058	0.418
610, 600	7, 8	-5769.978	-5769.863	0.115	4168.284	4168.305	0.021	57392.570	57392.572	0.002	57832.295	57832.287	-0.008	0.578
610, 540	8, 9	815.933	815.924	-0.009	-39433.850	-39433.785	0.065	-24059.627	-24059.613	0.014	46201.298	46201.235	-0.063	0.462
600, 530	8, 14	1225.032	1224.967	-0.065	-36890.151	-36890.122	0.029	-24938.431	-24938.428	0.003	44545.587	44545.559	-0.028	0.445
600, 530	13, 14	1811.767	1811.809	0.042	26470.193	26470.151	-0.042	-10446.315	-10446.305	0.010	28514.543	28514.502	-0.041	0.285
540, 530	8, 15	-2286.825	-2286.876	-0.051	-11728.796	-11728.800	-0.004	18579.918	18579.903	-0.015	22090.894	22090.889	-0.005	0.221
530, 520	15, 21	3444.900	3444.791	-0.109	59144.668	59144.720	0.052	-16833.752	-16833.767	-0.015	61590.050	61590.098	0.048	0.616
530, 510	20, 21	2307.495	2307.546	0.051	7116.348	7116.355	0.007	-21668.314	-21668.315	-0.001	22923.411	22923.419	0.008	0.229
540, 520	15, 245	3154.369	3154.353	-0.016	3055.811	3055.836	0.025	-31970.081	-31970.122	-0.041	32270.329	32270.370	0.041	0.323
540, 520	245, 17	832.798	832.780	-0.018	-10345.458	-10345.471	-0.013	-13555.107	-13555.105	0.002	17072.287	17072.292	0.005	0.171
540, 500	17, 18	-87.648	-87.690	-0.042	-46330.350	-46330.370	-0.020	-20448.186	-20448.197	-0.011	50642.249	50642.271	0.022	0.506
570, 500	17, 24	-3414.883	-3414.822	0.061	-32359.015	-32359.045	-0.030	26975.771	26975.800	0.029	42266.530	42266.566	0.036	0.423
570, 520	17, 23	-2568.727	-2568.769	-0.042	-63331.636	-63331.697	-0.061	7030.303	7030.321	0.018	63772.405	63772.469	0.064	0.638
520, 510	21, 22	-3442.739	-3442.692	0.047	-24758.897	-24758.938	-0.041	31878.145	31878.171	0.026	40510.141	40510.183	0.042	0.405
510, 440	29, 30	-1427.623	-1427.666	-0.043	5328.064	5328.046	-0.018	17145.173	17145.163	-0.010	18010.645	18010.633	-0.012	0.180
510, 440	28, 29	-669.317	-669.354	-0.037	24099.049	24099.020	-0.029	11015.216	11015.208	-0.008	26505.606	26505.576	-0.030	0.265
440, 430	31, 32	2510.813	2510.800	-0.013	-1365.057	-1365.059	-0.002	-25650.591	-25650.591	0.000	25809.308	25809.307	-0.001	0.258
440, 430	32, 33	1095.538	1095.466	-0.072	1072.878	1072.837	-0.041	-10962.294	-10962.233	0.061	11069.018	11068.947	-0.071	0.111

GPS Data Examination Sheet

(1/2)

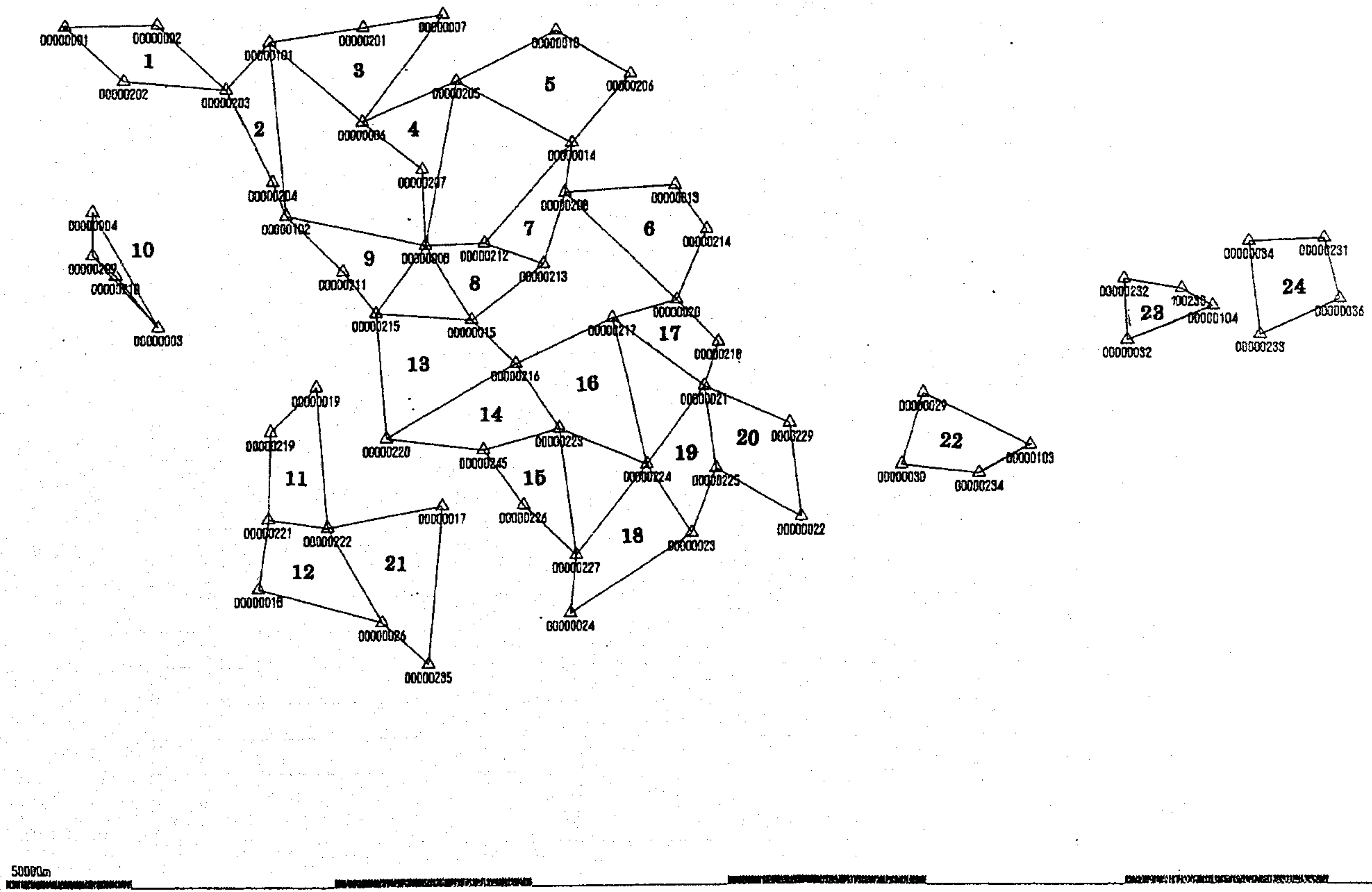
3-D Closure Error

Session No.	Triangle Block No.	Length (m)	Number of Station	Number of Side	DX (m)	DY (m)	DZ (m)	DS (m)	Allowable Error (m) -10ppm-
620	1	87454.111	3	3	0.009	0.003	-0.001	0.010	0.875
620	2	107868.686	3	3	0.001	0.000	0.000	0.001	1.079
620	3	155123.736	3	3	0.038	0.074	0.020	0.086	1.551
620	4	129852.941	3	3	0.032	0.072	0.022	0.081	1.299
620	14	123314.007	3	3	0.001	0.000	0.001	0.002	1.233
600	9	148688.194	3	3	0.019	-0.003	0.003	0.020	1.487
600	10	104025.463	3	3	0.009	0.004	0.000	0.010	1.040
600	11	102702.570	3	3	0.016	-0.004	0.002	0.017	1.027
600	12	91916.821	3	3	0.012	0.000	0.003	0.012	0.919
600	13	90721.512	3	3	0.003	0.001	0.000	0.003	0.907
540	17	119768.340	3	3	-0.010	0.000	0.002	0.011	1.198
540	21	110688.097	3	3	0.002	0.000	0.000	0.002	1.107
540	22	120233.632	3	3	-0.001	0.000	0.000	0.001	1.202
540	26	145238.230	3	3	0.003	-0.001	0.000	0.003	1.452
540	27	105481.890	3	3	0.004	-0.001	0.001	0.004	1.055
530	18	117027.620	3	3	0.001	0.001	-0.001	0.001	1.170
530	19	149983.428	3	3	0.005	0.001	0.001	0.005	1.500
530	20	104224.366	3	3	-0.001	0.000	0.000	0.001	1.042
530	24	136778.293	3	3	0.001	-0.001	0.000	0.001	1.368
500	30	115776.925	3	3	-0.010	0.002	-0.004	0.011	1.158
500	31	101377.517	3	3	0.000	0.000	0.000	0.001	1.014
500	32	118546.336	3	3	0.001	0.000	0.000	0.001	1.185
570	33	142887.825	3	3	0.001	0.001	0.005	0.005	1.429

(2/2)

Session No.	Triangle Block No.	Length (m)	Number of Station	Number of Side	DX (m)	DY (m)	DZ (m)	DS (m)	Allowable Error (m) -10ppm-
610	5	104677.533	3	3	-0.015	0.030	0.018	0.038	1.047
610	6	109460.711	3	3	-0.001	-0.003	0.003	0.004	1.095
610	7	126479.342	3	3	0.002	0.000	-0.001	0.002	1.265
610	8	100533.414	3	3	0.024	-0.035	0.004	0.042	1.005
610	15	101550.482	3	3	-0.001	-0.002	0.001	0.002	1.016
610	16	114382.030	3	3	-0.012	0.015	0.014	0.024	1.144
520	23	151956.564	3	3	0.001	-0.006	0.019	0.020	1.520
520	28	137790.966	3	3	0.001	-0.002	0.000	0.002	1.378
520	29	151033.270	3	3	-0.001	0.001	0.001	0.001	1.510
520	34	104628.496	3	3	-0.009	0.001	-0.001	0.009	1.046
510	25	103693.434	3	3	-0.001	0.000	0.000	0.001	1.037
510	35	119195.261	3	3	0.004	-0.002	-0.006	0.008	1.192
510	36	102202.477	3	3	0.002	-0.001	0.002	0.003	1.022
510	37	72517.174	3	3	-0.011	0.004	-0.002	0.012	0.725
510	38	93276.503	3	3	0.004	-0.001	0.001	0.004	0.933
440	39	80793.673	3	3	0.050	-0.007	0.016	0.053	0.808
440	40	80449.153	3	3	-0.031	-0.029	0.010	0.044	0.804
440	41	82890.330	3	3	-0.027	0.001	-0.004	0.027	0.829
440	42	92998.890	3	3	-0.004	0.002	-0.002	0.005	0.930
440	43	68048.762	3	3	-0.024	-0.043	-0.014	0.051	0.680
430	44	74506.213	3	3	-0.003	0.000	0.000	0.003	0.745
430	45	61810.471	3	3	0.005	-0.001	0.001	0.005	0.618
430	46	72697.764	3	3	0.007	-0.004	0.001	0.008	0.727
430	47	75910.332	3	3	0.005	-0.003	0.002	0.006	0.759
430	48	68537.217	3	3	-0.003	0.001	-0.001	0.003	0.685

GPS Observation Group for GPS Leveling



Comparison of Relative Geoidal Heights

Station Name	Height from the Geoid ①(m)	Height from the Ellipsoid ②(m)	Relative Geoidal Height (①-②)(m)	Remarks
GPS102	59.968	59.968	0.000	Fixed Station
GPS 1	145.266	144.947	0.319	
GPS 2	190.416	189.971	0.445	
GPS 3	51.686	53.454	-1.768	
GPS 4	88.777	90.173	-1.396	
GPS 5	142.427	143.259	-0.832	
GPS 6	105.373	104.955	0.418	
GPS 7	172.070	170.871	1.199	
GPS 8	61.517	62.501	-0.984	
GPS 9	86.724	88.201	-1.477	
GPS 10	185.410	184.368	1.042	
GPS 11	218.844	217.483	1.361	
GPS 12	130.041	129.269	0.772	
GPS 13	93.794	94.120	-0.326	
GPS 14	134.746	134.971	-0.225	
GPS 15	85.023	86.668	-1.645	
GPS 17	57.951	60.916	-2.965	
GPS 18	7.542	10.959	-3.417	
GPS 19	81.687	83.597	-1.910	
GPS 20	81.342	82.423	-1.081	
GPS 21	109.114	110.649	-1.535	
GPS 22	22.158	22.991	-0.833	
GPS 23	17.220	18.925	-1.705	
GPS 24	6.944	9.516	-2.572	
GPS 25	19.707	23.217	-3.510	
GPS 26	29.344	32.879	-3.535	
GPS 27	106.614	107.416	-0.802	
GPS 28	99.575	99.597	-0.022	
GPS 29	84.783	85.414	-0.631	
GPS 30	10.231	10.840	-0.609	
GPS 31	69.426	68.276	1.150	
GPS 32	63.096	62.512	0.584	
GPS 33	100.246	99.640	0.606	
GPS 34	85.202	83.802	1.400	
GPS 35	56.599	54.915	1.684	
GPS 36	17.922	16.468	1.454	
GPS 233	4.060	2.796	1.264	

3-4-8 Vector analysis of Z points

All the GPS satellite data received in each session was subjected to the vector analysis based on the WGS-84 spheroid as in the first year. The vector closure errors in each session, the closure errors of combined vectors in different sessions and the differences of redundant vectors in each session were within the tolerance, and a very highly accurate analysis summary was obtained by GPS observation.

In verification of the above vector analysis summary, it was confirmed that the survey accuracy of the Z control points in this study fully satisfied the requirement. (See "Checking of Closure Error of Observed Values" and "Comparison of Redundant Vector".)

3-4-9 Three-dimensional net adjustment computation of XYZ points

The GPS observation vector analysis summary was subjected to three-dimensional net adjustment computation using the ellipsoid Clarke 1880 adopted by Ghana in which the existing control points and the results of leveling with heights directly fitted to the XYZ points were set as given points. Thus, the geodetic coordinates, height and standard deviation of each XYZ point were obtained.

3-4-10 Z point computation by interpolation

The geodetic coordinates, heights and standard deviation of each Z point were obtained by the three-dimensional net adjustment computation (interpolation method) based on the ellipsoid Clarke 1880 adopted by Ghana, in which the XYZ points and the vector analysis summary were used as given points.

3-4-11 GPS observation in ground control point survey III (additional)

The progress of aerial photography was grasped accurately and the GPS observation network and the photographed districts were reviewed. As a result, 4 additional ground control points required for aerial triangulation and digital plotting were newly installed. Selection of these control points was made in the same conditions as in the ground control point surveys I and II. A total of 4 sessions of observation were conducted, in which simultaneous observation by 4 GPS receivers in each session was made using given XYZ points. (See the diagram of Additional GPS Observation Network.)

3-4-12 Major equipment used

The main equipment used in the GPS observation of the additional ground control points is as follows:

Item	Type
GPS receiver	TRIMBLE 4000SSE, 4 units
Software	TRIMBLE, GPSURVEY, TRIMNET, and KENKYU-SHA KEN-Q
Computer	TOSHIBA DYNABOOK, 1 set
Compact GPS	TRIMBLE ENSIN, 4 units

Summary of baseline computation

Group No.	Station comination for baseline		Computed Slope Distance(m)	Accuracy (m)
	1	2	23,113.440	TD= 92,806.745
1	2	203	23,845.312	dx = +0.012
	203	202	25,620.504	dy = −0.007
	202	1	20,227.488	dz = +0.001
				Ratio=0.144ppm
	203	101	16,161.700	TD= 94,874.639
2	101	102	43,774.179	dx = +0.013
	102	204	8,896.978	dy = −0.007
	204	203	26,041.783	dz = +0.007
				Ratio=0.172ppm
	101	201	23,761.421	TD= 109,461.531
3	201	7	20,524.753	dx = −0.006
	7	6	33,980.923	dy = −0.001
	6	101	31,194.434	dz = +0.001
				Ratio=0.053ppm
	6	205	26,022.469	TD= 105,678.680
4	205	8	41,530.304	dx = −0.001
	8	207	18,619.409	dy = −0.02
	207	6	19,506.499	dz = 0.001
				Ratio=0.021ppm
	205	10	28,142.008	TD= 106,454.911
5	10	206	22,079.494	dx = +0.002
	206	14	22,876.969	dy = −0.001
	14	205	33,356.440	dz = −0.000
				Ratio=0.023ppm
	208	13	28,224.646	TD= 100,086.206
6	13	214	13,598.048	dx = +0.001
	214	20	19,090.226	dy = −0.001
	20	208	39,173.288	dz = −0.001
				Ratio=0.020ppm
	14	208	12,279.276	TD= 79,549.148
7	208	213	18,524.618	dx = +0.007
	213	212	15,775.784	dy = −0.002
	212	14	32,969.470	dz = −0.004
				Ratio=0.102ppm
	212	213	15,775.784	TD= 75,496.679
8	213	15	22,703.528	dx = +0.015
	15	8	22,090.909	dy = −0.020
	8	212	14,926.458	dz = +0.010
				Ratio=0.355ppm
	102	8	36,158.321	TD= 90,800.643
9	8	215	21,046.750	dx = −0.005
	215	211	13,641.462	dy = −0.001
	211	102	19,954.111	dz = +0.001
				Ratio=0.052ppm
	209	4	10,843.096	TD= 69,045.366
10	4	3	33,460.337	dx = −0.007
	3	210	17,045.525	dy = +0.004
	210	209	7,696.407	dz = −0.002
				Ratio=0.118ppm

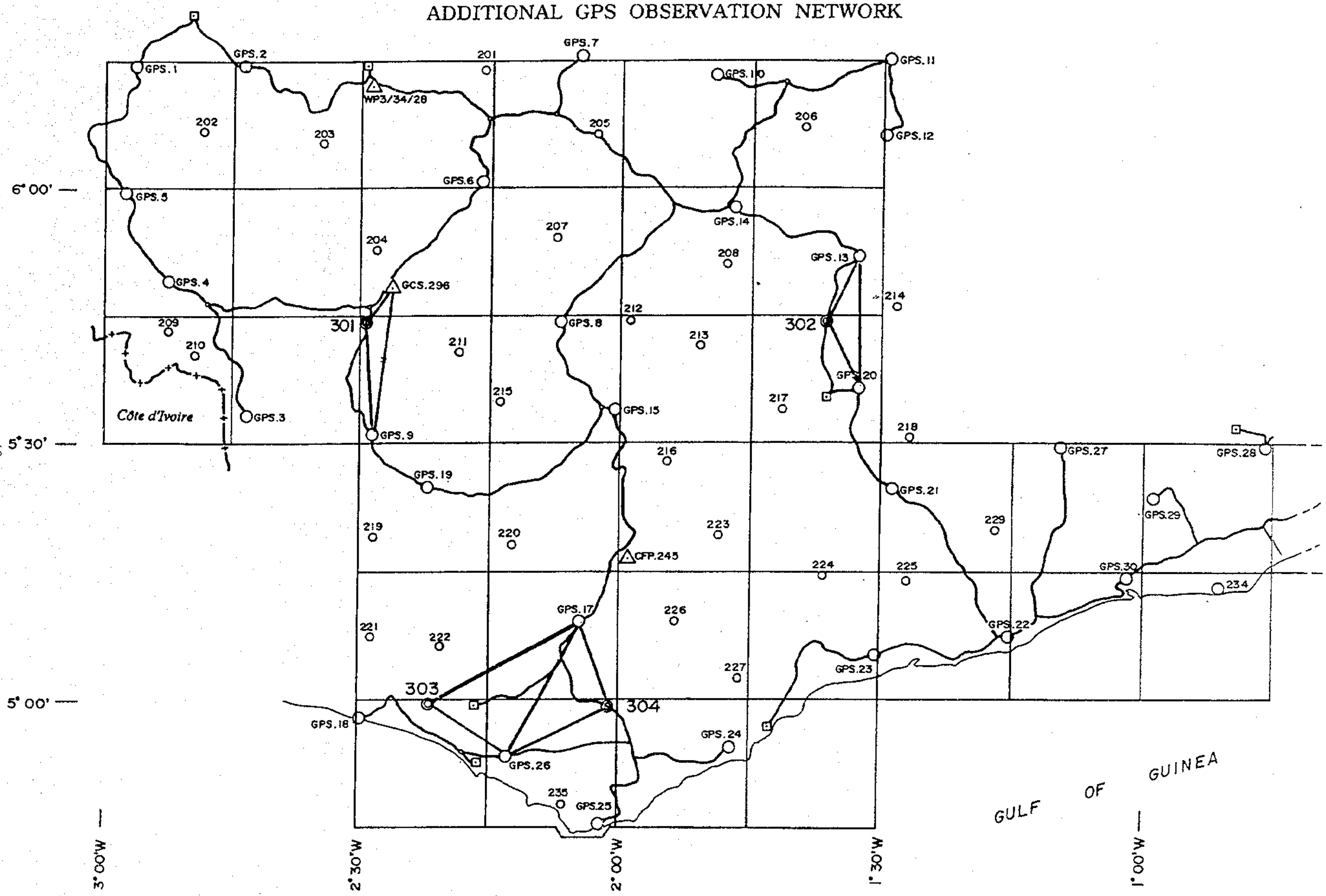
Group No.	Station comination for baseline		Computed Slope Distance(m)	Accuracy (m)
	219	19	15,545.705	TD= 86,271.911
11	19	222	34,296.738	dx = −0.026
	222	221	15,009.392	dy = +0.017
	221	219	21,420.076	dz = +0.000
				Ratio=0.359ppm
	221	222	15,009.392	TD= 92,412.094
	222	26	27,609.600	dx = +0.003
12	26	18	32,279.158	dy = −0.012
	18	221	17,513.944	dz = −0.008
				Ratio=0.155ppm
	15	216	15,690.607	TD= 108,257.976
13	216	220	37,241.843	dx = −0.009
	220	215	30,970.201	dy = −0.006
	215	15	24,355.324	dz = −0.001
				Ratio=0.096ppm
	220	216	37,241.843	TD= 101,220.363
14	216	223	19,422.494	dx = −0.015
	223	245	19,741.506	dy = +0.014
	245	220	24,814.520	dz = +0.007
				Ratio=0.214ppm
	223	227	31,326.789	TD= 86,239.838
15	227	226	18,319.993	dx = −0.043
	226	245	16,851.550	dy = +0.001
	245	223	19,741.506	dz = +0.009
				Ratio=0.113ppm
	217	224	37,040.750	TD= 107,424.341
16	224	223	24,045.178	dx = −0.003
	223	216	19,422.494	dy = −0.001
	216	217	26,915.919	dz = −0.003
				Ratio=0.044ppm
	217	20	17,134.092	TD= 73,116.173
17	20	218	15,139.772	dx = +0.001
	218	21	11,619.305	dy = +0.001
	21	217	29,223.003	dz = −0.000
				Ratio=0.017ppm
	224	23	20,637.564	TD= 100,969.858
18	23	24	36,848.911	dx = −0.002
	24	227	14,865.093	dy = +0.002
	227	224	28,618.290	dz = +0.001
				Ratio=0.023ppm
	21	225	20,087.100	TD= 81,665.078
19	225	23	17,167.803	dx = −0.042
	23	224	20,637.564	dy = +0.031
	224	21	23,772.610	dz = +0.009
				Ratio=0.039ppm
	21	229	23,524.833	TD= 91,672.292
20	229	22	23,185.185	dx = −0.002
	22	225	24,875.174	dy = +0.001
	225	21	20,087.100	dz = +0.001
				Ratio=0.022ppm

Group No.	Station comination for baseline		Computed Slope Distance(m)	Accuracy (m)
	222	17	29,603.515	TD= 112,497.205
21	17	235	39,588.283	dx = 0.004
	235	26	15,695.807	dy = 0.000
	26	222	27,609.600	dz = −0.001
				Ratio=0.039ppm
	29	103	29,990.404	TD= 82,254.219
22	103	234	14,538.416	dx = −0.001
	234	30	19,714.790	dy = −0.000
	30	29	18,010.610	dz = +0.000
				Ratio=0.015ppm
	104	32	22,713.169	TD= 61,245.116
23	32	232	15,418.601	dx = +0.000
	232	230	14,383.851	dy = +0.000
	230	104	8,729.495	dz = +0.000
				Ratio=0.007ppm
	34	231	18,472.580	TD= 78,820.321
24	231	36	15,470.086	dx = +0.000
	36	233	21,465.757	dy = +0.001
	233	34	23,411.898	dz = −0.001
				Ratio=0.015ppm

Comparison of Redundant Vector

Station No	DX(m)			DY(m)			DZ(m)			DS(m)			Allowable Error
	Lenght A	Lenght B	Diff.	Lenght A	Lenght B	Diff.	Lenght A	Lenght B	Diff.	Lenght A	Lenght B	Diff.	10ppm
225,21	-1920.099	-1920.097	0.002	-3091.461	-3091.471	-0.010	19754.686	19754.686	0.000	20087.099	20087.100	0.001	0.201
224,23	-1836.186	-1836.144	0.042	-11521.709	-11521.731	-0.022	17023.152	17023.143	-0.009	20637.564	20637.566	0.002	0.206
223,245	132.835	132.843	0.008	19074.462	19074.462	0.000	5086.681	5086.673	-0.008	19741.506	19741.504	-0.002	0.197
223,216	-1834.457	-1834.444	0.013	-11056.901	-11056.907	-0.006	15862.310	15862.311	0.001	19422.492	19422.494	0.002	0.194
216,220	463.534	463.525	-0.009	-32820.546	-32820.541	0.005	-17962.182	-17962.176	0.006	37241.843	37241.836	-0.007	0.372
212,213	1020.149	1020.134	-0.015	14848.652	14848.676	0.024	-5229.931	-5229.942	-0.011	15775.784	15775.809	0.025	0.158
222,26	2632.603	2632.598	-0.005	13843.484	13843.475	-0.009	-23742.730	-23742.739	-0.009	27609.597	27609.600	0.003	0.276
221,222	750.562	750.584	0.022	14838.312	14838.296	-0.016	-2131.539	-2131.536	0.003	15009.408	15009.392	-0.016	0.150

ADDITIONAL GPS OBSERVATION NETWORK



3-4-13 Vector analysis in ground control point survey III (additional)

The vector analysis of the additional control points was made in accordance with the same specifications as for the XYZ points and the Z points. The vector closure errors in each session, the combined vector closure errors in different sessions and the differences of redundant vectors in each session were within the tolerance, and a very highly accurate analysis summary was obtained. In verification of the above vector analysis summary, it was confirmed that the survey accuracy of the additional ground control points fully satisfied the requirement.

3-4-14 Three-dimensional net adjustment computation of the ground control point survey III (additional)

The vector analysis summary in GPS observation was subjected to three-dimensional adjustment computation based on the ellipsoid Clarke 1880 adopted by Ghana, using the results at the XYZ points and the heights directly connected to the control points in the ground control point survey III as given points. Thus, the geodetic coordinates, height and standard deviation of each XYZ point were obtained. (See Results of Survey of Additional Ground Control Points.)

3-4-15 Specifications of applied ellipsoid

The specifications of the ellipsoid applied by the agreement between the study team and SDG are as follows:

Item	Specifications
Applied ellipsoid	Clarke 1880 (semi-major axis 6,378,249.145m, ellipticity 1/293.465)
Plane coordinate system	Ghana Modified Transverse Mercator
Origin of coordinates	West of Greenwich 1° 00' North 4° 40'
Coordinate addition constant	Easting 300,000 m Northing 0 m
Zero meridian scale factor	0.99975
Height standard	M.S.L (existing control points of SDG)

ADDITIONAL GROUND CONTROL SURVEY RESULTS

Closure error

Observation st.	Station	Distance	Closure error
301/296/9	301 ~ 296 296 ~ 9 9 ~ 301	9,178.465m 32,022.304m 25,030.241m	Total dist.=66,231.011m dx=-0.0114m, dy=+0.0132m dz=-0.0325m Ratio=0.5562ppm
302/13/20	302 ~ 13 13 ~ 20 20 ~ 302	15,197.265m 28,382.447m 16,052.102m	Total dist.=59,631.815m dx=-0.0046m, dy=-0.0077m dz=+0.0114m Ratio=0.2433ppm
303/17/26	303 ~ 17 17 ~ 26 26 ~ 303	33,460.373m 32,855.475m 16,659.996m	Total dist.=82,975.844m dx=+0.0069m, dy=-0.0076m dz=+0.0069m Ratio=0.1494ppm
304/26/17	304 ~ 26 26 ~ 17 17 ~ 304	25,348.159m 32,855.475m 19,814.434m	Total dist.=78,018.068m dx=+0.0128m, dy=-0.0045m dz=-0.0162m Ratio=0.2708ppm

Double observation difference

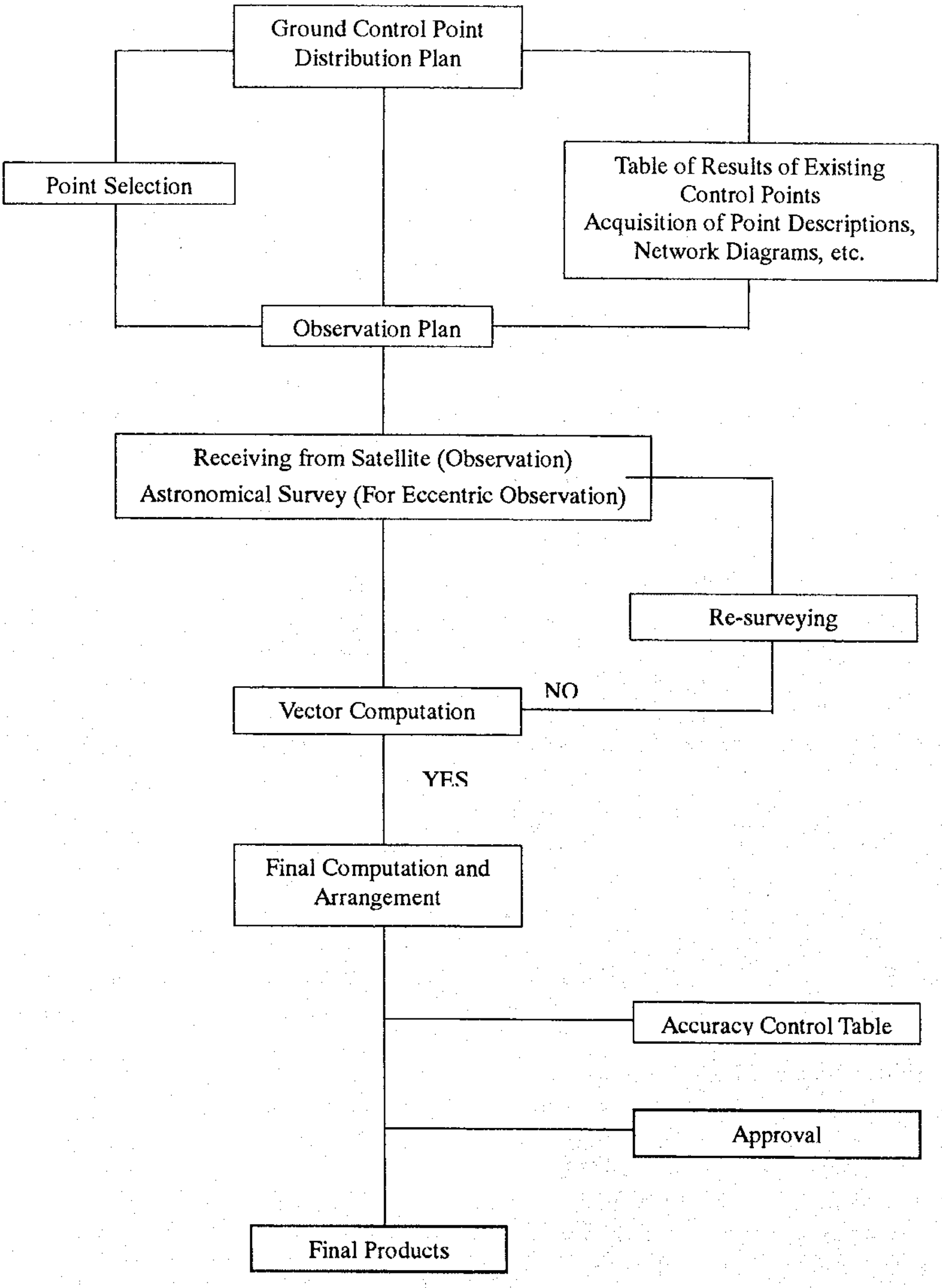
Station (year)	dx	dy	dz
296 ~ 9 ('96)	+ 2,899.106m	- 4,136.354m	-31,621.387m
('98)	+ 2,899.124m	- 4,136.386m	-31,621.407m
Difference	- 0.018m	+ 0.032m	+ 0.020m
13 ~ 20 ('96)	+ 2,837.442m	+ 396.848m	-28,237.463m
('98)	+ 2,837.456m	+ 396.844m	-28,237.469m
Difference	- 0.014m	+ 0.004m	+ 0.006m
17 ~ 26 ('96)	+ 1,950.879m	-15,277.521m	-29,021.966m
('98)	+ 1,950.883m	-15,277.534m	-29,021.944m
Difference	- 0.004m	+ 0.013m	- 0.022m
17 ~ 26 ('98)	+ 1,950.883m	-15,277.534m	-29,021.944m
('98)	+ 1,950.920m	-15,277.534m	-29,021.949m
Difference	- 0.037m	0.000m	+ 0.005m

Final Result of New Points

Station	Northing (m)	Easting (m)	Height (m)
301	+ 119,052.08	+ 134,572.81	+ 90.83
302	+ 118,845.13	+ 233,097.04	+ 80.32
303	+ 35,440.05	+ 152,629.94	+ 17.82
304	+ 35,528.86	+ 188,274.03	+ 69.86

(Ghana Modified Transverse Mercator)

3-4-17 Work flow of ground control point survey



3-5 Leveling

3-5-1 Outline

Leveling was performed for the areas where there are insufficient existing bench marks necessary to conduct aerial triangulation and digital plotting in order to maintain a high elevation accuracy for 1/50,000-scale topographic mapping. The coverage of photography, the existing leveling routes and the highways with relatively easy access were inscribed in the existing topographic maps so that block adjustment computation can be performed with a stable and high accuracy.

For the leveling routes in areas where aerial photography had not been performed yet, terrestrial photography was conducted and detailed sketches were prepared in order to make the prick points clear in the later process.

3-5-2 Field reconnaissance

Field reconnaissance of the planned leveling routes was carried out to investigate the road conditions, adaptability of the planned routes as observation routes and the existing leveling routes in the vicinity. The bench marks (prick points) to be installed in about 4km intervals were also selected.

3-5-3 Observation

By the use of a digital level and a barcode staff, observation was made efficiently and served to avoid repeated measurements due to misreading. For open-type routes, observations were made in both ways as a rule. The existing bench marks used as given points were also verified. For jointed routes, existing bench marks were checked at their start and joint points.

3-5-4 Additional leveling

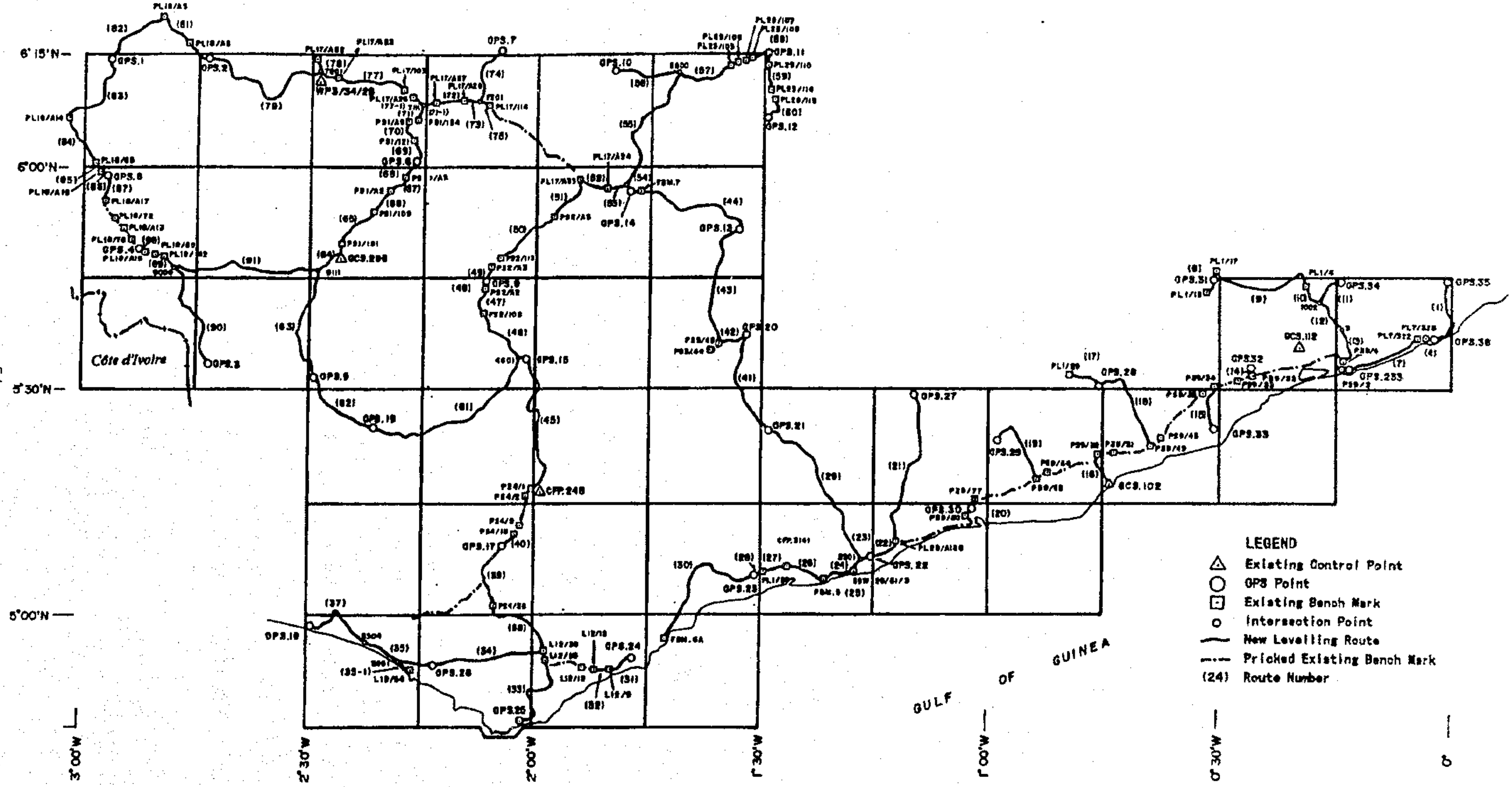
For the 4 additional ground control points added, leveling was conducted over a distance of approximately 230km in accordance with the same observation specifications. (See the diagram of Leveling Route on the next page.)

3-5-5 Major equipment used

The following main equipment was used for leveling:

Item	Type
Digital level	LEICA NA2000 4 units
Barcode staff	LEICA barcode staff 8 pieces
Computer	TOSHIBA DYNABOOK 1 set

Leveling Route



3-5-6 Computation

All the observed data was transferred to the computer. The computation of heights were performed to check whether there were any problems with the height of all bench marks (prick points), all the ground control points newly installed in the ground control point survey and those of the existing bench marks used as given points. The differences of each route on both ways and the differences between jointed routes were within the limit of within ±50 mm $\sqrt{S}$ (S=km). Thus, the results of observation were very good. (See Table of Closures for the Respective Route Section and Table of Closures for the Existing BMs on the following pages.)

Closures for the Respective Route Section

Route No.	Course	Distance	Closure	Tolerance	Remark
1, 4	PL7/325 ～ GPS. 35	20. 606 km	130 mm	226 mm	Open type
7	PL7/322 ～ PS9/2	22. 134	45	235	
8	PL1/19 ～ PL1/17	5. 338	6	115	
9	PL1/17 ～ PL1/6	29. 504	4	271	
10, 12, 13	PL1/6 ～ PS9/4	25. 960	13	254	
11	1002 ～ GPS. 34	7. 042	13	132	Open type
14	PS9/32 ～ GPS. 32	0. 590	1	38	Open type
15	PS9/34 ～ GPS. 33	10. 445	17	161	Open type
16, 17	PL1/29 ～ PS9/45	36. 810	94	303	
18	PS9/52 ～ GCS. 102	10. 618	10	162	Open type
19	PS9/65 ～ GPS. 29	22. 038	41	234	Open type
20	PS9/77 ～ PS9/80	3. 798	9	97	
21	PL25/A16B ～ GPS. 27	38. 424	186	309	Open type
22, 23, 24	PL25/A16B ～ SGW20/60/3	14. 030	13	187	
25	SGW20/60/3 ～ FBM. 5	7. 956	46	141	
26	FBM. 5 ～ CFP. 3141	11. 728	24	171	
27	CFP. 3141 ～ PL1/55	7. 710	16	138	
28, 30	PL1/55 ～ FBM. 5A	40. 458	27	318	
29, 41, 42	2301 ～ PS3/45	77. 136	54	439	
31, 32	L12/12 ～ GPS. 24	7. 147	22	133	Open type
33	L12/33 ～ GPS. 25	26. 097	243	255	Open type
34, 35, -1	L12/35 ～ L12/84	38. 912	65	311	
35, 37	3501 ～ GPS. 18	30. 425	35	275	Open type
38	L12/35 ～ PS4/25	20. 574	90	226	
39, 40	PS4/25 ～ PS4/10	22. 210	40	235	
43, 44	PS3/45 ～ FBM. 7	72. 836	175	426	
45, 46	PS4/1 ～ PS2/106	55. 018	353	370	
47	PS2/106 ～ PS2/A2	6. 540	11	127	
48, 49	PS2/A2 ～ PS2/A3	6. 350	7	125	
50	PS2/113 ～ PS2/A5	18. 450	18	214	
51	PS2/A5 ～ PL17/A33	9. 702	20	155	
52	PL17/A34 ～ PL17/A33	7. 618	27	138	
53, 54	PL17/A34 ～ FBM. 7	7. 608	17	137	
55, 57	5301 ～ PL25/105	49. 358	158	351	
56	5600 ～ GPS. 10	16. 795	47	204	Open type
58, 59	PL25/108 ～ PL25/114	15. 030	20	193	
60	PL25/115 ～ GPS. 12	7. 720	19	138	Open type
61, 62, 63	4601 ～ 9111	104. 862	130	512	
64	9111 ～ PS1/101	9. 114	16	150	
65	PS1/101 ～ PS1/108	12. 184	55	174	
66	PS1/108 ～ PS1/A2	7. 462	47	136	

Route No.	Course			Distance	Closure	Tolerance	Remark
67	PS1/A2	~	PS1/A3	5.926 km	4 mm	121 mm	
68, 69, 70	PS1/A3	~	PS1/A5	16.748	3	204	
71, 77-1	PS1/124	~	PL17/A26	8.156	124	142	
71-1	7111	~	PL17/A27	4.608	45	107	
72, 73, 75	PL17/A27	~	PL17/114	11.946	39	172	
74	7301	~	GPS. 7	15.813	10	198	
77	PL17/A23	~	PL17/103	21.930	49	234	
78	PL17/A22	~	PL17/A23	6.370	34	126	
79, 80	PL18/A6	~	7801	46.138	14	339	
81	PL18/A5	~	PL18/A6	9.118	0	150	
82	GPS. 1	~	PL18/A5	18.528	16	215	
83	PL18/A14	~	GPS. 1	20.074	16	224	
84	PL18/65	~	PL18/A14	14.454	17	190	
85	PL18/A16	~	PL18/65	1.466	16	60	
86	GPS. 5	~	PL18/A16	0.308	16	27	
87	PL18/A17	~	GPS. 5	7.100	16	133	
88	PL18/A19	~	GPS. 4	0.409	1	31	Open type
89	PL18/82	~	9000	5.654	17	118	
90	9000	~	GPS. 3	32.727	84	286	Open type
91	9000	~	9111	40.152	16	316	

Closures for the Existing BMs

Bench Marks			Distance	Closure	Tolerance	Remark
PL7/325	~	PL7/324	0.388 km	3 mm	31 mm	
PL7/324	~	PL7/322	0.796	6	44	
PS9/2	~	PS9/4	1.906	20	69	
PS9/33	~	PS9/32	0.632	4	39	
PS9/35	~	PS9/34	1.770	1	66	
PS9/45	~	PS9/43	3.388	1	92	
PS9/51	~	PS9/52	1.788	27	66	
PS9/65	~	PS9/64	1.818	8	67	
PS3/45	~	PS3/44	0.800	7	44	
L12/18	~	L12/12	4.732	4	108	
L12/33	~	L12/35	1.580	52	62	
PS4/10	~	PS4/9	1.652	3	64	
PS4/2	~	PS4/1	1.586	3	62	
PS2/A3	~	PS2/113	1.074	9	51	
PL25/106	~	PL25/105	1.160	35	53	
PL25/107	~	PL25/108	1.644	9	64	
PL25/114	~	PL25/115	1.470	16	60	
PS1/A5	~	PS1/124	2.524	4	79	
PL17/A26	~	PL17/103	1.678	9	64	
PL18/A19	~	PL18/76	5.124	16	113	
PL18/76	~	PL18/A18	2.960	16	86	
PL18/A18	~	PL18/72	5.094	17	112	
PL18/72	~	PL18/A17	5.000	16	111	
PL18/A19	~	PL18/80	3.046	16	87	
PL18/80	~	PL18/82	2.716	16	82	

3-5-8 Flowchart of Leveling

The flowchart of leveling is as shown below.