社会開発調査部報告書

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
NATIONAL GEOGRAPHIC DEPARTMENT, LAO P.D.R. (NGD)

No. 22

THE TOPOGRAPHIC MAPPING OF BOLIKHAMXAI PROVINCE IN LAO PEOPLE'S DEMOCRATIC REPUBLIC

GENERAL REPORT

FEBRUARY, 1996

INFRASTRUCTURE DEVELOPMENT INSTITUTE
PASCO INTERNATIONAL Inc.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
NATIONAL GEOGRAPHIC DEPARTMENT, LAO P.D.R. (NGD)

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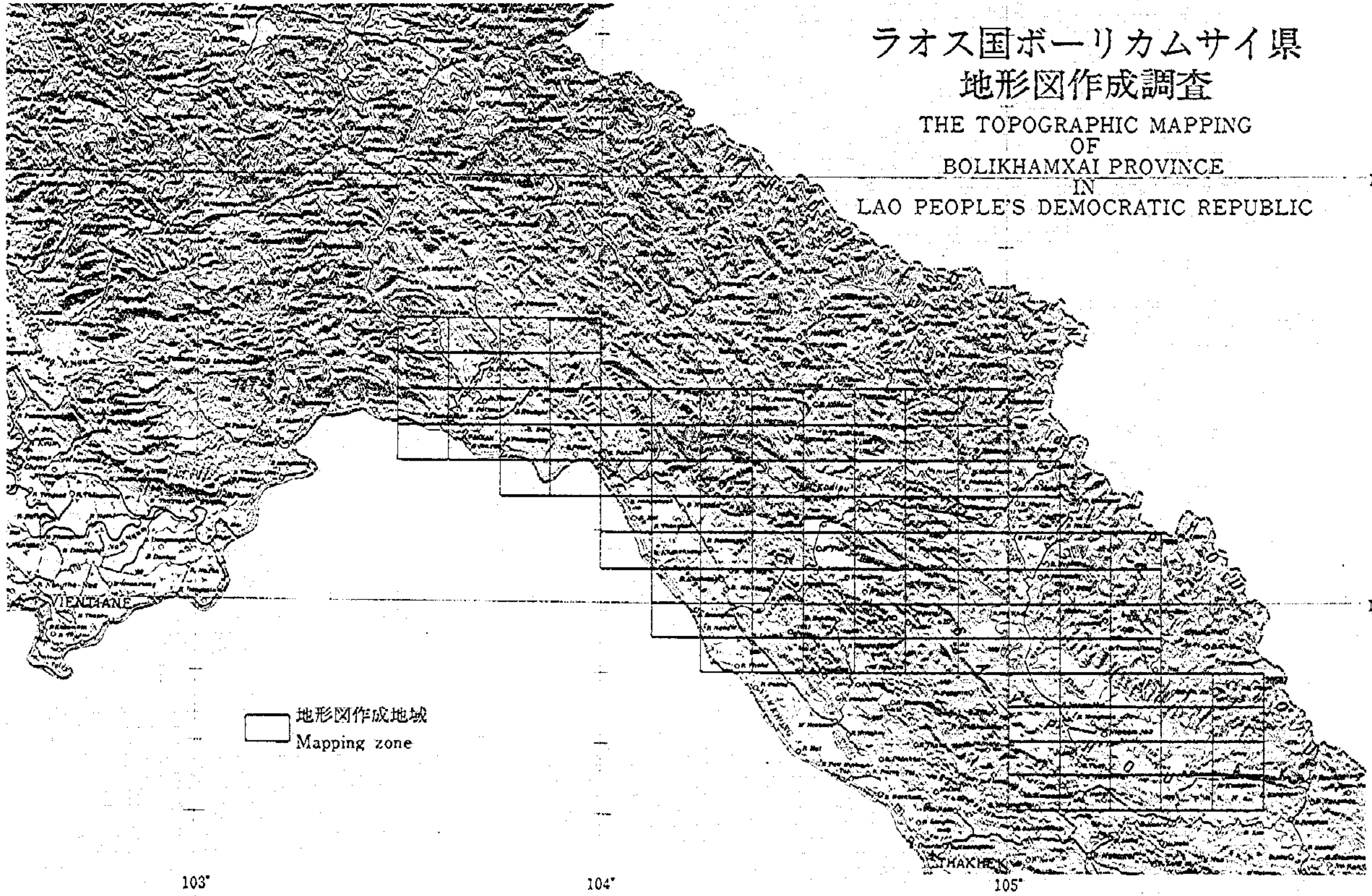

ラオス国ボーリカムサイ県
地形図作成調査
THE TOPOGRAPHIC MAPPING
OF
BOLIKHAMXAI PROVINCE
IN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
19°
18°
VIENTIANE
THAKHEK
地形図作成地域
Mapping zone
103°
104°
105°

PREFACE

In response to the request from the Government of Lao People's Democratic Republic, the Government of Japan decided to conduct a survey on the Topographic Mapping of Bolikhamxai Province and entrusted the survey project to the Japan International Cooperation Agency (JICA).

JICA sent to Laos a study team, headed by Dr. Tositomo Kanakubo, the Infrastructure Development Institute and composed of the members from the Infrastructure Development Institute and Pasco International Inc., several times between December 1992 and February 1996.

The team conducted field surveys in close cooperation with the officials concerned of the Government of Lao People's Democratic Republic. After the team returned to Japan, such works as aerial triangulation, stereo plotting, compilation and drawing were carried out and topographic maps were prepared, together with the present report.

I hope that this report, together with the above mentioned maps, will contribute to the formulation of development plans of the region and to the enhancement of friendly relationship between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Lao People's Democratic Republic for their close cooperation extended to the team.

February 1996

Kimio FUJITA
President
Japan International Cooperation Agency

February 1996

His Excellency Mr. Kimio Fujita
President, Japan International Cooperation Agency
Tokyo, Japan

Letter of Transmittal

Dear Sir,

Upon the successful completion of the study of THE TOPOGRAPHIC MAPPING OF BOLIKHAMXAI PROVINCE IN LAO PEOPLE'S DEMOCRATIC REPUBLIC, which was started from December 1992, I herein submit the final report on the study to you.

The report contains the descriptions of the outline of the study and technical operations of 1:25,000 Topographic Mapping conducted in cooperation with the National Geographic Department of Lao.

We are convinced that the above final report and 1:25,000 Topographic Maps will contribute to the land development and preservation as well as the improvement for the technology of surveying and mapping in Lao People's Democratic Republic.

We hope that the above study will enhance development projects and decision making in various policies of the region, in particular; promotion of agriculture and forestry, development of mining resources, establishment of new city planning, construction of transportation networks, development of power resources, location of tourist industry, prevention of natural disasters, preservation of natural and social environment.

During the execution of the study, we were given many kind cooperation by the National Geographic Department, the Japanese Embassy in Lao and other relevant organizations in Lao.

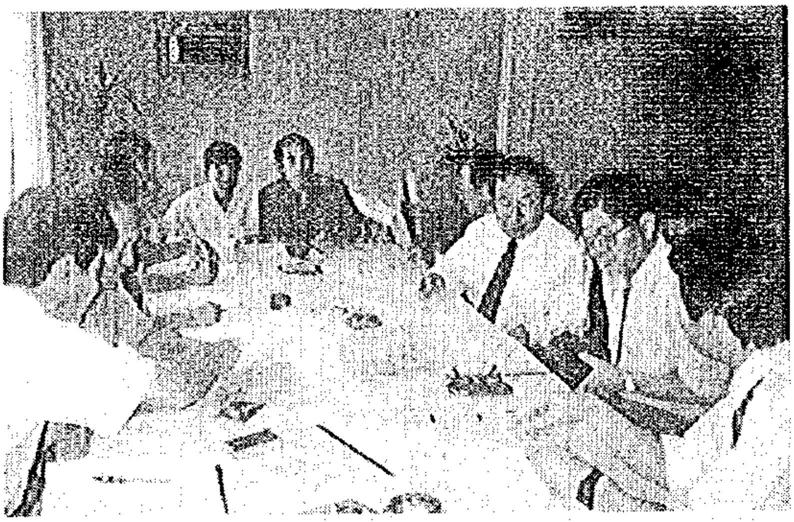
On behalf of the study team, I hereby express our heartfelt gratitude to their relevant officials of our government who gave kind guidance to us during the execution of the study, the officials concerned of the government of Lao People's Democratic Republic, and of the Japanese Embassy in Lao P.D.R. who supported us.

Yours sincerely,

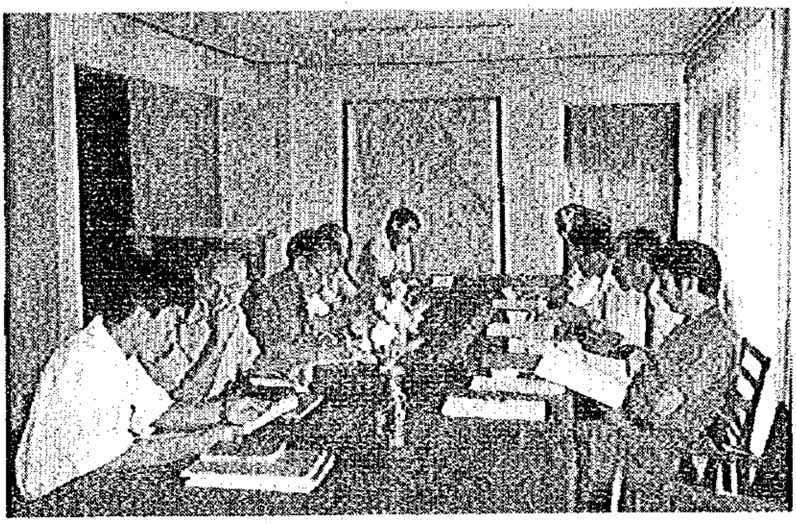
Tositomo Kanakubo

Tositomo KANAKUBO, Dr. Sc.
Leader, Study Team of Topographic
Mapping of Bolikhamxai Province
in Lao People's Democratic Republic

Photo-1



Meeting on Plan of Operation (At NGD)

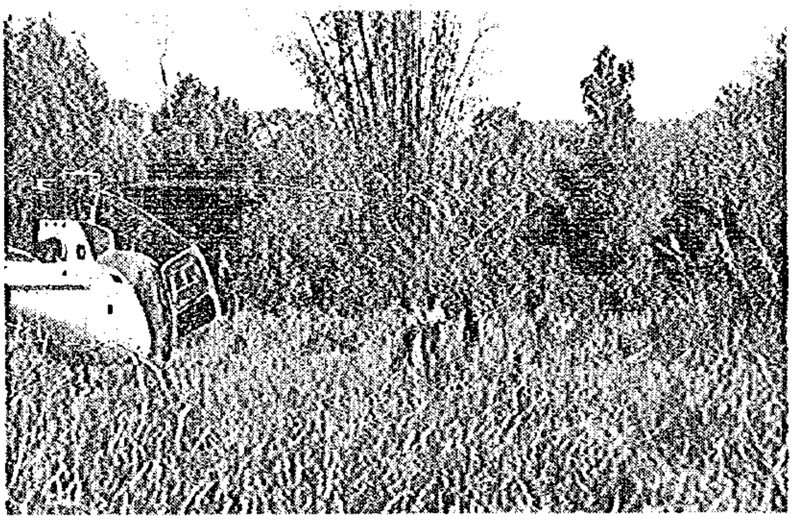


Minutes of Meeting

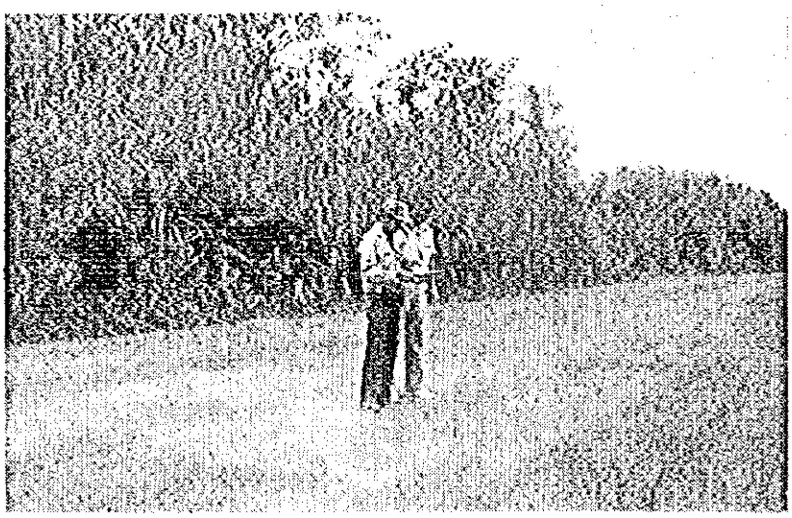
Signing on the Minutes of Meeting

Photo-2

Meeting in the Office

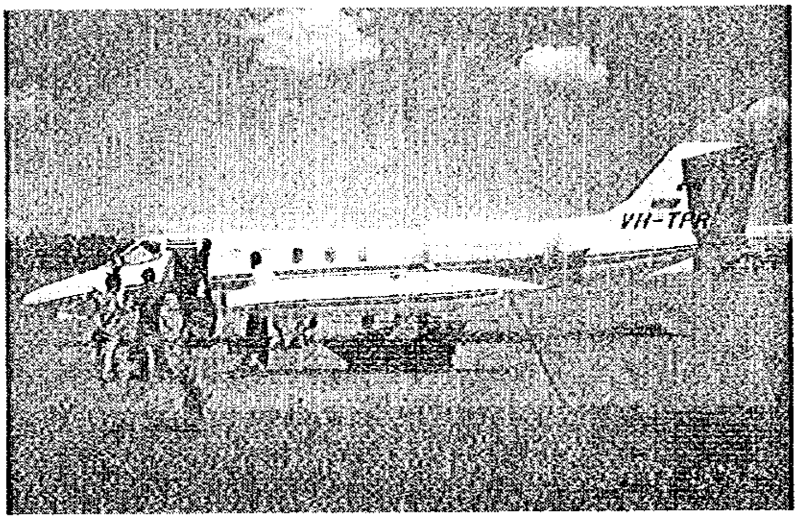


Reconnaissance Study of Control Points using Helicopter

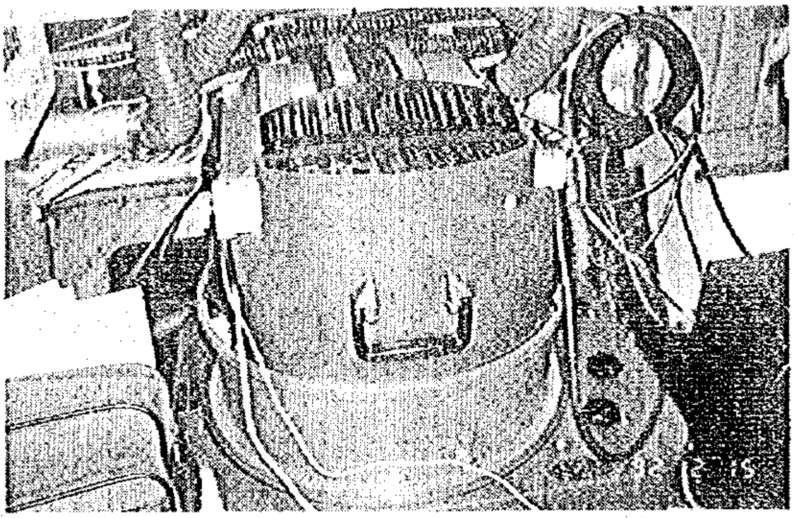


Reconnaissance of Existing Bench Marks

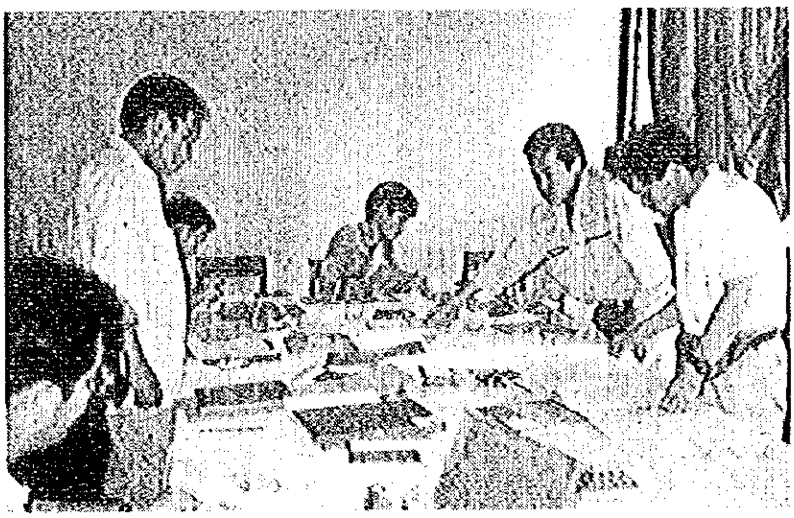
Photo-3



Aerial Survey Aircraft
Gates Learjet 35A

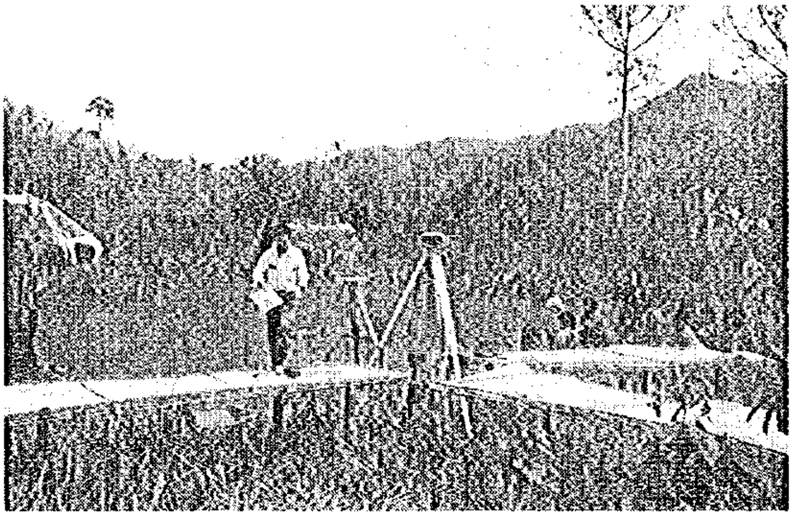


Aerial Camera RC-20

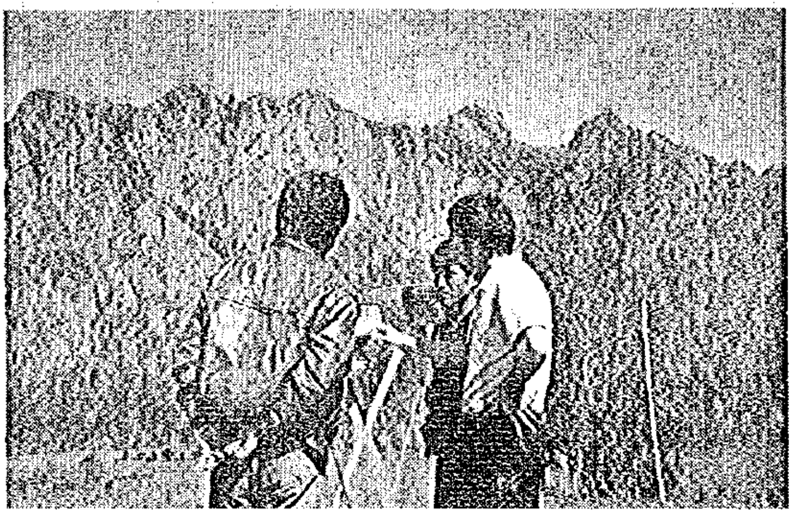


Office Work

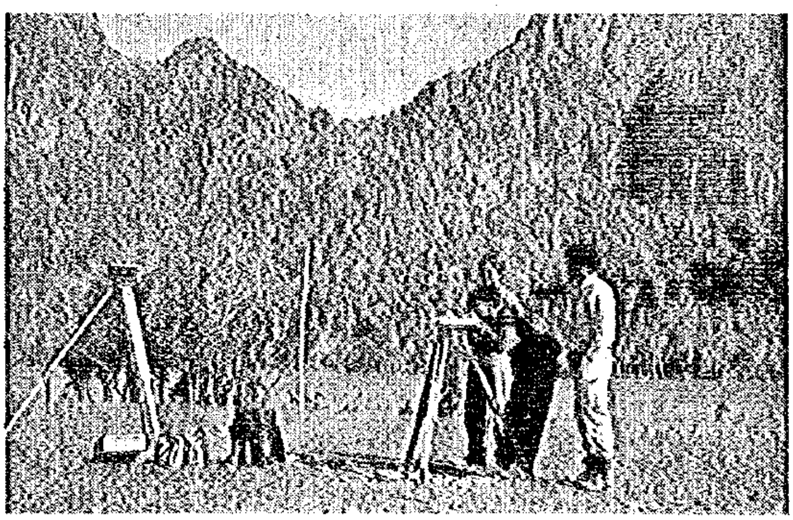
Photo-4



GPS Obsevation

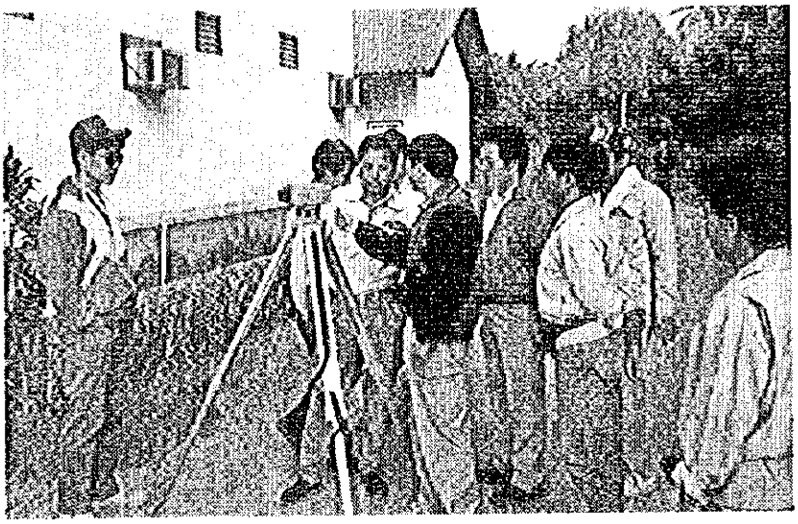


Explanation of GPS
Survey to Counterparts

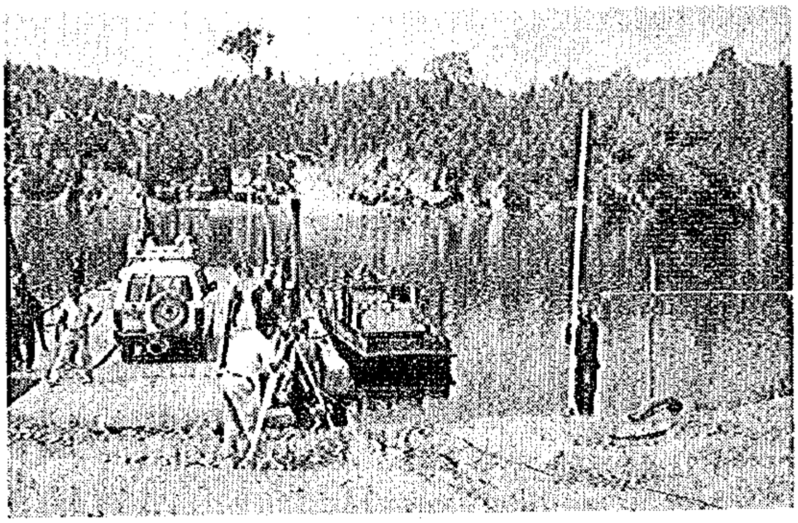


Pricking of Control Points
using Plane-table

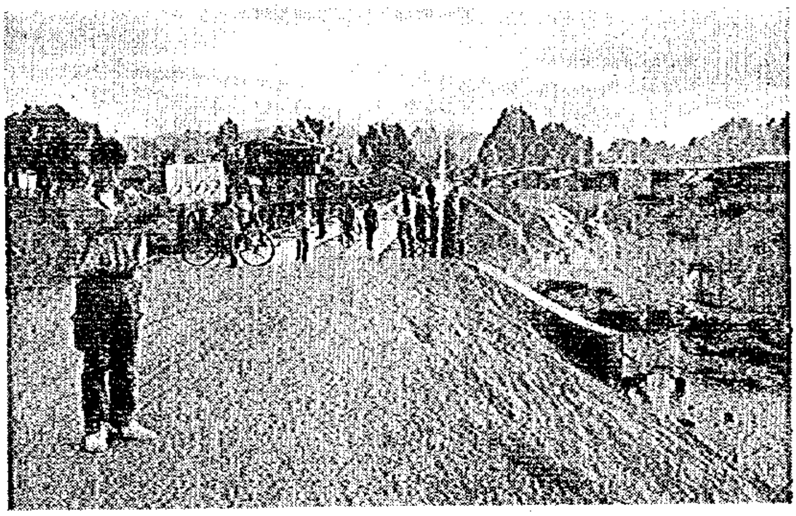
Photo-5



Explanation of
Digital Level NA2000
to Counterparts

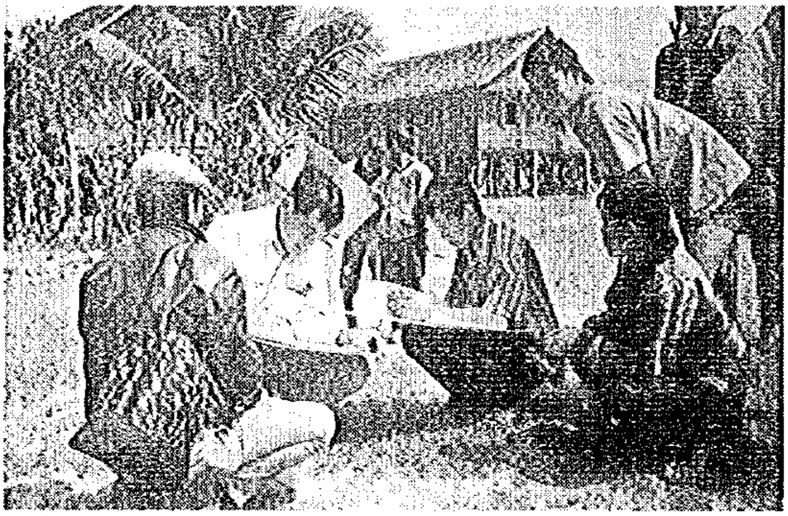


Cross-river Leveling



Pricking Survey of
Leveling Points

Photo-6

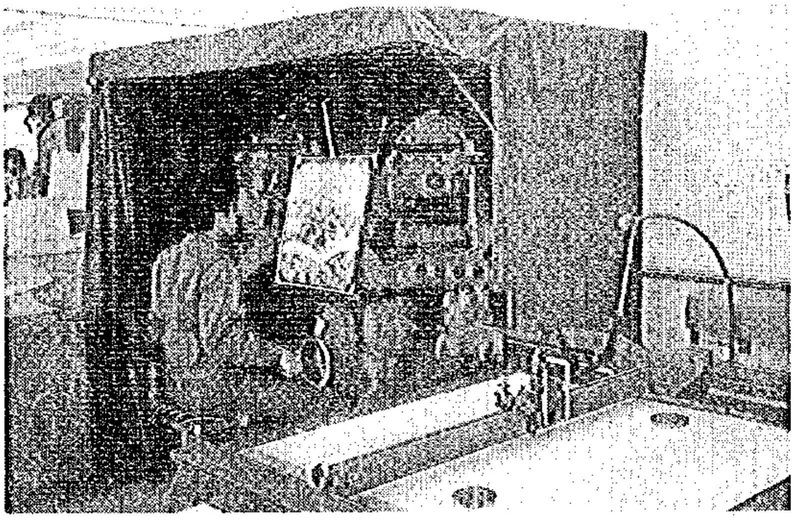


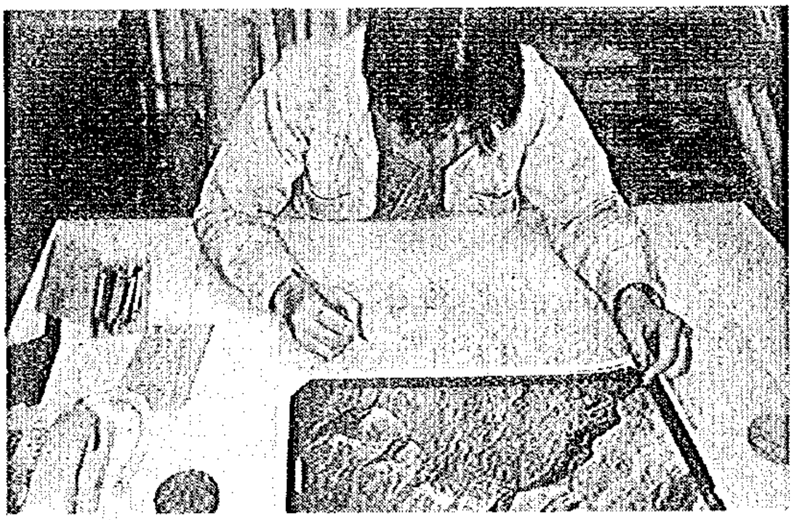
Field Confirmation

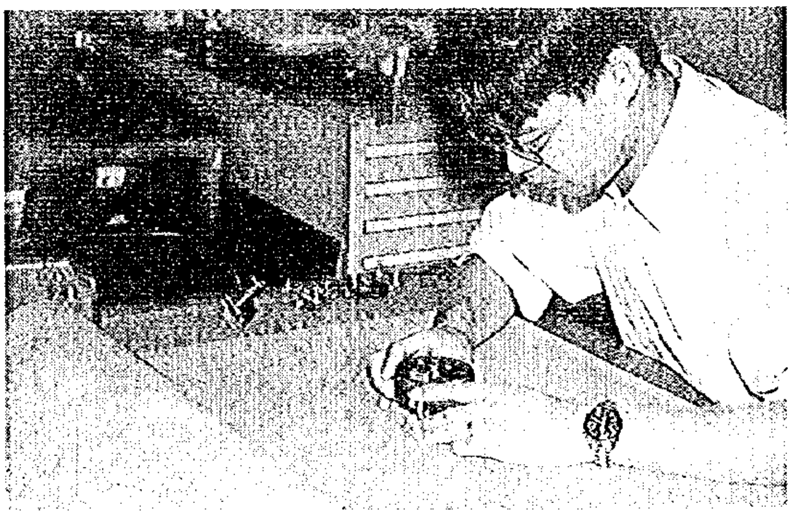
Proofing of Field Results

Signing on the Minutes of the Last Meeting

Photo-7


Stereo-plotting


Map Compilation


Scribing/Drafting

GENERAL REPORT
ON THE TOPOGRAPHIC MAPPING OF BOLIKHAMXAI PROVINCE
LAO PEOPLE'S DEMOCRATIC REPUBLIC

CONTENTS

ATTACHMENTS

1. INTRODUCTION

The topographic mapping of Bolikhamxai Province in the Lao People's Democratic Republic (hereinafter referred to as "Laos") was carried out in response to the request of the Government of Laos to produce 1/25,000 scale national base map of the area. Starting in December 1992, the project was completed in February 1996 after four years of work.

The study area falls within the bounds of 17°30'N to 18°40'N in latitude and 103°30'E to 105°37.5'E in longitude as shown in the map at the beginning of this report, encompassing some 13,000k m². The study area of Bolikhamxai Province is located east of the capital city, Vientiane, and connects with Vientiane city through Route 13, and also adjoins the northeast of the Mekong river which borders Thailand. The northeastern part of this province borders on Vietnam forming the watershed of Indochina along the Louang Mountain Ranges. This area is considered as one of the most promising areas for economic development.

This report describes the 1/25,000 topographic mapping of this area to produce the national base maps as conducted by the JICA team in terms of each process of work that was followed and results in the respective work processes. It is hoped that the maps prepared under this project along with the aerial photographs, control survey data and others will be put to the best use in various plans and surveys for development as well as conservation of this province and that this report will serve as a guide in those efforts.

2. OUTLINE OF THE WORK

2-1 Background of Request

The government of Laos, in recognition that the National Topographic Mapping is the most important basic study for preparation of social infrastructures related to urban and regional developments as well as for preservation of national lands, requested the technical cooperation program of Topographic Mapping of Blolikamxai Province to Japan in June 1991, for reason of as follows.

(1) Bolikhamxai Province located in the middle of Laos is a very promising district for national economic development, because of its location being adjacent to Vientiane Metropolitan Area and being the nearest economic route to Vietnam. The Government of Laos is now earnestly promoting medium scale development of an urban zone near Lak Xao as an axis for many kinds of projects related to agricultural and forestry development.

(2) The small scale national maps of Laos were prepared by the technical cooperation of USA and USSR as 1/50,000 scale base maps in 1965 and 1/100,000 in 1982, but they are too old to serve as fundamental data in making the recent national development preservation programs.

In response to the request of the Government of Laos, Japan International Cooperation Agency, the official agency responsible for the implementation of the technical cooperation programs of the Government of Japan (hereinafter referred to as "JICA") dispatched the Preliminary Study Mission in August 1992, and after a series of consultations with the National Geographic Department, the official agency of Laos (hereinafter referred to as "NGD"), and the Scope of Work (hereinafter referred to as "S/W") was agreed on August 12th 1992, between the two governments.

2-2 Requested Work and Agreement on Scope of Work

The request of the Government of Laos called for preparation of national base map to represent the Bolikahmxai Province at a scale of 1/25,000, the Japanese Mission discussed the Scope of Work with NGD in terms of the area to be converted, technical specification for surveying, flight plan for aerial photography, applicable map symbols, etc. and agreement was made in the forms of the Scope of Work and the Minutes of Meeting (See Attachment - 1).

2-3 Work Plan and Implementation

2-3-1 Specifications

(1) Aerial photography : Scale of 1/40,000 (by wide angle camera)

(2) Control point survey : 10^{-5} (relative accuracy)

(3) Leveling accuracy : 5cm $\sqrt{s}$ (s:km)

(4) Mapping

- Projection : UTM Projection (Zone 48)
- Spheroid : Everest 1830
- Horizontal datum : Indian datum 1975
- Vertical datum : Mean sea level of Hon Dau in Vietnam (Based on the Exiting BMs)
- Mapping scale : 1/25,000
- Neat lines : 5′ × 7.5′ in latitude and longitude
- Contour interval : 10m
- Number of colors : 5 colors

(5) Map accuracy

- Planimetry : 1.0mm on the map
- Spot height : 2/3 of contour interval
- Contour line : 1/1 of contour interval

2-3-2 Work Plans

Based on the S/W and Minutes of Meetings, the topographic mapping of Bolikhamxai Province was planned as a four year project starting from 1992, and the work plans for the respective years are outlined below.

(1) First Year (Former)

Work in Japan:

Planning /preparation

Report writing

Work in Laos:

Aerial photography	1/40,000 in scale 13,000k m² in area
Control point survey	26 points newly set on land

(2) First Year (Latter)

Work in Japan:

Planning/preparation

Aerial triangulation 818 models

Work in Laos:

Miner order leveling 580 km

River leveling 1 span

Pricking

Horizontal control 29 points (26 new points, 3 existing points)

Vertical control 730km(580km new leveling, 150km existing BMs)

(3) Second Year

Work in Japan:

Planning/preparation

Stereo-plotting 3,200k ㎡ (30 map sheets)

Compilation 3,200k ㎡ (30 map sheets)

Report writing

(4) Third Year

Work in Japan:

Planning/preparation

Stereo-plotting 9,800k ㎡ (82 map sheets)

Compilation 9,800k ㎡ (82 map sheets)

Report writing

Work in Laos:

Field completion 13,000k ㎡

(5) Forth Year

Work in Japan:

Planning/preparation

Scribing/Drafting 13,000k ㎡ (112 map sheets)

Printing 5 colors, 1,002 copies (112 map sheets)

Final report writing

The work flow over four years is shown in Table 1.

Table 1. FLOWCHART FOR THE PRODUCTION OF TOPOGRAPHIC MAPS

Working Flow	Results
Fist Year (Former) 1992～1993 Preparation Aerial photography Control point survey Reporting	Aerial photographs Field survey data Annual report
First Year (Latter) 1992～1993 Preparation Leveling Pricking Aerial triangulation	Field survey data Aerial triangulation results
Second Year 1993～1994 Preparation Field identification Stereo-plotting Compilation Reporting	Field survey data Plotting manuscripts Compiled manuscripts Annual report
Third Year 1994～1995 Preparation Stereo-plotting Compilation Field completion Reporting	Plotting manuscripts Compiled manuscripts Final manuscripts Annual report
Fourth year 1995～1996 Preparation Scribing Printing Reporting	Original scribed sheets & printing films Printed maps General Report

Shaded box: Work in Laos (Aerial photography, Control point survey, Leveling, Pricking, Field identification, Field completion)　　White box: Work in Japan

2-3-3 Implementation of Work Plans

The work plans for each year were implemented respectively as follows:

(1) First Year (Former)

(a) Work period: From 2 December, 1992 to 19 February, 1993

(b) Field surveys: From 11 December, 1992 to 10 February, 1993

(c) Numbers of personnel mobilized in field surveys:

18 JICA survey team members and

16 NGD counterparts

(d) Work planned and actually implemented:

Work process	Planned	Actual
Aerial photography	13,000 km²	13,000 km²
Control point survey	26 points	26 points
Reports writing	30 copies	30 copies

(2) First Year (latter)

(a) Work period: From 3 March, 1993 to 31 August, 1993

(b) Field surveys: From 5 March, 1993 to 3 May, 1993

(c) Numbers of personnel mobilized in field surveys:

14 JICA survey team members and

14 NGD counterparts

(d) Work planned and actually implemented:

Work process	Planned	Actual
Minor order leveling	580 km²	615 km²
Cross-river leveling	1 span	1 span
Pricking	26 points	29 points
GPS Control points	29 points	29 points
Leveling	730 km	760 km
Aerial triangulation	818 models	817 models

(3) Second Year

(a) Work period: From 10 September, 1993 to 25 March, 1994

(b) Field surveys: From 24 September, 1993 to 22 December, 1993

(c) Numbers of personnel mobilized in field surveys:

14 JICA survey team members and

10 NGD counterparts

(d) Work planned and actually implemented:

Work process	Planned	Actual
Field identification	13,000 km²	13,000 km²
Stereo-plotting	3,200 km²	3,200 km²
	(30 sheets)	(32 sheets)
Compilation	3,200 km²	3,200 km²
	(30 sheets)	(32 sheets)
Report writing	30 copies	30 copies

(4) Third Year

(a) Work period: From 21 July, 1994 to 31 March, 1995

(b) Field surveys: From 19 October, 1994 to 26 December, 1994

(c) Numbers of personnel mobilized in field surveys:

14 JICA survey team members and

10 NGD counterparts

(d) Work planned and actually implemented:

Work process	Planned	Actual
Stereo-plotting	9,800 km²	9,800 km²
	(82 sheets)	(80 sheets)
Compilation	9,800 km²	9,800 km²
	(82 sheets)	(80 sheets)
Field completion	13,000 km²	13,000 km²
Report writing	30 copies	30 copies

(5) Fourth Year

(a) Work period: From 1 August, 1995 to 14 February, 1996

(b) Work planned and actually implemented:

Work process	Planned	Actual
Scribing/drafting	13,000 km²	13,000 km²
	(112 sheets)	(112 sheets)
Printing	1,002 copies for each sheet	1,002 copies for each sheet
Final report writing	30 copies	30 copies

2-3-4 NGD Counterparts training in Japan

In the course of this mapping project, the following NGD members were in Japan as part of technology transfer program.

Name	Position	Period of visit
Mr. Bounkong SOUGATTY	Chief of Survey Division	33 days from 23 Aug. 1993 to 24 Sep. 1993
Mr. Vannasone CAHNTHBOUATHONG	Photogrammetric Section	33 days from 14 Mar. 1994 to 15 Apr. 1994
Mr. Phouangphanh SAYASANE	Deputy Chief of Cartographic Division	45 days from 11 Jan. 1995 to 24 Feb. 1995
Mr. Thongchanh MANISAY	Chief of Planning Division	59 days from 19 Sep. 1995 to 16 Nov. 1995
Mr. Boualay SAIGNASANE	Technical Director of NGD	23 days from 25 Oct. 1995 to 16 Nov. 1995

2-4 Outline of Fourth Year Work

While the contents of work performed each year from the First through Third Year are recorded in detail in the Reports submitted for the respective years, the work conducted for the fourth year is outlined below.

2-4-1 Outline

Based on the original manuscripts finalized in the third year, scribed sheets were prepared for final drafting before final products were printed in five colors.

2-4-2 Work Plan

The work for the fourth year was performed as planned as follows.

Work	Period	
Scribing	Early August, 1995 -	Late October, 1995
Proof prints for approval	Late September, 1995 -	Early November, 1995
Printing	Mid. November, 1995 -	Early February, 1996
Final Report Writing	Mid. November, 1995 -	Early February, 1996

2-4-3 Specifications

(1) Map symbols

The specifications for map symbols and marginal information for scribing were applied as agreed upon with NGD in third year's stage.

(2) Number of colors

The colors used and color partition were as follows.

Black - Marginal information, planimetry, annotation(in Latin alphabet) etc.
Red - Road surface, houses, buildings, annotation (in Lao alphabet) etc.
Blue - Water parts, annotation of water parts, aquatic plants, etc.
Green - Vegetation boundaries, forests etc.
Brown - Contour lines, etc.

(3) Number of map sheets

112 sheets

(4) Map sheet names

Map sheet names are as shown in Fig 10 .

(5) Number of drafting plates

5 color plates

(6) Number of printed copies

1,002 copies shall be printed for each sheet, of which 2 copies shall be kept in Japan.

2-4-4 Preparation of draft originals

Drafting was done by the color separation scribing method based on original compiled manuscripts to produce scribed sheets, mask sheets and annotation sheets, according to the specified map symbols and their application rules. Good quality material was used which was free from contraction/expansion and it was the same type of material as used for Japanese base maps.

(1) Image printing on scribing sheets

Images of manuscripts were contact-printed on diazo coated scribing sheets. Since original manuscripts come in separate sheets, registering holes were punched in each sheet beforehand to serve as a guide to ensure matching of original manuscripts and scribing bases when contact printing.

(2) Making of scribed sheets

Scribing was done for the respective colors starting with black and proceeding to red, blue, brown and green, in that order, according to the specifications. To ensure matching between sheets, each scribed sheet was overlaid on the next sheet to be scribed and printed in a different color. Register markings were provided as guides for sheet matching in plate making and printing: hook-shape markings on the four corners of neat line and cross markings both right and left outside of each neat line. The latter markings were taken off the printing plates at the commencement of final printing.

(3) Mask sheets

Mask sheets for planimetric features in complicated shapes were printed images of cut lines on the day light peel coat sheets by the photo mechanical method, and those for simple ones were made by overlaying a peeling coat sheet on the original manuscript and directly peeling off using a sharp knife. The same types of register markings as provided on the scribed sheets were also entered in the mask sheets.

(4) UTM grids

UTM grids, being common to all sheets, were scribed by coordinategraph and made into positives, which then were adjusted to suit the respective sheets.

(5) Longitude/latitude tick marks and neat lines

Locations of longitude/latitude tick marks on neat lines were drawn on the black scribed sheet for each map sheet.

(6) Annotation sheets

Based on annotation data, letters of prescribed types and sizes were made by photocomposer and then stick on places as specified.

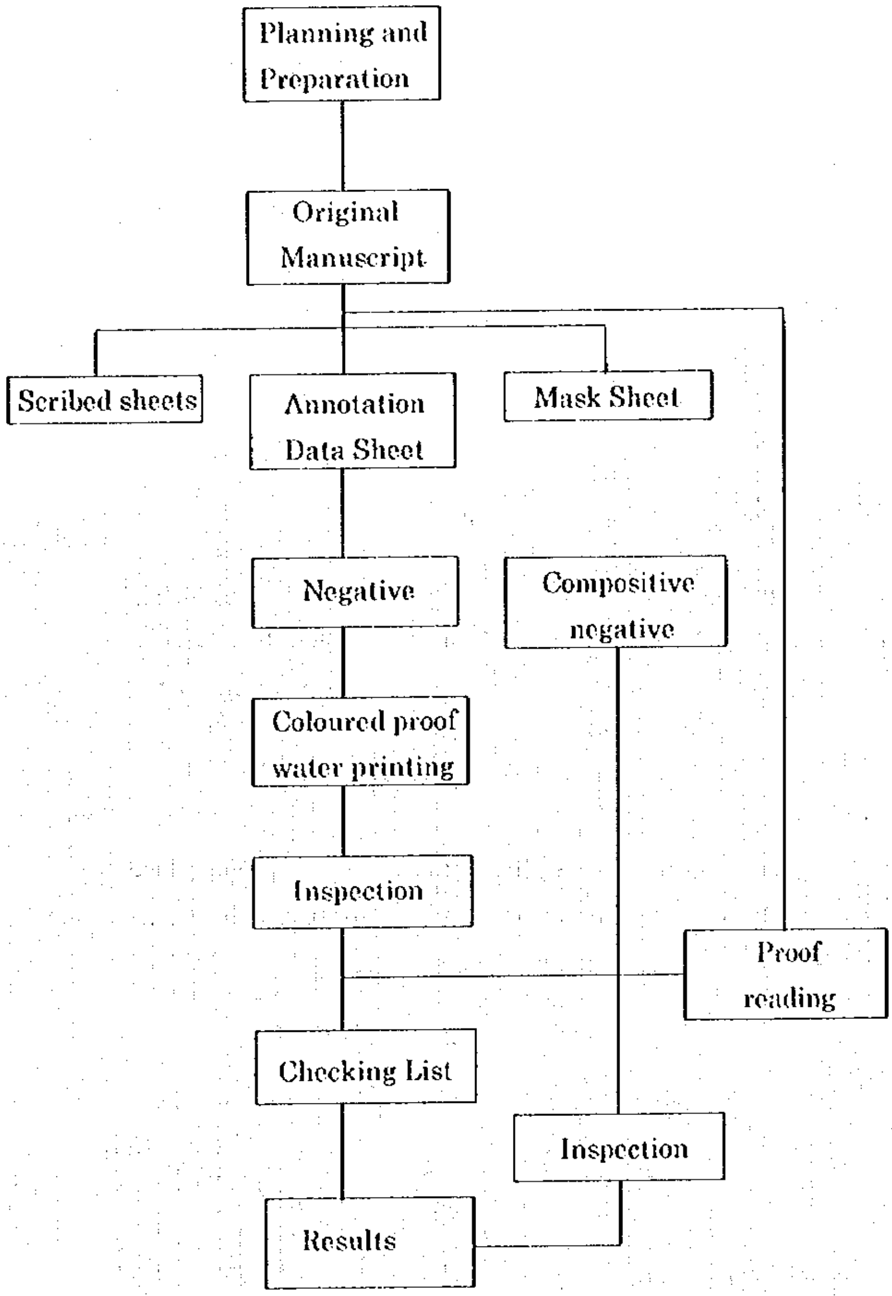
(7) Marginal information sheets

Marginal information sheets were applied as agreed upon with NGD in the Third year's stage. Data on magnetic declination in relation to the north on each map sheet were computed from the empirical formula "International Geomagnetic Reference Field" with the latest coefficients.

(8) Inspection of draft originals

From the draft originals, prints were made on polyester base in five colors for checking. Also similar inspection prints were made for NGD member's final checking, and questions resulting from the inspection were discussed with the NGD officials responsible for printing while they were in Japan. Necessary corrections were additionally made on the draft originals.

Flow of Drafting



2-4-5 Printing

Final topgraphic maps were printed by offset printing.

(1) Preparation of film for plate making

From the draft originals that come in 4-5 sheets, negative film to be used for plate making was prepared for each color.

(2) Printing plates

From the negative film, printing plates for the respective colors were made photographically using aluminum PS plates.

(3) Proof prints

From the printing plates as made above, proof prints were made by an automatic offset proof printing machine.

(4) Proofing

The proof prints were checked for the quality of coloring and matching. Defective sheets in matching were corrected and remade. Colors were checked by NGD counterparts visiting in Japan as trainees and with their agreement sample colors were determined.

(5) Printing

Printing paper was chosen for physical properties best suited for map printing in terms of representation and endurance. High quality printing ink was used that had good color tones least subject to change.

(6) Inspection

Each printed map sheet was checked for any presence of smears from printing, blurs, missing lines, matching, color tones, and all. Those that passed such rigorous inspection alone were adopted as final products.

(7) Preparation of integrated positive film

From the plates for the scribed sheets, mask sheets and annotation sheets, prepared separately for each color, one integrated positive film each was made for the respective colors for the convenience of future plate making in Laos.

3. TECHINICAL REPORT

3-1 Survey Planning

3-1-1 Objectives

The objective of the Study were to prepare at a scale of 1/25,000 topographic maps covering the area of Bolikhamxai Province, to serve as important basic maps for various projects such as development of social infrastructure in both urban and rural districts.

Main study items were as follows:

(1) To prepare base map and aerial photography

Aerial photography:	scale 1/40,000	area	13,000k ㎡
Topographic mapping:	scale 1/25,000	area	13,000k ㎡

(2) Technology transfer

Technology transfer of topographic mapping to the counterpart organization (NGD) of Laos through the Study.

3-1-2 Study area

The location of the study area to be mapped encompasses some 13,000k ㎡ ranging in latitudes from 17°30' N to 18°40' N and in longitudes from 103°30' E to 105°37.5' E as shown in the map at the beginning of this report.

3-1-3 Survey contents

This study was planned for four years project starting from December 1992 to February 1996. Yearly work flows and work volumes are shown in Table 1 and Table 2. The survey contents are as follows.

(1) Aerial photography (First year/First half)

By using an aerial camera with a wide angle lens and black/white panchromatic film, an area of about 13,000k ㎡ that needed to be covered for topographic mapping was to be photographed at a scale of 1/40,000.

(2) Control point survey (First year/First half)

Control points were to be newly set up as required for aerial triangulation and plotting. Some of them should be monumented to be preserved as permanent national assets.

(3) Minor order leveling (First year/Latter half)

Existing bench marks were concentrated along the national road route 13, so that they were not sufficient for vertical control for aerial triangulation. Therefore minor order leveling was to be conducted along some other existing roads to establish additional vertical control points.

(4) Pricking (First year/Latter half)

New GPS control points as well as existing and newly set bench marks were to be pricked at their precise locations on enlarged photographs.

(5) Aerial triangulation (First year/Latter half)

Aerial triangulation of the study was to be conducted based on independent models and block adjustment method.

(6) Field identification (Second year)

Field identification was to be conducted to verify on-site aerial photo interpretations performed in reconnaissance to conform with the specifications. The survey should cover the entire study area to collect data for keys for interpretation, selection of features to be represented, items for annotation, etc.

(7) Stereo-plotting (Second & Third years)

Based on the results and findings of aerial triangulation, control point survey, leveling and field identification, plotting of topographic details was to be conducted in 112 map sheets by using precise stereo plotter at a scale of 1/25,000.

(8) Compilation (Second & Third years)

Compilation should be conducted to produce 1/25,000 scale compilation manuscripts for 112 map sheets based on the plotted manuscripts and field identification data.

(9) Field completion (Third year)

Field completion should be conducted in the field for clarification of questions, unclear matters, changes over time that could occur in the course of plotting and compilation, and the findings were to be incorporated to produce correct original manuscripts. Confirmation of administrative boundaries and annotation of administrative names should be conducted by NGD.

(10) Drafting (Fourth year)

Draft originals were to be made for each color by scribing so as to produce 5-color printed sheets on which original manuscripts to be based .

(11) Printing (Fourth year)

Final maps were to be printed in 5 colors by offset printing machine in 1,002 copies for each map sheet.

Table 2 Work Volumes

Item	Specification	Volume
Aerial photography	Photo scale 1/40,000 (Wide angle camera)	13,000k ㎡ for mapping area, 30 courses, 927 photos
Control point survey	Satellite geodesy (GPS)	26 points for new set-up, and several existing control points
Leveling	Minor order leveling Cross-river leveling	615km 1 span
Pricking	GPS new control point Existing control point Miner order leveling Existing bench marks	26 points 3 points 615 km 150 km
Aerial triangulation	Block adjustment method	817 models
Field identification	To be used enlarged photos	13,000k ㎡
Stereo plotting & Compilation	Scale 1/25,000 (Contour interval 10 meters)	13,000k ㎡, 112 sheets
Field completion	- ditto-	-ditto-
Drafting	-ditto-	-ditto-
Printing	5 colors	112 sheets, 1002 copies each

3-1-4 Outline of the Study area

Laos is a landlocked country with most of its strip of land occurring on the left bank of the middle reaches of the Mekong River. The study area is located east of the capital Vientiane. It includes a rather flat land of the left bank of the Mekong River which borders Thailand, the steep Louang mountains which borders the west side of Vietnam, and mountain ranges which run from northwest to southeast. These hills are made of limestone and form a karst. There are steep mountains which range from several hundred to thousand meters in elevation. This makes the traffic between National Road 13, which runs along the Mekong River, and the center basin extremely difficult.

There are only two principal towns in the study area, namely the capital of Bolikhamxai province, Pakxan, and Lak Xao, being developed as a new town. Besides these two towns, small villages are scattered in the area. Neighboring to the south of the study area is Thakhek, the capital of Khammouan province. The Kading River which runs in the center of the study area, has branches which originate in the Louang mountains. The river runs along the west of Lak Xao and other basins, cuts across the mountain ranges, and finally joins the Mekong River at the southeast of Pakxan.

There are four main roads in the study area. The first is National Road 13. It starts from the capital Vientiane, runs along the left bank of the Mekong River, and ends at Savannakhet, which is located approximately 500km away in the southeast direction. It is paved only in Pakxan. The rest is currently under repair with the aids from other countries. The second road is National Road 8 which starts from B. Lao and heads east to the Louang mountains through Lak-Xao. It climbs the mountains and heads toward the port of Vinh in Vietnam. Route 8 has been completed in repairs on the east side of the Theun River, but a bridge on the west side for some 60 km is still under construction. The third road is National Road 12. It starts from Thakhek and heads east to the mountains and ends at Vietnam. This road is passable by car only during the dry season. The fourth road is a provincial road which starts from Lak Xao and ends at Gnommalat. This road is also passable by car only during the dry season. The roads other than the four mentioned above, are narrow paths. The overall traffic conditions in the study area are quite poor. In the towns along the Mekong River, people use boats to cross the river to cities on the other side of the river in Thailand.

Within the study area, the land forming river terraces along the Mekong River is rather fertile although it rolls a little, and rice is produced in the land near the waters. The most part of the remaining area is left as wasteland, shrubbery land, and spares forest due to the sparse population. This rather flat land along the Mekong River is only approx. 20 km wide and its northeast is blocked by the steep hills. Between the hills, there are small basins and narrow valleys. In theses basins, people live in small villages and grow rice. Among theses basins, Lax Xao Basin is rather developed. A new development plan has already started. The southeast side of the Louang mountains which borders Vietnam, comprise dense forest. There are few lumbermills along National Roads. The lumbers are gathered mainly at Lak Xao and they are exported overseas from Vinh port in Vietnam.

3-2 Aerial Photography

3-2-1 Outline

The entire study area of 13,000k m² were the subject of the aerial photography. Photographing scale and camera type were respectively 1/40,000 and wide angle lens as described in S/W. KEVRON Co., LTD., based in Australia, was contracted to undertake the aerial photography. Flight for photography was originally planned to be 25 courses in east-west direction. However, it was changed and 5 courses were added because of the delay of the border photographing permission from the Thai Government.

3-2-2 Flight course planning

Planning of flight courses for aerial photography was made on the 1/100,000 topographic Map taking into consideration the photo-scale, side-lap, aircraft, camera and so on. The topographic features of the study area are so steep and high that the side-lap was narrowed to 40%, and the overlap 60% as usual.

3-2-3 Subcontract of photography

Subcontract was concluded for 60 days schedule for photography with KEVRON Co., on December 12th, 1992, on approval of the JICA headquarters (See Attachment).

3-2-4 Implementation

The photography started from December 14th and completed on schedule. Photographing dates and numbers of photos for each course are shown in Table 3 and the map of photographing position is attached as Figure 1.

3-2-5 Photography base

The Vientiane airport was used for the base. In case of photography flights, a Security Officer from the Mapping Army Section was on board the airplane.

3-2-6 Instruments for photography

Major instruments to be used in the photographing work were as follows.

Aircraft	:	GATE LEARJET 35A No. 35-40
Aerial camera	:	WILD RC-20 15/23
Lens	:	UAGA-F 13149 F=152, 68mm
Flight guide	:	Garmin GPS Navigation System
Aerial film	:	AGFA Avi photopan PE-50

3-2-7 Photo processing and checking

Developing and other process of films after photographing were taken care of at NGD's facilities. The instruments used for the work were as follows.

Film developing machine	:	Kodak HC-110
Fixing printer	:	Zeiss KG30 (NGD)
Developing machine	:	Zeiss FE-120
Photographic paper	:	Agfa and Kodak RC paper

After printing photos, the following items were checked and photographing was carried out again.

Overlap, side lap

Cloud, shadow of cloud, uneven development

Deviation of flight course

Halation

Smoke of field burning

3-2-8 Film annotation

The films annotations were made in accordance with the specifications agreed with NGD. The course numbers were provided orderly from the north to the south as a rule, and afterwards the courses along the Mekong River were added. In case of dividing one course, the letters A, B, C... follow after the course number, orderly representing the position from the west side. The photos were numbered from west to east in the case of east-west direction, and from the upper stream to the down stream for the courses along the Mekong River.

3-2-9 Amount of work

The photographed results were as follows.

Film roll	6	rolls
Flight line	30	lines
Photograph	927	photos

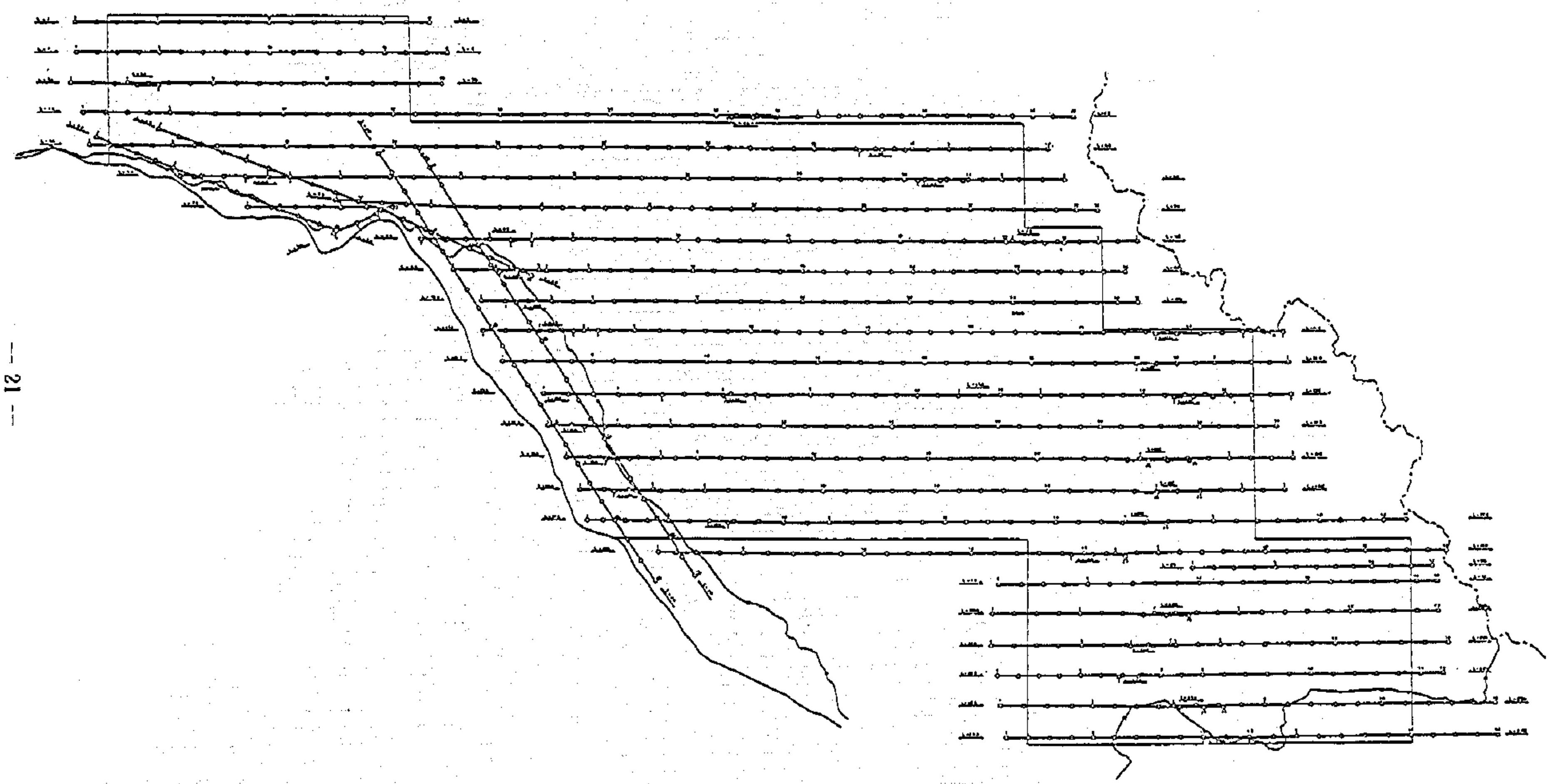
Table 3(1/2) PHOTOGRAPHING LIST

Course	Photo Date	Photo No.	Comp No.	Number	Roll	Remarks
1	92,12,21	131 -- 147	1 -- 17	17	4	
2	92,12,21	167 -- 184	1 -- 18	18	4	
3 A	93, 1,31	72 -- 76	1 -- 5	5	6	
3 B	92,12,21	149 -- 163	1 -- 15	15	4	
4 A	92,12,21	97 -- 129	1 -- 33	33	4	
4 B	93, 1, 3	3 -- 19	1 -- 17	17	4	
5 A	92,12,27	84 -- 123	1 -- 40	40	5	
5 B	93, 1, 3	39 -- 48	1 -- 10	10	5	
6 A	92,12,21	185 -- 190	1 -- 6	6	4	
6 B	92,12,27	42 -- 74	1 -- 33	33	5	
6 C	93, 1, 3	20 -- 27	1 -- 8	8	5	
7 A	92,12,22	3 -- 9	1 -- 7	7	4	
7 B	92,12,14	87 -- 122	1 -- 36	36	1	
8 A	92,12,20	75 -- 80	1 -- 6	6	3	
8 B	92,12,14	123 -- 150	1 -- 28	28	1	
8 C	93, 1, 3	30 -- 36	1 -- 7	7	5	
9 A	92,12,17	129 -- 133	1 -- 5	5	3	
9 B	92,12,14	12 -- 41	1 -- 30	30	2	
1 0 A	92,12,20	69 -- 72	1 -- 4	4	3	
1 0 B	92,12,14	43 -- 73	1 -- 31	31	2	
1 1 A	92,12,27	35 -- 40	1 -- 6	6	5	
1 1 B	92,12,21	56 -- 85	1 -- 30	30	4	
1 1 C	93, 1, 3	49 -- 55	1 -- 7	7	5	
1 2 A	92,12,21	23 -- 54	1 -- 32	32	4	
1 2 B	93, 1,31	57 -- 65	1 -- 9	9	6	
1 3 A	92,12,17	124 -- 127	1 -- 4	4	3	
1 3 B	92,12,15	142 -- 150	1 -- 9	9	2	
1 3 C	93, 1, 3	72 -- 85	1 -- 14	14	5	
1 3 D	92,12,15	159 -- 172	1 -- 14	14	2	
1 3 E	93, 1, 3	57 -- 63	1 -- 7	7	5	

Table 3(2/2) PHOTOGRAPHING LIST

1 4 A	92,12,20	63 -- 66	1 -- 4	4	3	
1 4 B	92,12,15	108 -- 141	1 -- 34	34	2	
1 5 A	92,12,20	56 -- 60	1 -- 5	5	3	
1 5 B	92,12,15	80 -- 106	1 -- 27	27	2	
1 5 C	92,12,28	11 -- 18	1 -- 8	8	5	
1 6 A	92,12,20	50 -- 53	1 -- 4	4	3	
1 6 B	92,12,15	53 -- 79	1 -- 27	27	2	
1 6 C	92,12,28	3 -- 9	1 -- 7	7	5	
1 7 A	93, 1, 2	17 -- 26	1 -- 10	10	5	
1 7 B	92,12,15	28 -- 47	1 -- 20	20	2	
1 7 C	93, 1, 3	86 -- 99	1 -- 14	14	5	
1 8 A	92,12,17	91 -- 112	1 -- 22	22	3	
1 8 B	93, 1,31	24 -- 42	1 -- 19	19	6	
1 9	93, 1,31	3 -- 23	1 -- 21	21	6	
2 0 A	92,12,17	64 -- 73	1 -- 10	10	3	
2 0 B	93, 1, 2	3 -- 16	1 -- 14	14	5	
2 1 A	92,12,17	53 -- 61	1 -- 9	9	3	
2 1 B	92,12,20	19 -- 33	1 -- 15	15	3	
2 2 A	92,12,17	31 -- 39	1 -- 9	9	3	
2 2 B	92,12,20	3 -- 18	1 -- 16	16	3	
2 3 A	92,12,17	40 -- 50	1 -- 11	11	3	
2 3 B	92,12,27	18 -- 32	1 -- 15	15	5	
2 4 A	92,12,17	13 -- 24	1 -- 12	12	3	
2 4 B	92,12,20	34 -- 47	1 -- 14	14	3	
2 5	93, 1,31	43 -- 55	1 -- 13	13	6	
2 6	92,12,19	4 -- 16	1 -- 13	13	3	
2 7	92,12,17	135 -- 152	1 -- 18	18	3	
2 8	92,12,15	3 -- 25	1 -- 23	23	2	
2 9	93, 1, 4	13 -- 34	1 -- 22	22	6	
3 0	93, 1,31	69 -- 71	1 -- 3	3	6	
Total				927		

Fig. 1 PHOTOGRAPHY INDEX MAP



3-3 Control point survey

3-3-1 Outline

In order to ensure accuracy of the aerial triangulation, control point survey was conducted by satellite geodesy using GPS units to determine horizontal positions and heights. Six(6) Trimble 4000SST instruments of dual frequency model were used for simultaneous observation at the control points. As for the connection to existing control points, observations were made in two phases, that is to compare with Krasovsky coordinates and Everest coordinates. In addition, it was necessary to check coordinate accuracy of secondary traverse points which were installed along the national road 13 in the study area by the former Soviet Union in 1981. Due to the above necessity, checking survey was executed from the Original Point in Vientiane (No.11) to the existing points in the study area.

Amount of the observation points were as follows.

New control point : 26 points

Existing reference point : 4 points for Krasovsky & 3 points for Everest

Checking survey for Krasovsky coordinates traverse points

: Approx. 120 km (Vientiane - Pakxan)

3-3-2 Implementation

The control point survey progressed smoothly by using helicopter occasionally because of many hard access points. However, among the control points which were previously planned, three points in the northern mountains were found to be located in an unsafe area. Therefore, the points were moved 8 to 13 km from the planned site.

Observation was made simultaneously at five or six points using GPS units of Trimble 4000SST. In order to obtain the height accuracy, five or six satellites were observed two hours from 11:00 to 13:00 the local time and the elevation angles of satellites were observed two hours from 11:00 to 13:00 the local time and the elevation angles of satellites more than 15 degrees were adopted. The observation network consisted of 11 groups as shown in Figure 2. The closure errors of each group were calculated to check the reliability of the observations in the field. The results obtained are as shown in Table 4, and summarized as follows.

	Range	Mean
Base line length	16 km - 48 km	32 km
dx	0.022 m - 0.428 m	0.225 m
dy	0.003 m - 0.141 m	0.072 m
dz	0.001 m - 0.246 m	0.124 m

Where dx, dy and dz stand for the coordinate closures of the geocentric coordinate system of ellipsoid WGS-84 to which GPS is referred.

There are 14 base lines measured twice on different days, and its data repeatability was checked and confirmed.

3-3-3 Checking of given points (Krasovsky coordinates)

Checking survey was made by GPS from the Origin of Vientiane (No.11) to traverse points in the study area. Table 5 shows the differences between the measured coordinates by GPS and given one. As the result of checking survey, it was found that the given points and also GPS observation data were sufficiently accurate as required.

Table 4 (1/3)

SUMMARY OF BASELINE COMPUTATION

Obs. Group	Station Combination for Baseline		Computed Slope Distance	Height Difference	Accuracy
	From	To			
1	0001	0005	29490.429 m	- 37.960 m	TD =107783.750 m
	0005	0104	15955.059	- 2.948	dx = - 0.428 m
	0104	0102	18902.686	12.291	dy = - 0.003 m dz = 0.102 m
	0102	0101	16206.985	1.115	ratio = 4.08 ppm
	0101	0001	27228.592	27.628	
2	0102	0104	18902.839	- 12.722	TD =134665.041 m
	0104	0005	15955.187	3.101	dx = - 0.042 m
	0005	0109	30007.110	- 8.076	dy = - 0.141 m dz = 0.018 m
	0109	0103	39203.559	110.525	ratio = 1.10 ppm
	0103	0102	30596.345	- 92.954	
3	0103	0109	39203.143	-110.502	TD =147246.139 m
	0109	0126	18256.233	- 2.661	dx = - 0.072 m
	0126	0017	16944.056	16.758	dy = 0.106 m dz = 0.066 m
	0017	0105	36336.036	123.094	ratio = 0.98 ppm
	0105	0103	36506.671	- 26.553	
4	0126	0114	27853.868	- 3.242	
	0114	0117	26709.526	1.563	TD =158296.624 m
	0117	0118	24062.635	4.029	dx = 0.079 m
	0118	0127	27288.564	4.082	dy = 0.052 m dz = - 0.018 m
	0127	0017	35437.944	10.399	ratio = 0.61 ppm
	0017	0126	16944.087	- 16.804	
5	0105	0017	36335.994	-122.852	
	0017	0127	35438.240	- 10.264	TD =165022.474 m
	0127	0110	24595.267	269.564	dx = 0.076 m
	0110	0107	23154.223	90.030	dy = - 0.095 m dz = 0.008 m
	0107	0106	28437.035	-216.724	ratio = 0.74 ppm
	0106	0105	17061.717	- 9.858	

Table 4 (2/3)

SUMMARY OF BASELINE COMPUTATION

Obs. Group	for Baseline		Computed Slope Distance	Height Difference	Accuracy
	From	To			
6	0107	0110	23154.209	- 89.977	TD =150891.751 m dx = 0.100 m dy = 0.076 m dz = - 0.005 m ratio = 0.83 ppm
	0110	0112	33274.610	82.076	
	0112	0113	24694.683	32.821	
	0113	0111	22483.685	- 9.755	
	0111	0108	21243.020	408.261	
	0108	0107	26041.544	-423.382	
7	0110	0127	24595.734 m	-269.444 m	TD =137750.116 m dx = - 0.040 m dy = - 0.050 m dz = 0.004 m ratio = 0.47 ppm
	0127	0118	27288.435	- 3.970	
	0118	0115	26318.174	25.916	
	0115	0112	26272.911	329.110	
	0112	0110	33274.864	- 81.646	
8	0112	0115	26272.727	-329.294	TD =150675.188 m dx = 0.022 m dy = - 0.035 m dz = - 0.001 m ratio = 0.27 ppm
	0115	0119	26313.648	337.249	
	0119	0116	39801.513	72.373	
	0116	0113	33592.563	- 47.484	
	0113	0112	24694.736	- 32.882	
9-1	0119	0121	25182.821	18.074	TD = 98845.399 m dx = 0.268 m dy = 0.101 m dz = - 0.014 m ratio = 2.90 ppm
	0121	0116	33860.655	54.343	
	0116	0119	39801.923	- 72.394	
9-2	0121	0124	48063.975	-353.957	TD =118123.212 m dx = - 0.610 m dy = - 0.106 m dz = 0.102 m ratio = 5.31 ppm
	0124	0120	33884.143	413.541	
	0120	0121	36175.095	- 59.495	
9-3	0116	0121	33860.655	- 54.343	TD = 89345.862 m dx = - 0.031 m dy = - 0.060 m dz = - 0.003 m ratio = 0.76 ppm
	0121	0120	36175.095	59.495	
	0120	0116	19310.112	- 5.201	

Table 4 (3/3)

SUMMARY OF BASELINE COMPUTATION

Obs. Group	Station Combination for Baseline		Computed Slope Distance	Height Difference	Accuracy
	From	To			
10	0119	0122	34399.818	-349.983	TD =172905.230 m dx = 0.034 m dy = - 0.070 m dz = 0.003 m ratio = 0.45 ppm
	0122	0123	35903.931	- 4.511	
	0123	0124	29354.686	18.542	
	0124	0121	48063.957	353.975	
	0121	0119	25182.821	- 18.074	
11	0021	0117	22938.839	- 17.199	TD = 59486.349 m dx = - 0.086 m dy = - 0.015 m dz = 0.027 m ratio = 1.54 ppm
	0117	0118	24063.143	4.280	
	0118	0021	12484.365	12.935	

Fig. 2 GPS OBSERVATION NETWORK

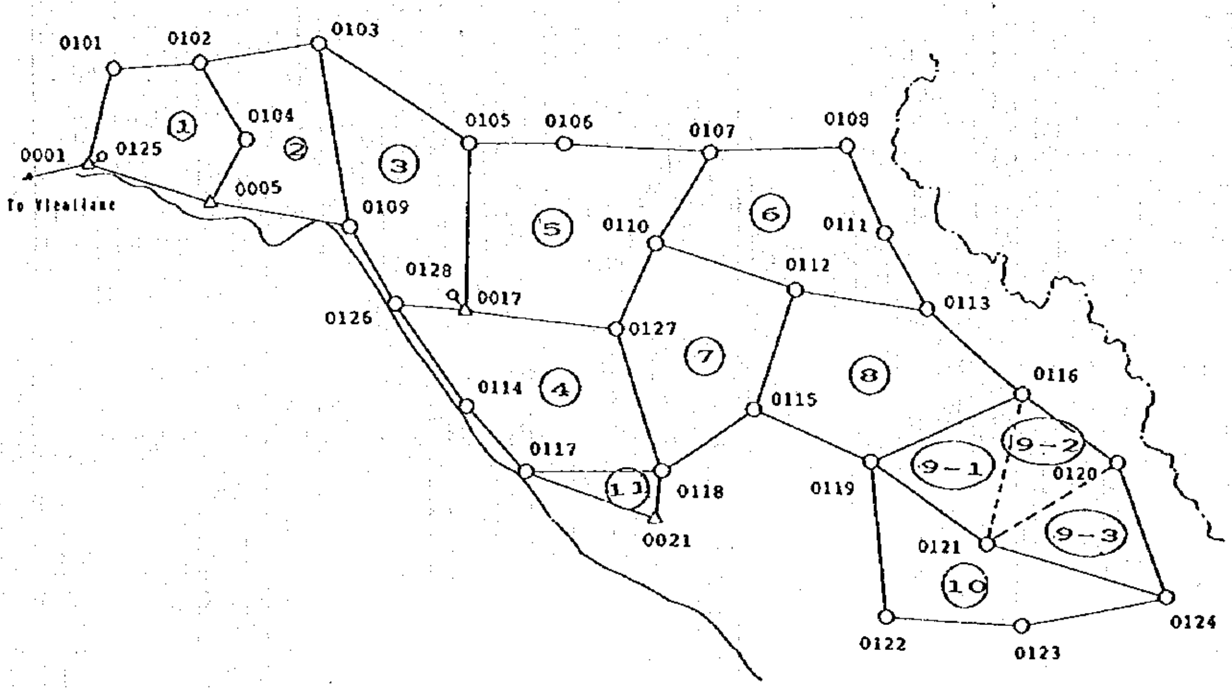


Table 5 Comparison Table between Given and Measured (Krasovsky Coordinates)

Point No.	Given UTM	Measured UTM	Difference
11	1 995 600.61 N	1 995 600.61 N	
	236 871.76 E	236 871.76 E	
8	2 000 714.84 N	2 000 714.85 N	+0.01
	261 483.49 E	261 483.42 E	-0.07
7	2 001 551.95 N	2 001 551.86 N	-0.09
	280 329.59 E	280 329.54 E	-0.05
13	2 013 196.07 N	2 013 195.87 N	-0.20
	295 818.92 E	295 818.68 E	-0.24
1	2 040 957.45 E	2 040 956.94 N	-0.51
	337 046.04 E	337 046.11 E	+0.07
2	2 040 600.67 N	2 040 600.15 N	-0.52
	324 590.86 E	324 590.96 E	+0.10
5	2 033 059.78 N	2 033 059.20 N	-0.58
	365 466.96 E	365 466.82 E	-0.14
17	2 009 773.16 N	2 009 773.14 N	-0.02
	419 436.98 E	419 436.83 E	-0.15
21	1 961 201.40 N	1 961 201.96 N	+0.56
	458 188.48 E	458 188.36 E	-0.12

RE: measured UTM was computed values only to fix No.11 as a starting point.

3-3-4. Re-adjustment computation of control points

(1) Outline

In response to a strong request of NGD, transformation of ellipsoid was planned to be carried out. It was difficult to convert GPS observation results to Everest coordinate using second order traverse points (Krassovsky coordinate points) established by ex-Soviets, because the shift value between Krassovsky and WGS84 was unknown.

Therefore, it was decided that additional GPS observation should be carried out to connect to the points established by the Mekong Committee located along the Mekong river.

The established network in the previous stage was connected to Mekong Committee's network reference to the Everest ellipsoid.

Re-adjustment computation of final network was executed in Japan based on these given points and added base lines. Moreover, to determine heights of new control points, direct leveling was carried out for new points where accessible, and for the difficult accesses points, provisional elevation was given by the interpolation of estimated geoid undulation for succeeding aerial triangulation.(See Clause 3-4-2(6))

(2) Observation

Additional observation to connect to control points of Mekong Committee was carried out at Pakxan and Thakhek on the middle of April, 1993 using 4 units of GPS receivers. As the result, 8 base lines were added to the previous network.

Observed results and final network were as shown in Table 6 and Fig.3.

Table 6 (Observed result)

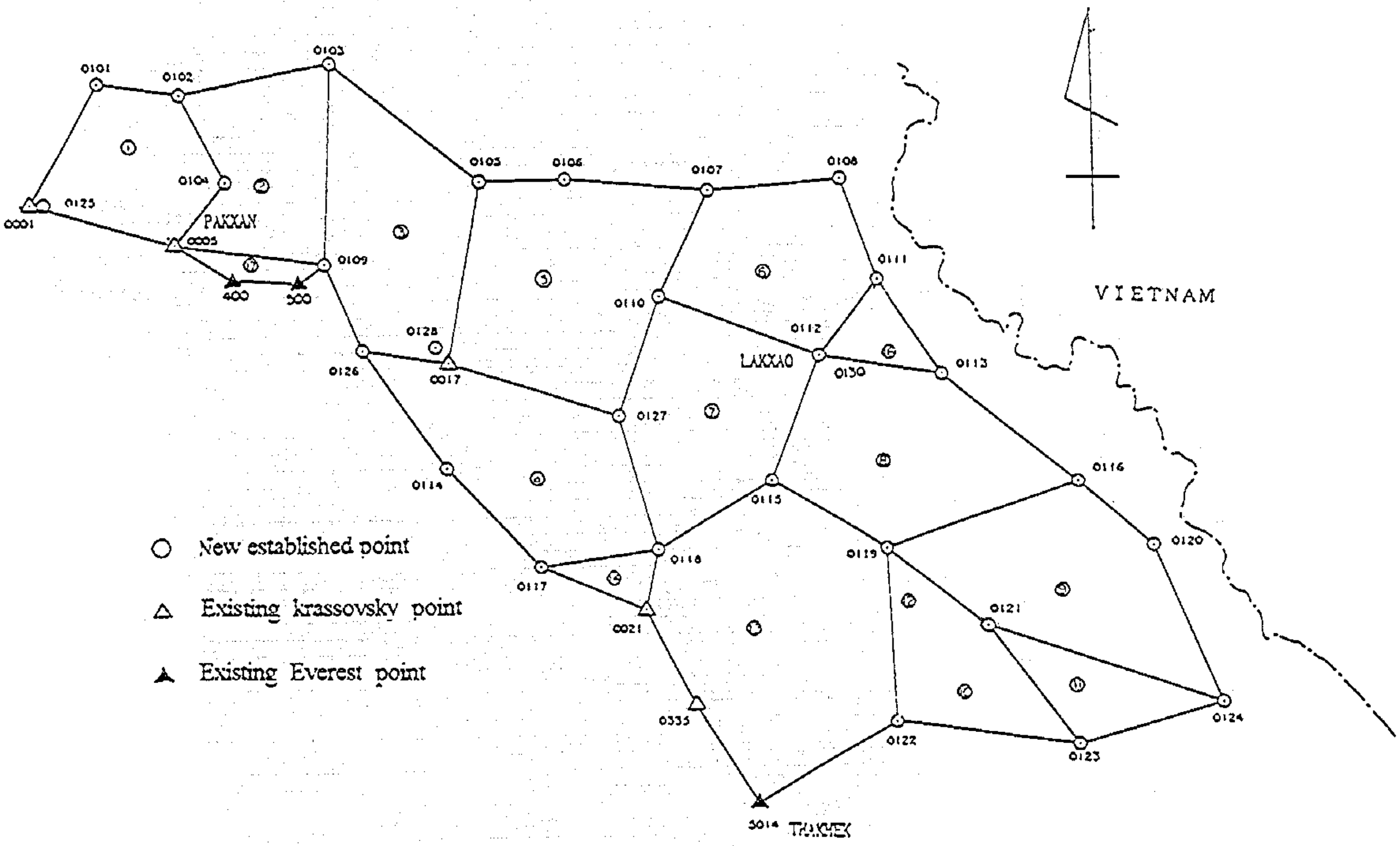
Area	Combination		Slope distance	Accuracy
PAKXAN	☆0001	☆0005	29,490.572	Total dit. 130,434.390 m
	☆0005	★0400	6,973.072	dx = - 0.058 m
	★0400	★0500	35,660.777	dy = +0.004 m
	★0500	☆0001	58,309.969	dz = - 0.004 m
				Ratio = 0.45 ppm
THAKEK	☆0021	0122	53,825.812	Total dit. 129,243.289 m
	0122	★5014	32,255.241	dx = +0.193 m
	★5014	0335	22,474.351	dy = +0.323 m
	0335	☆0021	20,687.886	dz = -0.030 m
				Ratio = 2.92 ppm

Re: ☆Existing points with Krassovsky coordinates

★Existing points with Everest coordinates

No mark number is temporary point

Fig. 3 FINAL NETWORK OF CONTROL POINT



Closing error between ★0500(PAKXAN) and ★5014(THAKEK) was found to be approx.1.5m to 202.7km distance (apprpx.1/135,000).
It was confirmed that those existing control points were useful for the datum conversion.

(3) Re-Adjustment Computation

(a) Given points and ellipsoids

Simultaneous adjustment was conducted using GPS analytical data obtained in the first year work and the second year work, fixing horizontals of three given points (400, 500, 5014) and height of one point (5014) . Reference ellipsoid of GPS is WGS-84 while Laos requested the geodetic system be referred to the Everest. The two ellipsoids, however, have their three spatial axes parallel respectively to each other, and therefore, WGS-84 based GPS observed values (dX, dY and dZ) expressed in a geocentric coordinate system can be strictly dealt with in the geocentric coordinate system referred to Everest ellipsoid.
Both ellipsoids have following parameters.

	Everest	WGS 84
Semi-major axis	6,377,276.000m	6,378,137.000m
1/ Flattening	300.8	298.26

(b) Observation equation

With respect to Point 1 and 2, the following equations were developed (unit : m)

$$
\begin{aligned}
v(\Delta X) = & [(N_1+h_1)/\rho''] \sin\lambda_1 \cdot \delta\lambda_1'' \cos\phi_1 \\
& + [(N_1+h_1)/\rho''] \sin\phi_1 \cos\lambda_1 \cdot \delta\phi_1'' - \cos\phi_1 \cos\lambda_1 \cdot \delta h_1 \\
& - [(N_2+h_2)/\rho''] \sin\lambda_2 \cdot \delta\lambda_2'' \cos\phi_2 \\
& - [(N_2+h_2)/\rho''] \sin\phi_2 \cos\lambda_2 \cdot \delta\phi_2'' + \cos\phi_2 \cos\lambda_2 \cdot \delta h_2'' \\
& + \Delta X ado - \Delta X obs
\end{aligned}
$$

$$
\begin{aligned}
v(\Delta Y) = & [(N_1+h_1)/\rho''] \sin\lambda_1 \cdot \delta\lambda_1'' \cos\phi_1 \\
& + [(N_1+H_1)/\rho''] \sin\phi_1 \sin\lambda_1 \cdot \delta\phi_1'' + \cos\phi_1 \sin\lambda_1 \cdot \delta h_1 \\
& - [(N_2+h_2)/\rho''] \cos\lambda_2 \cdot \delta\lambda_2'' \cos\phi_2 \\
& - [(N_2+h_2)/\rho''] \sin\phi_2 \sin\lambda_2 \cdot \delta\phi_2'' + \cos\phi_2 \sin\lambda_2 \cdot \delta h_2'' \\
& + \Delta Y ado - \Delta Y obs
\end{aligned}
$$

$$v(\Delta Z) = [(N_1+h_1-e^2N_1)/\rho''] \cos\phi_1 \cdot \delta\phi_1'' - \sin\phi_1 \cdot \delta h_1$$
$$+ [(N_2+h_2-e^2N_2)/\rho''] \cos\phi_2 \cdot \delta\phi_2'' + \sin\phi_2 \cdot \delta h_2$$
$$+ \Delta Z_{ado} - \Delta Z_{obs}$$

where

λ_1, ϕ_1	Geodetic longitude and latitude of point i (approximate)
h_1	Height from reference ellipsoid
$\delta\lambda_1$, $\delta\phi_1$	Correction to λ_1, ϕ_1 (unknown)
δh_1	Correction to h_1 (unknown)
X, Y, Z,	Geocentric coordinates of point i referred to the reference ellipsoid
ΔX	X_2-X_1 (X component of the geocentric coordinate difference)
ΔY	Y_2-Y_1 (Y component of the geocentric coordinate difference)
ΔZ	Z_2-Z_1 (Z component of the geocentric coordinate difference)
a	Equatorial radius of the reference ellipsoid
b	Polar redius of the reference ellipsoid
e^2	$= (a^2-b^2)/a^2$ First eccentricity
e'^2	$= (a^2-b^2)/b^2$ Second eccentricity
C	$= a^2/b$ Radius of curvature of meridional ellipse at the pole
η^2	$= e'^2\cos^2\phi$
V^2	$= 1 + \eta^2$
N_1	C/V Radius of prime vertical at point i
ρ''	Second corresponding to 1 radian
$v(\#)$	Correction to be added to observed value # shows kind of observation
ΔX_{ado}	Approximate value of ΔX computed by using λ and ϕ
ΔY_{ado}	Approximate value of ΔY computed by using λ, ϕ
ΔZ_{ado}	Approximate value of ΔZ computed by using λ, ϕ
ΔX_{obs}	Observed value of ΔX
ΔY_{obs}	Observed value of ΔY
ΔZ_{obs}	Observed value of ΔZ

(c) Adjustment computations

For network adjustment computations, a newly developed geodetic network adjustment computation program, PAG-U (Universal program for Adjustment of Any Geodetic Network), was employed. The reference ellipsoid and coordinate system on which the computations were based was Everest. In the table, h represents a height form the reference ellipsoid and H represents a height from the geoid.

The geometric patterns the program automatically recognized from the observed values were :

Pattern	Number
Triangle	158
Polygon	1
Traverse	117
Straight line	0

From the results of network adjustment, the accuracy of coordinate determination were as follows.

Maximum correction to add to the observed values :	1.81m
Standard deviation of an observation of unit weight :	0.60m

(4) Final results

The results of computations performed in above are given in Table-7.

The horizontal coordinates are those derived from the adjustment computations of (c), while the listed heights are the existing result, direct leveling and computed values as mentioned.

Table 7

TABLE OF GIVEN CONTROL

STATION NO.	LATITUDE	LONGITUDE	X UTM(M)	Y UTM(M)	ELEVATION(M)
400	18° 22' 35.5012	103° 39' 53.0275	2,031,828.785	358,954.270	156.66
500	18° 19' 7.8324	103° 59' 50.3370	2,025,589.022	394,055.855	151.28
5014	17° 23' 22.7007	104° 48' 33.1649	1,922,514.647	479,737.146	144.67

RESULTS OF NEWLY ESTABLISHED

STATION NO.	LATITUDE (NORTH)	LONGITUDE (EAST)	X UTM(M)	Y UTM(M)	ELEVATION(M)
0001	18° 26' 37.2093	103° 27' 40.2772	2,039,797.774	337,516.247	● 200.2
0005	18° 22' 27.5477	103° 43' 50.5569	2,031,903.217	365,925.647	● 162.8
0017	18° 9' 59.9451	104° 14' 32.2912	2,008,626.044	419,873.048	● 167.3
0021	17° 43' 43.9368	104° 36' 34.3724	1,960,073.944	458,608.443	● 164.7
0101	18° 39' 19.4670	103° 35' 33.0554	2,063,115.819	351,568.642	△ 171.79
0102	18° 38' 12.2889	103° 44' 41.5653	2,060,931.462	367,624.442	○ 171.200
0103	18° 41' 31.4762	104° 1' 44.5712	2,066,867.436	397.631.054	△ 262.62
0104	18° 29' 6.4701	103° 49' 38.3479	2,044,095.988	376,210.905	△ 158.79
0105	18° 29' 23.6590	104° 18' 8.4887	2,044,364.715	426,361.099	△ 289.01
0106	18° 29' 40.5764	104° 27' 49.8819	2,044,826.413	443,409.873	○ 297.958
0107	18° 28' 33.9807	104° 43' 56.7405	2,042,716.762	471,754.917	△ 513.48
0108	18° 29' 57.4107	104° 58' 40.0170	2,045,259.904	497,655.028	△ 935.67
0109	18° 20' 17.6588	104° 0' 43.6502	2,027,726.542	395,632.371	○ 153.863
0110	18° 17' 10.6888	104° 38' 25.0719	2,021,735.183	461,987.937	○ 424.212
0111	18° 19' 8.7677	105° 2' 48.8894	2,025,327.011	504,956.718	○ 527.433
0112	18° 11' 5.5412	104° 56' 11.3355	2,010,477.791	493,283.792	○ 504.713
0113	18° 9' 6.0148	105° 10' 2.2653	2,006,811.616	517,692.765	○ 536.369
0114	17° 59' 2.4237	104° 14' 15.5428	1,988,421.097	419,297.615	○ 147.14
0115	17° 57' 50.9563	104° 50' 42.6171	1,986,066.301	483,608.374	△ 176.29
0116	17° 57' 38.9264	105° 24' 50.4568	1,985,738.326	543,832.740	△ 583.390
0117	17° 48' 26.0129	104° 24' 33.3381	1,968,797.569	437.402.888	○ 148.616
0118	17° 50' 21.3347	104° 38' 1.6700	1,972,280.591	461,202.966	○ 151.461
0119	17° 50' 35.8111	105° 3' 32.4217	1,972,688.440	506,251.168	○ 512.520
0120	17° 50' 44.0890	105° 33' 3.0561	1,973,027.799	558,357.558	△ 558.38
0121	17° 42' 5.0320	105° 14' 40.8110	1,957,008.620	525,941.118	○ 530.184
0122	17° 31' 58.0470	105° 4' 25.4914	1,938,341.610	507,826.341	○ 163.152
0123	17° 29' 18.5576	105° 24' 31.3912	1,933,485.793	543,385.511	○ 157.613
0124	17° 33' 47.2356	105° 40' 26.5104	1,941,822.208	571,519.815	○ 174.948
0125	18° 26' 38.3857	103° 29' 10.1998	2,039,811.696	340,154.537	○ 160.643
0126	18° 11' 17.2740	105° 5' 1.3499	2,011,079.020	403,112.341	○ 151.208
0127	18° 4' 35.4484	104° 33' 49.1308	1,998,543.623	453,832.532	○ 155. 46
0128	18° 11' 43.1487	104° 13' 9.1133	2,011,807.978	417,443.048	○ 151.19

Re : Height

● known height

○ Height by direct leveling

△ Height by computation based on geoid slope

(5) Establishment of new control points (Additional work)

In response to the request of NGD , monumentation and observation of 6 new control points in 3 areas having the height potentiality to be developed in the future (Pakxan, Lak Xao and Nakai) were executed by GPS. Monumented locations were selected by NGD.

Observation to connect to established network was carried out in the middle of March, 1993 using 3 to 4 units of GPS receivers. As the result, 12 base lines were added to the Network.

Coordinates of 6 points were introduced to NGD after computation along with computation results and description sheets.

3-4 Leveling

3-4-1 Outline

Minor order leveling was conducted for the area where existing bench marks were not established yet, as necessary for aerial triangulation and plotting to keep elevation accuracy on 1/25,000 topographic maps.

Using existing bench marks as given points, minor order leveling was executed and new routes were determined based on existing maps and aerial photographs.

At the time of observation, pricking was also carried out at clearly identifiable points on two-times enlarged photos for aerial triangulation and plotting.

3-4-2 Implementation

(1) Reconnaissance

Reconnaissance survey was carried out to verify the leveling routes and to learn the road condition and accessibility for observation.

(2) Setting up of (Temporary bench marks:TBM's) and monumentation

Selection and setting up of pricking points, which should be pricked approx. every 2km along the routes, were executed.

The pricking points were set up as temporary bench marks at clearly identified features on photos or established on permanent structures such as bridges .

By the request of NGD, 20 semi-permanent monuments were set up every 5 to 8km on the route of Route 12, 8 (Thakhek - Lak Xao - B.Lao) where potentiality of development, and observation and description were also executed.

(3) Observation

Leveling was conducted by 4 teams using bar-code auto-digital level and bar-code staves. An existing second order bench mark on Rout 13 was used as the starting and closing point. Double run observation was executed on the hanging routes without closed loop.

Prior to observation, checking leveling was carried out between adjoining existing bench marks used as starting and closing point if there were any trouble. Newly established control points were connected to the leveling routes by direct leveling as much as possible. Also, reciprocal cross-river leveling was conducted at a ferry of Nam Theun on Rout 8.

Executed leveling routes were shown in Fig. 4.

(4) Accuracy

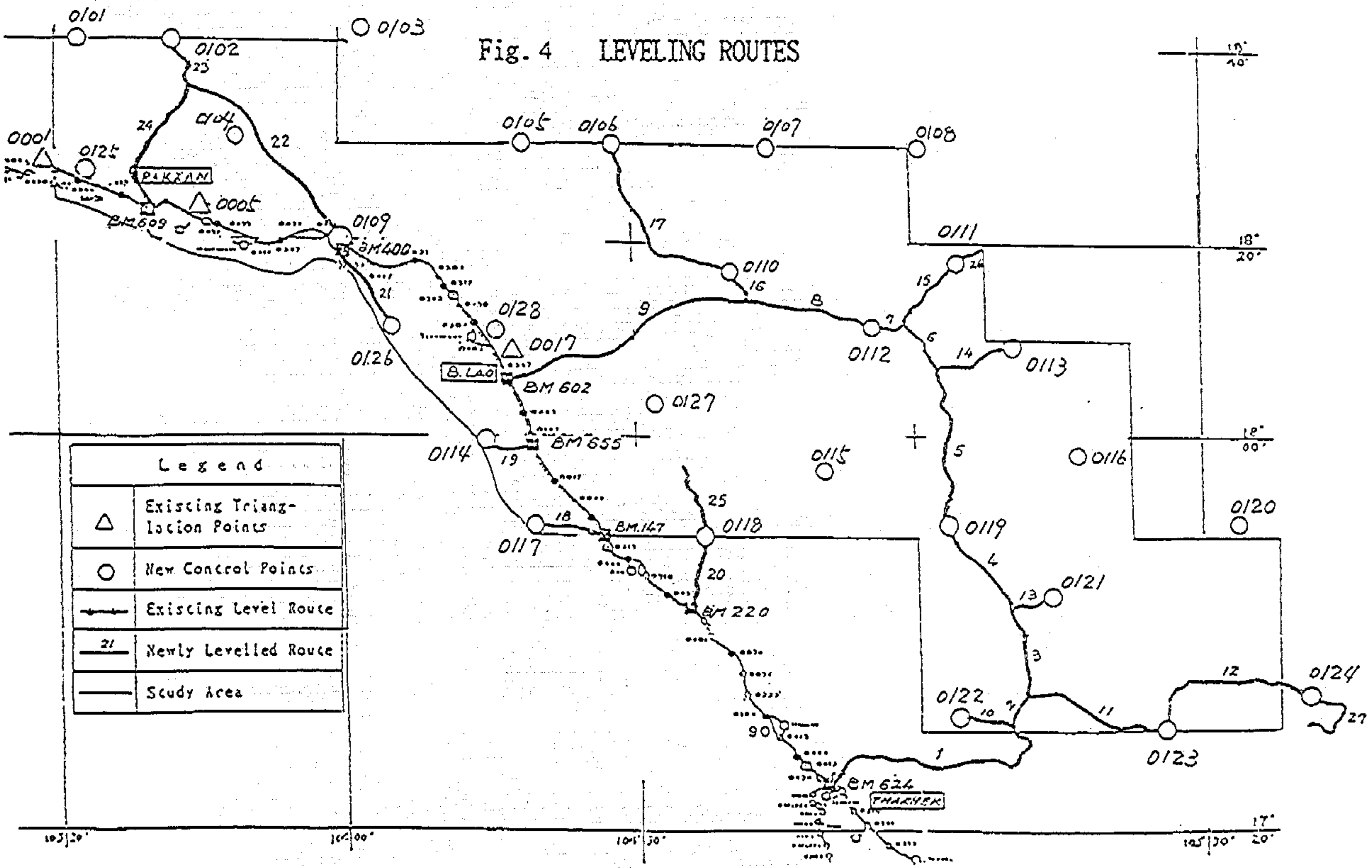
The leveling was carried out to ensure the accuracy of 50mm$\sqrt{s}$ (s:km) as specified in the S/W, but leveling results showed that it was good enough for third order leveling accuracy after final computation as mentioned below.

Table-8 Closures for the Respective Route Section

Route NO.	Course	Length mm	Closure mm	Tolerance mm	Remark
R1+R2+R3+R4+R5+R6+R7+R8+R9	BM0624-->BM0400	249	97	787	Loop type
R22+R24	BM0629-->GPS0122	77	48	435	Open type
R10	TBM0109-->GPS0122	9	63	141	Open type
R11	TBM0200-->GPS0123	29	25	264	Open type
R12	TBM0123-->GPS0124	39	36	308	Open type
R13	TBM0400-->GPS0121	13	43	180	Open type
R14	TBM6000-->GPS0113	18	19	212	Open type

Route NO.	Course	Length mm	Closure mm	Tolerance mm	Remark
R15	TBM7000-->GPS0111	19	12	212	Open type
R16	TBM8000-->GPS0110	10	2	158	Open type
R17	TBM0110-->GPS1711	46	29	339	Open type
R18	TBM0147-->GPS1804	9	61	150	Open type
R19	TBM0655--.GPS0114	13	27	180	Open type
R20	TBM0201-->GPS0118	16	23	200	Open type
R21	TBM0400-->GPS0126	17	4	206	Open type
R23	TBM2200-->GPS0102	15	73	187	Open type
R25	TBM0118-->GPS2509	17	31	206	Open type
R26	TBM2600-->GPS2606	12	5	173	Open type
R27	TBM0124-->GPS2709	20	48	223	Open type

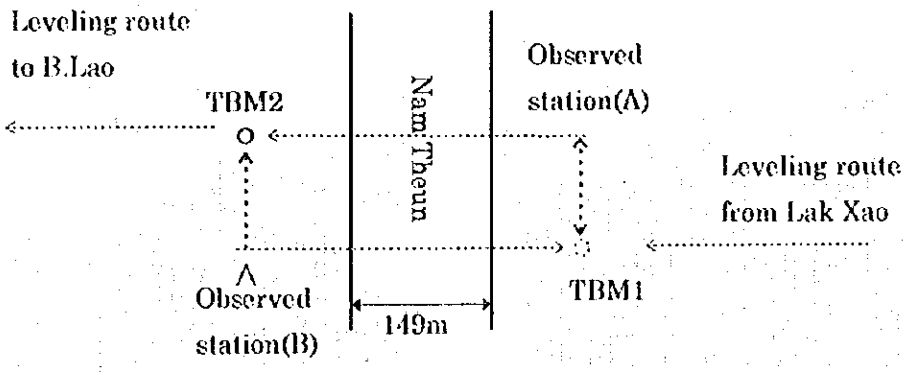
Fig. 4 LEVELING ROUTES



(5) Cross-river leveling

Cross-river leveling was performed at a ferry of the Nam Theun approx. 50km west of Lak Xao on Route 8. The Nam Theun has approx. 150m of width and runs across the route with a bridge under construction. Reciprocal leveling method with 5 measurements in 2 sets was adopted and observed simultaneously from each side of the river. The observation was arranged as shown in Fig.-5. Their respective mean values were adopted as the relative height differences between 2 points.

Fig. 5 CROSS-RIVER LEVELING



Reading station A	Set	Dist.(m)	Height difference(m)
	1	149	0.425
	2	149	0.429
	Mean	149m	0.427m

Reading station B	Set	Dist.(m)	Height difference(m)
	1	148	0.439
	2	149	0.441
	Mean	149m	0.440m

Final height difference		
Mean between A and B	149m	0.434m

(6) Determination of heights for control points

The heights were determined by direct leveling for those newly established control points which could be accessed among first year's points.
For those in the mountain area and other control points which had no access routes, computed values were employed to keep height accuracy for succeeding aerial triangulation. Computation of height for no leveled points was carried out using the interpolation of estimated geoid undulation.
The theory and formula are as follows;

- Estimation method of geoid undulation -

The heights derived from WGS-84 based GPS data are relative to the surface of the Everest ellipsoid, and therefore need to be converted to those of leveling. In Figure-6, plane x y is a plane on the reference ellipsoid surface.
P is an unilaterally chosen spatial point and the feet of perpendiculars of P and surrounding points P_1, P_2 and P_3 on the xy plane are P_0, P_{01}, P_{02} and P_{03} respectively. Height h_g from reference ellipsoid of point P, P_1, P_2 and P_3 is height from geoid. The coordinates of these points on the ellipsoid are represented by x' y', x_1' y_1', x_2' y_2', x_3' and y_3' and the intersecting points of their perpendicular to the geoidal surface as P_0', P_{01}', P_{02}' and P_{03}', respectively, with their geoidal heights as hg, hg_1, hg_2 and hg_3. Assuming h_{g1}, h_{g2} and h_{g3} are known and the geoidal surface is flat.

put

$$D = \begin{vmatrix} x_1 & y_1 & hg_1 \\ x_2 & y_2 & hg_2 \\ x_3 & y_3 & hg_3 \end{vmatrix}$$

and

$$u = (y_1 hg_2 + y_2 hg_3 + y_3 hg_1 - y_1 hg_3 - y_2 hg_1 - y_3 hg_2)/D$$

$$v = (hg_1 x_2 + hg_2 x_3 - hg_1 x_3 - hg_2 x_1 - hg_3 x_2)/D$$

$$w = (x_1 y_2 + x_2 y_3 + x_3 y_1 - x_1 y_3 - x_2 y_1 - x_3 y_2)/D$$

then

$$h_g = (1 - ux - vy)/w$$

further

$$H = h + h_g$$

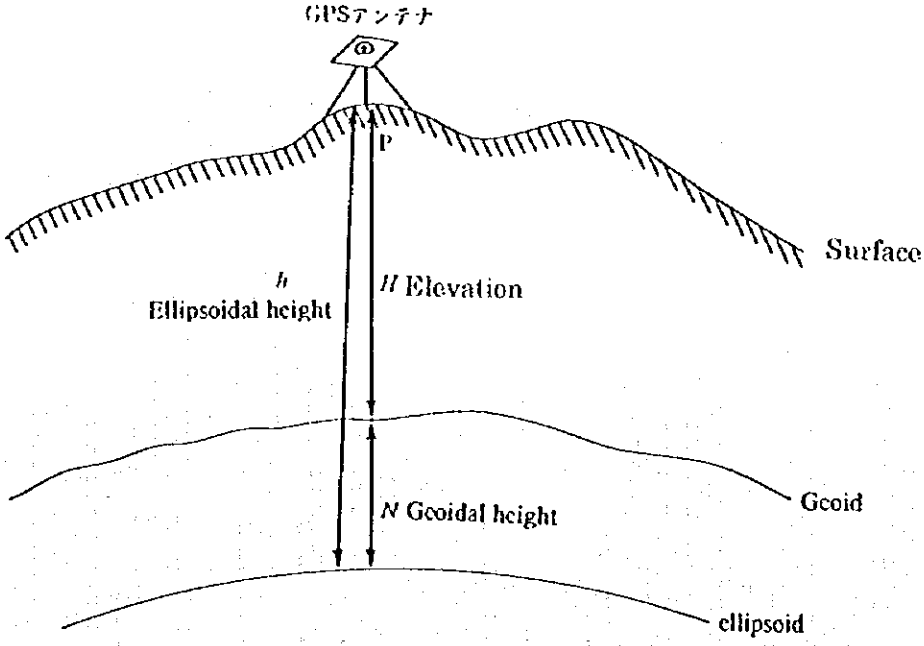
Actually, for h_{g1}, h_{g2} and h_{g3}, only relative rules are known, so that the geoidal height is assumed for one of these points to arrive at h_g of a proposed point.
In the study, however, there were no sufficient number of points with known

leveling heights available for the above computations, and therefore, heights of the proposed points were calculated of adjoining given points.

With respect to those points whose heights were determined by leveling, to compare heights from geoidal surface and those from the ellipsoidal surface, by assuming the geoidal height at Point 5014 (known point with Everest value at Thakhek) as 0, geoidal heights of the proposed points and heights and ellipsoidal heights of each point are given as Table 9.

Based on the above results, the estimated heights from the geoidal surface of the proposed points are given as H in Table 10. Relative geoid model estimated from the value of Table 9 are shown in Figure 7.

Fig. 6 ELLIPSOID AND GEOID



HEIGHT FORM ELLIPSOID AND FROM GEOID

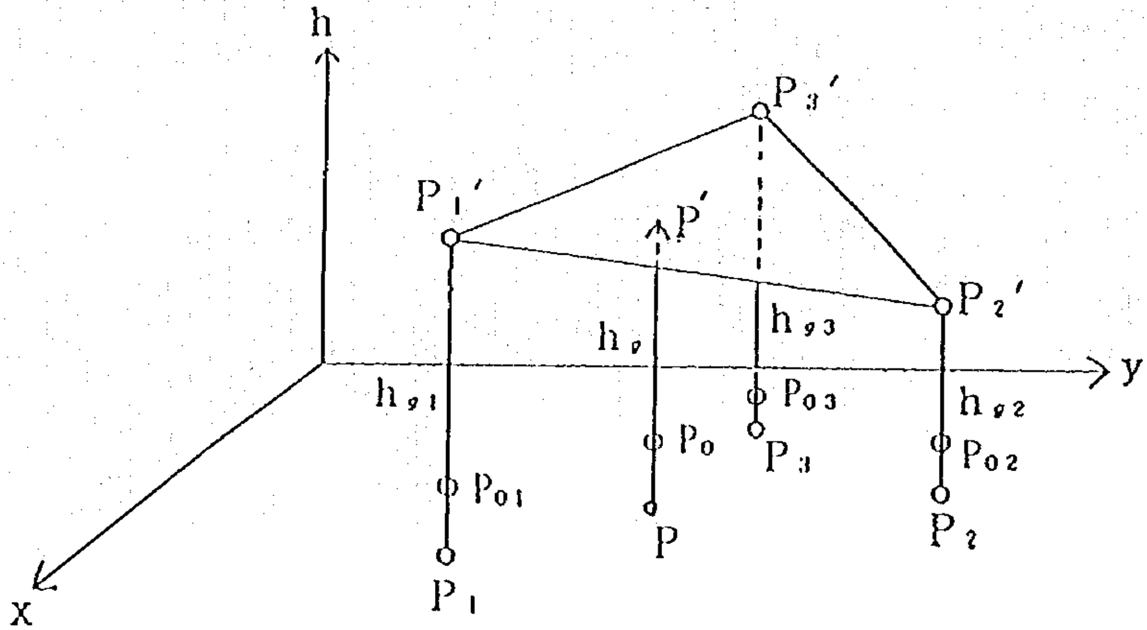


Table 9 Comparison between the ellipsoid and Geoid

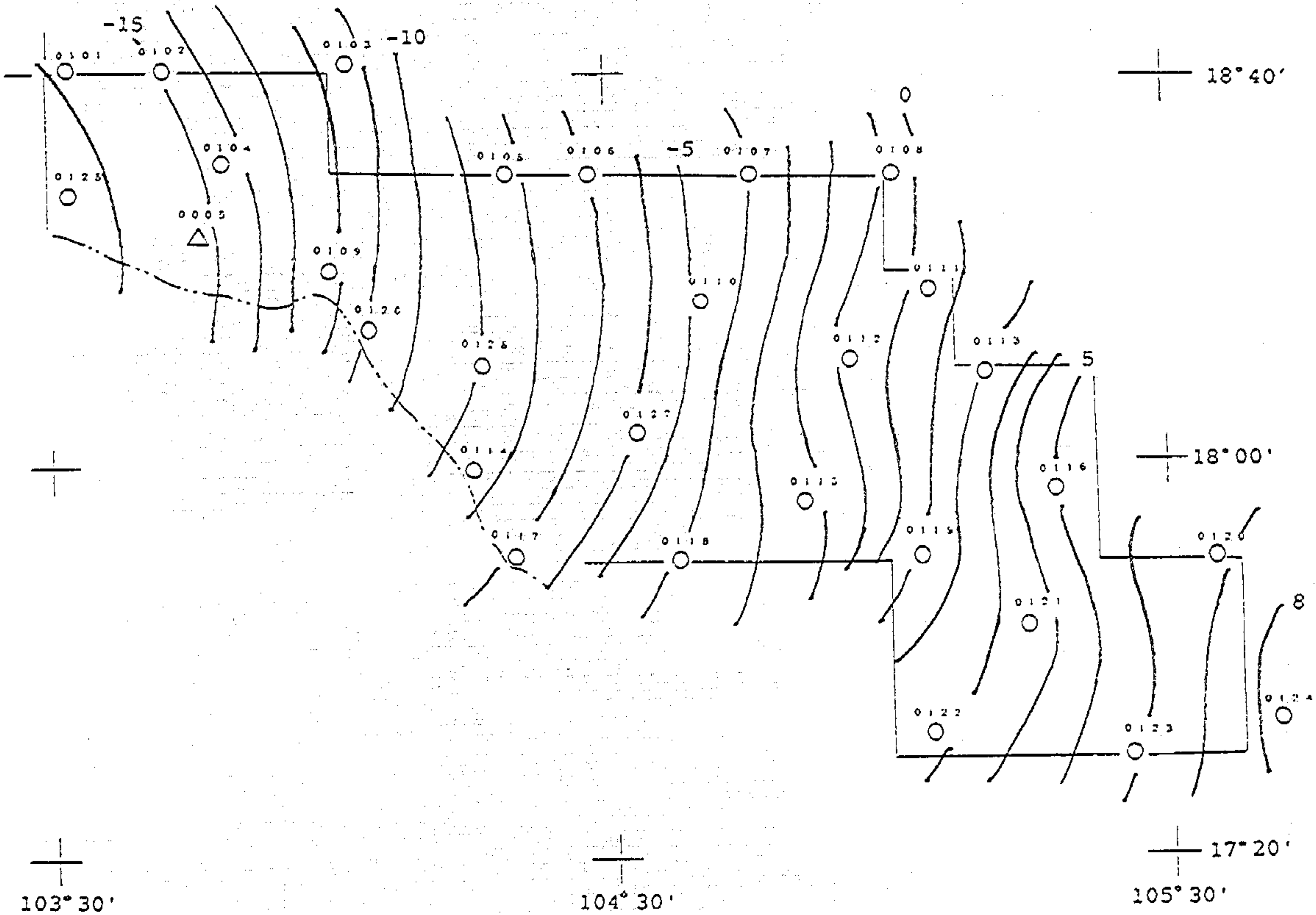
Point No.	Height from ellipsoid (h)m	Height from Geoid (H)m	Geoid Height (H-h)m
5,014	144.67	144.67 (Existing data)	0
1	183.12	200.2 (-ditto-)	17.08
5	147.14	162.8 (-ditto-)	15.66
17	158.22	167.3 (-ditto-)	9.08
21	160.85	164.7 (-ditto-)	3.85
102	156.16	171.2 (by direct level)	15.04
106	291.5	297.96 (-ditto-)	6.46
109	141.83	153.86 (-ditto-)	12.04
110	420.01	424.21 (-ditto-)	4.2
111	527.86	527.43 (-ditto-)	0.43
112	504.38	504.71 (-ditto-)	0.34
113	538.99	536.37 (-ditto-)	-2.62
117	142.16	148.62 (-ditto-)	6.46
118	147.67	151.46 (-ditto-)	3.79
119	514.32	512.52 (-ditto-)	-1.8
121	534.19	530.18 (-ditto-)	-4.01
122	165.63	163.15 (-ditto-)	-2.48
123	163.38	157.61 (-ditto-)	-5.77
124	183.47	174.95 (-ditto-)	-8.52
125	143.15	160.64 (-ditto-)	17.49
126	140.69	151.21 (-ditto-)	10.52
400	139.25	156.66 (Existing data)	17.41
500	139.82	151.29 (Existing data)	11.46

Re; It is assumed that the Geoid surface and the ellipsoidal surface coincide to each other at the control point No.5014.

Table 10 Computed height of New control point

Point No.	Height from ellipsoid (h)m	Estimated height	Estimated Geoid height (H-h)m
101	155.91	171.79	-15.88
103	251.05	262.62	-11.57
104	144.57	158.79	-14.22
105	280.59	289.01	-8.42
107	510.12	513.48	-3.36
108	935.1	935.67	-0.57
115	175.1	176.29	-1.19
120	595.32	588.38	6.94
127	150.53	155.46	-4.93
128	141.8	151.19	-9.39

Fig. 7 HEIGHT OF GEOID RELATIVE TO ELLIPSOID



3-5 Pricking

3-5-1 Outline

Aerial signals were not set up in the previous stage because establishment of control points and aerial photography were simultaneously carried out. Therefore, pricking of control points was conducted in this stage. (See Fig.8) Also, to keep height accuracy for aerial triangulation and plotting, newly established leveling points and existing B M's were pricked on the two time-enlargement photos.

3-5-2 Implementation

(1) Control points

Control points for horizontal control of aerial triangulation were pricked at clearly identifiable on four times enlargement photographs.

Pricking of control points were executed directly on the sites and eccentric points also were measured using the plane table, theodolite, EDM and GPS except one point (No. 0120). Azimuth was observed using the sun because of no visible control point available near the sites.

The accuracy was required of more than 1/7 of the standard deviation of established control point (approximately 3.57m).

Because of bad weather condition in the area, at control point No.0120 a eccentric element could not be obtained, but an aerial signal which had been set up before airplane re-flight was used instead of pricking as it was recognized on the photograph.

Totally 28 points were pricked including 3 existing points and 1 point was verified by aerial signal.

(2) Existing B M's

Existing bench marks on Routes 13 in the study area were pricked. In case it was difficult to do direct pricking, heights of BM were transferred to clearly identifiable on photos. The 30 points were pricked (approx. 150 km).

For some parts of existing leveling routes with missing bench marks, supplementary leveling was conducted.

Leveling routes where pricking was executed are shown in Fig. 4.

3- 6. Aerial Triangulation

3-6-1 Outline

Coordinates of the pass points and the control points to be used for plotting were measured by streo-comparator. And the block adjustment computations based on independent models were executed to obtain orientation elements as well as the coordinates of pass points. The aerial triangulation work was executed in Japan. (See Fig.9)

3-6-2 Work contents

(1) Volumes of work and Specifications

- Photo scale	1/40,000	
- Number of courses	30 courses	
- Number of models	817 models	
- Control point		
	Horizontal	29 points
	Elevation	278 points
- Adjustment	Block adjustment	
	Independent model method (PAT-M43)	

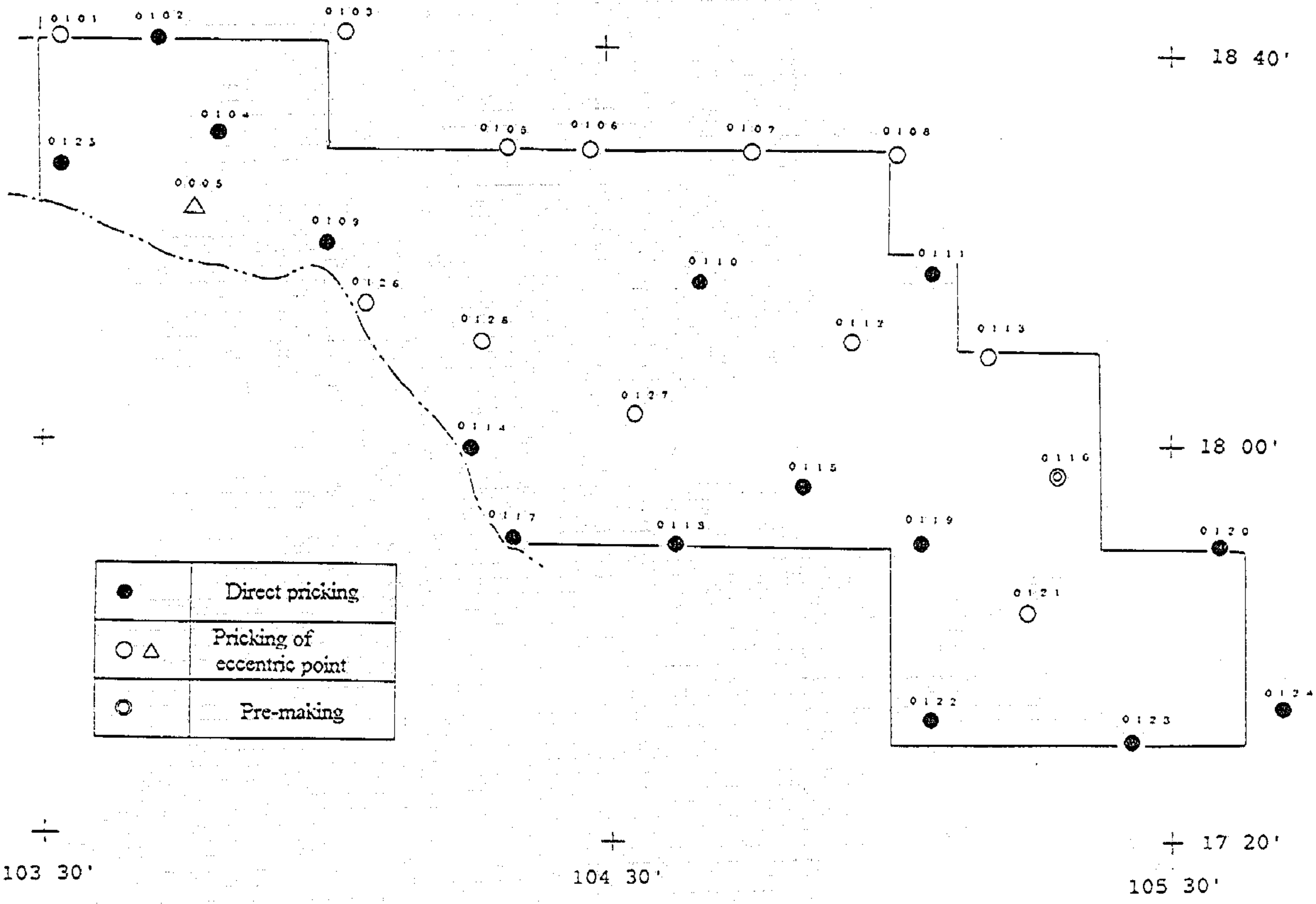
(2) Accuracy

In implementation of adjustment computations, the limitation for residuals of the control points used and discrepancy of pass points and tie points between neighboring models was based on the JICA Specification B.
Namely, it was within 1.6‰ of flight altitude for horizontal and vertical.
(9.7m for 1/40,000 scale of aerial photos)

(3) Major instruments used

Pricking device	PUG 4 (Wild)
Stereo-comparator	Stecometer (Zeiss jena)
Computer	FACOM M760-4 (Fujitsu)

Fig. 8 DISTRIBUTION OF PRICKED POINTS



(4) Aerial camera

Aerial camera — WILD RC-20

Focal length — 152.68mm

Lens — UNIVERSAL AVIOGON UAGA-F

Distortions

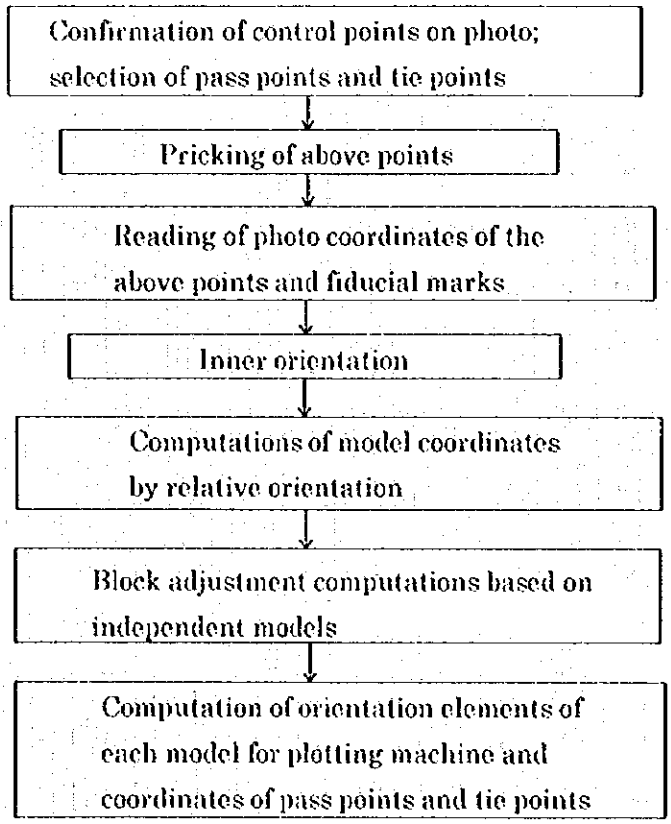
Radius (mm)	10	20	40	60	80	100	120	140
Distortion (μ)	0	+0.3	+0.1	0	0	+0.2	0	-0.5

Note : (1) + mark for withdraw from datum point.

(2) Value is the average on diagonal line.

3-6-3 Work procedure

Aerial triangulation was performed in the following procedure.



(1) Point selection and pricking

Pass points and tie points were selected so that photo coordinates could be measured correctly, using contact aerial photos. In consideration of block adjustment computation by independent model, 6 pass points in each model and one tie point in each model at where flight courses overlapping area were selected.

For transfer of pass points and tie points to film positives, PUG 4 was employed as a pricking device and the points were marked in red circles of 7mm in diameter each on contact aerial photos and positive films.

Transfer of the points including the control points whose locations were determined by pricking was performed stereoscopicaly with a pricking device by referring to the pricked photos, description of pricked control points and bench marks.

(2) Measurement of photo coordinate

Photo coordinates of geodetic control points, fiducial marks, pass points and tie points were measured by stereo-comparator in the unit of 1 micron. The measurement was executed two times independently, and it was carried out once more when the discrepancy of measured values exceeded 0.02mm, and then average of the values was adopted.

(3) Inner orientation

The observed values of fiducial marks were transformed to the coordinate system having the center of photo projection as the origin, and the measured values of other points were computed by the Helmert transformation. Based on the computed values, other measured values were transformed.

(4) Relative orientation

Relative orientation was made using all the points contained in the models, and corrections were made for atmospheric refraction.

(5) Adjustment computation

Adjustment computations were performed based on the independent model method, taking the entire study area in one block, for 1/40,000 aerial photos (see Fig. 9). PATM-43 Program was used.

Standard deviations and a maximum of control point residuals and pass point and tie point discrepancies resulting from aerial triangulation are as shown in Table11 and 12.

Table-11 Residuals of Control Points

Courses and models	Number of control points		Residual of control points (planimetry)		Residual of control point (height)	
	Planimetry	Height	S.D.	Max.	S.D.	Max
30 courses 817 models	29 points	278 points	0.77m (0.13‰)	1.69m (0.28‰)	0.30m (0.05‰)	1.19m (0.20‰)

Specified tolerance of flight height ratio ; 1.6‰ of planimetry and height

Table 12 Discrepancies of Pass and Tie Points

Photo Scale	Planimetry		Height	
	S.D.	Max.	S.D.	Max
1/40,000	0.30m (0.10‰)	1.11m (0.18‰)	0.29m (0.05‰)	0.99m (0.16‰)

Specified tolerance of flight height ratio ; 1.6‰ of planimetry and height.

In the aerial triangulation, good results, below the maximum value, could be obtained as shown above.

Fig. 9 AERIAL TRIANGULATION