社会開発調査部報告書

TOPOGRAPHIC MAPPING FOR ANGKOR ARCHAEOLOGICAL AREA IN SIEM REAP REGION OF THE KINGDOM OF CAMBODIA

FINAL REPORT

JULY 1998

INFRASTRUCTURE DEVELOPMENT INSTITUTE
KOKUSAI KOGYO CO., LTD.

TOPOGRAPHIC MAPPING FOR ANGKOR ARCHAEOLOGICAL AREA IN SIEM REAP REGION OF THE KINGDOM OF CAMBODIA

FINAL REPORT

INFRASTRUCTURE DEVELOPMENT INSTITUTE
KOKUSAI KOGYO CO., LTD.

Preface

In response to a request from the Government of the Kingdom of Cambodia, the Government of Japan decided to conduct the study on the Topographic Mapping for Angkor Archaeological Area in Siem Reap Region of the Kingdom of Cambodia and entrusted the Japan International Cooperation Agency (JICA).

JICA sent a study team four times to Cambodia, headed by Mr. Yoshitake Egawa, from January 1997 to May 1998.

The Team held discussions with the officials concerned of the Government of the Kingdom of Cambodia, and conducted field surveys at the study area. Consequently, the present results were prepared based on these surveys.

I hope that these results will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Kingdom of Cambodia for their close cooperation extended to the team.

July 1998

Kimio Fujita

President

Japan International Cooperation Agency

Letter of Transmittal

Mr. Kimio Fujita
President
Japan International Cooperation Agency

July 1998

Dear Sir,

It is a great honour for me to submit herewith the final report of the Study on the Topographic Mapping for Angkor Archaeological Area in Siem Reap Region of the Kingdom of Cambodia.

A study team, which consists of Infrastructure Development Institute and Kokusai Kogyo Co., Ltd. headed by myself, conducted field surveys and data analysis based on the terms of references instructed by the Japan International Cooperation Agency (JICA), from January 1997 to July 1998.

The study team held thorough discussions and investigations with officials concerned of the Government of the Kingdom of Cambodia.

The results were collected in the final report.

On behalf of the team I wish to express my heartfelt appreciation to the Officials concerned of the Government of the Kingdom of Cambodia for their warm friendship and cooperation extended to us during our stay in Cambodia.

Also, I wish to express my sincere appreciation to JICA, the Ministry of Foreign Affairs, the Ministry of Construction, the Embassy of Japan in Cambodia,Japanese Government Team for Safeguarding Angkor and other concerned government authorities for their valuable advice and cooperation given to us in the course of the site surveys and preparation of the final report.

Yours Faithfully,

Yoshitake Egawa
Team Leader
The Topographic Mapping for Angkor Archaeological Area in Siem Reap Region of the Kingdom of Cambodia

TOPOGRAPHIC MAPPING FOR ANGKOR

ARCHAEOLOGICAL AREA

IN

SIEM REAP REGION OF THE KINGDOM OF CAMBODIA

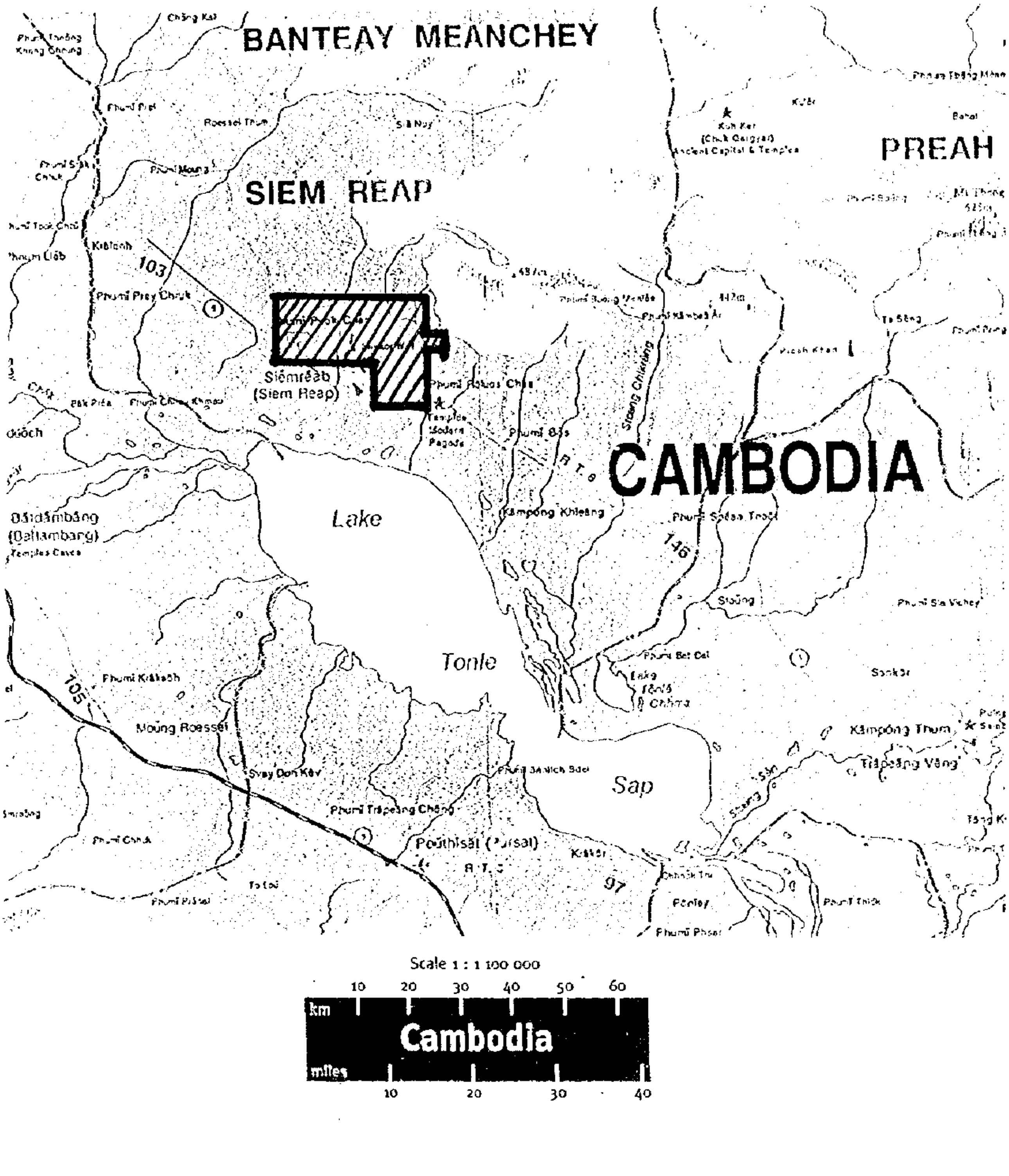
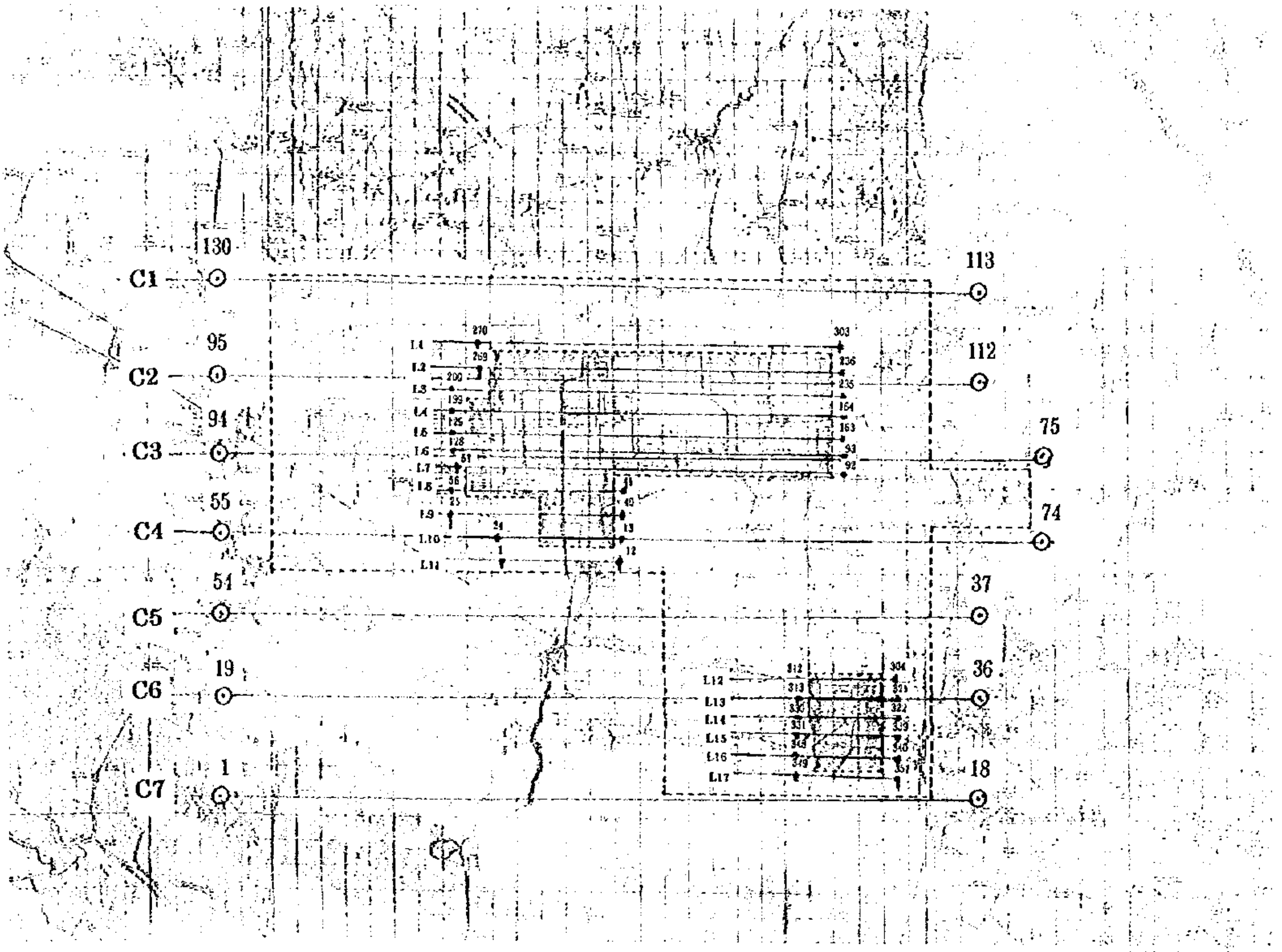


PHOTO INDEX
OF
TOPOGRAPHIC MAPPING
FOR
ANGKOR ARCHAEOLOGICAL AREA
IN
SIEM REAP REGION OF THE KINGDOM
OF
CAMBODIA

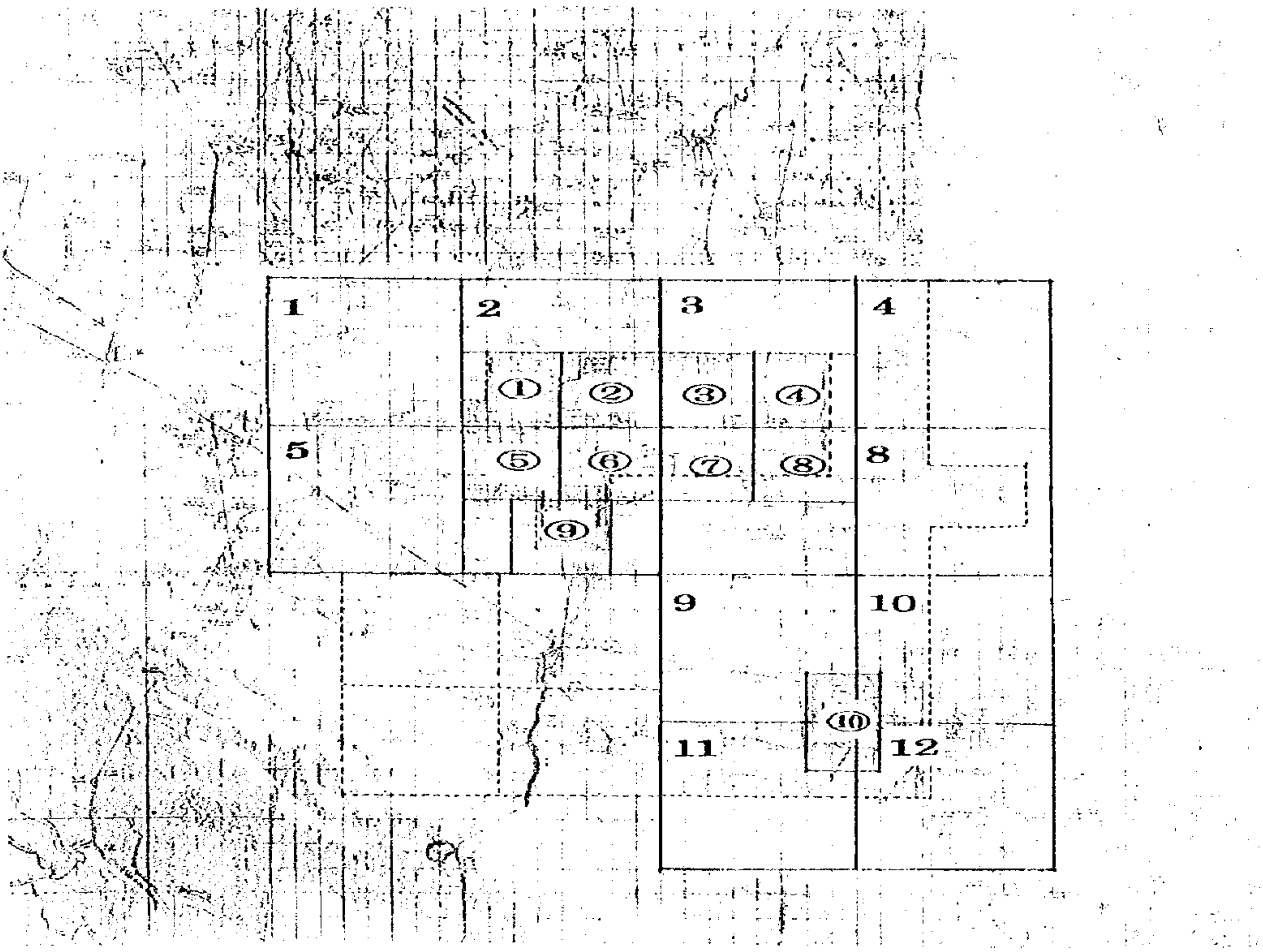
SCALE: 1/250,000



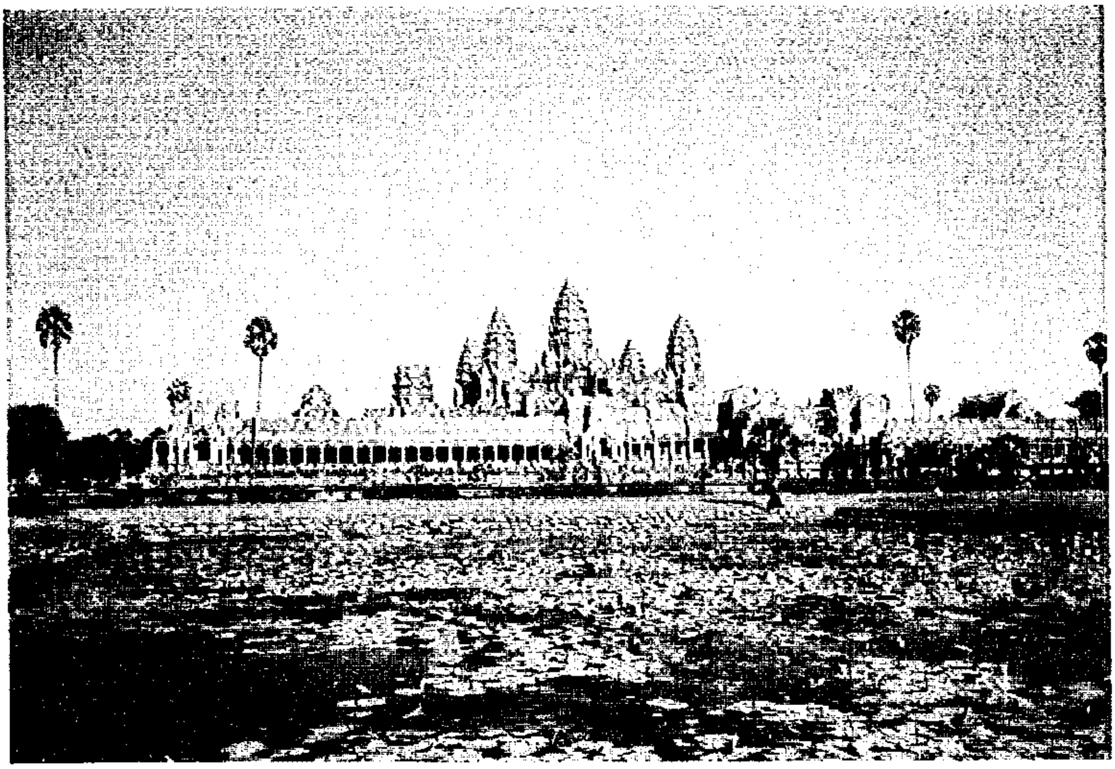
Mapping area	1:10,000 1:5,000	430 km² 100 km²
1:20,000 photo index	7 courses	130 photographs
1:5,000 photo index	17 courses	357 photographs

SHEET INDEX
OF
TOPOGRAPHIC MAPPING
FOR
ANGKOR ARCHAEOLOGICAL AREA
IN
SIEM REAP REGION OF THE KINGDOM
OF
CAMBODIA

SCALE: 1/250,000

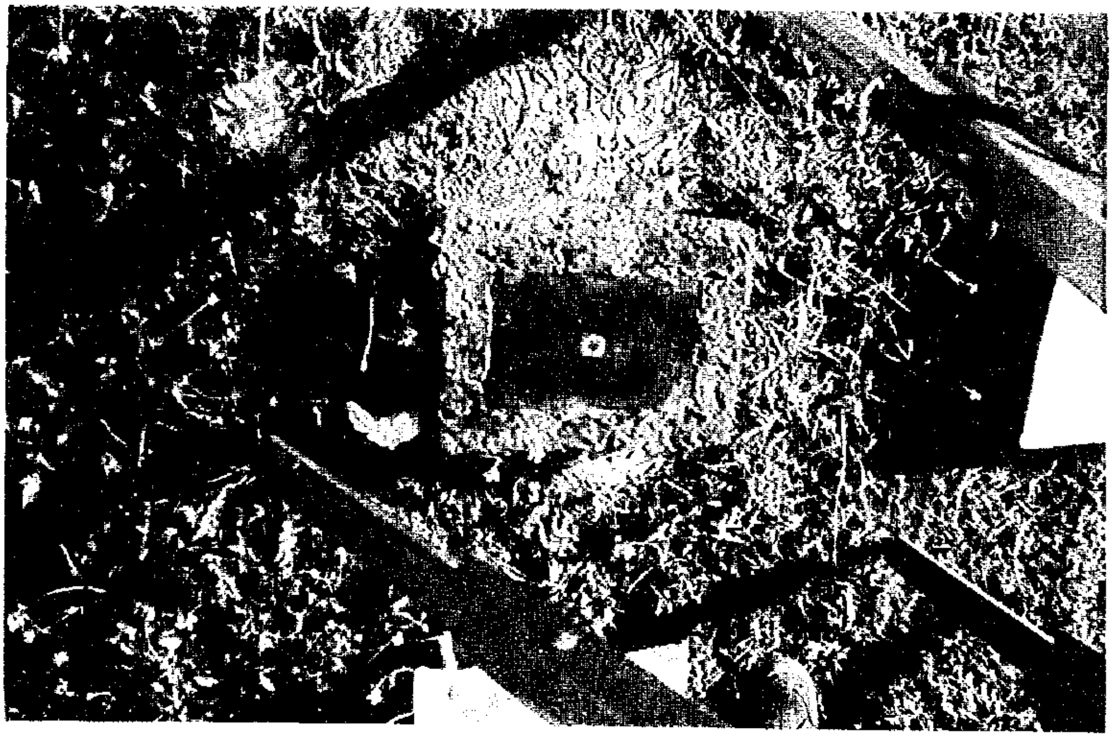


Mapping area	1:10,000 1:5,000	430 km² 100 km²
1:10,000 sheet index		12 sheets
1:5,000 sheet index		10 sheets

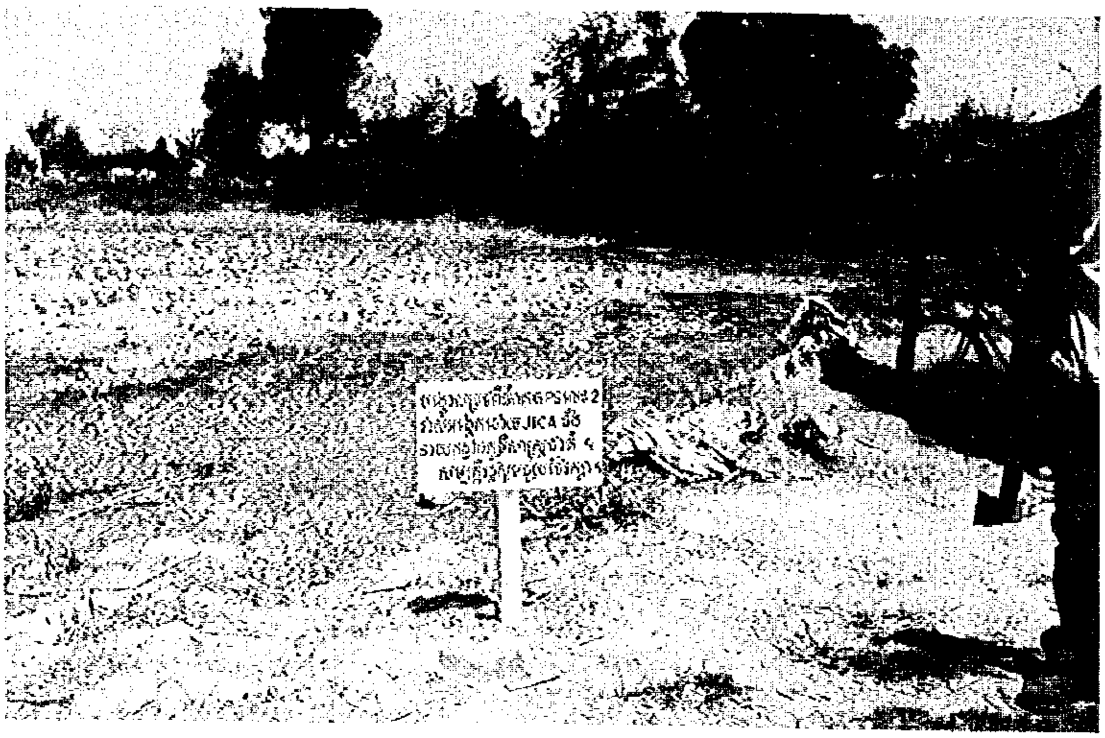


Angkor Wat

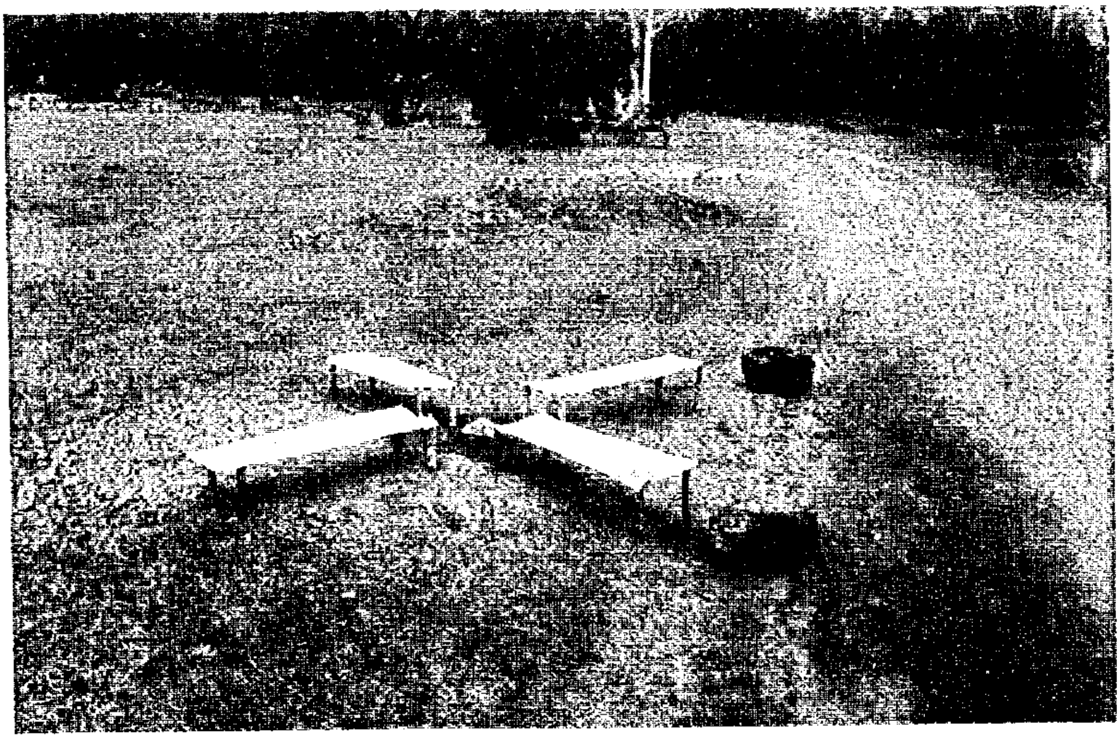
Preparation



Existing Control Point



New Control Point

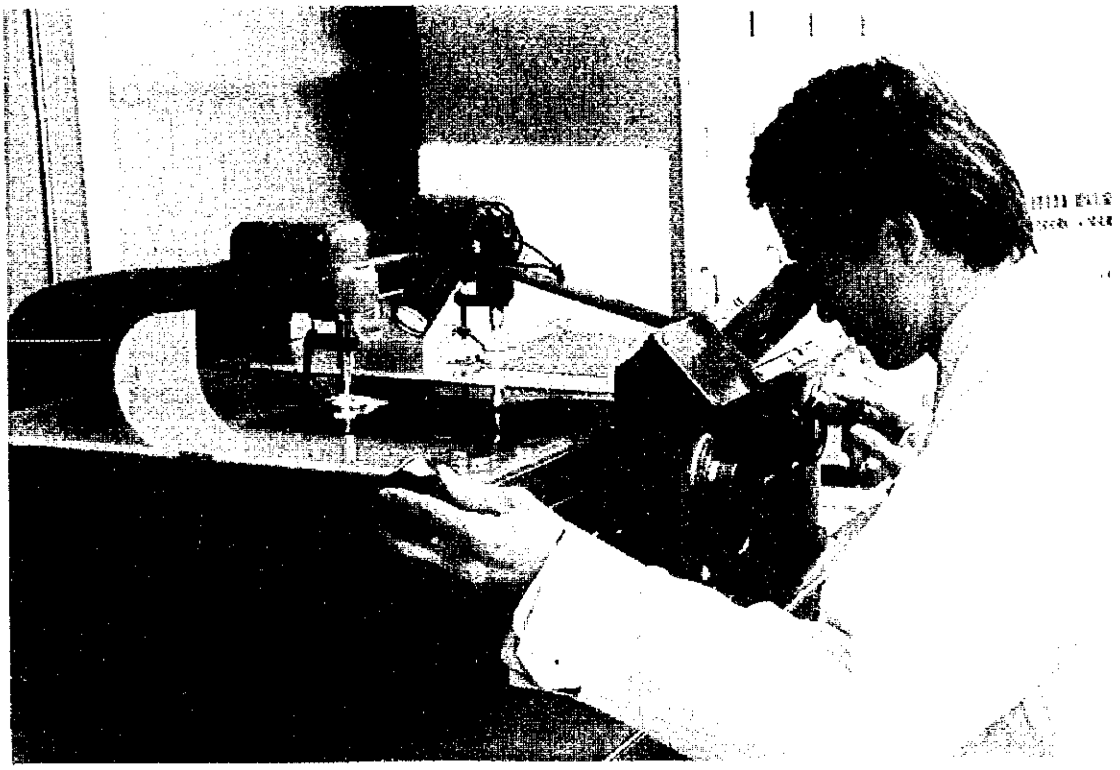


Air Photo Signal

GPS Observation

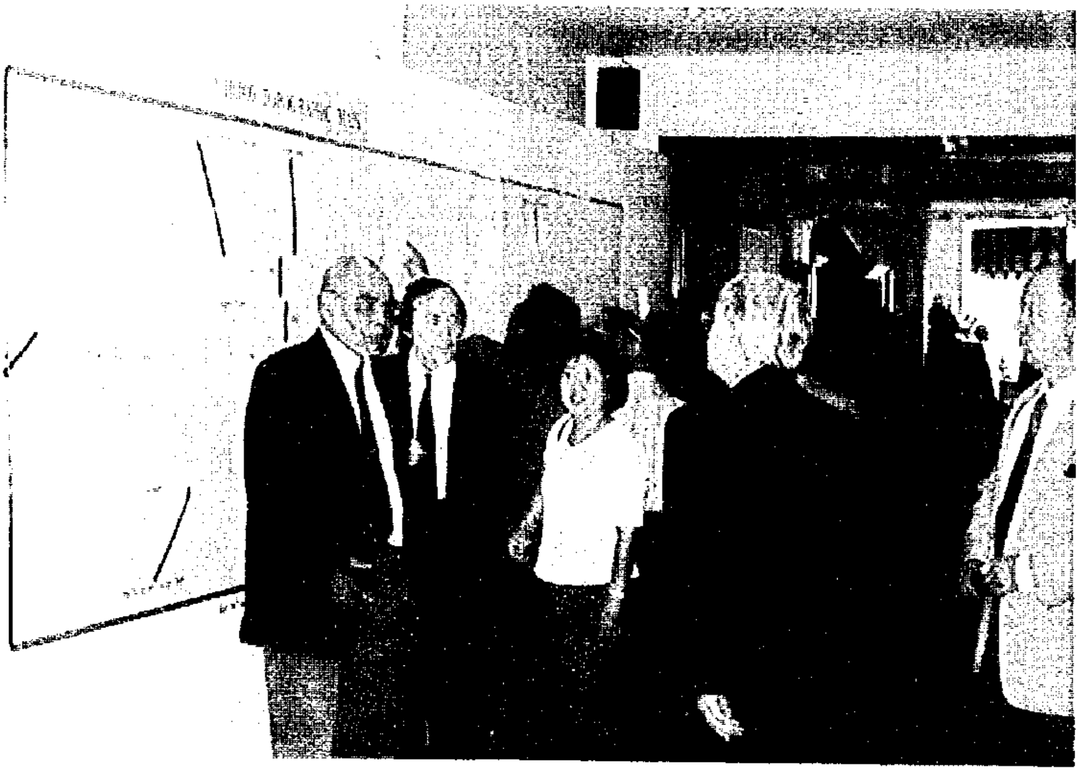
Levelling

Field Completion



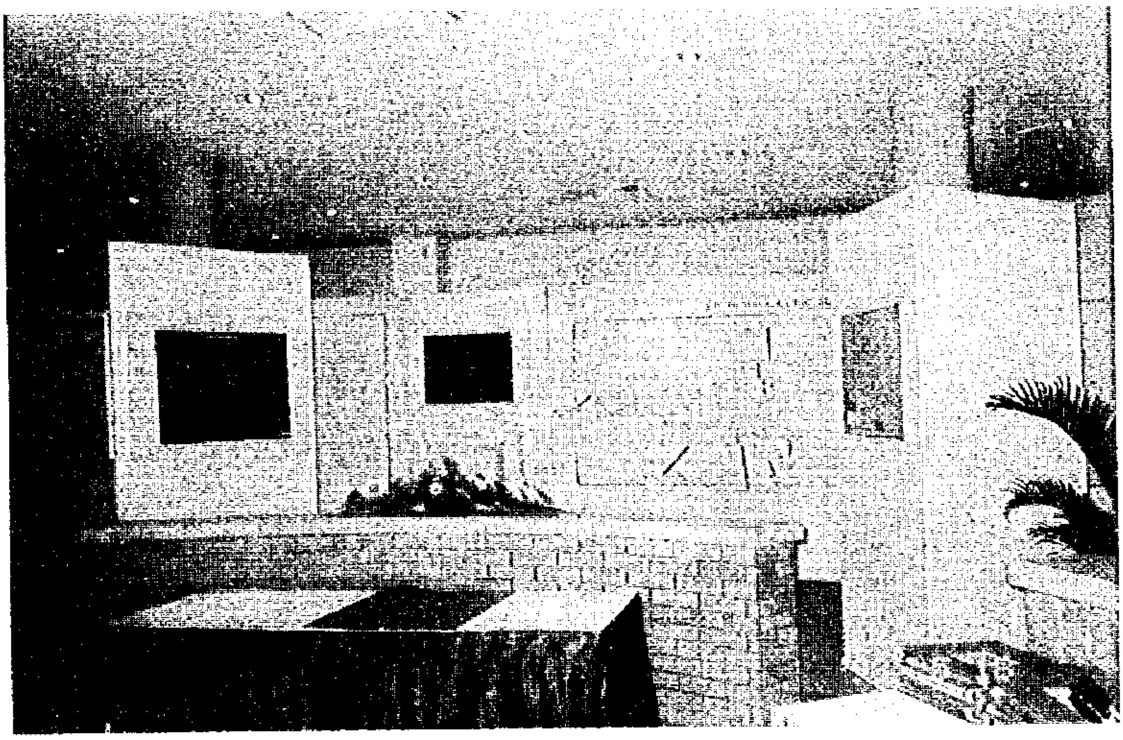
Aerial Triangulation Instrument (PUG- II)

Aerial Triangulation Instrument (STECOMETER)

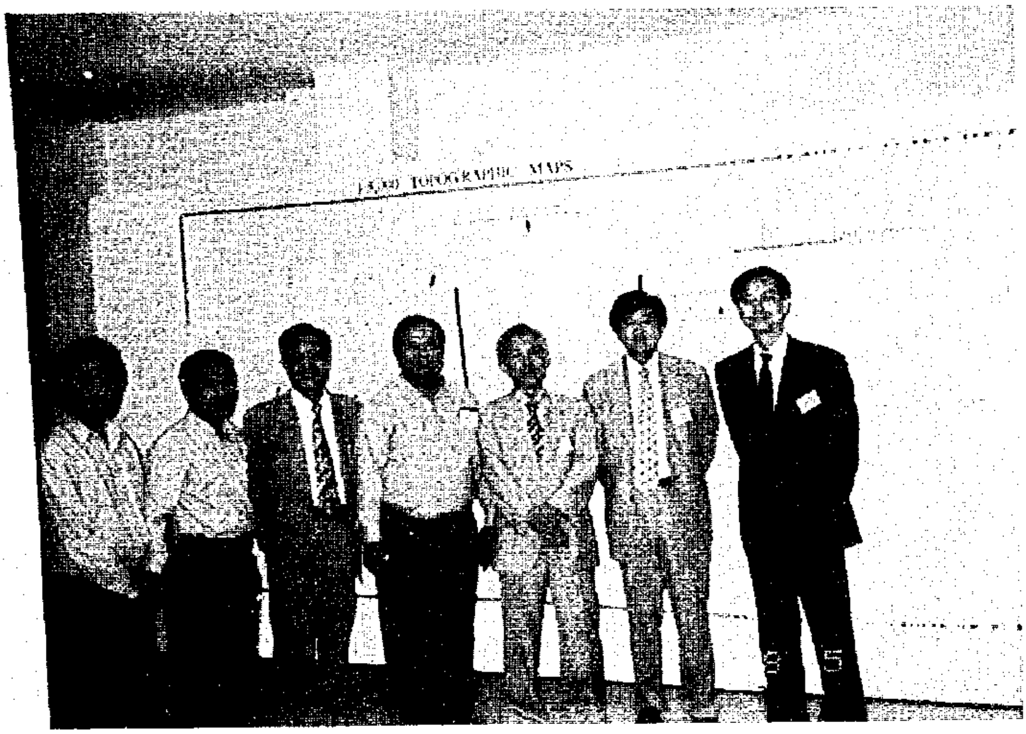


Map Exhibition in Phnom Penh
H.E. Mr. Vann Molyvann (left)

Map Exhibition in Phnom Penh

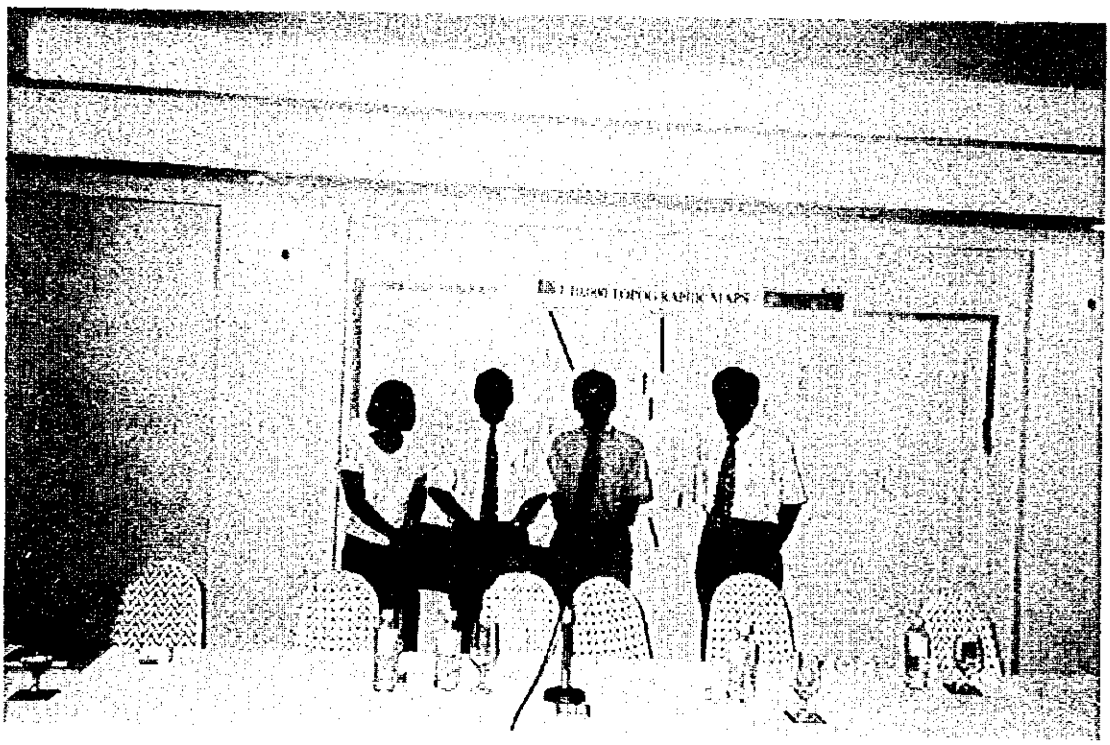


Map Exhibition in Phnom Penh

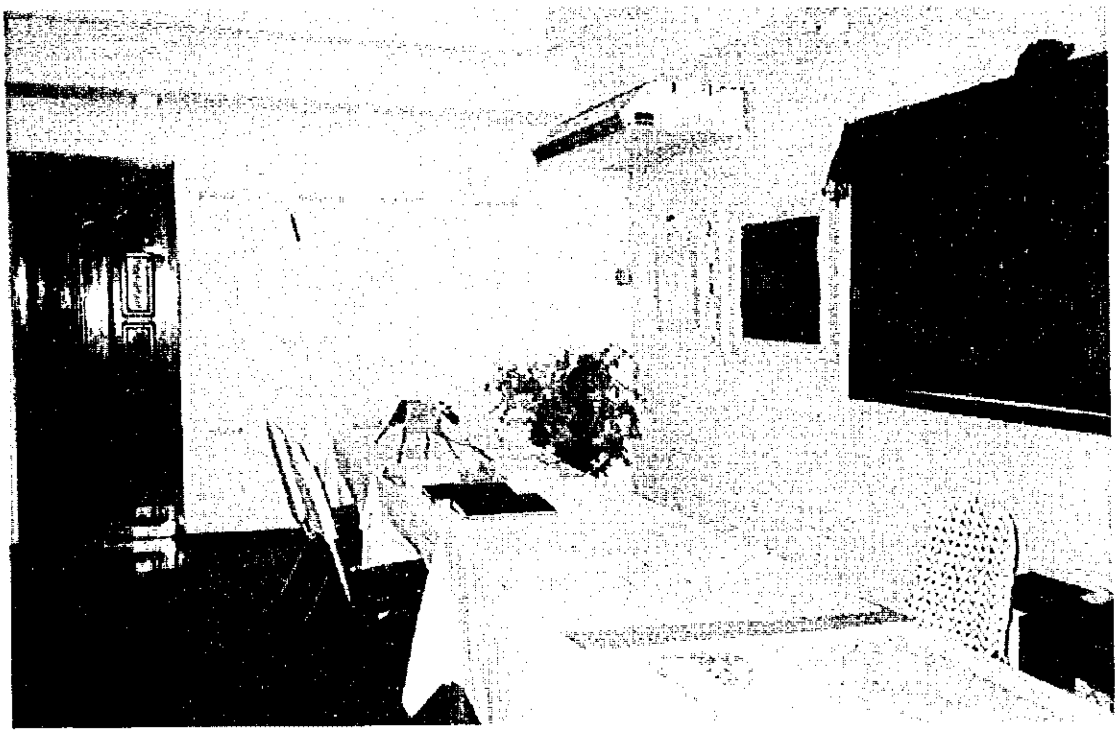


Map Exhibition in Phnom Penh

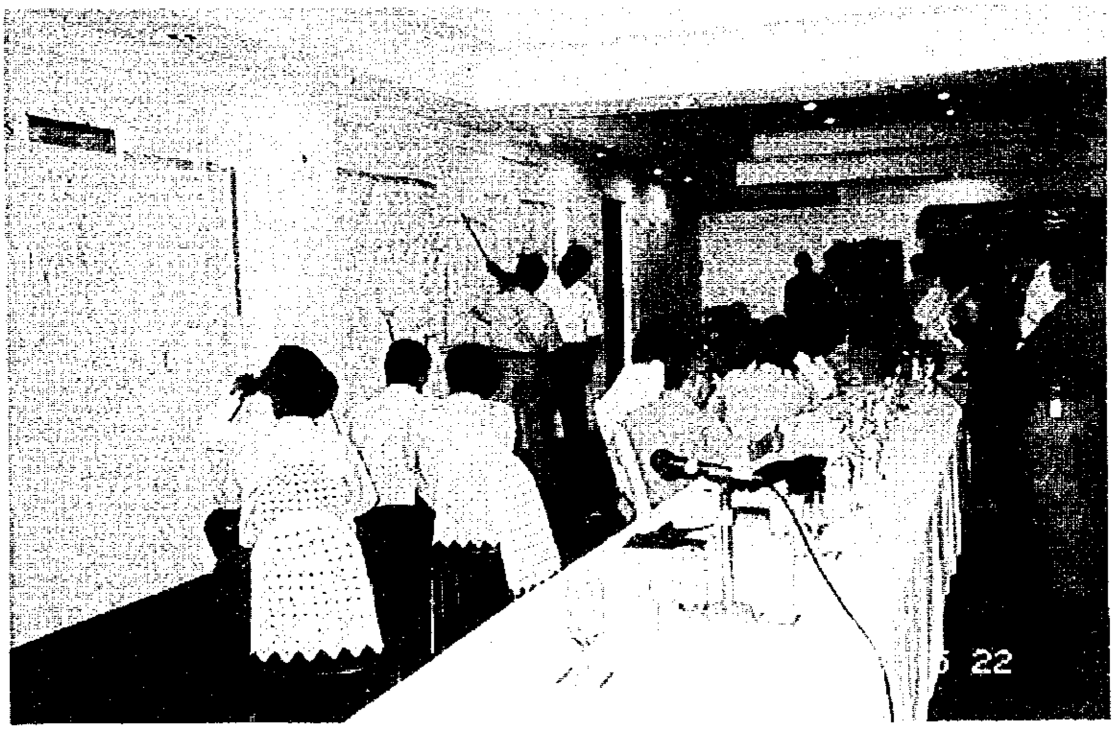
Workshop in Geographic Department



Workshop in Siem Reap



Workshop in Siem Reap



Workshop in Siem Reap

CONTENTS

CHAPTER 1 SEQUENCE OF EVENTS LEADING TO THE PROJECT

In October 1991, UNTAC was established based on the agreement made in Paris to comprehensively resolve political conflicts that led to the outbreak of civil war in Cambodia. As a result of the May 1992 elections for a constitutional assembly, the Government of the Kingdom of Cambodia was inaugurated in September of the same year. Thereafter, UNTAC ended its mission and left the government in charge of national reconstruction. As part of this post-war recovery, the Government is especially putting a lot of effort into the restoration of Siem Reap Province where the Angkor archaeological area, the symbol of Cambodia, is located. On the other hand, before the inauguration of the new government, UNESCO formulated the land use and environmental management plan (ZEMP) for 5,000km^2 of the Angkor area, which was implemented between 1992 and June 1994.

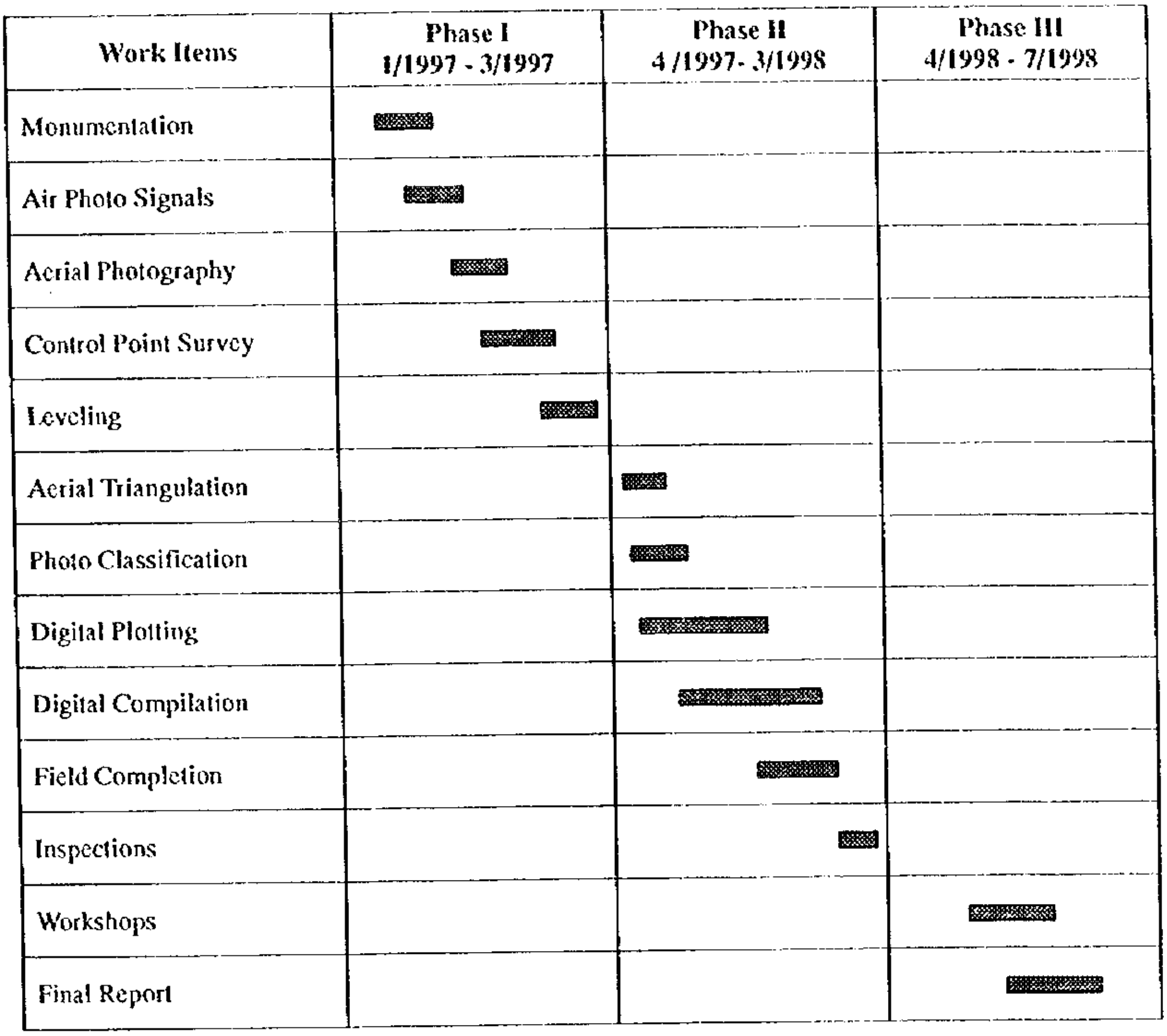
In October 1992, following the footsteps of the UNESCO program ZEMP, JICA implemented a project formulation study to formulate a proposal for the conduct of cooperation projects that would contribute to the socio-economic development of the region including Angkor. Then, in February 1993, the Cambodian Government submitted a request to the Government of Japan for the implementation of a study related to the formulation of a "Comprehensive Development Plan for Angkor Area and Siem Reap Province". During the International Conference on the Preservation of the Angkor Archaeological Area held in Tokyo in October 1993, the Japanese Government declared that it would implement the aforesaid study. Based on the above-mentioned conditions, JICA dispatched a preliminary study team in March 1994 which signed the S/W with the Government of Cambodia.

In June 1994, the Government of Cambodia held a round-table conference with the Pol Pot Party. However, the negotiations to end the war failed and consequently, social conditions deteriorated rapidly. As a result, the implementation of the study for the "Comprehensive Development Plan for Angkor Area and Siem Reap Province" had to be postponed, and in October 1994, JICA notified the Government of Cambodia of the immediate postponement of the study.

In July 1995, the Government of Japan examined conditions in the country to determine the future of the "Comprehensive Development Plan for Angkor Area and Siem Reap Province". It judged that in view of the presence of land mines in the study area and other security problems, the implementation of the study for the formulation of the said plan would be extremely difficult. Consequently, JICA offered to take aerial photos of the Siem Reap Region and Angkor Archaeological area, in order to produce a map that would contribute to the formulation of a development plan. The Government of Cambodia accepted this offer, and in January 1996, a "Cambodian Infrastructure Development Project Formulation Study Team" was dispatched by the Basic Study Department of JICA. This study team signed the minutes of meeting with the Minister of State Vann Molyvann, stipulating that JICA would examine the possibility of extending cooperation in the fields of topographic mapping, water and electric power supply to contribute to the recovery of Siem Reap Province including Angkor Wat, the symbol of Cambodia. Subsequently, the Government of Cambodia requested the cooperation of the Government of Japan for the production of a topographic map of the area in the northern and eastern sections of Siem Reap City where the Angkor ruins are mainly located. JICA responded by dispatching a preliminary study team in September 1996, which signed the S/W on September 26. Accordingly, the APSARA (Authority for the Protection of Site and Management of the Region of Angkor) was chosen as the Cambodian agency responsible for the project, and the Geographic Survey Department was chosen as the agency in charge of technical assistance.

CHAPTER 2 OUTLINE OF THE STUDY

The first phase of the study work was implemented from 26 January 1997 to 31 March 1997, while the second phase was carried out from 26 May 1997 to 27 March 1998. Although the field supplementary work carried out by the JICA Study Team was delayed for about six months due to unavoidable conditions at the site, it was resumed from 27 January 1998 to 25 February 1998. The workshops and presentation of study results were carried over to the third study phase. The table below shows the work flow from Phase I to Phase III.



Japanese engineers were dispatched to Siem Reap to conduct the field survey work at the site with the cooperation of the Cambodian counterparts. The aerial photography was entrusted to FINMAP FM-International Oy under the supervision of a Japanese expert. Aerial triangulation, digital plotting and digital compilation were carried out in Japan. Field completion was carried out by Japanese experts with the cooperation of the Cambodian counterparts, mainly to confirm the mapping annotations.

The annotations were made both in English and Khmer and were approved by the Cambodian government. The work items carried out in this study are shown below by study phase.

Phase	Work Item	Work Quantity				Summary
Phase I	Monumentation	New points		22 points		
	Air Photo Signals	Existing and new points		30 points		
	Aerial Photography	Monochrome	1:20,000	7 courses	130 pieces	
		Colour	1:5,000	17 courses	357 pieces	
	Control Point Survey	GPS		22 points		
	Leveling	Third Order Leveling		178 km		
Phase II	Aerial Triangulation			7 courses	94 models	
	Photo Classification	with 2x enlarged photos		430 km²		
	Digital Plotting	1:10,000		430 km² (12 sheets)		
		1:5,000		100 km² (10 sheets)		
	Digital Compilation	1:10,000		430 km² (12 sheets)		
		1:5,000		100 km² (10 sheets)		
	Field Completion	1:10,000		430 km² (12 sheets)		
		1:5,000		100 km² (10 sheets)		
Phase III	Workshops	Workshop in Phnom Penh				
		Workshop in Siem Reap				
	Final report					

2.1 Field Work

2.1.1 Monumentation

Permanent monuments were installed at the 22 control points established through Global Positioning System (hereafter referred to as "GPS"). To ensure the preservation of these monuments, sign boards were put up alongside each monument to specify their significance.

Monumentation is shown in Fig. 2-1.

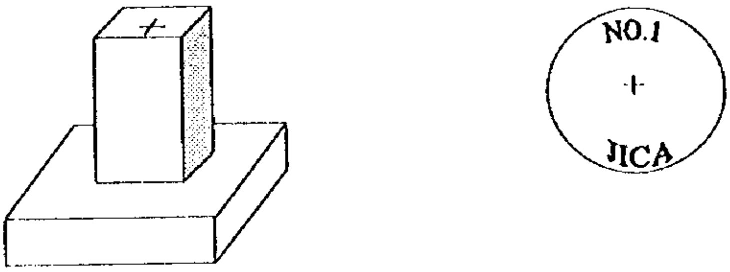


Fig. 2-1 Monumentation

2.1.2 Air Photo Signals

Prior to aerial photography work, air photo signals were installed for a total of 30 points: 8 existing points and 22 new points. Three white pieces of cloth, each measuring 90cm × 30cm, forming a Y-shape were used as air photo signals.

Air photo signal formats and sizes are shown in Fig. 2-2.

Nylon bags	Nylon bags	Nylon bags	Paint	Paint
Given point 1	Given points 5	Given points 2	Given point 1	Given point 1
New points 3	New points 19			
Total 4	Total 24	Total 2	Total 1	Total 1

Fig. 2-2 Air Photo Signals

2.1.3 Aerial Photography

Aerial photographs were taken on February 19, 20, 21 in 1997, at a scale of 1:20,000, in black and white, covering 577km^2. There were 7 flight courses, with a total of 130 black and white photographs.

Furthermore, colour aerial photographs were taken at a scale of 1:5,000, covering the 1:5,000 Topographic mapping area (100km^2), for the use of future archaeological conservation planning and photo interpretation. There were 17 flight courses, with a total of 357 colour photographs.

The aircraft used was a Rockwell Turbo Commander 690A and the aerial camera was a Leica Wild RC-20 with a focal length of 153.18mm. Overlap of all photographs was 57-62%.

Film annotations are shown in Fig. 2-3.

Fig. 2-4 shows the 1:20,000 black and white photographs flight index.

Fig. 2-5 shows the 1:5,000 colour photographs flight index.

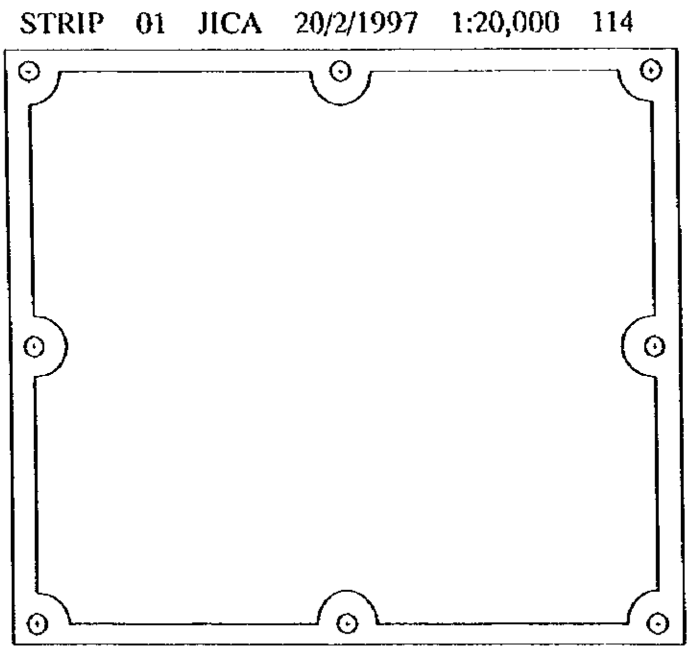


Fig. 2-3 Film Annotations

Fig. 2.4 1:20,000 Black and White Photographs Flight Index

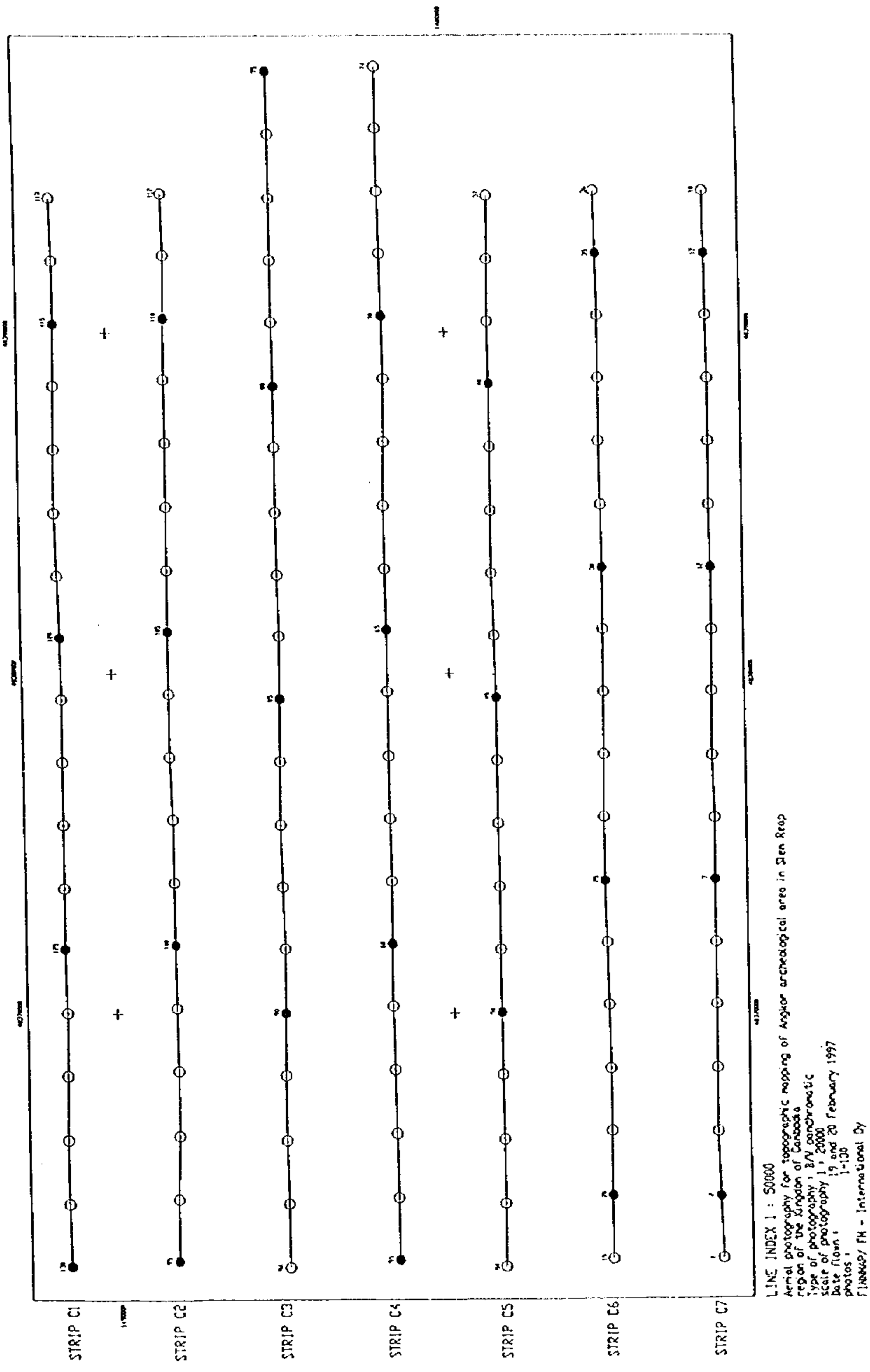
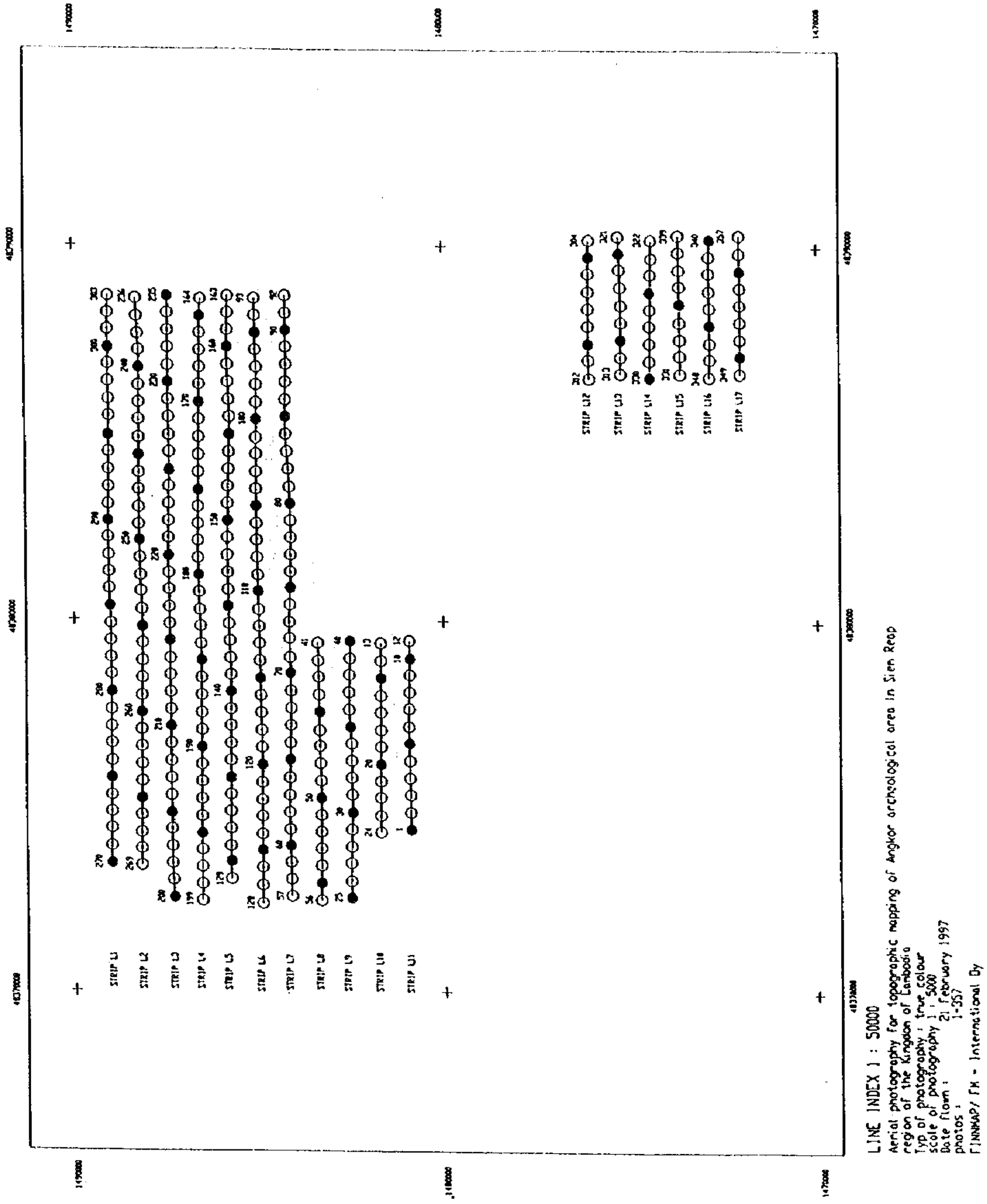


Fig. 2.5 1:5,000 Color Photographs Flight Index



2.1.4 Control Point Survey (GPS Survey)

Twenty two (22) points were established by GPS using GPS control points established by Institut Géographique National -- France International (hereafter referred to as "IGN") in 1994 as given points. Relative positioning survey, which simultaneously uses four or more satellites, was carried out to conduct one set of observations lasting at least two hours and acquire data at an interval of 30 seconds. Four GPS Trimble 4000SSE were used for the observations.

The seven GPS points installed by IGN in 1994 and the 22 newly installed GPS points were used to form the 13 loops shown in Fig. 2-6. The errors of closure of these loops are indicated in Table 2-1.

Accordingly, the relative error for each point is approximately 1.5cm.

2.1.5 Leveling (Third Order Leveling)

Third order leveling was carried out using as given points 12 bench marks established by IGN in 1994 along highway 6 and the road that passes through Angkor Wat.

The instrument used for levelling were Nikon AE-5 levels.

The levelling was carried out along 178km as shown in Fig. 2-7.

The accuracy of levelling is indicated in Table 2-2.

Accordingly, the relative error for each point is approximately 1cm.

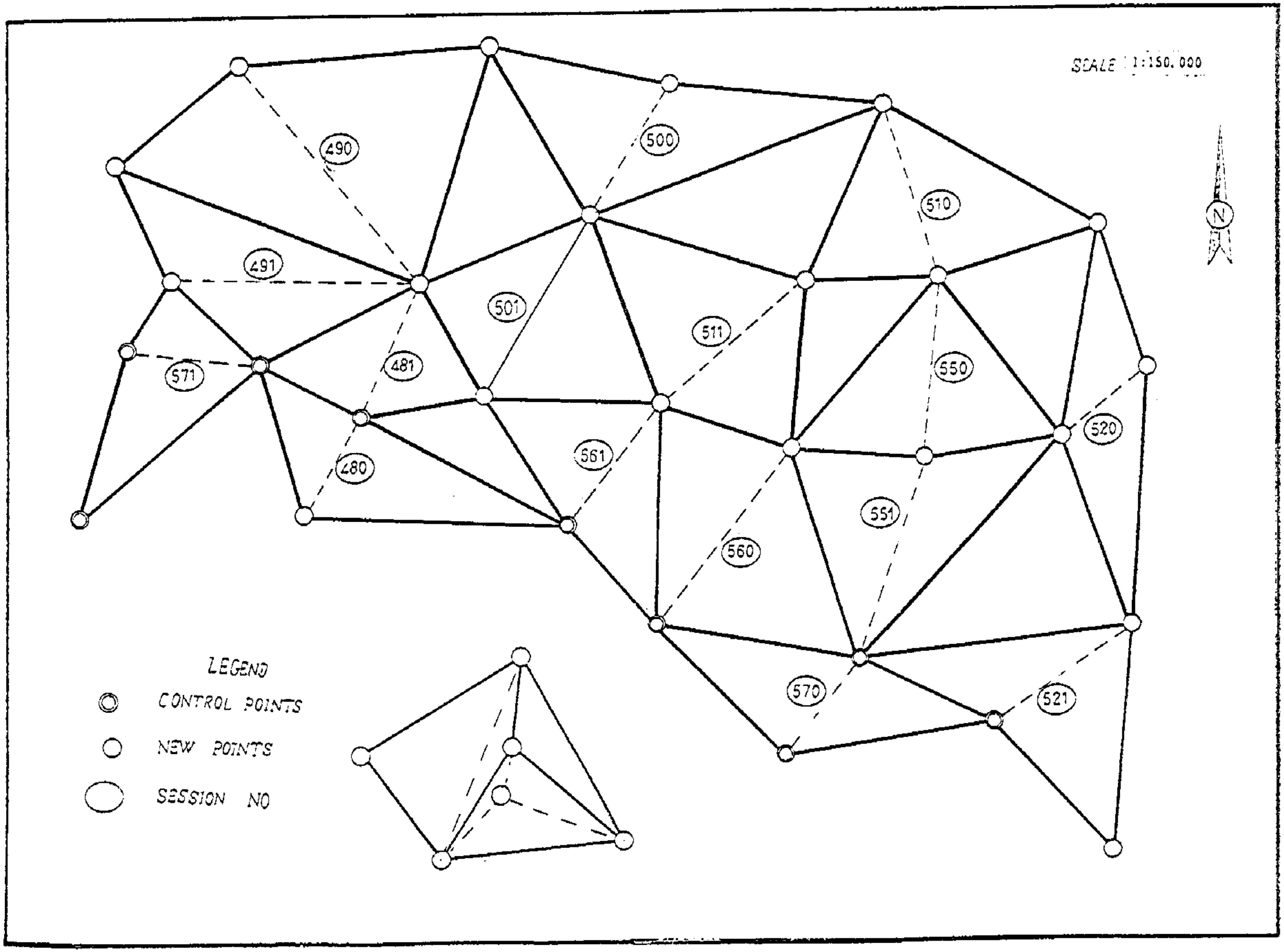


Fig. 2.6 Session Map of Control Points

Table 2-1 Checklist of GPS Points (Standard Deviation)

STATION	△X (m)	△Y (m)	△H (m)
No. 1	0.005	0.006	0.094
No. 2	0.006	0.008	0.071
No. 3	0.005	0.006	0.111
No. 4	0.004	0.005	0.128
No. 5	0.004	0.005	0.127
No. 6	0.005	0.006	0.037
No. 7	0.004	0.005	0.072
No. 8	0.004	0.005	0.040
No. 9	0.004	0.005	0.084
No. 10	0.004	0.005	0.101
No. 11	0.004	0.005	0.017
No. 12	0.004	0.005	0.017
No. 13	0.004	0.004	0.041
No. 14	0.003	0.004	0.045
No. 15	0.004	0.004	0.061
No. 16	0.004	0.005	0.075
No. 17	0.005	0.006	0.100
No. 18	0.004	0.006	0.030
No. 19	0.005	0.005	0.047
No. 20	0.010	0.010	0.027
No. 21	0.012	0.014	0.034
No. 22	0.009	0.011	0.023

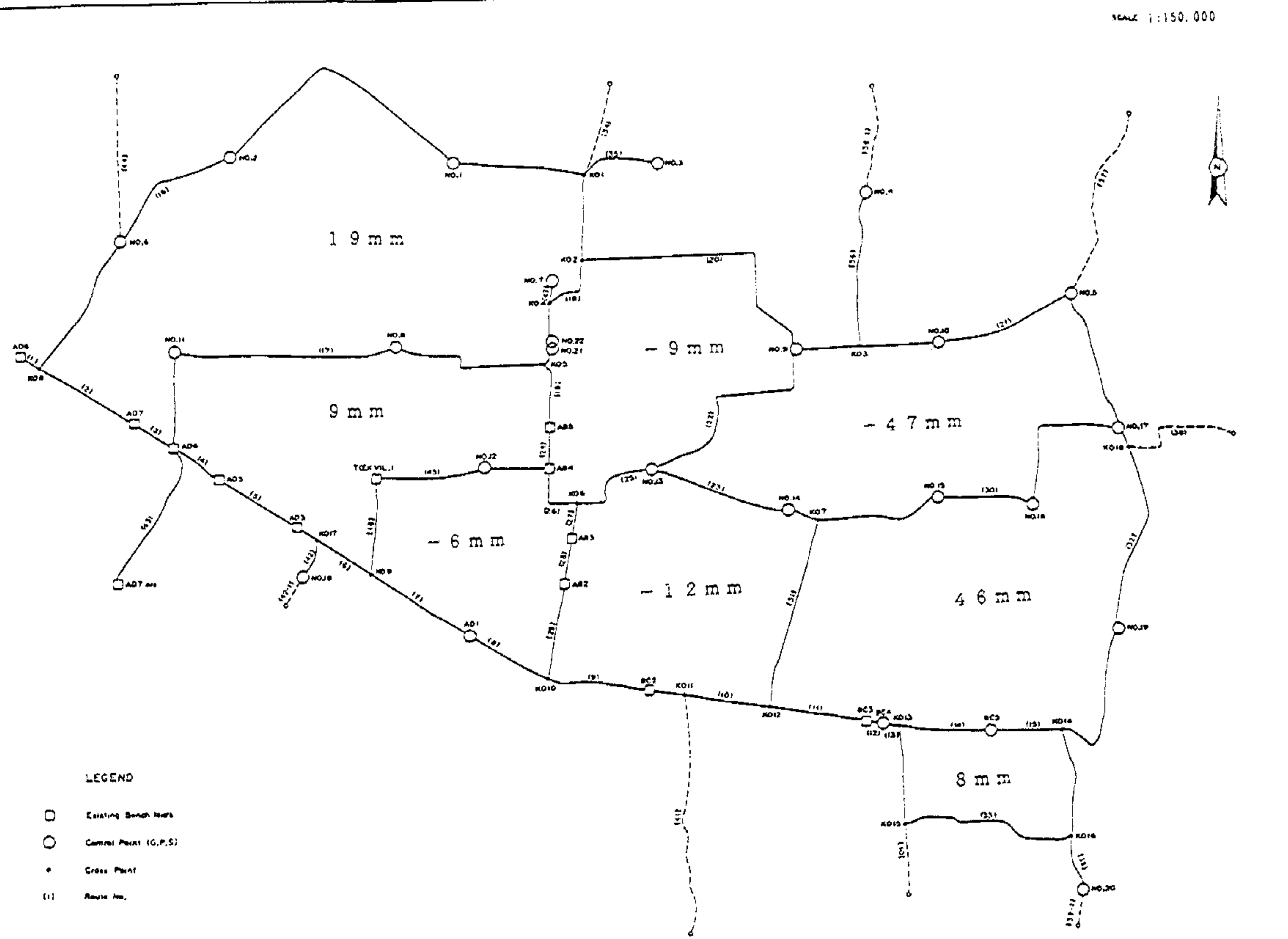


Fig. 2.7 Leveling Routes

Table 2-2 Checklist of Leveling (Errors of Closure)

ROUTES	DISTANCE (km)	LIMIT (mm)	ERROR (mm)
No. 9 – No. 17	12.612	35	-32
No. 9 – No. 13	6.572	25	11
AD8 – KO8 – AD7	4.402	31	20
AD7 – AD6	0.786	13	-11
AD6 – AD5	1.696	19	-10
AD5 – AD3	2.554	23	11
BC2 – KO11 – KO12 – BC3	5.710	35	8
AB2 – AB3	1.918	20	-3
AB3 – KO6 – AB4	2.040	21	-3
AB4 – AB5	1.626	19	-4
AD3 – KO17 – KO9 – TOEK VIL.1	4.880	22	-21
TOEK VIL.1 – AB4	5.408	23	23
AD6 – KO5 – AB5	15.342	39	16
KO8 – No. 6 – KO1 – KO2 – KO4 – KO5	26.826	51	0
KO9 – KO10	5.840	24	16
AB2 – KO10	2.542	15	-3
KO10 – BC2	3.132	17	-11
BC3 – BC4	0.442	6	2
BC4 – KO13	0.560	7	0
KO13 – BC5	2.722	16	-10
KO6 – No. 13 – KO7	7.734	27	16
KO7 – KO12	5.536	23	-18
BC5 – KO14 – KO18 – No. 17 – KO7	24.578	49	32
KO13 – KO15 – KO16 – KO14	11.360	33	-1
KO2 – No. 9	7.980	28	7

2.1.6 Photo Classification

Photo classification was carried out using enlarged black and white aerial photos (1:20,000) to confirm planimetric features that were unclear in the photos and the names of roads, rivers, schools, etc. for annotation.

2.1.7 Field Completion

Field completion was carried out using a plane table at the scales of 1:10,000 and 1:5,000 to confirm unclear annotation items and planimetric features for digital plotting and digital compilation. The annotations were made in English and Khmer, and were inspected and approved by the Geographic Survey Department in Cambodia (refer to approved English/Khmer legend and annotation list in Annex).

2.2 Work in Japan

2.2.1 Aerial Triangulation

Aerial triangulation was carried out on 95 models taken within 7 flight courses, using black and white aerial photos (1:20,000). The analytical method was adopted.

Pricking instrument:	WILD PUG-II
Measuring instrument:	ZEISS JENA STECOMETER

The bundle block adjustment method was adopted using GPS points for XY coordinates and direct leveling points for elevation.

32 control points were used to determine horizontal positions, and 122 control points were used to determine vertical positions.

Control point residuals for aerial triangulation are as indicated in Table 2-3.

The aerial triangulation results were highly accurate, as the following were obtained: 1/8,000 flight height for horizontal positions (generally around 1/5000), and 1/11,000 flight height for vertical positions (generally around 1/5,000).

This superior accuracy is due to the fact that it has been possible to place control points approximately at each corner of the block and to have the leveling routes intersect at right angles with the courses at both ends of the block.

Moreover, the 1:10,000-scale map produced by IGN in 1994 was inspected for accuracy. After reading the horizontal and vertical positions, aerial triangulation was applied and deviations of 5 to 6 meters for horizontal positions and 50 to 60 cm for vertical positions were confirmed. As such deviations for horizontal positions correspond to approximately 0.5mm on the map, this map was judged highly accurate.

Table 2-3 Checklist of Aerial Triangulation

Course Name	Model Number	X, Y Number	H Number	X, Y Max. Error (m)	X, Y Mean Error (m)	H Max. Error (m)	H. Mean Error (m)
C-1	16	5	17				
C-2	16	9	22				
C-3	19	11	29				
C-4	19	9	28				
C-5	11	4	13				
C-6	7	4	14				
C-7	7	2	9				
Total	95	32	122	1.066	0.366	0.908	0.281

2.2.2 Plotting

In accordance with the S/W, the plotting scale was 1:10,000 for 430km² and 1:5,000 for 100km². However, according to the details of the meeting held on 23 February 1998, the mapping (1:5,000) of the Roluos area in the southeast region will be moved 1km to the north to include the Indratataka ruins. Subjective interpretations of the archaeological ruins are kept away as less as possible from the plotting.

An analytical plotter was used and digital plotting was done for planimetric features and contour lines.

The topographic map was found to be accurate when adjoined with the three sheets of the 1:10,000 topographic map of the southwest region produced by IGN in 1994.

The plotting density of single points was one point for every angle of 3cm to 4cm. Intermediate contour lines were set at an interval of 10m for the 1:10,000 map scale and 5m for the 1:5,000 map scale. Supplementary contour lines, especially for areas that are essential for the indication of the ruins, were set at intervals of 2.5m and 1.25m, respectively.

Plotting instrument: ZEISS PLANICOMP P-3

Contour intervals

1:10,000	Intermediate contour lines	10m
	Half interval contour lines	5m
	Quarter interval contour lines	2.5m
	Supplementary interval contour lines	1.25m
1:5,000	Intermediate contour lines	5m
	Half interval contour lines	2.5m
	Quarter interval contour lines	1.25m

2.2.3 Compilation

Compilation was carried out using a digital compilor and in accordance with the specified map symbols. Names of villages, roads, rivers, etc., and public facilities were annotated in English and Khmer. The annotations were checked and approved by the Cambodian government. The digital compilor used was MICROSTATION made by Intergraph (Bentley).

2.3 Survey Standards

The following ellipsoid and projection method used by the French IGN team in 1994 were adopted:

· Reference ellipsoid	GRS-80		
	Semi-major axis	a = 6,378,137m	
	Flattening ratio	f = 1/298.257222101	
· Projection method	UTM projection method		
	Zone number ·	48	
	Origin of coordinates	Latitude	Equator 0°
		Longitude	105° E
		L0 =	0.00m
		X0 =	500,000.00m
		Y0 =	0.00m
· Elevation datum	The mean sea level at MUI NAI-HA TIEN (Lat=10°20' N, Long=104°30' E) was chosen as the 0m elevation datum.		

2.4 Digital Data

This study produced 1:10,000 and 1:5,000-scale topographic maps by digital mapping. Consequently, all topographic and planimetric features represented on these maps were acquired as digital data. In the course of this study, 3 types of digital data were produced.

(1) Topographic map digital data

(2) GIS digital data

(3) Plot data for topographic map output

(1) Topographic Map Digital Data

Topographic map digital data consist of the following items which define the physical characteristics of topographic and planimetric features.

① Code classifying the physical characteristic
② Type of data (line, point, etc.)
③ Type of line
④ Thickness

⑤ Colour classification
⑥ X,Y coordinates

By the use of the classification codes, the data have been organised in layers (refer to Table 2-4).

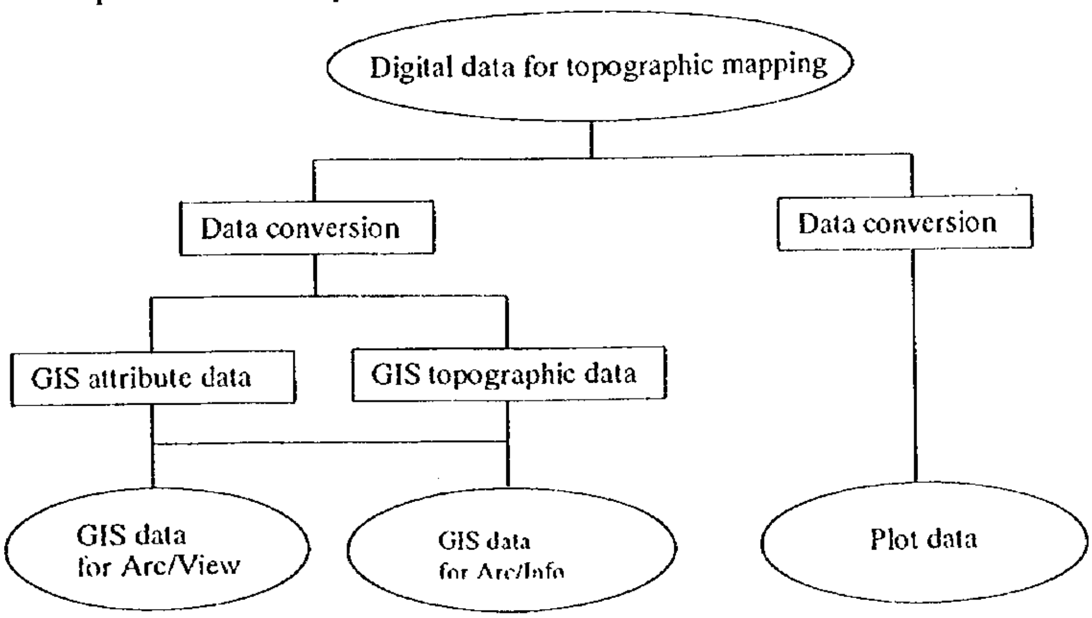
(2) GIS Digital Data

GIS (Geographic Information System) digital data consist of topographic data and attribute data. Topographic data can be obtained by converting digital data for topographic mapping using the specified method. Attribute data are information obtained from the examination of necessary attribute information. GIS digital data produced as part of this study were obtained by converting the above-mentioned digital data for topographic mapping (Arc/Info and Arc/View).

- Topographic data for GIS: Obtained by converting digital data for topographic mapping
- Attribute data for GIS: Physical characteristics of topographic and planimetric features (name), colour classification, type of line, line thickness.

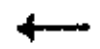
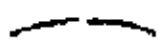
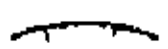
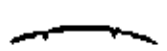
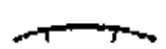
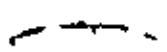
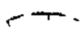
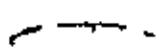
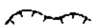
(3) Plot Data for Topographic Map Output

Plot data for topographic map output contain the pen "up-down" instructions as well as other information such as line type, line thickness and colour classification, which are necessary to print topographic or planimetric features on paper or mylar. Consequently, it is generally necessary to produce such output data from digital data. In this study, plot data were produced so that maps can be printed immediately.



	Classification (color)	Code	Feature names	Map symbols 1:5,000	Map symbols 1:10,000	Data type: Surface	Line	Circle	Arc	Point	Direction	Annotation	Hidden	Line thickness	Scale classification 1:5,000	Scale classification 1:10,000	Application	Notes
1	CONTROL POINT (BLACK)	7303	Control point (1997)	J ⊙ 12.34	J ⊙ 12.34					o				4	o	o	Value indicated up to the second decimal. Input during compilation according to control point list.	
2		7301	Control point (1994)	F △ 23.45	F ▲ 23.45					o				4	o	o	Representation of all given GPS points. Value indicated up to the second decimal. Input during compilation according to control point list.	
3		7302	Bench mark (1994)	F ⊡ 34.56	F ⊡ 34.56					o				4	o	o	Representation of all given bench marks. Value indicated up to the second decimal. Input during compilation according to control point list.	
4		7311	Spot height (level)	· 45.67	· 45.67					o				4	o	o	Input during restitution according to photographs containing pricked elevation points. Value indicated up to the second decimal.	
5		7312	Spot height (photogrammetry)	· 12.3	· 12.3					o				4	o	o	As a standard, acquisition of one point per 4~5 cm square. Value indicated up to the first decimal. Many points have been set in the archaeological area.	
6	ROAD (BLACK)	2102	Road (double line)				o							3	o	o	Roads with a width of 4m or more.	
7		2103	Road (single line)				o							6	o	o	Village streets. Streets with a shoulder width of 1.5m or more, but less than 4m.	
8		2109	Unclear road				o							3	o	o	Roads within the archaeological area with a width of 4m or more.	
9		2203	Bridge (double)				o							8	o	o	Acquired in the form of line data. The width between the lines corresponds to the width of the road.	
10		2205	Bridge (single)				o							8	o	o	Acquired in the form of line data. Corresponds to single line road symbol.	
11		2106	Trail				o							6	o	o	Roads with a width under 1.5m. Applied to mountain trails, and paths or ridges between fields and rice paddies.	
12		6101	Embankment				o							2	o	o	Also applied to fill and cut road sections, and to embankments in residential areas and around the archaeological area. Moats and embankments around the archaeological area are represented by contour lines at the scale of 1:10,000.	
13		5227	Weir				o				o			4	o	o	In this case, the river flows to the right.	
14		4219	Culvert							o				6	o		Acquired at the scale of 1:5,000. Even culverts without water are represented.	
15		5228	Water gate				o				o			4	o	o	Applied to structures used for water drainage/intake and water regulation.	

TABLE 2-4 MAP SYMBOLS

	Classification (color)	Code	Feature names	Map symbols 1:5,000	Map symbols 1:10,000	Data type: Surface	Line	Circle	Arc	Point	Direction	Annotation	Hidden	Line thickness	Scale classification 1:5,000	Scale classification 1:10,000	Application	Notes
16	WATER (BLUE)	5101	Water channel				o							3	o	o	Exact representation of bank position using a double line. Waterways with a width of at least 4m.	
17		5104	Water channel				o							3	o	o	Applied to the representation of channels and natural rivers using a wavy single line. Waterways with a width of less than 4m.	
18		5105 5109	Lake/Pond			o	o			o				3	o	o	Exact representation of bank position. Represented by the letter W for plotting.	
19		5241	Flow direction							o				4	o	o	Used to indicate main rivers. In case a field survey was not possible, survey points and contours were used to input flow direction during compilation. In case the flow direction symbol intercepted the symbol of a road adjacent to the river, the flow direction symbol has been shifted.	
20		6338	Swamp/Marsh				o							3	o	o	Applied to permanently flooded areas where grass grows. Also applied to fallow lands, especially for paddy cultivation.	
21	CONTOUR LINE (BROWN)	7101	Contour line (index)				o						o	4	25m	50m	Slope covering is not represented.	(see table below)
22		7102	Contour line (main)				o						o	2	5m	10m		
23		7103	Contour line (intermediate)				o						o	2	2.5m	5m		
24		7104	Contour line (supplementary)				o						o	2	1.25m	2.5m		
25		7109	Contour line (special supplementary)				o						o	2		1.25m		
26		7105	Depression (index)				o						o	4	25m	50m		
27		7106	Depression (main)				o						o	2	5m	10m		
28		7107	Depression (intermediate)				o						o	2	2.5m	5m		
29		7108	Depression (supplementary)				o						o	2	1.25m	2.5m		
30		7221	Cliff				o							2	o	o	Applied to both earth cliffs (steep slopes formed from soil collapse) and rocky cliffs (rocky steep slopes).	

5000	1000		
Intermediate	Supplementary		42.5
Supplementary	Special		41.25
Main	Main	40	
Supplementary	Special		38.75
Intermediate	Supplementary		37.5
Supplementary	Special		36.25
Main	Intermediate	35	
Supplementary	Special		33.75
Intermediate	Supplementary		32.5
Supplementary	Special		31.25
Main	Main	30	
Supplementary	Special		28.75
Intermediate	Supplementary		27.5
Supplementary	Special		26.25
Index	Intermediate	25	
Supplementary	Special		23.75
Intermediate	Supplementary		22.5
Supplementary	Special		21.25
Main	Main	20	
Supplementary	Special		18.75
Intermediate	Supplementary		17.5
Supplementary	Special		16.25
Main	Intermediate	15	
Supplementary	Special		13.75
Intermediate	Supplementary		12.5
Supplementary	Special		11.25
Main	Main	10	
Supplementary	Special		8.75
Intermediate	Supplementary		7.5
Supplementary	Special		6.25
Main	Intermediate	5	
Supplementary	Special		3.75
Intermediate	Supplementary		2.5
Supplementary	Special		1.25
Index	Index	0	

	Classification (color)	Code	Feature names	Map symbols 1:5,000	Map symbols 1:10,000	Data type: Surface	Line	Circle	Arc	Point	Direction	Annotation	Hidden	Line thickness	Scale classification 1:5,000	Scale classification 1:10,000	Application	Notes
31	VEGETATION (GREEN)	6301	Vegetation boundary				O							2	O	O	Applied to classify different vegetation areas.	
32		6302	Crop boundary				O							2	O	O	1:5,000: Minimum acquisition unit: 2cm square 1:10,000: Acquisition of clear boundaries of cultivated lands.	
33		6331	Forest							O				2	O	O	High forests. This area also includes other forest types.	
34		6339	Shrub							O				2	O	O	Low forests. This area also includes other forest types.	
35		6334	Waste land							O				2	O	O	Especially applied to bare land and woody grassland.	
36		6333	Bamboo							O				2	O	O	The symbols are laid out for bamboo groves and plantations. This area also includes other forest types.	
37		6313	Cultivated field							O				2	O	O	Applied to all cultivated land, such as fields and rice paddies.	
38	ARCHITECTURE (RED)	3001	House			O	O							3	O	O	Applied to all buildings, including ruins and pagodas. All structures are represented using their real shape. Buildings are delineated clockwise, whereas courtyards are delineated counterclockwise. In consideration of the density of the ruins, pagodas that are less than 1mm on the map are ignored. Concerning major pagodas, the elevation of the top of the pagoda and the elevation of its foundations are measured and delineated.	
39		3523	Temple and Monument							O				3	O	O	Applied to all temples and monuments.	
40		3524	School							O				3	O	O	Applied to all schools.	
41		6140	Wall				O							4	O	O	Applied to all walls, besides walls of ruins. The center line is acquired.	
42	ARCHITECTURE (BROWN)	5212	Revetment				O							4	O	O	Applied to concrete or masonry for the protection of the slopes of roads, river banks, lakes, etc. Also applied to structures for the protection of the slopes of ruins.	
43		6110 (top) 6199 (bottom)	Revetment			O	O							4	O	O		
44	ANNOTATION (PURPLE)		Temple Pond Village	Pr. Roluos Tr. Svay Ph. Khnan								O			O	O	Pr. (Prasat) Tr. (Trapeang) Ph. (Phum)	

2.5 Distribution of Results

1) CD-ROM

JICA agreed that the Cambodian side may make copies of the CD-ROM, and distribute them to the public, on the following conditions:

① They will be distributed to non-profit organizations contributing to the development of Cambodia's social economy and for the conservation of the Angkor archaeological area.

② The Cambodian side will take measures to prevent the illegal publication of the CD-ROM.

2) Aerial Photographs

Negatives of aerial photographs shall be kept by JICA in Tokyo until the Cambodian side prepares equipment and an appropriate storage facility. During this period, the Japanese side shall reproduce paper prints when requested by APSARA or the Geographic Survey Department through the JICA Cambodia Office under the following procedures.

① The user that requests prints of aerial photographs shall submit a copy of the order to either APSARA or the Geographic Survey Department.

② APSARA or the Geographic Survey Department shall convey the order to JICA Cambodian side.

③ All expenses including shipping and transportation shall be borne by the requestee and paid to the Infrastructure Development Institute-Japan.

The Cambodian side agreed that JICA can reproduce paper prints for research and internal use from negatives of aerial photographs.

3) Topographic Maps

Topographic maps must be made available to many people and efficiently used. Places where 1:10,000 and 1:5,000 topographic maps can be obtained must be clearly indicated.

Consequently, the following sentence was printed in the bottom left corner of the map;

"This map is available at the Geographic Dept. in Phnom Penh, and in APSARA or the International Documentation Center in Siem Reap.

2.6 Technology Transfer

2.6.1 On-the-job Training

In the course of this study, monumentation, air photo signal installation, GPS survey, leveling, photo classification and field completion were carried out in the Kingdom of Cambodia. These operations were implemented jointly with the participation of counterpart personnel from APSARA and the Geographic Survey Department, under the guidance of the Japanese Study Team. It was a good opportunity for many counterpart members to learn the renowned Japanese quality control system.

The technologies covered during the training and the participants were as follows:

① Technologies: air photo signal installation, GPS survey, leveling, photo classification and field completion.

② Participants: 4 members of the Geographic Survey Department, 1 member of APSARA.

2.6.2 Counterpart Training in Japan

Two members of the Geographic Survey Department received training in Japan as part of this study. The period and fields of training were as follows:

① Training period: March 1998.

② Training items: Actual training in GPS, digitisation and GIS at a private company (Kokusai Kogyo Co., Ltd.), visit of Geographic Survey Institute and Japan Mapping Center.

2.6.3 Workshop in Phnom Penh

A workshop was held from May 20 to 22, 1998 at the Geographic Survey Department, to promote the efficient use of the final results. In the morning of the 20th, the work jointly carried out by both countries for a combined period of over a year, in the course of this study, was confirmed using slides, and a lecture was held on the importance of the map data mentioned in Chapter 3 of this Report and on map reading examples. For 2.5 days, from the afternoon of the 20th, lectures and practice sessions were held on how to display and print data using the submitted CD-ROM, and how to compile and analyse data using Arc/Info, a GIS software. In addition to the expected members of the Geographic Survey Department, personnel from other ministries and government agencies attended the workshop. The number of participants was around 30 persons per day.

2.6.4 Workshop in Siem Reap

On June 22, 1998, JICA and APSARA jointly held a 3-hour workshop titled "Importance of Recently Produced Maps of the Angkor Archaeological Ruins", in a conference room of the Nokor Kok Thlok Hotel. The workshop was honoured by the presence of the Governor of the Province of Siem Reap. As APSARA in Siem Reap does not have the necessary equipment, the workshop did not cover CD-ROM output, or compilation/analysis of data using Arc/Info. However, an exhibition similar to the Phnom Penh exhibition mentioned hereunder was held, and map reading examples and the importance of map data covered in Chapter 3 of this Report were introduced. In addition to all the expected government agencies existing in Siem Reap, representatives of the French Institute for the Far East and other foreign research institutes were also present, and a lively debate on topographic map interpretation ensued. Many participants were impressed with the significance and high quality of the topographic map produced in this study, and a number of organisations immediately requested a copy of the map from APSARA. The activities of this study, which was carried out for a combined period of over a year, were illustrated using slides. The exhibition was attended by approximately 40 persons.

2.6.5 Map Exhibition

JICA and APSARA jointly held the "Exhibition of Newly Produced Maps for the Angkor Archaeological Area" from May 18 (1:00 to 4:00 PM) to May 19, 1998 (10:00 AM to 5:00 PM), in the Hotel Sofitel Cambodiana in Phnom Penh. The objectives of this exhibition were to divulge the completion of the "Topographic Map for Angkor Archaeological Area" and to promote the use of this map. The venue, dates and time of this exhibition were chosen to coincide with the "Fifth Plenary Session of the International Co-ordinating Committee for the Safeguarding and Development of the Historic Site of Angkor" held by UNESCO, and its preliminary meeting, held on May 18 and 19 respectively at the Sofitel Cambodiana. The following exhibits were displayed.

① Explanations on the details and objectives of the study.

② Mosaics of the 1:10,000- and 1:5,000-scaled maps and explanations of notable points.

③ Aerial photographs (including oblique aerial photos and enlarged aerial photos of Angkor Wat. A mirror stereoscope was provided to enable stereoscopic vision.)

④ Explanations of the results of this Study.

⑤ Explanations on how to obtain final products of this Study.

⑥ Presentation of examples of GIS applications using Powerpoint.

Each person attending this exhibition was awarded with a beautiful 1:50,000-scale reduced printout of the 1:10,000-scale topographic map.

A total of approximately 100 persons, e.g. government officials such as H.E. Minister Vann Molyvann and various embassy representatives including the Japanese ambassador, participated actively to an enthusiastic Question & Answer session.

This exhibition was prepared and managed with the cooperation of the Geographic Survey Department, in addition to the sponsors here-above mentioned.

2.6.6 Others

The "Fifth Plenary Session of the International Co-ordinating Committee for the Safeguarding and Development of the Historic Site of Angkor" mentioned above was presided jointly by the Japanese and French ambassadors. Because of its importance, the meeting was attended by a number VIPs, such as ambassadors and high officials of the Government of Cambodia. Prof. Yoshiaki Ishizawa, the dean of the foreign department of Sophia University, who investigated the Angkor ruins after the fall of the Khmer Rouge regime, presented his paper entitled "Investigation of the Ruins of the Angkor Region and Regional development -- Uses for the New 1:5000 Topographic Map". He confirmed the significance of the information provided by the topographic maps produced in this Study.

CHAPTER 3 INTERPRETATION OF TOPOGRAPHICAL MAPS FOR THE ANGKOR RUINS

3.1 The Significance of Topographical Maps and Aerial Photography

A large number of scientific surveys have been made since the French Institute for the Far East (Ecole Française d'Extreme-Orient) was founded exactly 100 years ago. But most of them have concentrated on researching inscriptions, carvings, and buildings. Irrigation networks, roads, and other aspects of infrastructure have received secondary treatment. This is partly because there used to be no detailed topographical map covering the entire Angkor area, but primarily because outdoor surveys have been extremely limited owing to problems of public order, especially over the last 20 years. The rise of the Angkor Empire was supported by well-developed irrigation and road networks. And the decline of the latter is agreed by many observers to have led, although indirectly, to its fall. If this is so, it should be particularly important today to learn from past experience and lessons, with a view to the immediate issue of rebuilding Cambodia's infrastructure.

The irrigation networks and roads of the Angkor Empire often remain in the form of micro-topographical features. And by analysing the overall layout and time-related changes as well as reconstructing individual aspects of infrastructure, we should be able to understand aspects such as the thinking behind planning and the awareness of problems at the time.

Today, much of the Angkor area is covered in forest or thick undergrowth, and the "prospects" necessary for outdoor surveys are exceedingly bad. It is extremely difficult to understand the micro-topography and reconstruct the infrastructure through surface investigation alone. The present survey was based on information from above ground, i.e. aerial photography. As a result, we were able to make detailed and precise records of a topography that is thought to have unknown archaeological significance, providing grounds for various theories that have since been deduced by various scientific disciplines.

The topographical maps and aerial photographs obtained in the present survey contain a very large amount of information. By carefully deciphering this information on the basis of various existing theories, we are able to develop these theories further, or produce new interpretations. In this Chapter, we shall introduce some idea of these.

3.2 The Overall Topography of the Survey Area

The survey area is part of a plain that extends over the southern foothills of the Kulen Mountains and slopes very gradually from north-northeast to south-southwest. Satellite images of the border between this plain and Lake Tonle Sap show that it describes a well-formed arc and that the contours at the height of the lake's surface are arc-shaped (Fig. 3.1). Again, if we take a detailed look at the contour lines on an existing 1:50,000-scale map, we see that the inland area is also arc-shaped (Fig. 3.2). Although the topographical and geological characteristics of this plain have not been discussed until now, these features are clearly indicative of an alluvial fan of the river Siem Reap. Below, we will call this the "Siem Reap Fan".

The present survey area lies in the middle reaches of this Siem Reap Fan, its elevation being about 30 metres in the north-northeast and 8 metres in the south-southwest. Meanwhile, Phnom Bakheng (elevation 99 metres), in the centre, and Phnom Bok (elevation 212 metres), in the eastern extremity, remain in the form of mounds.

3.3 The Fan and the Rise of the Angkor Empire

3.3.1 Fans and the Origins of Power

The fact that the foundations of the Angkor Empire were built on an alluvial fan is extremely provocative.

Fans, by nature, are landforms that are usually created when sediments are uniformly deposited on a fan-shaped slope each time a river seriously floods, its flow swinging back and forth with its fulcrum on the apex of the fan. Therefore, the land surface is fed with nutrients carried from the forests upstream. The soil is continually renewed and generally rich, avoiding the leaching characteristic of tropical zones. Also characteristic of a fan is the repeated divergence and convergence of numerous small rivers. Since these rivers are small, they can be divided or otherwise controlled even in epochs of low technological levels. The numerous points of divergence and convergence, meanwhile, mean that unified management of the entire river basin is essential. Moreover, control in upstream areas has a decisive impact on irrigation downstream. Consequently, as Koichi Takaya (*1) has also pointed out, massive accumulations of power tend to occur in fan areas. In Japan, too, organised farming originated in fan areas, whether or not its power was massive.

3.3.2 The Siem Reap Fan and the Origins of Power

Today, the rivers that flow in the Siem Reap Fan have eroded the land surface and they can no longer freely renew their course through the fan surface. In other words, the Fan has now become terraced, and this prevents the rivers from freely renewing their course. But, as we will state later, at least at the time of the Angkor Empire, and even subsequent to it, the difference in height between the riverbed and the fan surface was only 2-3 metres. Therefore, each time there was serious flooding, the river would have changed its course and the soil would have been renewed, resulting in fertile soil. And since the rivers would have been continually diverging and coming together (as one would expect from a fan), the natural conditions for massive power to grow – and thus for orderly irrigation practices to be established – are thought to have been in place.

3.4 Rivers

3.4.1 The Siem Reap River System

The Siem Reap is the largest river in the survey area. It originates in the middle of the Kulen mountains at a maximum elevation of 487 metres and flows down in a generally southwestern direction, meandering gently.

Near Phum Khlat, about 10 kilometres from the East Baray (reservoir) at an elevation of around 40 metres, the river Siem Reap, having descended from the Kulen mountains to the plains, diverges into the river Siem Reap in the narrow sense, (flowing southwards) and the Ou (means river) Phaat (flowing southwest). The name "river Siem Reap" will be used in this narrower sense from now on, unless otherwise specified. The Ou Phaat goes on the divide into the Ou Cal la on, the Ou Ta Ou, the Ou Ta Siv, the Ou Khlok, and others. The river Siem Reap stretches some 80 kilometres from its source to its estuary. The basin area is 670 square kilometres, and the average annual flow volume is 3-4 billion tons. The peak flood flow near the North Baray is 100-200 tons/second, but near Siem Reap city it is apparently only 20-30 tons/second (*2). This is the only river in the survey area that does not run dry even in the dry season.

At the convergence of this river Siem Reap and the Ou Phaat, there is a weir said to have been built by King Rajendravarman I (944-968). Many commentators think this was used to divert the river Siem Reap (in the broad sense) southwards from its previous course that flowed towards the Ou Phaat (west-southwest). But since fans are formed by an alternating motion with a fulcrum on the apex of the fan, the main course of the river Siem Reap (in the broad sense) could not always have been the present Ou Phaat. All we can say is that, at the time when Rajendravarman's weir was built, the main course of the river Siem Reap happened to be the Ou Phaat.

The nature of the river Siem Reap (in the broad sense) differs greatly between the Siem Reap in the narrow sense and downstream of the Ou Phaat. In the former, irrigation has been achieved through large-scale irrigation facilities, and there has been a notable lowering of the riverbed. These features are not so prominent in the latter.

3.4.1.1 The River Siem Reap

The river Siem Reap shifts its course southwards after flowing beyond Rajendravarman's weir. For about 4 kilometres, unlike the gentle meandering until that point, it takes a straight course characteristic of an artificial river. After this, it flows down in a generally southerly direction from an elevation of around 35 metres, while again meandering gently back and forth, characteristic of a natural river. When it arrives at the north embankment of the East Baray it changes its direction to a westerly one, and once again flows in a straight line suggesting artificial contrivance. Then, after flowing down for about 4 kilometres, from around the French Weir the river divides into one channel that flows to the west and one that flows to the south.

The west-flowing channel arrives at the West Baray via the north and west moats of Angkor Thom.

The channel that flows south from the French Weir continues a meandering course characteristic of a natural river for some 700 metres, and then becomes a straight man-made river heading due south. After flowing down for about 6.5 kilometres, it starts to lose its linearity and turns to the south-southwest, eventually arriving at its mouth on Lake Tonle Sap. If we trace the course of this less linear, south-southwesterly section back upstream and continue northeastwards from the point at which the Siem Reap changes to a due north direction, the site of an old channel can clearly be seen. The extension of this channel seems to continue past Sras Srang (the Royal Bath) and through the East Baray, rejoining the river Siem Reap at a point before it arrived at the north embankment of the East Baray. Therefore, it is highly likely that the river Siem Reap followed this course just before the construction of Angkor. As for the section that flows south-southwest from the vicinity of Angkor Wat, meanwhile, the course is unnaturally straight, though not so much as further upstream; this is probably an artificial feature from a more recent era. Although there is a "canal" (water channel) from the Angkor era that descends south-southwest from the south moat of Yasodharapura, it is possible that the course of the river Siem Reap followed this in the era directly before the construction of Angkor.

In areas upstream of Siem Reap city, the river Siem Reap cuts deeply into the Fan as it flows down. Therefore, the area along the river north of the East Baray, where the groundwater is low and water can only be drawn with difficulty, is the driest part. This is in spite of the fact that the Siem Reap is the largest river in this region. Although there are traces of agricultural field divisions, at present this area has been left as sparse woodland. On satellite images, vegetation seems to be extensive along the river Siem Reap. However, this is not because water is abundant but, conversely, because it is in short supply. But in the days of the Angkor Empire, the erosion of the river Siem Reap had not yet taken place, and the Fan was a shallow valley, as will be discussed later.

About 2 kilometres downstream from the point where the south-flowing river Siem Reap arrives at the East Baray and changes its direction westwards, there are places where the linearity of the artificial channel breaks up and it meanders northwards on a localised basis for about 200 metres. The depth of the valley in this vicinity is about 9 metres. But the site of the original artificial channel still remains as it was, terraced with a height differential of only about 3 metres compared to the Fan surface.

At a point 700 metres east of the Victory Gate at Angkor Thom, the remains of the Spean Thma bridge can be seen. At this point the Siem Reap, after flowing westwards, descends southwards linearly from a point between the northwestern edge of the East Baray and the northeastern edge of Angkor Thom. Here, as in the example mentioned earlier, only this part meandered to the east and the riverbed from the period when the bridge was built is preserved as a terraced riverbank. The depth of the valley in this area is about 7 metres, but the height of the Fan surface and that of the terrace only differ by 2.5 metres. Moreover, the bridge is a 14-span imitation arch (corbel arch) bridge built of sandstone, and sandstone blocks were interred at the position of the riverbed at the time. The difference in height between the Fan surface and the former riverbed is only about 2.5 metres (the difference with the present riverbed is 4.4-4.5 metres, showing how much the bed has sunk since the bridge was built).

3.4.1.2 The Ou Phaat

The area along the Ou Phaat is not so badly eroded as the Siem Reap, and includes extensive arable land from its upstream areas. To reflect this form of land use, it is criss-crossed by numerous crude embankments of up to 2 metres in height (functioning as canal walls). In the river Siem Reap, massive irrigation facilities are regularly distributed at points such as the East Baray, the West Baray, and the North Baray. Here, however, there are some that are functioning at the moment, others that are not, some that would probably only function in the event of serious flooding, and others that, conversely, would probably only function at times of minor effluence. These and other facilities are arranged on a non-governmental basis. They give a strong impression of having been developed by relatively small authorities. At present, the situation of water management seems to be a chaos.

A bridge thought to have been built in the Angkor era can still be seen at a point 300 metres west-northwest from the northwestern end of the West Baray. The Tao river that flows nearby has a riverbed 1.5 metres lower than the foundation platform of this bridge. This clearly shows that the bed has also fallen by 1.5 metres in the Ou Phaat.

The Ou Ta Ou flows down from northeast to southwest to the north of the West Baray, then changes to a westerly direction after meeting the north embankment of the West Baray. The extension of this Ou Ta Ou before it meets the embankment can be seen on the southwest side beyond the West Baray, suggesting that the course has not changed greatly since the Angkor era. But the fact that there is little erosion seems to show that the Ou Phaat went through a series of natural meander within a certain range and provided water and nutrients for farmland.

3.4.2 The Roluos River System

The Roluos river flows along the border between the Siem Reap Fan and a fan formed by the Ou Rung to its east. It is one of the main sources of water for Angkor. It has a source of 370 metres in the Kulen Mountains, from where it travels about 40 kilometres to its mouth in Tonle Sap. It is said to have a water collection area of 281 square kilometres and an average annual flow volume of 450 million tons (*2) at the water gauge in Kompong Thkeu (downstream of the Roluos ruins).

For the Roluos, there are no data to quantify the lowering of the riverbed. But the fan on the right bank, i.e. the Siem Reap side, is clearly terraced towards the Roluos valley plain. In upstream areas beyond an elevation of 30 metres or so, abandonment of farming and deforestation due to aridity can be discerned, as in the case of the Siem Reap.

3.4.3 Causes of Riverbed Lowering

The Siem Reap Fan has an extremely small inclination of about 1:1,000. Consequently, when riverbed lowering occurs, it has a significant impact on irrigation systems; for example, it may make it impossible to draw water. It is certain that the bed was higher at the height of the Angkor Empire. But whether the lowering of the riverbed and the decline of the Angkor Empire from the 13th century onwards are temporally related is an important question.

The lowering of the riverbed may have been caused by (1) reduced water levels in Lake Tonle Sap, (2) changes in the amount of rainfall, (3) changes in flow volume due to changes in the catchment area, (4) shortcuts in the flow course.

If we assume (1), reduced water levels in Lake Tonle Sap, to be the cause, a similar lowering of riverbeds would be seen in all the rivers, or to the same extent in downstream areas as upstream (or more so) for any one river. But this is not the case.

As for (2), changes in the amount of rainfall, it is known that between the 4th and 12th centuries temperatures rose and rainfall increased in many parts of the world. Hideo Suzuki (*3) suggests a connection between this and the rise and fall of the Angkor Empire. At the same time, however, he also introduces the notion that the 12th century on the Indochina peninsula was a time of extreme aridity, quoting H.H. Lamb's "Climate History and the Modern World", London and New York, 1982. A number of Angkor researchers share the view that flow volumes in rivers were greater in the days of the Angkor Empire than they are today. But this is not enough to explain certain phenomena; for example, the fact that the lowering of the riverbed in the Siem Reap was far greater than that in the Ou Phaat.

If (3) were true, the flow volume in the Siem Reap would increase as a result of Rajendravarman's weir while that of the Ou Phaat, conversely, would decrease. But in both cases the riverbed has lowered.

Even given the three phenomena in (1), (2), and (3) above, it would still be hard to judge whether riverbed lowering would occur as seen in this site. But if there had been a shortcut in the flow course as suggested in (4), this would cause the riverbed to sink.

The course of the Siem Reap has been greatly modified through irrigation works since the days of the Angkor Empire. Its course through the alluvial fan originally featured a succession of gentle bends, but was changed to a straight course through modification works. Let us assume that the course of the Siem Reap, meandering back and foith before reaching the North Baray, was modified to a straight one. If we now measure the change in length using 1:50,000 scale topographical maps, we find that it would be 0.63 times the original length. Minor bends in the course are abbreviated on 1:50,000 topographical maps, owing to limitations on the amount of detail. So the actual rate of contraction would have been even greater. There must undoubtedly have been shortcuts like this on the Ou Phaat and other rivers in the Siem Reap river system, and indeed on the Roluos, although to a different extent.

From the East Baray the Siem Reap descends westwards in a straight line, then enters the West Baray after filling the moat at Angkor Thom. On its way, the River Siem Reap diverges off to the south near the present-day French weir. As this is closer to the direction of maximum inclination of the Fan, this diversion can only be a shortcut, and is bound to have caused a considerable lowering of the riverbed. The degree of riverbed lowering is at its greatest between near the beginning of the western diversion at the East Baray and near the end of the southern diversion at Angkor Wat after the divergence. This is consistent with the above argument. There is a theory that this divergence does not date from the construction of Angkor Thom but from the 16^{th} century. If so, a major lowering of the riverbed has also taken place since then.

3.5 The Development of the Angkor Irrigation System

3.5.1 The East Baray

The East Baray consists of 1850 metres of embankment from north to south and 7210 metres from east to west. The embankments are between 4 and 7 metres high. In the days of the Angkor Empire, the Baray apparently lost its functions and the reason why is told to be sedimentation. But in fact, rather than the bed of the Baray being higher than the surrounding area, near the north embankment there are several spots where the Baray bed is 1-1.5 metres lower.

In the centre of the west embankment of the East Baray, a platform-type elevation (180 metres north-south, 250 metres east-west) with a height of 5 metres can be discerned jutting out westwards. This corresponds to an extension of the east-west road that leads to the Victory Gate from Phimeanakas, and hints that the platform is of historical significance.

Meanwhile, about 400 metres inside the East Baray, i.e. to the north of the south embankment, there is a conspicuous elevation that is 0.5 to 1 metre higher than its surroundings and extends from east to west in a straight line. From its relationship with the north moat of Yasodharapura, as will be discussed below, this is thought to be the original south embankment when the East Baray was first constructed. The embankment is thought to have been later shifted southwards to its present position as a way of increasing water storage capacity. We will call these two the primary East Baray and the secondary East Baray, respectively.

In the northeastern section of the East Baray, plantation fields have been arranged in chequered formation, while in the northeastern extremity there is a square pond that would have served as a water supply for them. This work is said to date from the Pol Pot era.

3.5.2 The West Baray

The West Baray was allegedly built by King Udayadityavarman, who reigned from 1051. The land on which it was constructed inclines gently to the southwest. The elevation on the northeast is around 20 metres and that on the southwest about 12 metres, giving a differential of 8 metres. Here an embankment measuring 7,950 metres fróm east to west and 2,110-2,145 metres from north to south was constructed. The height of the embankment is 16 metres on the southwest side and 7-8 metres on the northeast, showing a difference of 8-9 metres.

On the slopes of the south embankment of the West Baray, the remains of Ak Yom temple are buried at a point 2300m from the western edge of the Baray. Since it was the oldest temple in the Angkor area, a position due west of Phnom Bakheng was probably chosen for the construction of Ak Yom. The straight road that probably linked them together is thought likely to have become the south embankment of the West Baray. But if the Ak Yom site that remains today was the centre of the temple, the direction of the Ak Yom temple from Phnom Bakheng lies slightly clockwise of due west. South embankment east of Ak Yom temple may have shifted northwards from the Ak Yom – Phnom Bakheng line. This may indicate a correction to a true east-west direction.

The north embankment appears to have been constructed on a line extending from the north embankment of the north moat of Yasodharapura.

The ground level inside the embankment is no higher than the exterior, and no particularly marked sedimentation can be discerned.

Jacques Dumarcay (*4) says that, in later times, the Baray had an artificial channel that poured water from the top of the embankment, as shown in Fig. 3.3 (b), and that the remains of it can be seen in the West Baray. If such an artificial channel did exist, it would have been higher or more massive than all the other structures. In fact, nothing of the sort can be found.

3.5.3 The North Baray

The North Baray is said to have been built by Jayavarman VII in 1181, when he re-conquered Angkor and became king. It measures 3,600 m east to west and 950 m north to south; its embankments are around 4-5 m in height. It is smaller than the east and West Baray. The distances between the north embankment of the North Baray and the north and south embankments of the primary East Baray are identical at about 1,350 m. This can hardly be a coincidence. It is highly likely that these two Baray originated from the east-west roads that were originally constructed at equal intervals. In all probability, the bottom of the water channel on the north side of the East Baray had already started sinking at the time when the North Baray was constructed. To avoid discharge from this channel, the south embankment of the latter had to be built to the north of this in order to construct a Baray between the roads. Perhaps this is why the distance between the southern and northern embankments of the two Baray is only about 950 metres.

The bottom of the Baray is lower than the surrounding ground in several places, but, like the East and West Baray, no major sedimentation can be discerned.

3.5.4 The Outer Moat at Yasodharapura

Yasodharapura was built on the natural hill of Phnom Bakheng by King Yasovarman I, between the end of the 9th century and the beginning of the 10th. The outer moat that was constructed at the time is as often shown in the literature. But this is the first time that the detail topography of the embankments and other supporting evidence has been shown on a topographical map. Of the moats, those that still clearly retain their original topography today are the southern one and the southern half of the western one. While the land outside the south moat is at an elevation of 18-19 metres, the bottom of the moat is 16-17 metres, showing about 2 metres of excavation. The embankments on either side of the moat have a maximum height of around 23 metres, with about 5 metres of mounding. A canal leads off to the south-southwest from the centre. As for the west moat, the amount of mounding is about the same as in the south moat, but hardly any excavation can be discerned. The fact that this has only occurred in the south moat may be because it was made level with the bottom of the lower canal. Or it may have been in order to drain off the large volumes of ground water that must have appeared when the moat of Angkor Wat was excavated in later years, through a conduit channel that was probably on the southwest extremity of the Angkor Wat moat.

The northern half of the west moat has been merged with the West Baray, and no traces of it can be found on the bottom of the latter.

Traces of the western edge of the north moat ought to remain, since it was neither on the site of the West Baray nor on that of Angkor Thom. It would have been most logical for the south embankment of this north moat to be used by the conduit channel leading to the West Baray, to be discussed later. This means we can regard the embankment adjoining the existing conduit to its south as the south embankment of the north moat. An embankment that could be the north embankment runs from west to east. But while the width of the south and west moats is about 200 metres, this one is nearly 300 metres wide, which would appear illogical. However, since nothing else resembling them can be discerned, I shall here assume these to have been the embankments on either side of the north moat.

The south embankment of the north moat appears to be on a line extending from the south embankment of the primary East Baray. The north embankment, meanwhile, is in line with the north embankment of the West Baray. Again, it is obvious that the passage of water to the West Baray was via the north moat. This is because the east embankment of the west moat was used as the east embankment of the West Baray and the west embankment of the west moat was removed during construction work on the West Baray site (Fig. 3.4).

If the moats around Yasodharapura were constructed symmetrically with Phnom Bakheng at their centre, the east moat would lie about 100 metres east of the east moat of Angkor Thom, constructed later. But no topography suggestive of this can be discerned. Even if the topography of the time were still extant today, this could only be the elevation that extends northwards from the eastern edge of the south moat. This connects with the eastern embankment of the east moat of Angkor Wat. It lies about 200 metres adrift of the position it would occupy if strict symmetry were maintained.

As we have seen up to now, the remains of the south and west moats are clearly visible, while those of the north and east moats are not (even accounting for the fact that they have been merged with subsequent structures). The visibility of the south and west moats is thought to be because they lie at the point of lowest elevation at Yasodharapura, the height of the embankments thus being pronounced. But with the north and east moats, the ground elevation is high, so the embankments were low or excavated.

The outer moats at Yasodharapura are about 200 metres wide. This is far wider than the later ones at Angkor Thom (75 metres) or the Siem Reap today (40 metres). Massive volumes of water must have been needed to fill these. If we assume that they depended on river water, the flow volume of the Siem Reap at the time must have been considerably greater than it is today. On the other hand, it is possible that the groundwater was not so deep in those days and that this was largely relied upon. The moats of Angkor Wat, still thought to be fed by groundwater today, have the same width of 200 metres, while Sras Srang is twice as wide, at 400 metres. Could this be mere coincidence?

3.5.5 The Inner Moat at Yasodharapura

There are records in existing literature (*5) that a square inner moat surrounding Phnom Bakheng used to exist within the outer moat.

The moat directly to the north of Phnom Bakheng is now part of the south moat of Angkor Thom. The remains of an embankment showing that the moat extended westwards can be clearly seen. After the construction of the West Baray, this moat could conceivably have been constructed to lead water to the outer moat. But the water level in the West Baray is lower than that of Angkor Thom, showing that it could not be fed from the former. Also, since the ground level of the conjectured moat extension is slightly higher than Angkor Thom, it would be hard to see how water was led in from the latter.

The moat to the south of Phnom Bakheng is only clear on the lower slopes of the hill. Although its east-west extension cannot be traced by topographical means, on 1:20,000 aerial photographs a dark belt indicative of high soil moisture appears to extend to the outer moat. If we may hypothesise northern and southern moats for Phnom Bakheng in this way, we can see why it was decided to position the outer moat here during the subsequent construction of Angkor Thom. Moreover, this would also mean that symmetry was maintained in the earlier construction of Yasodharapura.

In the area sandwiched between the northern and southern moats of Phnom Bakheng, the topography clearly indicates artificial contrivance (e.g. ponds, mounds, etc.). This topography has an obvious linear symmetry on the axis of a line passing from east to west, with Phnom Bakheng at its centre. This suggests that the area was of special historic significance, as well as supporting the existence of northern and southern moats.

If the outer moat was divided into three sections by two inner moats, the moat could be kept permanently filled with water by aligning moats of different elevations from north to south in the fashion of terraced fields. However, this terraced arrangement cannot be proved through the topography of the bottom of the west moat as it now remains.

The remains of another moat can be discerned running from north to south, to the east of the approach road leading from Angkor Wat to Angkor Thom. A north-south depression can also be discerned to the west of Phnom Bakheng. Although it is not clear how far these extended, it is possible that they crossed Yasodharapura from top to bottom. This is supported by the micro-topography inside Angkor Thom, as well as mention of the existence of water channels criss-crossing Angkor Thom in reports by 16th-century Portuguese travellers (*5).

3.5.6 The Outer Moat of Angkor Thom

Angkor Thom is said to have been built by King Jayavarman VII. The south embankment of its north moat was arranged on a line extending from the north embankment of the East Baray. This was done deliberately so that the outer moat of Angkor Thom could receive water from the north embankment ("wall") of the East Baray, while the outer moat of Yasodharapura received its supply from the south embankment of the primary East Baray. The south moat, as stated above, is thought to have used the east-west inner moat to the north of Phnom Bakheng in Yasodharapura. Although the Bayon temple is situated in the centre of Angkor Thom, it is originally thought to have been on the south embankment of Yasodharapura's north moat.

The dimensions of the outer moat are as follows.

Inside: north – 3,080 metres, south – 3,030 metres, west – 3,035 metres, east – 3,030 metres.
Outside: north – 3,280 metres, south – 3,260 metres, west – 3,260 metres, east – 3,230 metres.

Although the moat was supplemented by water from the Seam Reap, it probably relied largely on groundwater, then at a higher level than it is today (as in Angkor Wat and Sras Srang).

3.5.7 The Relationship Between the East Baray and Yasodharapura

When Yasovarman I built Yasodharapura, the position of the north moat was first decided, then the road on the south of that moat was extended eastwards. Using this road, the East Baray was then constructed with this as its southern embankment. At this time, the northern embankment of the East Baray was by no means continuous, and the Seam Reap is thought to have flowed in from the north through these gaps. The water that was thus stored in the East Baray then filled the moat at Yasodharapura. Later, when Angkor Thom was built and water came to supplied from the north side of the East Baray's north embankment, the south embankment of the East Baray is thought to have been moved further south to increase its water storage capacity.

3.5 The Principle of the Baray System

A major characteristic of the irrigation system in this region is its dependence on massive reservoirs called "Baray". These Baray are all rectangular, with their longitudinal axis in the east-west direction. This means that they run diagonal to the contour lines (with the exception of Indratataaka). At first sight, their rectangular shape and obliqueness to contour lines would appear illogical. That is, taking the case of the West Baray, its long axis is 7.9 kilometres long and its short axis 2.2 kilometres, with a total of 20.2 kilometres of embankments. If this had been built square while maintaining the same water storage area, the embankments would extend for 16.7 kilometres, bringing the amount of construction work down to 83%. And if it were round, they would be 14.8 kilometres long and the work volume would be reduced to 73%. It is also thought that if the long axis of the Baray ran parallel to contour lines, their water storage efficiency would improve.

Jacques Dumarcay (*4) claims that, while the earlier Baray took water from natural rivers as in Fig. 3.3 (a), subsequently they were all built with an artificial channel above the embankment, as in (b), from which water was poured in. If such an artificial channel did exist, it would have been more massive than all the other structures, and its remains would be clearly visible in each Baray. In fact, nothing of the sort can be found.

To use water efficiently in areas that have a gentle gradient in a single direction, the water has to flow at the minimum inclination required for the flow to continue, rather than in the direction of the greatest inclination. The water reservoir time is prolonged by making the course as long as possible, and this also helps to maintain the head.

When constructing the city of Angkor, many parallel roads were built running north to south and east to west, with Phnom Bakheng as their central coordinate. These roads were made of mounded earth, and thus also formed embankments. Dwellings are also thought to have existed alongside the roads. Of these roads, those that ran in an east-west direction led water to the southwest as it flowed down from the northeast, and also served to store this water, in combination with the north-south roads. Since these L-shaped Baray used two embankments (roads) to store water, their water storage volume could be increased by lengthening the embankments or raising their height. When the water storage capacity is increased in this way, a C-shaped three-sided reservoir can be produced by adding a third road (embankment) on the north side. If then a further embankment is added on the east side, and the northeastern corner is cut open and then closed off after the maximum volume of water has been collected during floods, more water can be stored. Though lacking conclusive evidence, this would provide a logical explanation to all the issues, including the apparently illogical shape and orientation of the Baray, the flexibility of the construction plans, the ease of the work, and the construction of terraced Baray.

Reference bibliography

1) Koichi Takaya, "A proposed classification of paddy fields in terms of appearance", in Chusei_Watanabe ed. "The World of Southeast Asia", 1980, pp. 307-337, Sobunsha

2) Hideo Suzuki, "Linguistic change caused by climatic change", NHK Books, 1990

3) Ferenc Garami, Dr. Istvan Kertai, "Water Management in the Angkor Area", 1993, Budapest

4) Jacques Dumarcay, Historical evolution of the Khmer-style water reservoir, materials distributed at the 5th Report Meeting of the Angkor Site International Survey Team, "Scientific study of the Angkor ruins", hosted by the Sophia University Angkor Site International Survey Team, 1997.

5) Bernard P. Gloslier, "ANGKOR ET LE CAMBODGE AU XVIe SIECLE", 1958, Presses Universitaires de France, translated into Japanese by Yoshiaki Ishizawa and Etsuko Nakajima, 1997, Rengo Shuppan

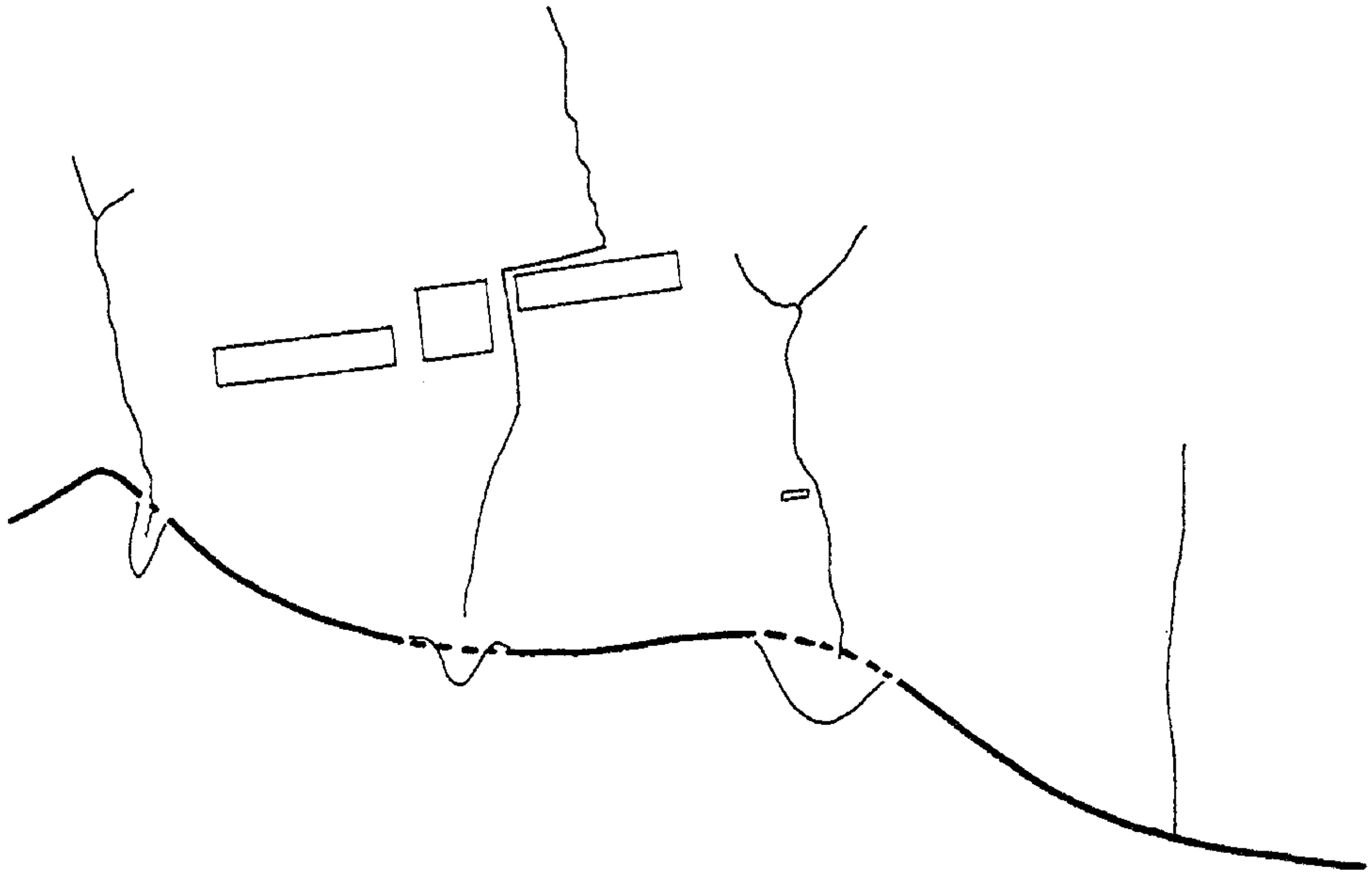


Fig. 3.1 The Arc-Shaped Shoreline of Lake Tonle Sap

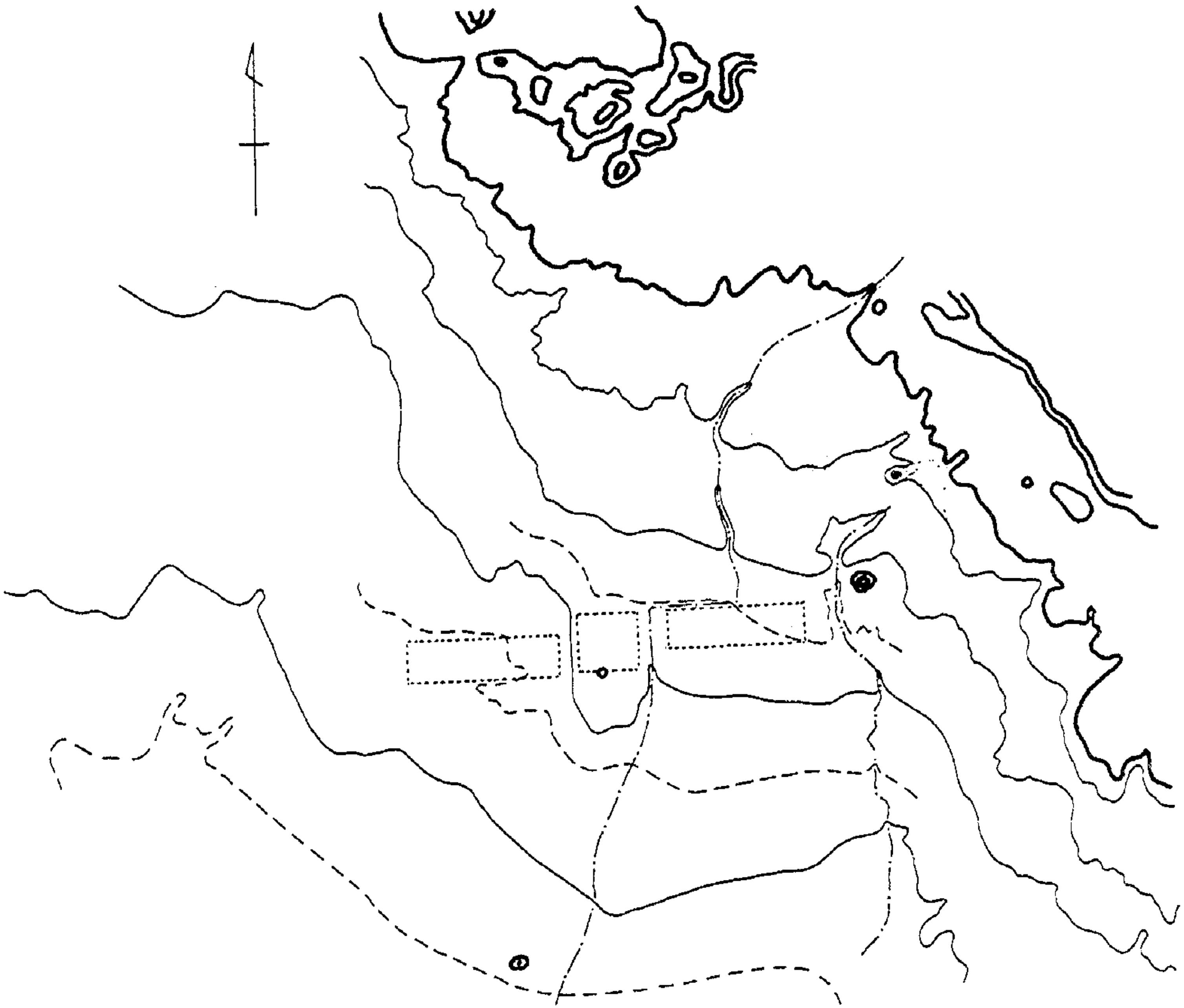


Fig. 3.2 Contour Lines Showing the Siem Reap Alluvial Fan
Solid Lines: 10m, Broken Lines: 5m, Thick Lines: 50m

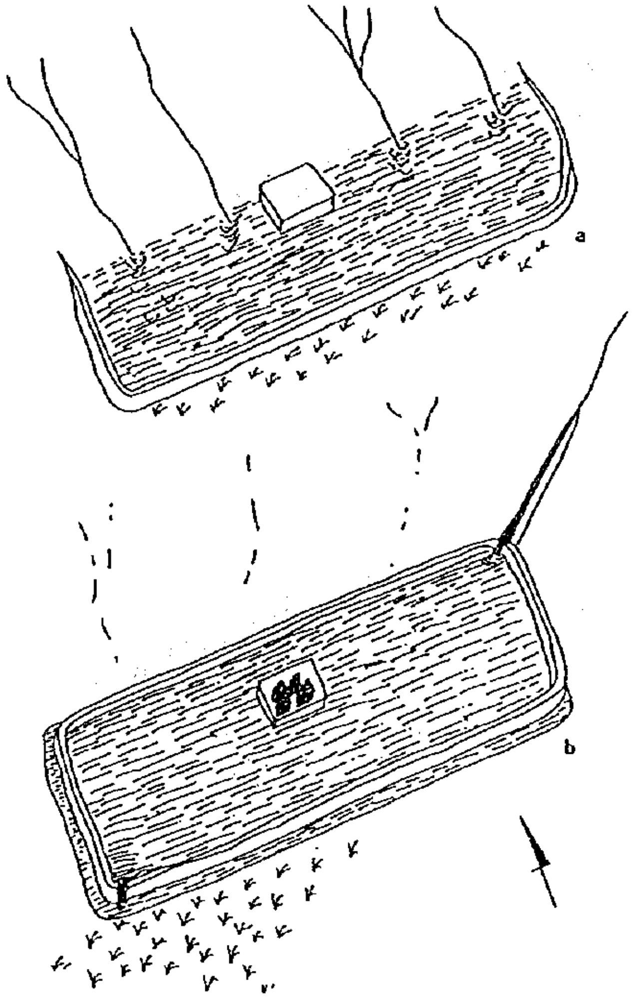


Fig. 3.3 The Consequence of Baray Type: a) Older Type, b) Newer Type (after Jacques Dumarcay)

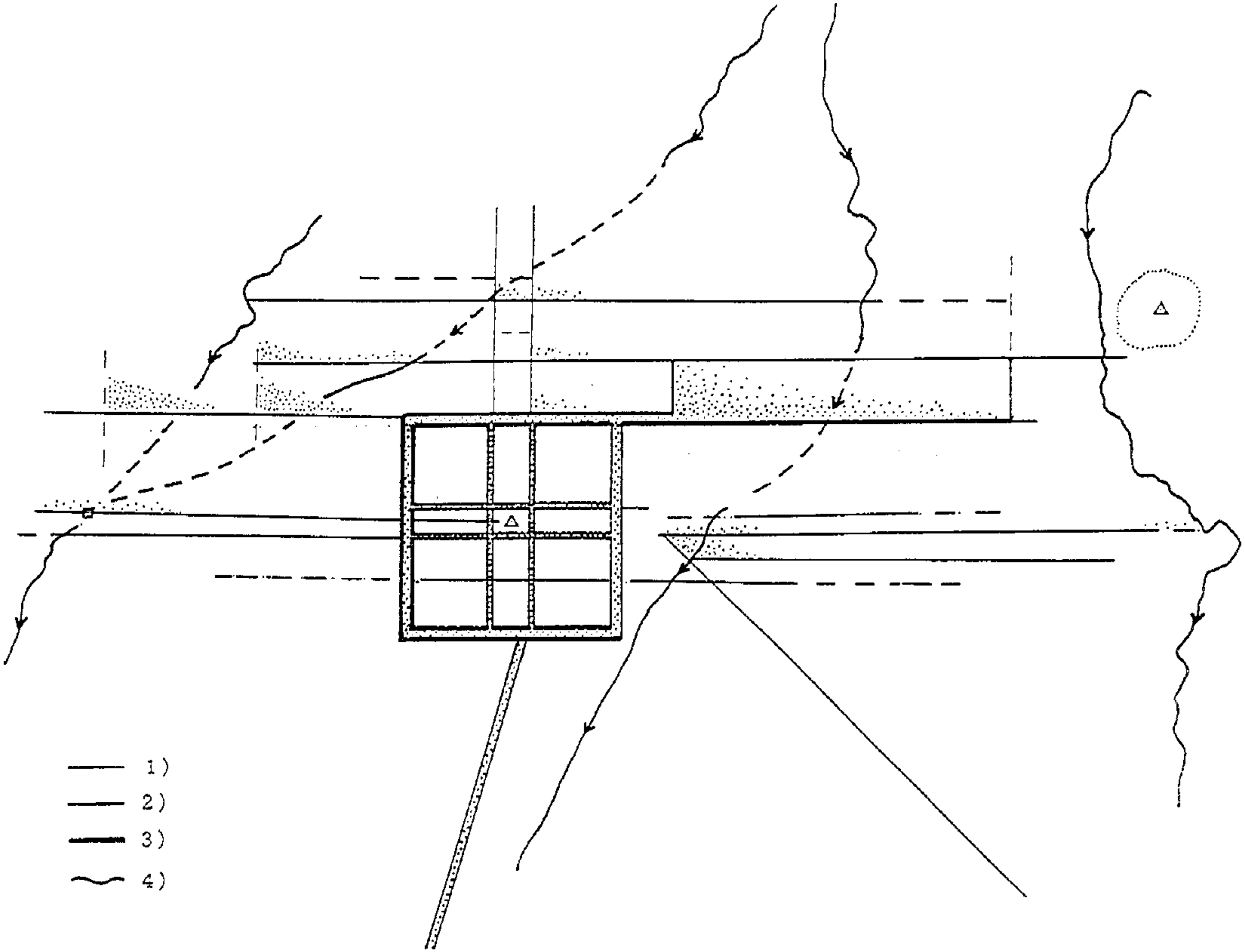


Fig. 3.4a 1[st] Stage of Angkor Area: 1) Low Embankment, 2) Medium Embankment, 3) High Embankment, 4) River Channel

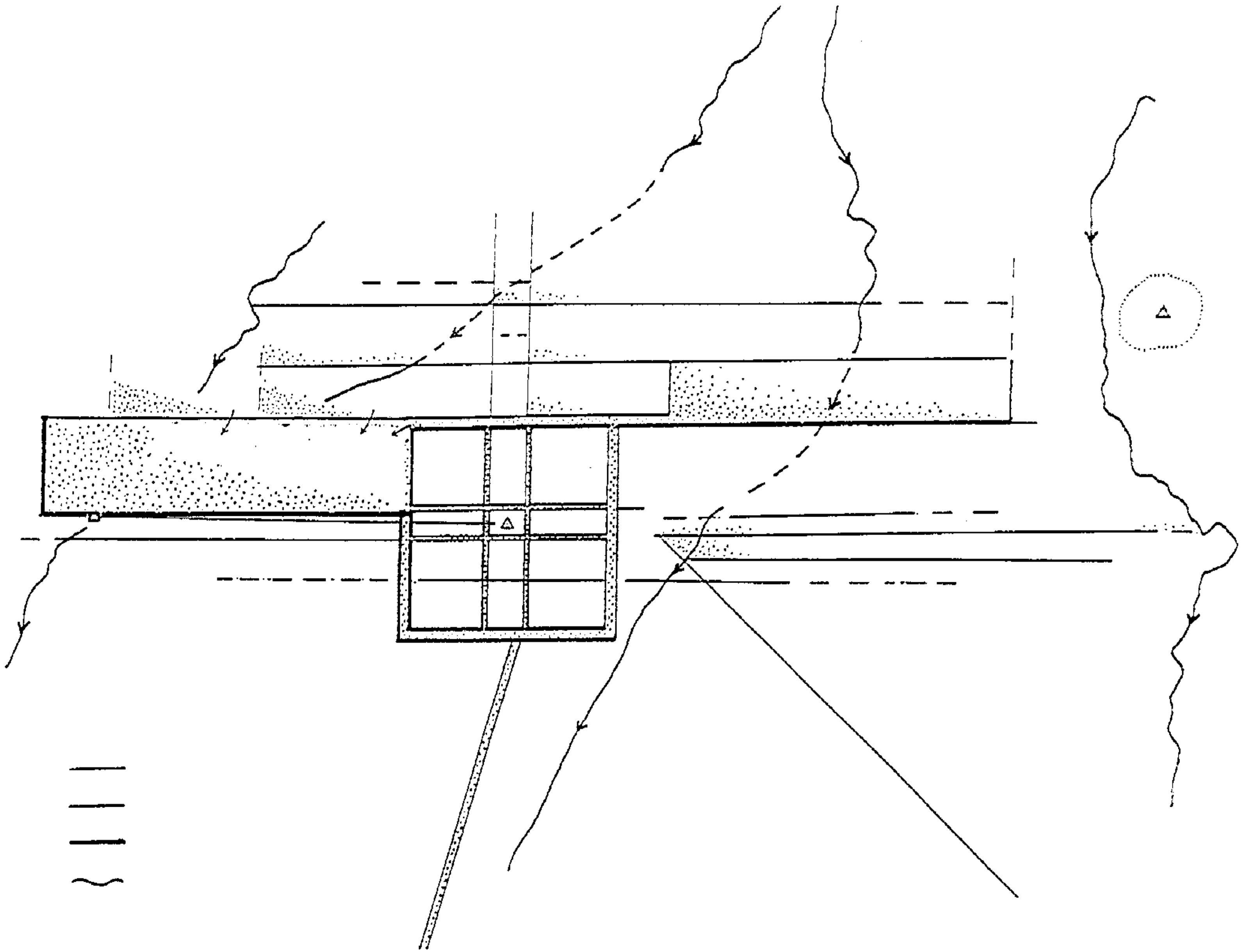


Fig. 3.4b 2nd Stage of Angkor Area

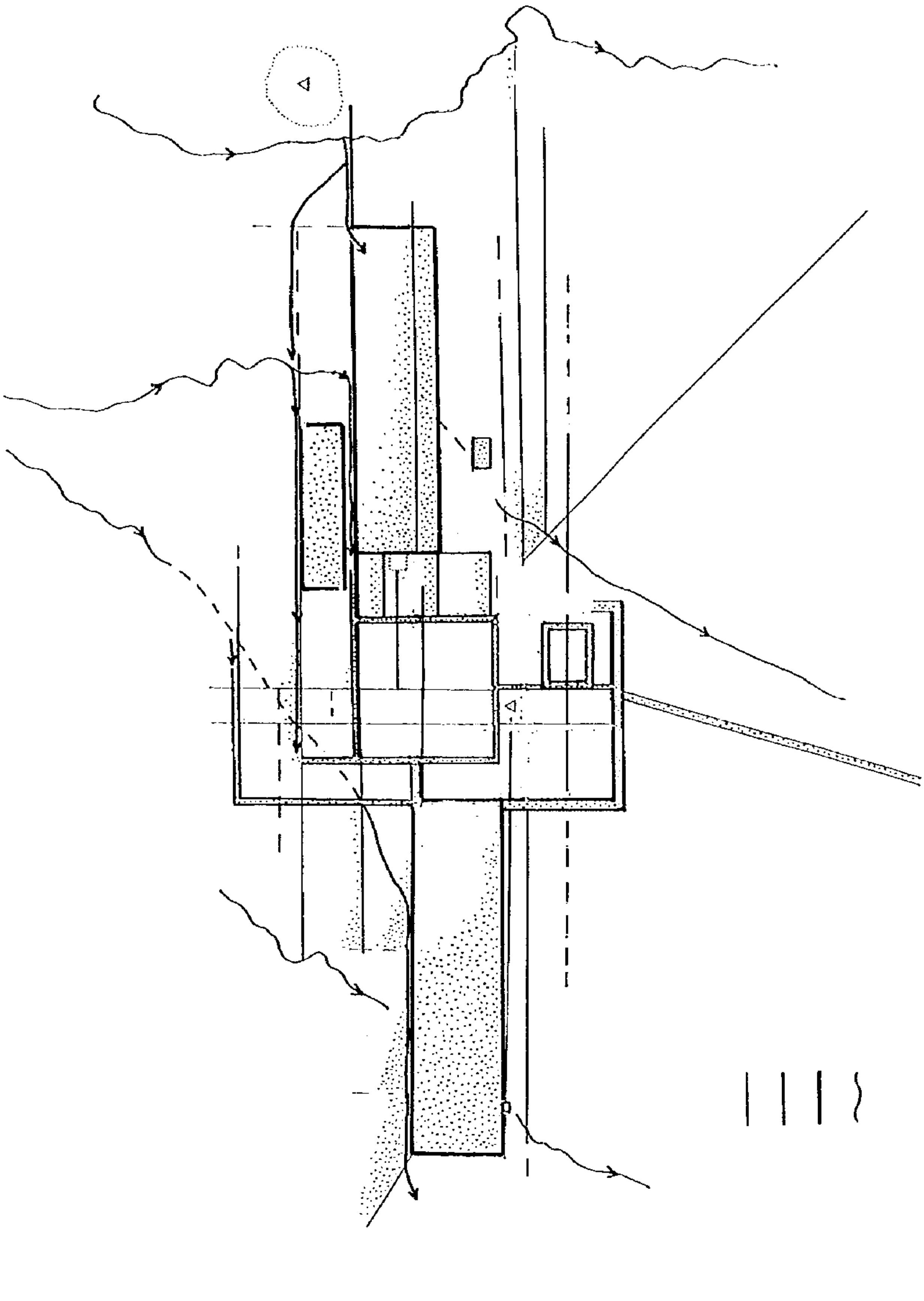


Fig. 3.4c 3rd Stage of Angkor Area