No. 52

THE GOVERNMENT OF PAPUA NEW GUINEA

THE DETAILED DESIGN
ON
ROAD CONSTRUCTION PROJECT
IN
BEREINA-MALALAUA

FINAL REPORT

JANUARY 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of Papua New Guinea, the Japanese Government decided to conduct the Detailed Design on Road Construction Project in Bereina-Malalaua (the Study) and entrusted the Study to Japan International Cooperation Agency (JICA).

JICA sent to Papua New Guinea a study team headed by Mr. Teruo Yoshimatsu, Nippon Koei Co., Ltd comprising members from Nippon Koei Co., Ltd, Katahira & Engineers Inc., and Pasco International Inc. several times from October 1987 to November 1989.

The team held discussions with officials concerned of the Government of Papua New Guinea and conducted field surveys. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the Project and to enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Papua New Guinea for their close cooperation extended to the team.

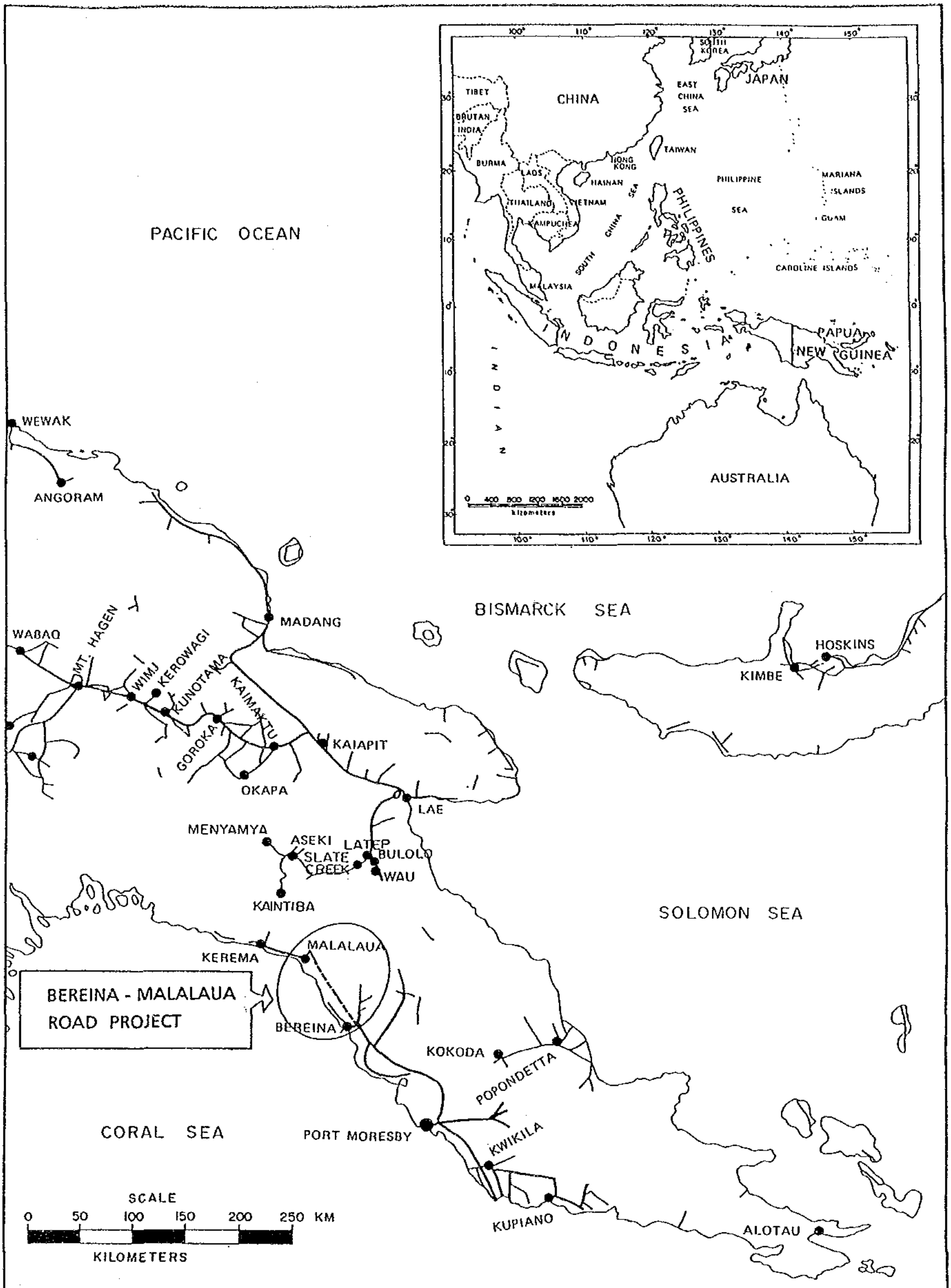
January, 1990

Kensuke Yanagiya

KENSUKE YANAGIYA

President

Japan International Cooperation Agency



PROJECT LOCATION MAP

Flood Level Survey Preparation

Meeting at DOFP
on 2 Nov. 1987

Observation work by G.P.S.
at station JP-07
Ilavala Hill.

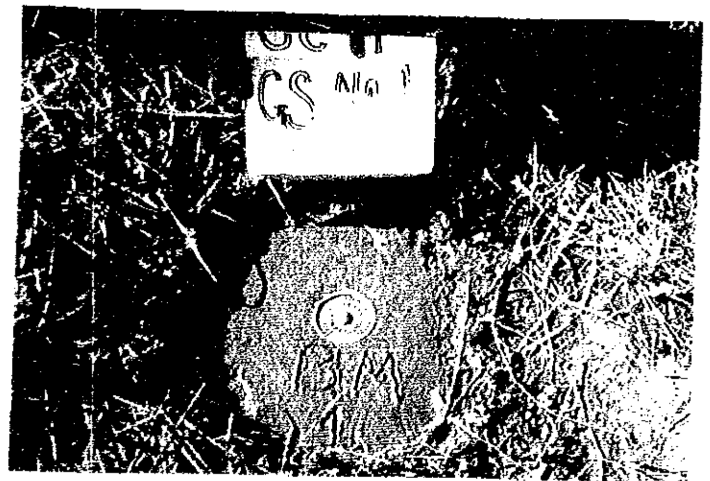
Road Centerline Inspection

Auxiliary point
near Malalaua

Installation of Concrete Monument
of GPS Point

Joint Inspection on the Water Level Gauge
at Miaru

Tidal observation
at sea side
of Iokea



Concrete bench
mark for
leveling


Bridge Centerline Inspection at Makara


Meeting with DOW IN June 1988


Bridge Centerline Inspection at Taiena

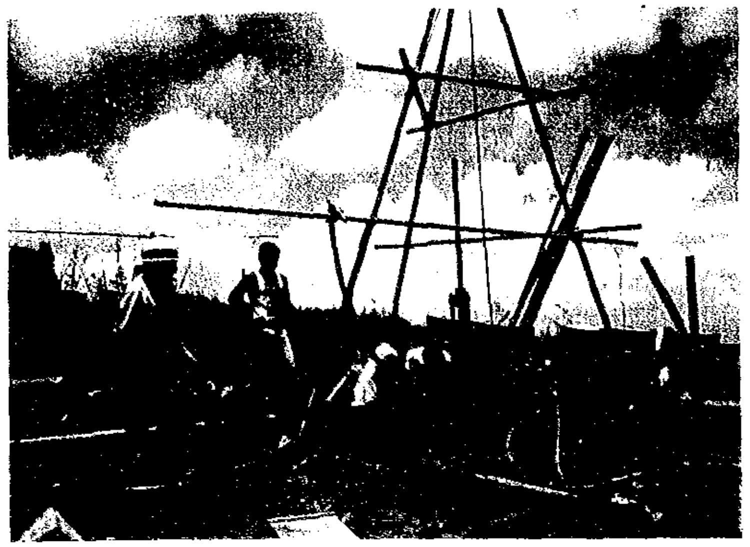

Cone Penetrometer Survey in Palipala-Kapuri


River Cross Section Survey at Miaru


River Water Depth Survey
at Devola Creek

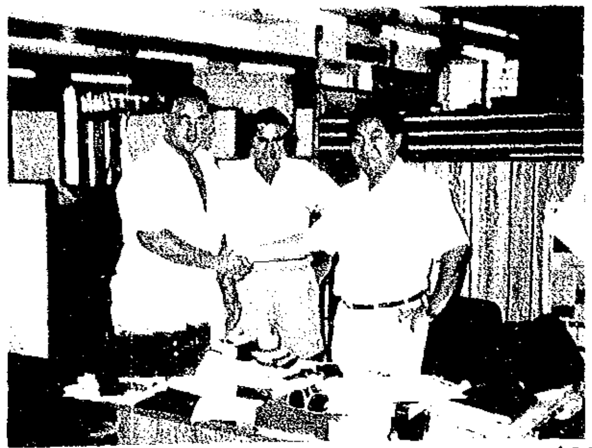

Access Road Survey near Iokea

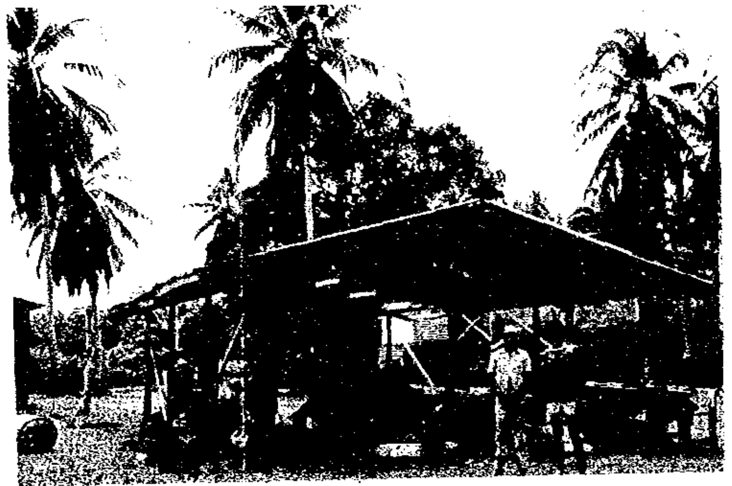

River Water Depth Survey

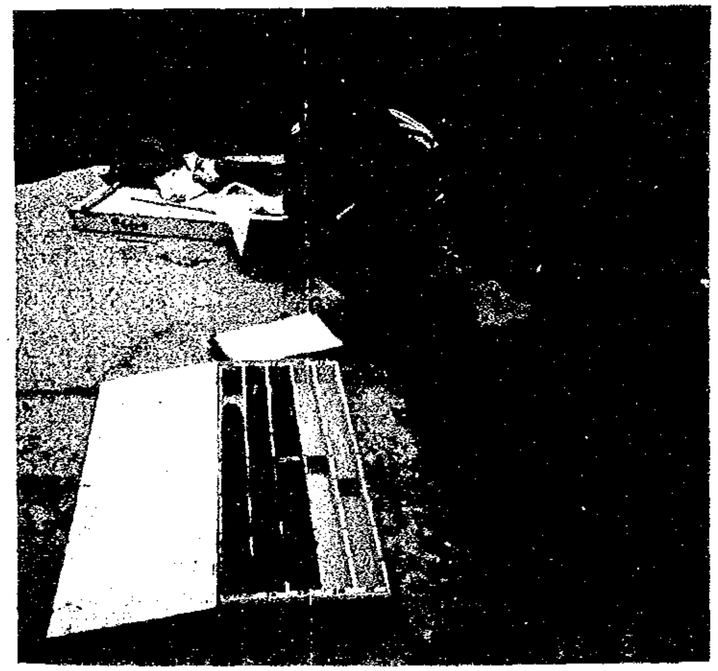

Boring Work at Palipala Hill


Boring Wort at Eboa Quarry


Access Road Survey to Eboa Quarry


Final Payment to New Guinea Water Drillers
based on judgement of DOW

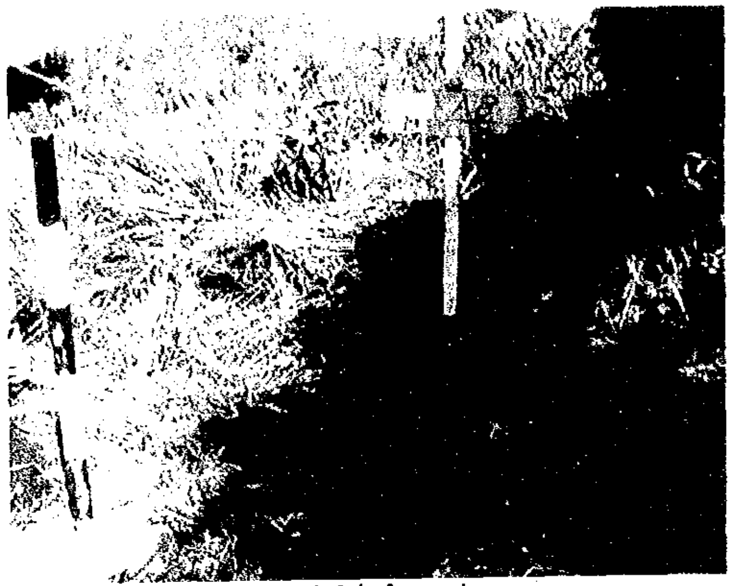

Boring Team Camp at Terapo


Sampling by Raymond Sampler


Movement of Boring Equipment
by Helicopter


Boring at Miaru


Boring works in Alika Swamp


Establishment
of control point


Hand over of Survey Point at Taiena


Joint Inspection on Mapped Area


Clearing for Leveling Survey


Road Centerline Survey


Clearing for Traverse Survey


Babanongo Quarry Survey


Angabanga Quarry Survey

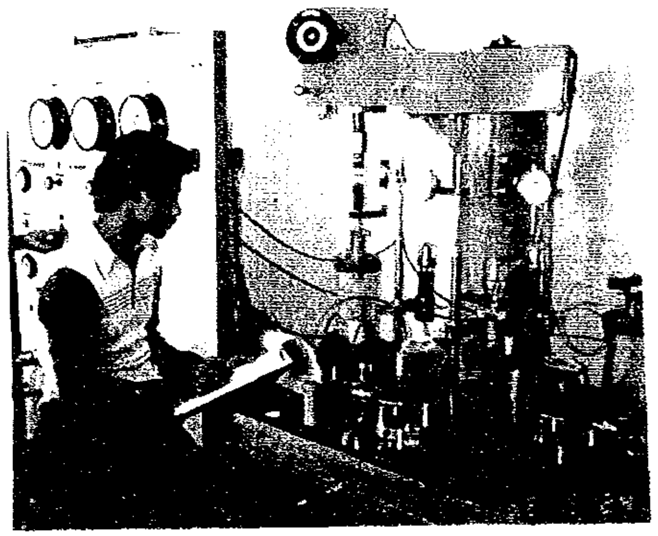

Center line Peg at Lakekamu

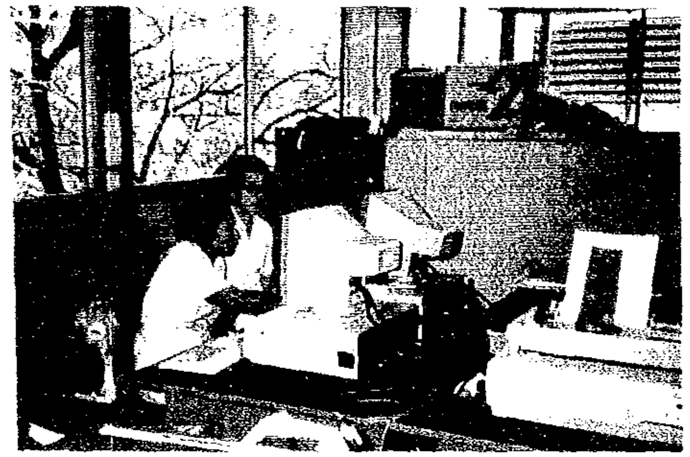
Karama
river
Quarry

Test Pit Survey at Malalaua Quarry

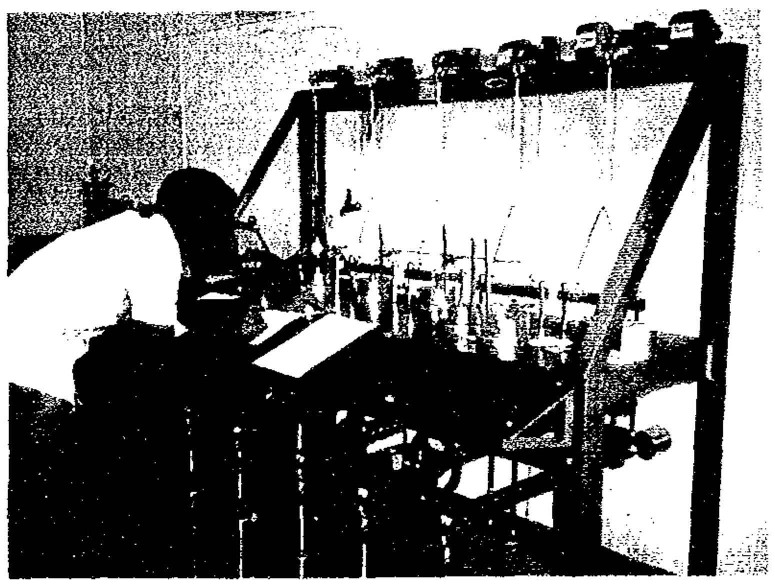
Road Derign by CAD System

Triaxial
compression
test





Finalization of document preparation



Consolidation Test

Escort and Explanation on Survey
to Village People at Koaru

Meeting with DOW upon the Submission
of Draft Final Report
October 31, 1989

5

TABLE OF CONTENTS

CONTENTS OF THE FIGURES

Pages

CONTENTS OF THE FIGURES

Pages

CONTENTS OF THE FIGURES Pages

CONTENTS OF THE FIGURES Pages

CONTENTS OF THE TABLES

Pages

CONTENTS OF THE TABLES

Pages

ABBREVIATION

PNG	Independent state of Papua New Guinea Government
JICA	Japan International Cooperation Agency
OECF	Overseas Economic Cooperation Fund
DOW	Department of Works (PNG)
DOT	Department of Transport (PNG)
DOFP	Department of Finance and Planning (PNG)
OIDA	Office of International Development Assistance (DOFP)
H Beam	Universal Beam
GPS	Global Positioning System
UTM	Universal Transverse Mercator System
EDM	Electric-optical Distance Meter
CAM	Computer Aided Manufacturing
N value	Same with SPT value
K value	Coefficient on the lateral resistance of subsoils
LL	Liquid Limit
PI	Plasticity Index
CBR	California Bearing Ratio
CA	Catchment Area
HWL	High Water Level
FWL	Flood Water Level
CSP	Corrugated Steel Pipe
Q100	100 year flood volume
Q50	50 year flood volume
LWL	Low Water Level
D50	Grain size at 50% passing in sieve analysis
RC	Reinforced Concrete
NAASRA	National Association of Australian Road Authorities
BS	British Standards
ASSHTO	American Association of State Highway and Transportation

ADT	Average Daily Traffic
TRRL	Transport and Road Research Laboratory
AS	Australian Standards
AMC	Asphalt Medium Curing

UNITS

cm	Centimeter
m	Meter
m^2	Square meter
m^3	Cubic Meter
mm	Millimeter
km	Kilometer
km^2	Square Kilometer
ft	Feet
m/s	Meter per second
m^3/s	Cubic meter per second
Vol	Volume
l/m^2	Liters per square meter
%	Percent
C°	Centigrade
Min.	Minute
Nos.	Number
D. or dia.	Diameter
HP	Horse power
kw	Kilowatt
MPa	Mega pascal
KPa	Kilo pascal
kgf/cm^2	0.0980665 MPa
(metric) ton f	1,000 Kgf
(gross) tonne	1,016 Kgf
(short) ton	907.2 Kgf

CHAPTER I INTRODUCTION

1. THE STUDY

1.1 Introduction

The project described in this report is for construction of a road from Bereina to Malalaua, approximately 80 km, part of the 575 km Trans-Island Highway linking Port Moresby, the Capital of Papua New Giuinea (PNG), to Lae, the second largest city of the country.

The Trans-Island Highway Project has been a national goal since PNG gained political independence in 1975 to link the Papua side with New Guinea by road across the steep Owen Stanley Ranges.

The 170 km road section from Port Moresby to Bereina is already open to the public. The 125 km from Lae to Slate Creek is also open to public, but a further 70 km from Slate Creek to Aseki is barely jeepable. The remaining section of 210 km from Bereina to Aseki through Kaintiba is not yet connected by any road.

The project route of 575 km was first identified in the feasibility study by British consultant, Rendel & Partners of August 1979 to July 1980.

The technical investigation and preliminary design for the section from Bereina to Malalaua was conducted by Australian consultant, Cardno & Davies from December 1980 to September 1982 (Cardno & Davies Study).

Based on the above works, the Governments of PNG and Japan exchanged Notes to finance the proposed Project in July 1985.

The detailed design of the Bereina to Malalaua road (the Study) was requested from PNG Government to Japan in February 1987.

The Government of Japan entrusted the Study to the Japan International Cooperation Agency (JICA), the official agency responsible for the implementation of the technical cooperation programs of the Government of Japan, and JICA dispatched to PNG a contact mission headed by Mr. H. Tamamitsu in April 1987 and a preliminary study mission headed by Mr. Y. Murakami in June 1987, the Scope of the Works (S/W) of the study was discussed and signed by the officials of the two Governments on 24th June 1987.

1. 2 Objective of the Study

The main objective of the study is to prepare the detailed design for a road construction project in Bereina - Malalaua as a part of the Trans-Island Highway in PNG.

The Study began in November 1987 and was completed in January 1990. The main Subjects of study were as follows :

(1) To provide detailed maps at 1:1000 scale as basic topographical data for the Study.

(2) To investigate subsurface conditions by mechanical borings at bridge sites, swamps and quarries.

(3) To prepare design drawings, to propose a construction plan and to estimate the project cost.,

(4) To prepare tender documents suitable for open international tender.

1. 3. Working Schedule

The Study was completed following the schedule shown in the general work flow of Figure 1-1.

1. 4. Study Organization

The Study was carried out by the study team under the supervision of the Advisory Committee organized by JICA, which comprised Japanese government officials chaired by Mr. Murakami. The Study Team was headed by Mr. Yoshimatsu and consisting of twenty three (23) Experts from Nippon Koei Co., Ltd., Katahira & Engineers Inc. and Pasco International Inc. keeping close collaboration with the counterpart team organized by DOW.

The organization of the Study is illustrated in Figure 1-2.

1. 5. Acknowledgements

The Study Team's special thanks are hereby expressed to the DOW's team of counterparts under guidance of the Secretary Mr. A.I. Temu and the First Assistant Secretary Mr. Frank Leonard, without whose constant support and timely guidance the Study could not have proceeded. The Study Team would like to reiterate its sincere appreciation to :

Mr. Mike J. Sharp
Mr. John Bolt
Mr. F. Roland Jones
Mr. Unage Ata
Mr. W. Krishnathasan
Mr. Harold T. M. Insley
Mr. Kevin J. McConell
Mr. D. James
Mr. E. Still
Mr. William Morehari
Mr. Miauje Tava
Mr. AL. Smaller

The study team would also like to thank the members of the PNG Steering Group comprising representatives of various government agencies concerned, who have shown kind attention to the progress of the Study,

The Study Team obtained information from a large number of people during the course of the Study, officials of other government agencies, contractors, consultants, and other people in related fields in the private sector. The Study Team received full cooperation on almost all occasions not only in Port Moresby but also in villages in the Project area. It is impossible to name all those involved in this space, but the Study Team would like to express its sincere thanks to them all.

Fig. 1 - 1 WORK FLOW OF THE STUDY

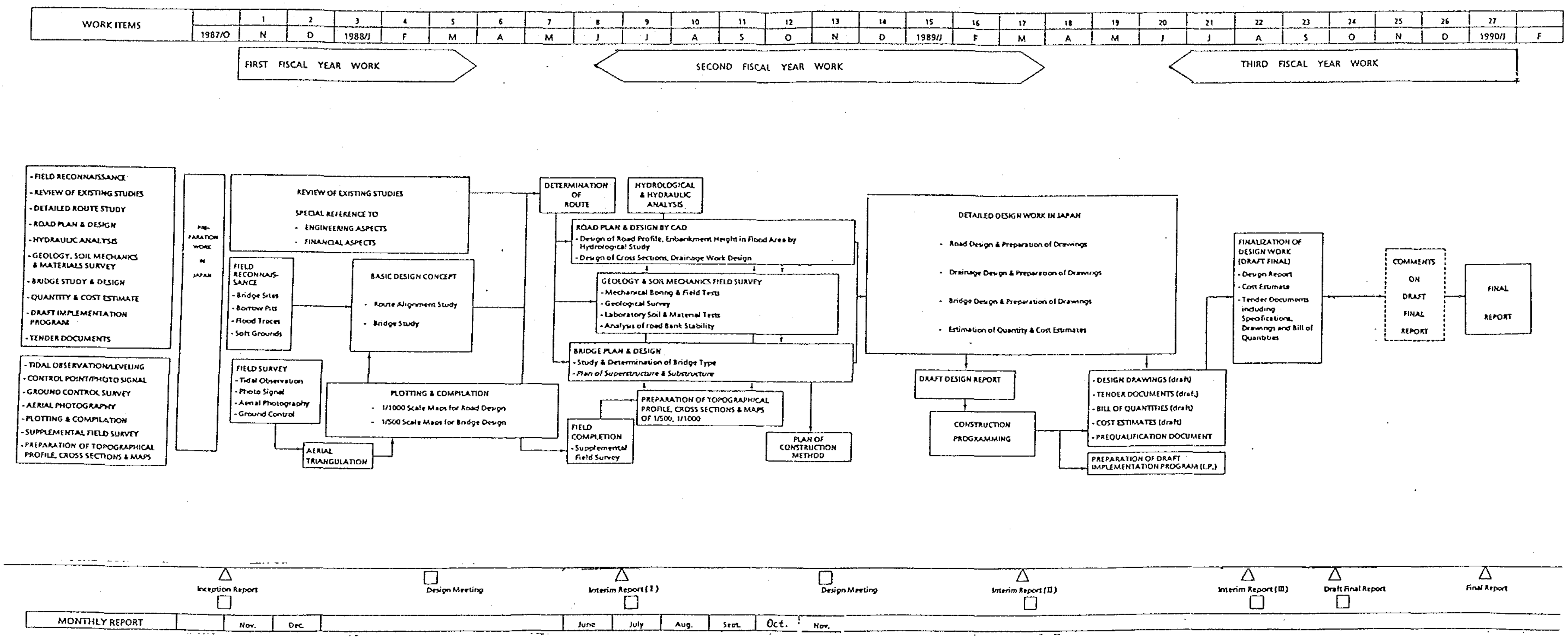
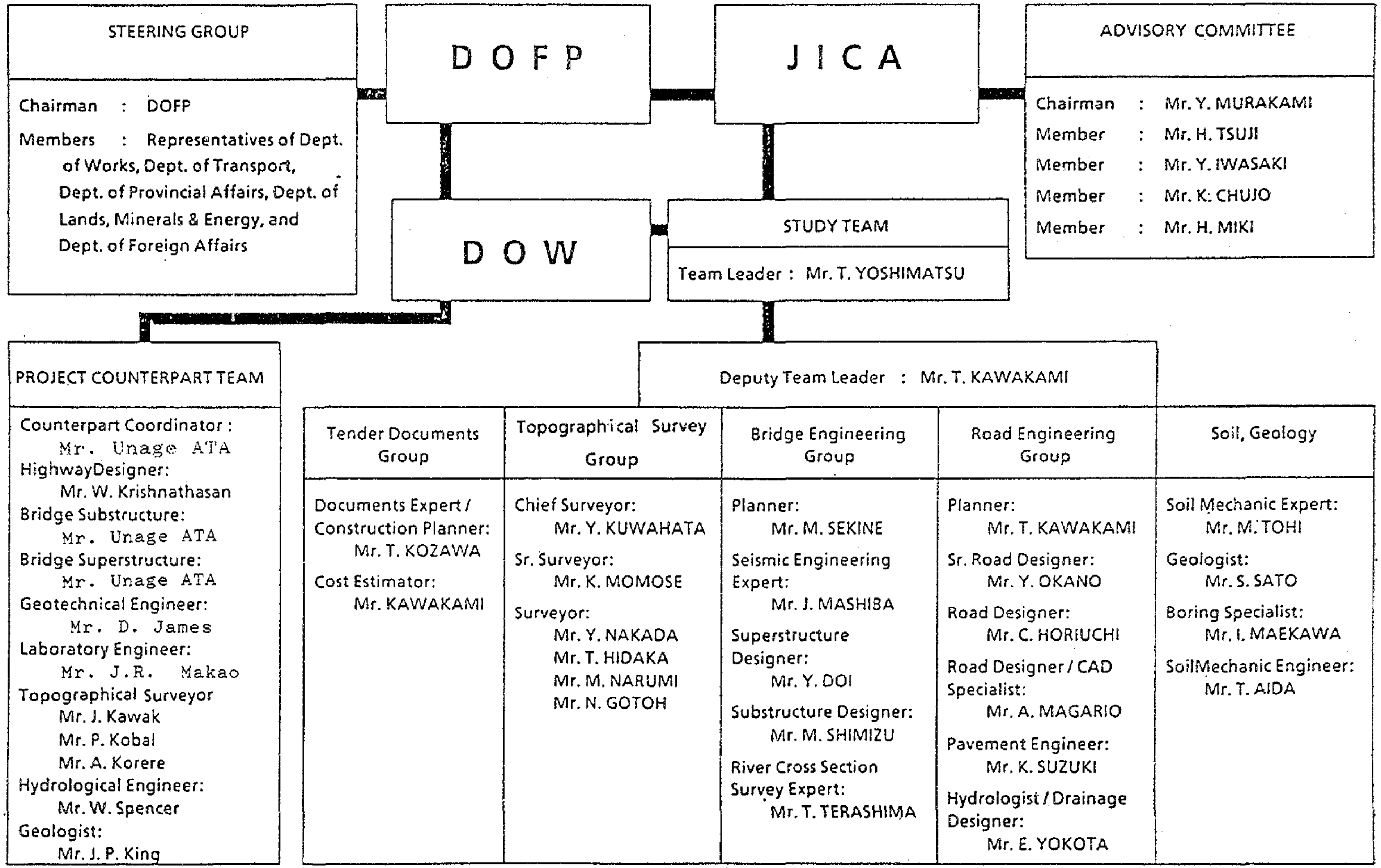


Fig. 1-2 ORGANIZATION OF THE STUDY



2. THE PROJECT

2.1 Summary of the Project

A part of Trans-Island Highway, Bereina-Malalaua section of approximately 80 km was divided into two (2) Construction packages as follows :

LOT I	Bereina to Miaru River Section		
	Contract NO. TC 120-33-814/A		
	Length of Project Road	:	33,500m
	Number of Bridges (2 lanes)	:	3No.
	Excavation	:	830,000m^3
	Embankment	:	740,000m^3
	Construction Periods	:	36 months
LOT II	Miaru River to Malalaua Section		
	Contract NO. TC 120-33-814/B		
	Length of Project Road	:	47,096m
	Number of Bridges (1 lane)	:	6No.
	Excavation	:	260,000m^3
	Borrow	:	350,000m^3
	Embankment	:	590,000m^3
	Sandmat	:	170,000m^3
	Construction Periods	:	48 months

2.2 Present Situation of the Site

The Project area covers two (2) Provinces, Central and Gulf, including the towns or villages of Bereina, Babanongo, Apanaipi, Iokea, Lese oalai, Popo, Terapo and Malalaua.

The people living in the area between Bereina to Miaru river can reach Port Moresby by road only in the dry season, and people living in the remoter area between Miaru river to Malalaua have to travel always by water transportation.

Therefore, the people have strongly desire the realization of the road for better provision of medical services and easy exchange of goods.

However, six (6) big rivers, the Miaru, Kapuri, Lakakamu, Tauri, Makara and Sappaharo and seven(7) kilometers of swamps near Kapuri river have made road construction difficult. The project area, therefore, has been left like isolated islands on land though the villages are located within 250 km from the Capital.

2.3 National Goal Project

The construction of the Bereina-Malalaua road is another step towards realizing the national goal to link Port Moresby to Lae by road.

People in the Highlands and New Guinea side will have to wait a little longer for opening of the Malalaua-Aseki-Latep section which will be the next step towards providing them with a more economical transportation service than the present airway service.

CHAPTER II LOCAL CONDITIONS

1. CLIMATE

Climatic conditions in the Project area are taken from the "Climatic Tables for Papua New Guinea" issued by Commonwealth Scientific and Industrial Research Organization, Australia in 1975.

1.1 Mean Monthly and Annual Rainfall

Station Name	YRS. OF RECORD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL (mm)
KEREMA	44	231	232	264	289	437	386	347	331	336	299	209	209	3612
TERAPO	1	73	165	218	302	74	21	11	19	56	187	59	225	1601
POPO	5	221	156	167	152	53	67	53	44	86	100	87	192	1396
BEREINA	14	210	220	210	131	42	28	21	26	55	53	43	172	1182
KAIRUKU	36	240	277	226	134	46	44	28	14	40	40	54	133	1282
PT. MORESBY	42	177	199	170	103	62	30	29	16	26	31	49	105	995

1.2 Mean Monthly and Annual Temperature (Deg. C)

Station Name	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL (C°)
KEREMA	27.2	27.1	27.0	26.5	26.1	25.6	25.1	24.9	25.3	26.0	26.6	27.0	26.2
BEREINA	26.7	26.7	26.7	26.5	26.4	25.2	24.9	25.2	25.7	26.1	26.5	26.7	26.1
PT. MORESBY	27.5	27.3	27.2	26.9	26.8	26.1	25.7	26.0	26.4	27.1	27.5	27.7	26.8

Absolute Max. 36.8C° ~ Min. 10.4C° have been recorded in the above area.

1.3 Direction of Wind (Monsoon)

December to April : from NE (land side) to SW (sea side)
May to November : from SW (sea side) to NE (land side)

The above information shows that the project area has

- Rainy season from December to April and dry season from May to November.

- Average number of days per month with rainfall more than 5mm is 8 days in rainy season and 2 days in dry season.

2. ACCESS WAY

JICA study team surveyed local conditions for accessibility to the Project site by roads, waterways and airways in 1988 as follows :

2.1 Access by Roads

The Hiritano highway that runs about 170km from Port Moresby to Bereina is an improved national highway, and is the only access road to the beginning point of the Project. The highway is well maintained by DOW and is scheduled to be up-graded from gravel road to paved road. It is possible to carry plant on trailers at a speed of 60km per hour or more. Another important access road connects the section between Bereina and Apanaipi through Iokea for a distance of about 62km. JICA study team surveyed the road conditions in August 1988 and found the situations as follows :

- The first 19km from Bereina to Kivori bailey bridge in Central Province is generally satisfactory with a minimum curvature of 20m, however, the gradient at 8km from Bereina has a steep down slope of 14 per cent to 20 per cent over a stretch of 600m which needs improvement.

- The next section from Kivori bridge to Iokea of about 27km has a narrow width of less than 4.5m and in the steep rolling hills with up and down gradients of 16 to 20 per cent in the stretch of 12km from Oaipu to Iokea which need upgrading.

- The last section from Iokea to Apanaipi of about 16km has a narrow width of less than 5m on an acceptable alignment but needs upgrading work in gradient and road surface.

- The soil surface road in Gulf Province is closed in every rainy season due to non-trafficability.

It took three (3) hours to drive the 62km road from Bereina to Apanaipi in August 1988.

On the other hand, JICA study team investigated the 70km of road from Kerema to Sappaharo creek at Malalaua in August 1988. This road stretch will also provide very important access from Kerema which is the only existing port in the Project area. The road conditions are acceptable except for the following points :

- Drainage sections at four (4) points are not inadequate, since overflow always occurs in times of flood.
- Three pile-bent H-Beam bridges and three timber-beam bridges should be reinforced for the trailers required to carry plant to Malalaua.

It took one hour to drive the road section from Kerema to Malalaua in August 1988.

2.2 Access by Waterways

The waterway from Port Moresby to Kerema is one of the most reliable access routes to the Project site including a regular 50 ton cargo ship service available throughout the year.

The landing jetty 150m into the sea is the only existing facility at Kerema port which has no unloading / loading equipment. At 7km up stream in Silura creek, there is a natural landing slipway which serves as a river port which will be useful for unloading of construction machinery from a barge with a ramp.

The wave heights are low in the rainy season and high in the dry season due to the monsoon. Therefore, the cost is not navigable by small vessels less than 50 tons in the dry season. (Fig. 2-1)*

Note Figures and tables with mark * are attached in Appendices (page 202 to page 340)

The following places along the coast are considered as possible places where barges or pontoons could approach to load and unload materials, if ghats will be constructed.

- Port Chalmers at the Tauri river mouth
- Iokea village
- Pin upoka point facing to the Yule island

There is also a natural port for inland waterways at Iokea where used by the small boats of people living in the Project area even in the dry season. The waterway reaches as far as Malalaua, Terapo and Lese Oalai from Iokea.

JICA study team investigated the river waterway depths in August 1988 to sound the possibility of construction barges / pontoons entering the site through the following rivers and estuary, with the results shown below :

units meters

Water way	Water Depth		
	at Mouth	Max.	Min.
Miaru river	1.0	8.0	1.8
Lese estuary	3.0	9.2	2.0
Kapuri river	1.5	10.0	3.9
Lakekamu river	3.0	10.0	3.0
Tauri river	1.3	11.0	2.2

The branch creeks from Tauri river to Sappaharo and Makara bridge sites are deeper than 4.5m, the above depths at mouth were surveyed at high tide.

According to the above results, the Lakekamu river was found to be potentially the most reliable inland waterway for the Project. The Tauri and Kapuri rivers will need to be dredged at their mouths if used as waterways for the Project. The Lese estuary is also a good waterway which does not require dredging at its mouth.

2.3 Access by Airways

Air fields are located at Bereina, Iokea, Lese Oalai, Terapo Mission, Malalaua and Kerema in the Project area.
A daily regular flight is available by Talair but this does not stop at Bereina air field for lack of customers since opening of the Hiritano highway in 1985.
Access by helicopter is very convenient in the Project area, and many helipads for helicopter landing were cleared during the field investigation by JICA in 1988.

3. RIVER WATER MOVEMENT

River water movement in the main rivers was observed for 24 hours a day in September to October 1988. Bridge construction is considered based on the following characteristics of water flow changes :

3. 1 Miaru River

The peak water level occurs only once per day and the flow does not change even at high tide due to the distance and big difference in elevation from the sea.
The water velocity was about 1.0m per second or less on 30 September 1988.
The highest flood level was estimated at 5.0m which is only 0.5m above the bank height of the river to overflow into "the saucer". The design velocity in flood is estimated at 1.8m per second.

3. 2 Kapuri River

The water level of about one meter is affected by tide level with a timelag of about two hours. The flow changes from down to up-stream at high tide. The water velocity was about 0m~0.5m per second for both directions.
The highest flood level is not recorded at Kapuri river, but according to information from local inhabitants the flood depth from ground level is 1.4m in elevation.

3.3 Lakekamu River

The water level of about one meter is affected by tide level with a timelag of about one hour. The flow changes to up-stream at high tide. The water velocity was less than 1.0m/s on 3 October 1988.
The flood water level is estimated at 2.5m which is only 0.5m above bank height to overflow into "the saucer".
The design velocity is estimated at 3.2m/s at flood period.

3.4 Tauri River

The water level of about 0.7m is affected by tide level with a timelag of one hour and a half. The flow changes to up-stream at high tide. The water velocity was less than 1.0m/s on 5 October 1988.
The flood water level is estimated at 2.5m as for the Lakekamu river. The design velocity is estimated at 1.6m/s at flood period.

4. WATER DEPTH IN SWAMP

The water depth in the swamps is a critical factor for the earth works.

4.1 Alike Swamp

When the boring works at the Alike swamp were done, the deepest water depth of about 3.0m was surveyed at the central waterway, and about 2.0m at both sides in swamp in September 1988.
Generally the water is flowing towards the sea at a velocity of less than 0.1m per sec..

4.2 Kapuri Swamp

Both sides of Kapuri river are swamp with a standing water depth of about 0.5m or less in September 1988. However an old river trace near Ilavala hill has a water depth of about 1.0m. These depths are variable with the flood volume by the season.

4.3 Makara Swamp

The swamp near Makara river is always submerged at high tide.

These local conditions should be given to Tenderers for the Project together with drilling logs and test results done at the DOW Material Testing Laboratory.

CHAPTER III TOPOGRAPHICAL SURVEY

1. FIELD SURVEY

1.1 Tide Observation

(1) Simultaneous tidal observations were undertaken for the purpose of determining the mean sea level. Three (3) points: Roro-Aiara-Waima, Moro and Koaru on the sea shore were originally proposed for observation. However, Roro-Aiara-Waima near Bereina proved to be severely affected by sedimentation and observation of low tide level failed even when the location was shifted towards the mouth of the Angabanga river. Koaru near Malalaua was strongly affected by waves due to a shoaling beach so the portable gauge had to be placed at the quay of Yule island 22 kilometers from Bereina to the south.

The mean sea level at each gauge station was calculated not only from the height-variations automatically recorded over one month but also from water levels taken by manual observation every two (2) days.

The locations of the tide gauges and the direct leveling lines are shown in Figure 3-1*. In the direct leveling, 9 monumented bench marks (BM) were installed as explained in detail in Appendix.

(2) Based on the average of the mean sea levels at three (3) points, the following five (5) elevations on the basic GPS station near the Air field of Bereina were calculated by direct leveling survey or by calculation of height difference observed by GPS. The five survey lines (A to E) are illustrated in Figure 3-2*.

A. The elevation of 7.934 m was given from the height of the existing first order Trig. Station (AA009) provided by National Mapping Bureau of PNG by means of the height difference observed by GPS. However, this elevation may not be of high accuracy because the height of the existing traverse point was determined indirectly by means of angle measurement.

B. The highest elevation of 8.326 m was given from the mean sea level at the Moro near Iokea by means of the height difference observed by GPS.

C. The second highest elevation of 8.298 m was given from the mean sea level at Iokea by means of direct leveling up to the GPS station near Miaru river bridge site together with calculation of height difference observed by GPS.

This elevation is also reliable as the results of direct leveling has satisfied the level of accuracy specified in the JICA standards.

D. The lowest elevation of 8.151 m was given from the mean sea level at Yule island.

However this elevation is not reliable because there was missings in the tidal observation.

E. The middle elevation of 8.189 m was given from the mean sea level at the Angabanga river. This elevation is not reliable too due to an unfortunate failure in observation of the lowest water level.

(3) From the above, the elevation at the basic GPS station near the Air Field of Bereina was determined as 8.312 m as the average of the two (2) reliable elevation of B and C.

This conclusion was accepted by the DOW as shown in the minutes of the first design meeting.

1.2 Control Points / Photo Signal

Prior to taking aerial photographs of the Project area, a total of 29 control points were provided and 20 of these were monumented in concrete. The locations of these points are shown in Figure 3-3*.

Another 19 points of photo signals were additionally distributed to enhance the accuracy of the maps.

The coordinates and elevations of all 30 control points including the basic GPS station are listed in Table 3-1.

1.3 Aerial Photography

Aerial photography was started on 15th November 1987, immediately after provision of ground marks, by MAPMAKERS PTY LTD (P.O. Box 6575, Boroko PNG) appointed by the JICA survey team.

Fourteen (14) courses of the survey (runs) were proposed as shown in Figure 3-4* based on the road centerline confirmed at the inceptional meeting for the Study in November 1987.

The first films were taken by the 20th November 1987, and sent to Australia for processing, and returned to PNG within two(2) weeks.

The aerial photo sheets were developed by MAPMAKERS and carefully reviewed one by one. Three (3) courses, 2, 7 and 13, had to be reflown on the instruction of the JICA survey team on account of deviation of course and cloud shadow.

A total of 228 photos at approximately 1:5,000 scale were handed-over around the end of January 1988.

1.4 Control Point Observations (GPS)

The JICA survey team surveyed the 30 control points by GPS while the aerial photography was being taken by aircraft.

The positions of the control points were surveyed by the following equipment:

GPS Receiver	4000 SX GPS SURVEYOR Trimble Navigation Co., Ltd. made in USA.	3 sets
Computer	DT- One Lap-top Computer Data General Co., Ltd. made in Japan	3 sets

Table 3-1 CO-ORDINATES OF GPS OBSERVATION POINT (A. N. D. System)

	GEOGRAPHIC			UTM Zone 55	
STATION	LATITUDE (S)	LONGITUDE (E)	HEIGHT (m)	NORTHING	EASTING
JP-01	8 04 33.5657	146 09 41.5141	3.829	9107203.223	407615.143
JP-02	8 05 10.2744	146 09 09.5363	4.087	9106073.793	406638.694
JP-03	8 06 48.8553	146 10 17.5802	2.097	9103050.449	408727.530
JP-04	8 08 07.1898	146 10 11.0644	1.116	9100644.219	408533.037
JP-05	8 09 31.0540	146 10 45.2102	1.079	9098070.701	409583.260
JP-06	8 10 44.7575	146 11 22.7261	2.404	9095809.432	410735.873
JP-07	8 11 17.3915	146 12 30.9673	49.113	9094811.330	412826.050
JP-08	8 12 13.4537	146 12 56.2938	1.895	9093091.069	413604.391
JP-09	8 12 23.8015	146 15 26.3320	1.054	9092782.001	418195.882
JP-10	8 13 48.0980	146 16 41.0016	1.349	9090197.294	420485.271
JP-11	8 14 52.4794	146 17 22.3427	89.121	9088222.307	421753.653
JP-12	8 16 24.3035	146 17 24.1881	3.455	9085402.348	421815.133
JP-13	8 18 39.4221	146 18 09.7133	4.687	9081255.114	423215.145
JP-14	8 20 13.4814	146 19 30.3552	30.461	9078370.690	425686.865
JP-15	8 21 39.1324	146 20 36.2239	63.836	9075743.627	427705.989
JP-16	8 22 16.1413	146 21 45.7058	9.893	9074610.527	429832.957
JP-17	8 23 44.4624	146 21 32.0686	5.112	9071897.393	429420.295
JP-18	8 25 06.0181	146 22 05.3766	18.073	9069394.365	430442.978
JP-19	8 25 54.8376	146 22 27.2224	47.795	9067896.129	43113.438
JP-21	8 27 01.9357	146 24 33.8631	19.488	9065841.444	434989.175
JP-22	8 29 24.9306	146 25 43.4129	30.114	9061453.144	437122.316
JP-23	8 28 50.1191	146 25 57.2753	28.735	9062522.864	437544.593
JP-24	8 31 06.6752	146 27 35.5213	22.541	9058333.379	440554.353
JP-25	8 32 10. 8413	146 28 49.3574	12.341	9056365.873	442814.345
JP-26	8 32 54. 9561	146 29 47.8436	17.838	9055013.440	444604.084
JP-27	8 35 09. 6406	146 29 52.3830	28.514	9050877.342	444748.253
JP-28	8 36 57.4352	146 30 08.5215	41.351	9047567.514	445245.856
JP-29	8 37 16. 3197	146 30 52.6605	8.627	9046989.289	446569.673
BASE	8 38 20. 9065	146 30 22.4934	8.312	9045004.587	445676.212

* Under-lined stations were monumented by NMB

Transit Instrument	WILD T2 Wild Co., Ltd. made in Switzerland	1 set
Electronic Distance Meter	HP-3808 B Yokogawa Hewlett Packard Co., Ltd. made in Japan	1 set

The coordinates of the first order traverse station (AA-009) given by the National Mapping Bureau at Bereina was connected to the newly established basic GPS station (the base point) near Bereina Air Field to provide the azimuth, distance and height difference between the control points and the base point.

1.5 GPS Coordinated Transformation

All the GPS station coordinates, relating to the WGS84 (World Geodetic System 1984) ellipsoid which was adopted by GPS surveying, were transformed to zone 55 of UTM projection based on the A.N.D. (Australian National Datum).

Three steps of the coordinates transformation were executed as follows:

Step 1: from WGS84 System to WGS72 System

Step 2: from WGS72 System to Local Geodetic System

Step 3: from Local Geodetic Systemto UTM projection

TRIVEC™ utility program was used for geographical coordinated transformation computation between WGS84 and WGS72, and, between WGS72 and Local (AND).

The values of ellipsoid systems are as follows:

Ellipsoid	Semi-major axis (m)	Flattening
WGS84	6,378,137.00	1/298.2572221
WGS72	6,378,135.00	1/298.26
A.N.D.	6,378,160.00	1/298.25

Systematic transformation parameter values between each ellipsoid are as follows:

	dx	dy	dz
A.N.D. → WGS72	+116.385	+45.113	−144.585
WGS72 → WGS84	0.00	0.00	+4.50
rotation about x, y, z axes (arc sec)			
	.0000	.0000	−.5545
scale (ppm)		.2263	

The height values of the GPS stations were converted into the height from geoid.

The coordinates and elevation heights of 29 GPS control points are listed in Table 3-1.

1.6 Additional Traverse Surveying

A total of nine (9) new control points were established between AA009 existing control point near Bereina town and JP17 GPS Point at the Kuaba school near the Miaru river for supplemental survey in August 1988 by conventional traverse surveying using WILD T2 theodolite and WILD DI300 E.D.M. equipment. These points were marked with star pickets driven into the ground. The coordinates of new traverse points are listed in Table 3-2.

Table 3-2 COORDINATES OF NEW TRAVERSE POINTS

STATION	NORTHING (m)	EASTING (m)	HEIGHT (m)
A-1	9,050,815.884	442,882.622	154.42
A-2	9,055,931.394	442,767.349	45.39
A-3	9,055,856.116	439,568.683	107.18
A-4	9,058,385.378	439,019.171	56.58
A-5	9,063,102.219	435,133.874	75.65
A-6	9,066,000.789	433,568.238	63.62
A-7	9,066,211.702	433,932.223	54.00
A-8	9,070,769.102	430,068.531	55.81
A-9	9,071,342.886	429,486.907	40.81

2. INDOOR WORK

2.1 Aerial Triangulation

A total of 14 strips and 209 models of photographs along the proposed road were used for photo-coordinates measurement. As for the pass point, one point was taken near the principal point of the photograph and other points were taken at both sides of a line orthogonal to the photobase. Plural tie points were selected at crossing of strips.

For measurement, a stereo comparator (Zeiss Jena STECOMETER) was used, thereby making two independent measurements. Where the measurement values were within 20 microns, their average value was adopted and, where greater than this, another series of measurements was made before adopting the mean of all measured values.

The program used for adjustment of strips based on the independent model method was 'PAT-M43' developed by Stuttgart University of West Germany. For adjustment computation a weight was given to each point according to its purpose.

a. Model point
   X, Y : 1.000 Z : 1.000

b. Center point of projection
   X, Y : 0.250 Z : 1.000

c. Control points used for horizontal adjustment computation
   X, Y : 100.000

d. Control points used for vertical adjustment computation
   Z : 100.000

e. Control points for reference only are not used for adjustment computation
   X, Y : 0.0 Z : 0.0

The weight of each control point must be less than 1/100 in the computation of aerial triangulation, if the accuracy of a control point is to be given to a centimeter, since the measurement accuracy on the photo is within 20 microns, and 1.2 m in actual distance. Therefore, it was assumed necessary to give a weight of 100 times to the measured value of the control point. Adjustment computations were performed in the order of horizontal, vertical, horizontal, vertical, each curvature correction and horizontal, correction.

The accuracy was given in terms of mean square errors for the results of model points, projection center and control point after adjustment with weights. The results are tabulated as follows:

No. of Model	No. of Control Points		Horizonted Residuals of Control Points		Vertical Residuals of Control Points		Tie - point Max. Horizontal Discrepancy	Tie - point Max. Vertical Discrepancy
	Horizontal	Vertical	Mean Square Error	Max. Value	Mean Square Error	Max. Value		
209	26	28	m 0.08	m 0.16	m 0.03	m 0.10	m 0.24	m 0.24
Allowable limit			m 0.15	m 0.30	m 0.15	m 0.30	m 0.30	m 0.30

19 Azimuth points, which had been related to monumented GPS control points, were measured by STECOMETER in the same way as the pass-points, tie-points and control-points. The distance and bearing angle of azimuth points from related GPS points are listed in Table 3-3*.

2.2 Stereo-Plotting & Compilation

The plotting equipments used were AUTOGRAPH A8, and STEREO-METROGRAPH. Photogrametric orientation was done based on pass-points, tie-points, control-points, and pricked level-points. The allowable errors of orientation at each point were within 0.5 mm on the map for horizontal locations and within 1/3 of contour interval for elevations. The results for each model were within these tolerance limits.

Spot height points as well as control points were spaced at 5 cm intervals on map. Each of these points was measured twice in units of 0.1 meter and their mean value was taken as the determined value. With regard to contour lines, the intermediate contour represented in orange color were to have been delineated at 1 m intervals and the index contour with black at 5 m intervals. However, half and quarter contours were delineated at 0.5 m and 0.25 m intervals where the terrain was very flat area. Detailed plotting was carried out by delineating planimetric features, using field data classified on enlarged photos as reference. The boundaries of vegetation and water were represented in green and violet so that their boundaries could be clearly seen during the drafting stage. 46 plastic film base sheets up to 2m wide were used for plotting work for the 80 km of proposed road corridor area. For compilation, the film base using one and the same material as the plotting sheet was overlaid on the plotting sheet, precisely resisted, and the necessary features were edited and represented according to the map symbols and the system of representation adopted by DOW and the National Mapping Beurau.

2.3 Manuscripts of 1:1,000 Maps

The manuscripts of the 1:1,000 scale maps were completed by the beginning of March 1988, and were presented to DOW at the First Design Meeting in March 1988.

2.4 Fair Drawings of 1:1,000 Maps

A total 119 sheets of 1:1,000 scaled topographical fair drawing maps with a 1 m contour interval along the proposed route (250 m width for 80 km in length), and a total of 28 sheets of 1:500 scaled topographical fair drawing maps with a 0.5 m contour interval for the 7 proposed bridge sites (500 m × 500 m) were completed by the end of February 1989. A sheet index of the 1:1,000 scaled topo-maps and sample of fair drawing are shown in Figures 3-5* and 3-6*.

2.5 Photogrammetric Profile and Cross Sections

A total 1941 sections of three dimensional terrain coordinates were measured by analytical stereo plotter using the 1:5,000 aerial photos, aerial triangulation results and data on the proposed center line determined by designers. The measured data were saved in magnetic tape for auto plotting purposes. And, the saved data were down loaded to 5.25" floppy disket for road design purpose using CAD/CAM system. The plotting work for a total of 120 sheets of longitudinal profile and a total of 240 sheets of cross sections were completed by the end of March 1989. Sample drawings of the longitudinal profile and cross sections are shown in Figures 3-7* and 3-8*.

CHAPTER IV GEOTECHNICAL INVESTIGATIONS

1. GEOLOGY OF THE PROJECT

The information presented is cited mainly from the following reports:

A : *Geological and Materials Investigation for the Bereina - Malalaua Road*, by J.A. Buleka (1981) ;

B : Geophysical Investigation of Bridge Sites for Bereina - Malalaua road, by P.J. Hill (1980) ;

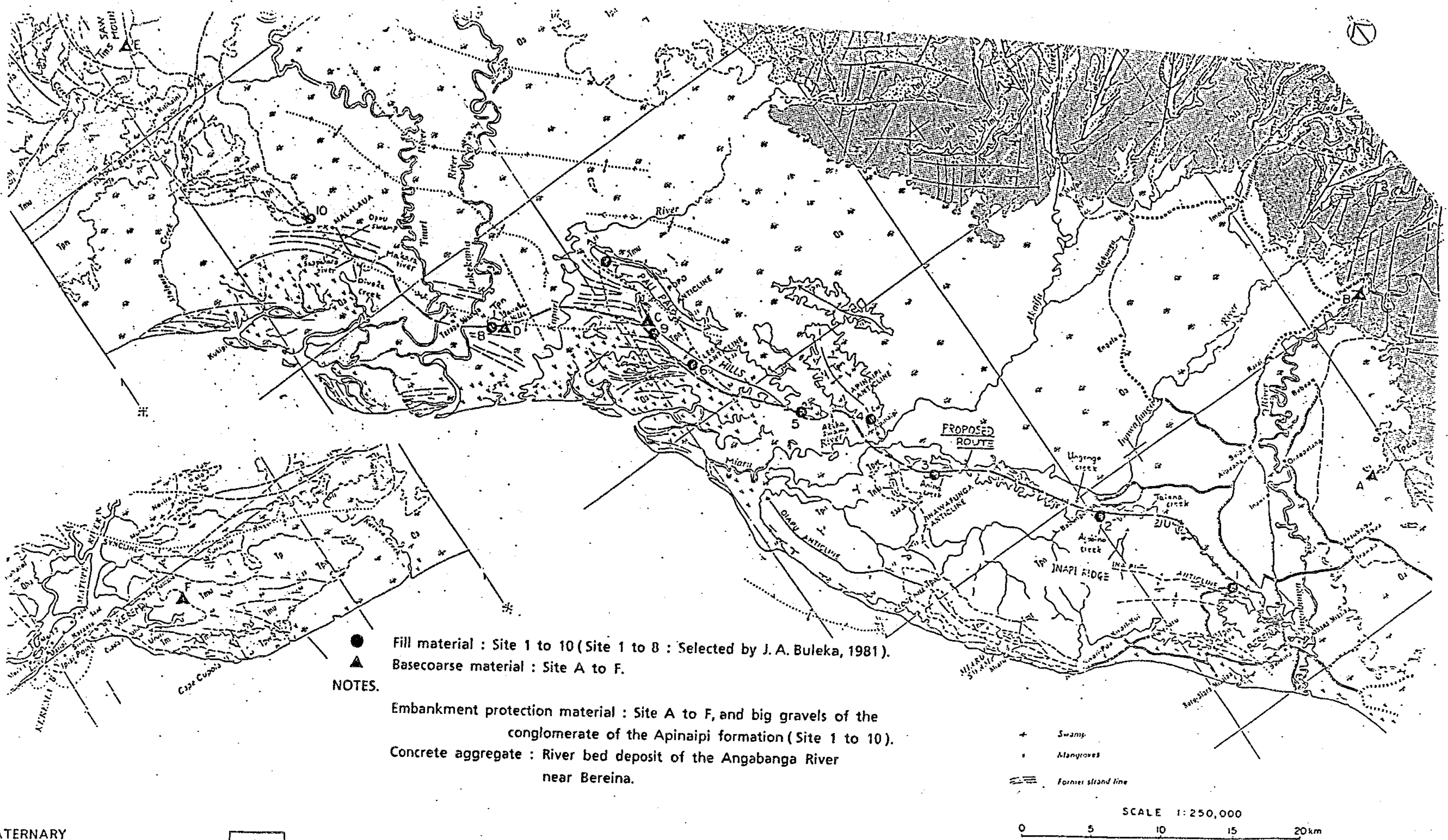
C : Geotechnical Report (Vol. 8) of the Hiritano Highway Stage II, Bereina - Malalaua Link by Cardno and Davies PNG Pty. Ltd.

1.1 General Geology

The general geology and the stratigraphy in the Project area are shown in Figure 4-1 and Table 4-1 respectively based on the Yule 1 : 250,000 geological sheet (Brown, C. M., 1977) and the Wau 1 : 250,000 geological sheet (Dow, D.B., Smit, J.A.J. and Page, G.W., 1975).

The proposed road is located in the coastal area of the Central and Gulf Provinces of PNG. The area consists of a flat coastal plain with gently sloping hills. These hills extend NNW / SSE along the coast and are called Inapi ridge, Palipala hills and Ilavala hills. The main rivers in the project area originating from the eastern and northeastern mountainous areas are the Angabanga river, Inawafunga river, Miaru river, Kapuri river, Lakekamu river and Tauri river from south to north on the coastal plain. All these rivers meander in the area.

The coastal plain is composed of unconsolidated alluvium and littoral deposits (Qa ; *gravel, sand, silt, clay, peat, with some reef limestones*) of the Quaternary age. Most of the coastal plain is covered with swamps. Large mangrove swamps exist in the eastern coastal plain of the



QUATERNARY		Qa	Gravel, sand, silt, mud, carbonaceous mud, clay, peat: alluvium and littoral deposits
TERTIARY			
PLIOCENE	Apinaipi Formation	Tpn	Calcareous and non-calcareous tuffaceous sandstone, pebble and cobble conglomerate, siltstone, mudstone; minor limestone, volcanic agglomerate, fine white and coarse brown tuff and brecciated lava
	Mount Davidson Volcanics	Tpda	Basaltic and minor andesitic agglomerate, tuff, lava, lava breccia, with intercalated volcanically derived conglomerate and sandstone increasing westward
	Wedge Hill Limestone	Tpw	Coralgal limestone, calcareous sandstone, pebble conglomerate; minor calcareous mudstone, siltstone
LATE MIOCENE TO EARLY PLIOCENE	Miaru Mudstone	Tmu	Mudstone, shale; minor thin interbeds of siltstone, sandstone, limestone and conglomerate; volcanic interbeds towards base
MIDDLE TO LATE MIOCENE	Aure Beds	Tms	Biohermal limestone grading laterally into marl, limestone with some siltstone, sandstone and conglomerate
		Tma	Greywacke, siltstone; mudstone; minor pebble conglomerate; calcareous interbeds, lignite bands and carbonaceous lamellae
	Talama Volcanics	Tmt	Andesitic to basaltic agglomerate, tuff, lava breccia, lava; intercalated volcanically derived conglomerate, sandstone, minor mudstone

Fig. 4-1 GEOLOGY & QUARRIES IN THE PROJECT AREA

Table 4-1 GEOLOGY (1) SYMBOLS & LITHOLOGY

AGE	FORMATION	SYMBOL AND LITHOLOGY
QUATERNARY	Alluvium and Littoral Deposits	Qa : Gravel, sand, silt, mud, carbonaceous mud, clay, peat, etc.
TERTIARY Pliocene	Apanaipi Formation	Tpn : Calcareous and non-calcareous tuffaceous sandstone, pebble and cobble conglomerate, siltstone, mudstone; minor limestone, volcanic agglomerate
	Mount Davidson Volcanics	Tpda: Basaltic and minor andesitic agglomerate, tuff, lava, lava breccia, with intercalated volcanically derived conglomerate and sandstone increasing westward.
	Wedge Hill Limestone	Tpw : Coralgal limestone, calcareous sandstone, pebble conglomerate; minor calcareous mudstone, silt-stone, etc.
Late Miocene to early Pliocene	Miaru Mudstone	Tmu : Mudstone, shale; minor thin interbeds of siltstone, sandstone, limestone and conglomerate; volcanic interbeds towards base.
Middle to late Miocene	Aure beds	Tms : Biohermal limestone grading laterally into marl, limestone with some siltstone, sandstone and conglomerate.
		Tma : Greywacke, siltstone, mudstone; miner pebble conglomerate; calcareous interbeds, lignite bands and carbonaceous lamellae.
	Tamala Volcanics	Tmt : Andesitic to basaltic agglomerate, tuff, lava breccia, lava; intercalated volcanically derived conglomerate, sandstone, minor mudstone, etc.

After the geological maps of Brown, C.M., YULE, 1 : 250,000 (1977) and Dow, D.B., Smit, J.A.J. and Page, R.W., WAU, 1 : 250,000 (1974).

Table 4-1 GEOLOGY (2) TERRAIN UNITS

TERRAIN UNITS	FEATURES
1	Well drained hills, ridges, valleys, foothills. Deep water table. Examples : Inapi Ridge, Palipala Hills.
2	Level or gently undulating. Soils are of low plasticity and high permeability. Flood-free but subject to high water tables. Examples : South of Lese Oalai to Ch. 56. 6. South of Ilavala Hills.
3	Low lying land locally flat. Soils of medium or high plasticity and relatively low permeability. Flood-free but subject to high water tables. Examples : Some river and creek banks, e.g. Ungongo Creek. Some re-entrants in Inapi Ridge.
4	Normally dry land but flood-prone. Examples : South of Malalaua. River levees.
5	Normally inundated land but surface dries occasionally, or seasonally. Surface soils are firm, over-consolidated. Examples : Ch. 57. 2 to 64. 3. Ch. 73. 3 to 74. 3.
6	Permanently inundated land. Surface soils are very soft, virgin consolidated. Examples : Alika Swamp, Opou Swamp, Makara River bank.

(Ch. : Distance (km) from Bereina start point)

Geotechnical Report (Vol. 8) of the Hiritano Highway Stage II,
Bereina - Malalaua Link by Cardno and Davies PNG Pty. Ltd.

Palipala hills. Some remnant sand ridges (Former shoreline dun) running NW / SE are seen in the area between the Palipala hills and Malalaua town.

The hilly lands are composed mainly of sedimentary rocks ; sandstone, conglomerate, siltstone, mudstone, etc., of the Apanaipi formation (Tpn) of the Tertiary Pliocene age. Geological structures of the Apanaipi formation show NNW / SSE trending anticlines which are Inapi, Oiapu and Inawafunga anticlines in the Inapi ridge, Apanaipi anticline in the north of Apanaipi village, and Lese and Popo anticlines in the Palipala hills. The hilly lands are generally covered with eucalypt savannah.

In the area near the Miaru swamp on the coast, east of the Inapi ridge, the Wedge hill limestone formation (Tpw ; limestone, sandstone, conglomerate, mudstone, siltstone, etc.) of Pliocene age, Miaru mudstone formation (Tmu ; mudstone, shale, etc.) of late Miocene to early Pliocene age, and the Tamala volcanics formation (Tmr ; composed of andesitic to basaltic agglomerate, tuff, lava, etc.) are distributed in a narrow area along the Oiapu anticline.

The eastern mountainous area is formed by the Mount Davidson volcanics formation (Tpda ; basalitic agglomerate tuff, lava etc.) of Pliocene age, and the northern mountainous area which is called Saw mountains is composed of the Aure beds formation (Tms ; mainly limestone) in the middle and late Miocene ages. These mountainous areas are covered with very dense rain forest.

1.2 Geology Along The Route of The Proposed Road

The route for the proposed road is shown in Figure 4-1 and is described below :

From the Bereina town to the Apanaipi village, the proposed road is located in the eastern foothills of Inapi ridge, traversing small hilly ridges and creeks such as Taiena creek, Agobino creek and Ungongo creek near the Babanongo village, and Anina creek. These creeks form narrow swamps as they join with the flood plain of the Inawafunga river.

At Apanaipi village, the route crosses the Miaru river and runs north along the southwest edge of the Apanaipi anticline, then crosses the Alika swamp and continues along the western foothills of the Palipala hills. At the northern end of the Lese anticline of the Palipala hills, the route swings northwest and runs along the former shoreline dunes (sand ridges) then crosses the Kapuri river to the Ilavala hills, where wide swamps are developed. From the Ilavala hills it crosses the Lakekamu river and the Tauri river near Terapo mission and then runs north to Malalaua town along the existing old road. In the section between Tauri river and Malalaua town, the route crosses some swampy areas, such as Makara river, Divola creek, Sappaharo river and Opou swamp.

The following is a summary of the geological conditions along route of the proposed road.

(1) Bereina town - Babanongo village

The route from Bereina town to Babanongo village traverses a series of narrow swampy re-entrants along small creeks (Taiena creek, Agobino creed, etc.) and separated by branching spurs from northeastern edge of the Inapi ridge (Inapi anticline).

The branching ridges (terrain unit 1) are formed with weathered sedimentary rocks, mainly conglomerate of the Apanaipi formation. The rocks are generally highly weathered and in unsound condition on the surface.

(2) Babanongo village - Apanaipi village

The proposed route traverses similar conditions to that of the above section between Bereina town and Babanongo village along the northeastern foothills of the Inapi ridge.

The swampy re-entrants (terrain unit 3) are found in the Ungongo creek, Anina creek, etc. The thickness of recent deposits (alluvium and come colluvium) is estimated to be about 4.5 meters (ref. results of seismic exploration).

The small ridges are formed by conglomerate and sandstone of the Apanaipi formation, which are highly weathered and in unsound condition.

At the Apanaipi village the route crosses the Miaru river (river bank ; terrain unit 3). The depth of the Apanaipi formation rocks is estimated to be 18 to 48 meters beneath the river (ref. results of seismic exploration).

(3) Apanipi village - northern end of Lese anticline

The route runs along the western foothills of the Apanaipi anticline and Lese anticline (Palipala hills). It crosses the Alika swamp (about 400 meters in length ; (terrain unit 6) at about 2.5 kilometres north of Apanaipi village. The depth of the Apanaipi formation bed rocks is estimated to be 7 to 25 meters from the ground surface at the middle section of the swamp (ref. results of seismic exploration).

The other sections are formed mainly with weathered sandstone and conglomerate of the Apanaipi formation (terrain unit 1). The rocks are generally highly weathered and in unsound condition. Medium hard to hard sandstones are exposed in some ridges and small stream beds.

(4) Northern end of Lese anticline - Terapo Mission

The route passes the wide swamp flood plain terrain units 2 and 5 via the Ilavala hills (terrain unit 1) to the Terapo mission. It crosses the

Kapuri river at the middle portion of this section and the Lakekamu river near the Terapo mission (river bands ; terrain unit unit 3).

The area is formed with the former shoreline dunes (sand ridges ; composed of mainly sandy materials) which run northwest. Very soft silty and clayey swamp deposits cover the dunes in some portions. The thickness of the soft swamp deposits is estimated to be several meters in depth.

The depth of bedrocks seem to be rather deep and is estimated to be 50 meters or more except for the area near the Ialvala hills (ref. results of seismic exploration).

The Ilavala hills are formed with mainly weathered sandstone of the Apanaipi formation. Medium hard and hard rocks are exposed in some portions of the hill slope.

(5) Terapo Mission - Malalaua Town

The route crosses the Tauri river (river bank ; terrain unit 3) near the Terapo mission and then traverses swampy flood plain along the former shoreline dunes (terrain units 4 and 5). The swamps are located near the Makara river (terrain unit 6), Divola creek, Sappaharo river and Opou swamp (pertain unit 6), which are formed by very soft silty and clayey deposits of several meters thick.

The thickness of unconsolidated deposits beneath the Tauri river is estimated to be about 8 meters (ref. results of seismic exploration).

2. FIELD INVESTIGATIONS CONDUCTED

JICA study team conducted the first investigation on the Project road in November 1987. The second investigation was carried out from July to November 1988, using the mechanical borings and field geological inspection.

2.1 Mechanical Boring

Drillings at 24 points were conducted with standard penetration test, pressiometer test, sampling of soils, the locations are shown in Table 4-2.

Drillings was done by New Guinea Water Driller Pty. Ltd (Lae) under the supervision of JICA Drilling Expert and completed on 3rd November 1988.

The three sets of drilling machine were selected and brought from Japan for easy transportation by helicopter ; YBM-05 (300kg) with water pump of SP-30 type (60kg) and Engine of Yanmer NF80 (70kg). Other drilling tools, field testing tools, and sampling tools were also brought from Japan.

2.1.1 Drilling sites and results

The locations of boreholes are shown in Figure 4-2*.
Twenty seven (27) boreholes were first proposed for investigation at the First Design Meeting with DOW in March 1988. However three(3) of these were canceled during the drilling works on the advice of DOW.
Main details of these bore holes are given below and in Table 4-2.

Table 4-2 MECHANICAL BORING CONDUCTED

Hole No.	Location	Depth (m)	SPT (points)	PT (points)	Sampling (nos)
B1	Taiena creek	10.0	10	–	–
B2	Agobino creek	11.0	11	–	–
B3	Ungongo creek	10.0	8	–	1
B6	Miaru river (L)	20.0	19	–	3
B7	Miaru river (R)	40.0	39	3	3
B8	Alika swamp	20.8	14	–	4
B9	Kapuri river (L)	20.0	15	–	3
B10	Kapuri river (R)	50.0	46	1	3
B11	Lakekamu river (L)	10.0	10	1	2
B12	Lakekamu river (R)	8.0	8	–	2
B13	Tauri river (L)	15.0	7	1	2
B14	Tauri river (R)	15.0	9	1	2
B15	Makara river (L)	25.0	20	–	3
B16	Makara river (R)	40.0	35	–	4
B17	Divola creek	30.0	24	–	4
B18	Sappaharo creek (L)	23.0	19	1	4
B19	Sappaharo creek (R)	23.0	19	–	4
B20	Opou swamp	25.0	19	1	3
S2	Swamp	11.0	10	–	1
S3	Swamp	10.0	9	–	1
S4	Swamp	17.0	15	–	2
Q1	Palipala hills	30.0	–	–	–
Q2	Ilavala hills	30.0	–	–	–
Q3	Eboa quarry site	10.0	–	–	–
TOTAL 24 holes		503.8	366	9	51

NOTES
(1) SPT: Standard Penetration Test
(2) PT: Pressiometer Test
(3) Sampling: Undisturbed sample (Thin-walled tube)
(4) Q1, Q2 and Q3: Core boring

Number of Boreholes Location, Purpose, Reason for Cancellation

Group A

20-Boreholes : (B1 to B20)	At banks of rivers/creeks, To sound bearing layer of bridge foundation and to analyze soft ground

Note : B4 at Ungongo flood viaduct and B5 at Anina swamp were cancelled due to change of the structure from bridge to pipe culvert

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Group B

4-Boreholes : (S1 to S4)	At swamp To take undisturbed samples for the analysis of soft ground

Note : S1 near Agobino creek was cancelled due to change of terrain from swamp to rolling :

Group C

3-Boreholes : (Q1 to Q3)	At hilltop To sound hardness of rock for pavement material

Note : The detailed locations of Q1 to Q3 are shown in Figure 4-3* to 4-5* of Appendix 2.

The results of drilling logs are summarized in Figure 4-6* to 4-9*, more detailed drilling logs are compiled in the separate Local Condition Reports.

2.1.2 Standard penetration test (SPT)

SPTs were conducted at boreholes of groups A & B in order to obtain records of the penetration-resistance of subsoils by Raymond sampler which can take disturbed soils in its core. The resistance of soil is estimated by the number of blow by a 63.5kg hammer to penetrate 30cm and expressed as N value.

2.1.3 Pressiometer test (K value)

The K value test was done by a pressiometer at major bridge site to sound the lateral resistance of subsoils in the bored holes by expansion of a rubber tube using pressurised nitrogen(N_2)gas.
The results were examined for the design of pile foundations and are shown in Table 4-3*.

2.1.4 Thin walled tube sampling

Undisturbed soil samples are required for physical testing of soils ; to analyze the void ratio, cohesion, compression index and coefficient of consolidation.
A thin walled tube sampler of 75mm dia with a length of about 100cm was used for the sampling.

2.2 Geological Site Inspection

The JICA Geologist was stationed in the field camp for the month of September 1988 with the drilling crews, to investigate the geological conditions along the road route.

Based on the above site inspections, the site geology was analyzed and is discussed in the next Section.

3. SITE GEOLOGY REVEALED

3.1 General

The general geology of the Project has already been discussed in the previous section in this chapter and a geological map and profile at a scale of 1 : 2,000 along the route was prepared in the Cardno & Davies Study.

In amplification of the above results, the following were revealed on the site :

a) Stratigraphy

Geology along the project road route consists of the Apanaipi formation and alluvial deposits. The Apanaipi formation is of Tertiary Pliocene age, mainly composed of sandstone, siltstone and conglomerate. The alluvial deposits are of Quaternary age, composed of unconsolidated layers of clay, silt, sand, gravel, peat, etc., which form the alluvial plain, alluvial fans, talus, colluvial slopes, etc.. Coral limestone is seen below the Lakekamu and Tauri rivers, which may be included in the Apanaipi formation.

b) Weathering of the Apanaipi formation

According to the field survey, weathering of the Apanaipi formation is assumed to be as follows :

- Surface part 0.5 to 1 m deep, highly weathered and decomposed condition, which is very similar to that of the alluvial deposits.

- Borehole No. Q1 (Palipala hills, mainly fine grained sandstone) suggests that the depth of highly weathered condition (D[1] class of rock classification) is more than 30 m.

- Borehole No. Q2 (Ilabala hills, mainly coarse grained sandstone) suggests that the depth of highly weathered D class rock is 5 m from ground surface. Rock from 5 m to 30 m deep is moderately weathered CL[2] class rock.

- Fresh and hard rocks could not be found in boreholes No. Q1 and Q2.

- CM[3] to CH[4] class hard and fresh rocks are seen in some existing borrow pits below 10 m depth from the ground surface. While such fresh rocks may be very rare in shallow places along the project route, there is some possibility of finding them deeper than 10 m.

<u>Note</u> Rock classifications are given below :

1） D: Very soft, highly weathered, fractured and/or altered rocks. Rock-forming minerals are highly weathered. Joints and cracks are very loose, easily collapse by week hammering, which contain clay and other materials. Very dull sound is emitted when hammered.

2） CL: Soft and weathered rocks. Rock minerals are weathered. Exfoliation occurs easily along joints and cracks by hammering. Joints and cracks contain clay and other materials. Dull sound is emitted when hammered.

3） CM: Slightly soft and moderately weathered rock. Rock-forming minerals, except quartz, are weathered or altered. Exfoliation occurs along joint and cracks by hammering. Joints and cracks sometimes contain clay and other materials. Slightly dull sound is emitted when hammered.

4） CH: Fairly hard and slightly weathered rocks. Rock-forming minerals, except quartz, are weathered or altered. Tightness of joints and cracks is slightly reduced and each block is apt to be exfoliated along joints and cracks which sometimes contain clay and other materials, stained by limonites. Slightly dull sound is emitted when hammered.

c) Alluvial deposits and swamps

At the northern end of the Lese, the route swings northwest and runs along former shoreline dunes (sand ridges), then crosses the Kapuri river to the Ilavala hills, where wide swamps are developed on the alluvial floodplain.

From the Ilavala hills the route crosses the Lakekamu river and Tauri river near Terapo mission and then runs north to Malalaua town along the existing old road. In this section, the route is located on the alluvial plain, crosses some swampy areas, such as Makara river, Divola creek, Sappaharo river and Opou swamp.
These alluvial deposits from Palipala hill end to Malalaua investigated are illustrated below as the schematic geological profile in Figure 4-10* to 12*.
Details reviewed through mechanical borings are discussed hereinafter.

3.2 Site Geology

3.2.1. Bereina town - Babanongo village

The route from Bereina Town to Babanongo village traverses a series of narrow swampy re-entrants along small creeks (Taiena creek, Agobino creek, etc.) and separated at the northeastern edge of the Inapi ridge (Inapi anticine) by branching ridges.

The branching ridges are formed of weathered sedimentary rocks, mainly conglomerate of the Apanaipi formation. The rocks are generally highly weathered and in unsound condition for about 20m deep or more. The small creeks form unconsolidated alluvial deposits such as alluvial fans, river beds and talus.

In this section, boring investigations were performed in Taiena creek and Agobino creek. The geological conditions of both creeks were found to be as follows :

a) Taiena Creek.

Borehole No. B1 (depth 10 m) was drilled on the left bank of the creek. The results are summarized in the geological profile of the site as shown in Figure 4-13*, namely :

- Surface soil is about 1 m thick composed of silty sand with roots, some gravels, etc..
- Below surface soil, silty clay of alluvial deposit is seen till the bottom of borehole.
- N-values of the silty clay are 11 to 12 at depths from 1 m to 4 m and 18 to 31 at depths from 4 m to 10 m.

b) Agobino creek

Borehole No. B2 (depth 11 m) was drilled on the left bank of the creek. The results are shown in the geological profile as shown in Figure 4-14* and following are given :

- Surface soil is very thin at the borehole point because the boring point was very close to the recent river bed.
- The whole length of the borehole revealed silty clay of alluvial deposit. N-values of this layer are 7 to 12 in the depth from 1 m to 4 m, 17 to 22 in the depth from 4 m to 7 m and 36 to 39 in the depth from 7 m to 11 m.

3.2.2 Babanongo village - Apanaipi village

The project route traverses similar conditions to that of the above section between the Bereina town and Babanongo village along the northeastern foot hills of the Inapi ridge.

The branching small ridges are formed of highly weathered conglomerate or sandstone of the Apanaipi formation.
Boring investigations were made in the Ungongo creek and Miaru river. Geological conditions of the both Ungongo creek and Miaru River are as follows :

a) Ungongo creek

Borehole No. B3 (depth 10 m) was drilled on the left bank of the creek. The geological conditions are shown in the geological profile as shown in Figure 4-15*, namely :

- In the borehole No. B3, surface soil depth is about 1 m. Below surface soil, sandy clay, clay and silty clay of alluvial deposits are seen in the depth from 1 to 2 m, 2 to 5 m and 5 to 10 m respectively.

- N-values of each layer are :

Surface soil	:	Depth 0-1 m	N=4
Sandy clay	:	Depth 1m-2m	N=no data
Clay	:	Depth 2m- 5m	N=6-7
Silty clay	:	Depth 5m-10m	N=14-36

- On the right bank of the creek, a layer of sand with gravel was noted in the portion between clay and silty clay layers with a thickness of 2 to 3 m, which had been confirmed by the auger borings Cu1 and Cu2 undertaken by the Cardno & Davies Study.

b) Miaru river

Bore holes No. B6 (depth 20 m) on the left bank of the river and No. B7 (depth 40 m) on the right bank were drilled. The results are summarized as below and shown in Figure 4-16*.

- Borehole No. B6 shows the depth from ground surface to 1 m is surface soil, from 1 m to 4 m is sandy silt and from 4 m to 20 m is fine to medium grained sand, partly with gravels.

- Borehole No. B7 shows that the depth from ground surface to 3.4 m is silty sand, from 3.4 m to 4.5 m is silty clay and from 4.5 m to 40 m is silty sand.

- Soil layers, their thickness and N-values observed in boreholes No. B6 and B7 may be summarized as follows in order of depth from ground surface to end of holes.

Surface soil :	B6	Thickness	1m	N=no data
	B7	Very thin		
Sandy silt and silty sand :	B6	Thickness	3m	N=3-5
	B7		3.4m	N=3-4
Silty clay :	B6	Lacked		——
	B7	Thickness	1.1m	N= no data
Sand and silty sand :	B6	Thickness more than	16m	N=6-26
		(Upper	8m	N=6-20)
		(Lower	8m	N=3-18)
	B7	Thickness more than	35.5m	N=3-18

No hard layer to support the bridge foundation was found.

- Apanaipi formation may be developed below the above Quaternary deposits, in the zone deeper than 40 meters.

3.2.3 Apanaipi village - Northern end of Lese anticline

The route runs mostly on alluvial fan and talus deposits developed along the western foothills of the Apanaipi anticline and Lese anticline (Palipala Hills). The Apanaipi anticline and Palipala hills are formed by sandstone or conglomerate of the Apanaipi formation which shows nearly similar condition to that of the former section. The route crosses the Alika swamps (alluvial plain deposits, about 450 meters in width) at about 2.5 kilometers north of Apanaipi village.

Alika swamp

Borehole No. B8 (depth 20.8 m) was drilled in the swamp. The geological conditions are summarized below and are shown in Figure 4-17*.

- Water depth of the swamp at the borehole point was about 1.80 m during drilling work in September 1988.

- From ground surface to a depth of 1.8 m is formed of peat, from 1.8 m to 4.7 m is silty clay, from 4.7 m to 7.2 m is sand, from 7.2 m to 18.7 m is silty clay and 18.7 m to 20.8 m is sand, silty sand and clayey silt.

- N-values are all 2 to 12 from surface to a depth of 18m. Sand, silty sand and clayey silt layers in the bottom zone of the borehole from 18 m to 20.8 m show 32 to more than 50.

- Referring to the investigation results by Cardno Davies Study the sand layer which is found in the depth from 4.7 m to 7.2 m in the borehole No. B8 may be continuously developed in the whole section of the swamp.

- Seismic exploration results performed by the Cardno & Davies Study indicate that the baserock of the Apanaipi formation (Vp = 1.8 km/s) exists in a depth of 25 meters below ground surface at the maximum. These results suggest that the bottom sandy and the silty layers which show rather high N-values may correspond to the surface zone of the Apanaipi formation.

3.2.4 Northern end of Lese Anticline - Terapo Mission

The route crosses a wide swampy alluvial flood plain between the northern end of the Lese anticline and the Ilavala hills. It crosses the Kapuri river in the middle of the above swampy plain and the Lakekamu river near the Terapo Mission.
Former shoreline dunes (sand ridges mainly composed of sandy materials) develop in this area in a north west-southeast direction.

And, very soft silty to clayey swamp deposits several meters thick are seen covering the dunes.

The bedrocks of Apanaipi formation may exist at depth, more than 50 m deep except for the area near the Ilavala hills and the Lakekamu river.

The Ilavala hills are formed mainly of highly to moderately weathered D to CL class coarse gained sandstone of the Apanaipi formation.

Boring investigations were undertaken at the Kapuri river, Lakekamu river and in the swamp area developing on the both sides of the Kapuri river.

Geological conditions of this section are summarized in the schematic geological profile of Figure 4-10* & 4-11*.

a) Kapuri river

Boreholes No. B9 (depth 20 m) and No. B10 (depth 50 m) were drilled on the left and right banks of the river respectively. The geological conditions may be summarized as follows and are shown in Figure 4-18*.

- Borehole No. B9 shows that the section from ground surface to the depth 2.6 m is composed of silty clay, from 2.6 m to 10.2 m is clayey sand and from 10.2 m to 20.0 m is silty sand.

- Borehole No. B10 shows that from ground surface to the depth of 1.5 m is clay, 1.5 m to 3.5 m is peat, 3.5 m to 28 m is silty sand and 18 m to 50 m is silty clay.

- Thickness and N-values of each layer observed in boreholes No. B9 and B10 may be summarized as follows in order of depth from ground surface to the end of holes.

Silty clay, clay and peat :	B9	Thickness	2.6m	N=3
	B10	Thickness	3.5m	N=0-3

Clayey sand :	B9	Thickness	7.6m	N=3-13
	B10	Lacked		—
Silty sand :	B9	Thickness more than 9.8m		N=12-41
	B10	Thickness more than 14.5m		N=7-27
Silty clay :	B10	Thickness more than 32m		N=6-20

- Bedrocks of the Apanaipi formation may exist below the depth of more than 50 m.

b) Swamp area

Boreholes No. S2 (depth 11 m), No. S3 (depth 10 m) and No. S4 (depth 17 m) were drilled in the swamp area on the both sides of the Kapuri river. No. S2 and No. S3 are located at approximately 600 meters from the river to Palipala hills and Ilavala hills side respectively. No. S4 distants about 2.8 kilometers from the No. S3 to the Ilavala hills side. Geological conditions are summarized in the schematic geological profile of Figure 4-10* and as follows :

- Soil layers and thier N-values in the above three boreholes are shown below :

Silty to sandy clay :	S2	Depth 0m-5.5m	N=2-8
	S3	Depth 0m-3.5m	N=3-6
	S4	Depth 0m-3.4m	N=3-4
Clayey to silty sand, party clay :	S2	Depth 5.5m-11m	N=4-11
	S3	Depth 3.5m-10m	N=3-14
	S4	Depth 3.4m-17m	N=3-13

- Sandy layer in the above may be the former shoreline dunes (sand ridges), which is assumed to be continuously distributed below the whole swamp area. In the boreholes of the Kapuri river (No. B9 and B10), the thickness of this sand layer is about 15 m or more.

- The clayey layer covering the above sandy layer is distributed widely in the swamp area but the thickness of this layer seems to be rather thin, may be several meters in the whole swamp section. The records of auger borings performed by Cardno & Davies Study also indicate that the thickness of this layer is about 5 m at the maximum.

c) Lakekamu river

Boreholes No. B11 (depth 10 m) and No. B12 (depth 8 m) were drilled on the left and right banks of the river respectively. The geological conditions are shown in Figure 4-19* and as follows :

- Borehole No. B11 shows that the section from ground surface to the depth of 5.5 m is sandy clay, 5.5 m to 8.5 m is sand and 8.5 m to 10 m is coral limestone.

- Borehole No. B12 shows that the depth from ground surface to 1 m is sandy clay, 1 m to 4 m is clayey sand to sand and 4 m to 8 m is coral limestone.

- Thickness and N-values of each layer in both boreholes are as follows :

Surface soil :	Thickness 0.5m	
Sandy clay :	Thickness 1m(B11)-5m(B12)	N=3-5
Clayey sand and sand :	Thickness 3m	N=6-13
Limestone :	Thickness more than 1.5m(B11) and 4m(B12)	N=42 or more than 50

- The coral limestone which may be Apanaipi formation is assumed to be developed continuously below the Lakekamu river.

3.2.5 Terapo mission - Malalaua town

The route crosses the Tauri river near the Terapo Mission and then traverses the Makara river, Divola creek, Sappaharo creek and Opou swamp along the swampy alluvial flood plain.
Boring investigations were carried out the above rivers, creeks and swamp. The geological condition of this section is shown in the schematic geological profile of Figure 4-11* & 4-12* and indicates as below :

a) Tauri river

Boreholes No. B13 (depth 15 m) and No. B14 (depth 15 m) were drilled on the left and right banks of the river respectively. the geological conditions of the site are summarized in Figure 4-20* and are discussed as follows :

- Borehole No. B13 shows that the section from ground surface to the depth of 4.5 m is surface soil and sandy clay of alluvial deposits, and from 4.5 m to 15 m is coral limestone, silty mudstone, sandstone and conglomerate of the Apanaipi formation.

- Borehole No. B14 shows that surface soil and sandy clay of alluvial deposits are seen in the section from ground surface to the depth of 5.8 m, and from 5.8 m to 15 m is coral limestone, silty mudstone and sandstone of the Apanaipi formation.

- Thickness of the alluvial deposits (surface soil and sandy clay) in the both boreholes are 4.5 m to 5.8 m, and their N-values are 0 to 6. This alluvial deposits of Tauri River may not be seen at about 200 m point towards the Makara river.

- N-values of the coral limestone and the Apanaipi formation are 14 to 30 in the surface logs for about 1 m deep and 46 to 50 or more below 1 m.

- The coral limestone and the Apanaipi formation are assumed to be continuously developed below the Tauri river, and also may be continued to the coral limestone of the Lakekamu river as shown in Figure 4-10*.

b) Makara river

Boreholes No. B15 (depth 25 m) and No. B16 (depth 40 m) were drilled on the left and the right banks respectively. The geological condition is shown in Figure 4-21* and discussed as below :

- Soil layers of the alluvial deposits and N-values of each layer may be summarized as follows :

Surface soil and silty clay to clay :	B15	Depth 0m to 4m	N=5-6
	B16	Depth 0m to 2m	N=6
Sand :	B15	Depth 4m to 9.7m	N=5-7
	B16	Depth 2m to 6m	N=8-10
Clay :	B15	Depth 9.7m to 20m	N=5-7
	B16	Depth 6m to 23m	N=5-10
Silt to silty day :	B15	Depth 20m to 25m	N=8-26
	B16	Depth 23m to 30m	N=15-26

- The baserocks of the Apanaipi formation may exist in the zone deeper than 40 m.

c) Divola creek

Borehole No. B17 (depth of 30 m) was drilled on the right bank of the creek. The soil layers and these N-values in the borehole No. B17 may be summarized as follows :

Surface soil :	Depth 0 to 0.5m	N=no data
Sand :	Depth 0.5m to 5.5m	N=3-13
Clay :	Depth 5.5m to 21m	N=3-10
Clayey sand to sand :	Depth 21m to 30m	N=12-22

The above sand layer in the shallow zone is assumed to be continued to the sand layer in the Makara river which may be the former shoreline dunes.

d) Sappaharo creek

Boreholes No. B18 (depth 23 m) and No. B19 (depth 23 m) were drilled on the left and right banks of the river. The geological conditions are summarized in the geological profile of Figure 4-22* and are discussed as follows :

- Soil layers of alluvial deposits and those N-values are as follows :

Surface soil and sandy clay :	B18	Depth 0-1m	N=3
Sandy clay :	B19	Depth 0-13m	N=4-7
Clayey sand-sand :	B18	Depth 1m-6m	N=3-11
	B19	Depth 3m-8m	N=4-11
Clay-sandy clay :	B18	Depth 6m-20m	N=3-7
	B19	Depth 8m-21.5m	N=3-7
Sand-silt :	B18	Depth 20-23m	N=9-11
	B19	Depth 21.5-23m	N=24-58

- All the above layers are assumed to be continued to the same soil layers in the Divola creek.

e) Opou swamp

Boreholes No. B20 (depth 25 m) was drilled at the shoulder of existing road in the swamp. Drilling log is shown in Figure 4-12*. The soil layers of alluvial deposits and these N-values are as follows :

Road embankment : Depth 0 to 2m N=3-7

Gravelly clay,
Peat and bogwood : Depth 0 to 6.4m N=15-more than 50

Sandy clay to clay : Depth 6.4m to 25m N=2-15

No sand layers were found in this borehole.

3.2.6 Construction material source site

For the embankment materials and pavement materials, boring investigations were performed in the Palipala hills, Ilavala hills and Eboa quarry site (small hills near Eboa village). The geological conditions of each site are discussed as follows :

a) Palipala hills

Borehole No. Q1 (depth 30 m) was drilled at the hilltop of the Palipala hills near the project route at CH. 54+00 as shown in Figure 4-3* of Appendix.

Geological conditions may be summarized as follows :

- The height of hill is nearly 80 m above the alluvial plain. The lower half of slopes of the hill is covered by thin talus deposits and the upper half is covered by only surface soils with grass. The talus deposits are composed of sandy materials with rock fragments, and the thickness may be several meters.

- Outcrops of bedrocks which are mainly loose and highly weathered fine grained sandstone and partly conglomerate of the Apanaipi formation and scattered only in the upper half slope of the hill.

- Bore hole No. Q1 shows that :

  Surface soil : Depth 0-0.35m

  Sandstone, partly siltstone : Depth 0.35m-30m

Sandstone is fine grained, D-CL class highly weathered rocks. Siltstone is very soft. Recovered cores are mostly decomposed rocks, being sandy materials with small rock fragments. Some cylindrical cores were seen at depth but these were easily broken by hand or hammering. No fresh or hard rocks could be found in this borehole.

b) Ilavala hills

Borehole No. Q2 (depth 30 m) was drilled at the northern hilltop of the Ilavala hills. The location is shown in Figure 4-4*. Geological condition may be summarized as follows :

- The height of the hill is about 50 meters above the surrounding alluvial plain (colluvium slope). The foot of the slope is covered thinly with talus deposits which are formed of sandy materials with rock fragments.

- Bedrock outcrops which are mainly highly weathered coarse grained sandstone and partly conglomerate of the Apanaipi formation are scattered on the upper slopes of the hill.

- Borehole No. Q2 shows that all portions from ground surface to the end of borehole 30 m deep are composed of coarse grained sandstone with thin layers of conglomerate and siltstone. D class highly weathered and decomposed rocks are seen in the section from ground surface to 5 m. Below 5 m, CL class moderately weathered rocks increased linearly to the bottom of hole. CL class rocks show many cylindrical cores but these are easily broken by hammering. No fresh and hard rocks could be found in this borehole.

c) Eboa quarry site

Eboa quarry site is located at about 15 km east of the Bereina town as shown in Figure 4-5*. Borehole No. Q3 (depth 10 m) was drilled at the top of eastern hill of the Eboa quarry site. The geological conditions may be summarized as follows :

- The height of hill is about 60 m above the surrounding alluvial swampy plain. Foot of hill slopes is covered by very thin talus deposits which are formed of sandy materials, many rock fragments and boulders.

- Bedrocks are agglomerates of the Mount Davidson Volcanics formation of Tertiary Pliocene age. There are many outcrops on the slopes which are mostly hard and massive conditions.

- Borehole No. Q3 indicates that all logs from ground surface to the hole bottom 10 m deep are composed of CL and CM class moderately to slightly weathered agglomerates.
  Cores of the CL class rocks are formed by mostly rock fragments but CM class rocks are formed by many cylindrical cores which are hard and nearly fresh condition.

d) Test pit at Malalaua quarry

- JICA study team planned for Miaru river to Malalaua Section to apply the gravelly soil from Malalaua quarry or sub - base and base courses by cemment stabilization.
  To assure the total deposits, four (4) test pits were newly dug in the quarry in July 1989.
  The locations of four (4) test pits and their soil layers are shown in Figure 4 - 23* in Appendix.

- Besides the above, JICA study team found that conglomerate appeared below the sandy gravel layer at the existing Malalaua quarry which was not assured in the investigation of 1988.

- It was judged accordingly that sandy gravel deposits are situated in the limited layer of 2.5 - 3.5m thick below the overburden of 5.0 - 6.0m which will oblige the extra soil excavation of 350,000m^3.

4 LABORATORY TESTS CONDUCTED BY DOW

4.1 Soil Laboratory Tests on Soft Ground

4.1.1 Sampling

Samplings for the soil tests on soft ground were made with thin walled tubes (undisturbed) and Raymond samplers (disturbed). These samples, obtained by mechanical borings on sites, were carried by helicopter to the DOW Materials Testing Laboratory. The test results were incorporated in the Local Condition Reports.

4.1.2 Test method by item

The test methods applied were those of the Australian Standards (AS) together with the Japan Industrial Standards (JIS) and the quantity tested by items are shown in Table 4-4.

4.1.3 Summary of physical properties

The Physical properties of soils were checked by the natural water content, the wet density, the fine-grained soil content, the plasticity chart and the void ratio. The results are shown in Figures 4-24* to 4-28* of Appendix. The natural water contents of sandy soils are in the range of 25% to 40%, and those of silty or clay soils are of 35% to 75%, but the sample of B9 (Kapuri river) only was 96%. The wet densities of silty or clay soils are 1.6 ton / m^3 to 1.9 ton / m^3 and those of sandy soils are 1.8 ton / m^3 to 2.0 ton / m^3. The fine-grained soil contents (less than 74 μm) of silty or clay soils are 58% to 99% and those of sandy soils are 11% to 32%.

The plasticity chart of soil samples from each borehole calculated shows that LL & PI of them are distributed along the A-line. Most of silty and clay soils are classified MH or CH soil group of AASHTO.

The void ratios of sandy soils are 0.7 to 0.9 and those of silty or clay soils are 0.9 to 1.8 but the sample of B9 was 2.5.

Table 4-4 METHOD & NUMBER TESTED FOR SAMPLES FROM BORING

Test Item	Method Number	Quantity UD[3]	D[4]
Natural water content	AS 1289. B1. 1	49	—
Liquid limit	AS 1289. C1. 1	(30)	(62)
Plastic limit	AS 1289. C2. 1	(30)	(62)
Shrinkage limit	AS 1289. C4. 1	(30)	(62)
Specific gravity	AS 1289. C5. 1	(42)	—
Particle size distribution	AS 1289. C6. 1 and C6.3	(56)	(49)
Unconfined compression	JIS[1] A1216-1977	31	—
Triaxial Compression	JSF[2] C (AS 1289. F4. 1 equivalent)	39	—
Consolidation	JIS[1] A1217-1980	41	—
PH	AS 1289. D3. 1		—

Note: 1) Japanese Industrial Standard

2) Standard of Japanese Society of Soil Mechanics and Foundation Engineering

3) UD : Undisturbed

4) D : Disturbed

Most soils of the soft ground are well saturated with more than 96% water content in the voids.

The specific gravities of sandy soils are 2.60 to 2.74 and those of silty and clay soils are 2.48 to 2.82.

4.1.4 Summary of mechanical properties

The mechanical properties of soils were checked for shear strength (cohesion); compression index; coefficient of consolidation; and elastic modulus and the results are shown with relationship of the depth sampled in Figure 4-29* to 4-32* respectively.

The cohesion of soft ground is 0.06 kgf/cm^2 (5.9 KPa) to 0.35 kgf/cm^2 (34.3 KPa), but the sample of B11 (Lakekamu river) showed 0.55 kgf/cm^2 exceptionally. The value of cohesion in the Project area falls in the range from 0.06 kgf/cm^2 (5.9 KPa) to 0.2 kgf/cm^2 (19.6 KPa).

The compression indexes show very small values of 0.11 to 0.23 in sandy soils and 0.25 to 0.7 in silty or clay soils.

The coefficients of consolidation are 20 cm^2/d to 200 cm^2/d which decrease according to the depth.

The elastic modulus (E_{50}) of soft ground at shallow portion are 6 kgf/cm^2 (588 KPa) to 29 kgf/cm^2 (2842 KPa), and at deeper portion are 3 kgf/cm^2 (294 KPa) to 17 kgf/cm^2 (1,666 KPa).

It is pointed out that the thick soft silty clay layer from Makara river to Sappaharo creek has a very low Elastic modules of 6.1 kgf/cm^2 (598 KPa) on average and 10.3 kgf/cm^2 (1009 KPa) in the shallow portion.

4.2 Embankment Materials

4.2.1 Sampling

The samplings for the soil tests were taken at prospective borrowpits at Palipala hills, Ilavala hills, Malalaua hills, Lakekamu river mouth and Babanongo existing pit. the materials sampled were taken to the DOW Laboratory and tested there by DOW technicians.

4.2.2 Test methods

The test methods mostly applied were of AS as shown in Table 4-5, but the Triaxial Compression Test was done with the Standard of Japanese Society of Soil Mechanics and Foundation Engineering (JSF).

4.2.3 Summary of test results

Test results of these materials are summarized in Table 4-6.

The materials excavated in Inapi ridge between Bereina and Miaru river are weathered conglomerates and weathered sandstone. They are applicable to the sub-base course as discussed hereinafter. The representative material of this zone was sampled from the existing borrow pit near Babanongo village (Sample No.: 88/265) which is composed of sandy gravel.

The material of the Palipala hills (No.: 88/266) is composed of weathered sandstone containing some content of finer parts less than 75 µm which may not be applied for sand mat material. According to the grain size analysis, the material is classified as silty sand containing 25 per cent (%) silt.

The material of Ilavala hills (No.: 88/310A) is composed of weathered sandstone containing rather a smaller content of finer parts (less than 75 µm) than that of Palipala hills.

Table 4-5 METHOD & NUMBER TESTED FOR EMBANKMENT MATERIALS

Test Item	Method of Number	Quantity	KEY
Natural water content	AS 1289. B1. 1	5	Nat w
Liquid limit	AS 1289. C1. 1	4	LL
Plastic limit	AS 1289. C2. 1	4	PL
Shrinkage limit	AS 1289. C4. 1	4	LS
Specific gravity	AS 1289. C5. 1	(5)	GS
Particle size distribution	AS 1289. Cb. 1 and Cb. 3	5	PSD
Compaction	AS 1289. E1. 1 and E2. 1	5	MDD Opt w
CBR	AS 1289. F1.1	8	
Triaxial compression	JSF C*	3	TCT

* STANDARD OF JAPANESE SOCIETY OF SOIL MECHANICS AND FOUNDATION ENGINEERING

Table 4-6 EMBANKMENT MATERIALS TESTED

Test Item \ Location		Palipala Hills 88/266	Ilavala Hills 88/310A	Malalaua Hills 88/349	Lakekamu River Mouth 88/351	Babanongo 88/265
Nat w (%)		8~12	7	50	8	6
LL (%)		29	39	61	—	39~41
PL (%)		16~17	22	29	—	25~26
PI		12~13	17	32	—	14~15
LS (%)		4~5.5	8	9	—	8.5~9.5
Gs						
PSD (%)	Gravel	0	28	1	0	64~66
	Sand	75~76	62	22	99.5	23~27
	Silt Clay	24~25	10	77	0.5	9~11
MDD (t/m^3)		1.71~1.76	1.77	1.2	1.58	2.05~2.09
Opt w (%)		16	15	36	12	10
TCT	Cd(kgf/cm^2)	0.35	0.65	—	—	1.6
	Ød(degree)	33.5	37.5	—	—	44
CBR (%)	Opt w	3.9	12	11, 14	8.2	15
	Nat w	3.3, 6.8, 9.4	5.3, 8.2	3.7	—	—

PI : Plasticity Index
MDD : Maximum Dry Density
Opt w : Optimum Water Content

The grain size analysis classified the material as gravely sand containing 10%-finer silt which could be applicable for the sand mat layer, if well engineered with perforated pipe drainage.

The material (No.: 88/349) of Malalaua hills near the airfield taken from surface soil is composed of sandy silt. The natural water content is high at 50%, and its dry density is low at 1.2 ton/m^3 with the optimum water content (o m c) of 36%. This material is so highly cohesive that it will only be recommended as embankment material after re-checking.

Instead of this silty material, the material (No: 88/309) from the existing borrow pit further north, 2.0 km from Malalaua hills, is suitable for road filling material of which the maximum dry density is 2.03 ton/m^3 with the o. m. c of 11%.

The coast sand (No: 88/351) was sampled from the mouth of the Lakekamu river and tested. The content of finer parts less than 75 μm is only 1.0%, therefore the sand is no great problem as the material for mat layer.

4.3 Pavement Materials

The pavement material tests for subbase, base course and cover aggregate were carried out in the DOW Materials Testing Laboratory. The test items and testing methods are shown in Table 4-7.
The detailed results are shown below :

4.3.1 Subbase materials

(1) Non Treated Sandy Gravel

The naturally occurring sandy gravel materials (gravel-sand-clay) taken from three existing borrow pits ; near Bereina, near Babanonga village and Malalaua north 2 km, were tested, and shown in Table 4-8* to 4-10*.

Bereina sandy gravel :
Natural water content is 6~7%, Plastiicity index is 16~23%, Maximum size is about 50 mm and percent passing of 75 μm sieve is 11~14%, Grain-size distribution is well-graded.
Maximum dry density is 2.05~2.09 and Soaked CBR value is 30~50%.

Babanonga sandy gravel :
Natural water content is 6%, Plasticity index is 14~23%, Maximum size is about 50 mm and percent passing of 75 μm sieve is 14~15% and Grain-size distribution is well-graded.
Maximum dry density is 2.05~2.08 and Soaked CBR value is 15%.

Malalaua sandy gravel :
Natural water content is 8~10%, Plasticity index is 7~11%, Maximum size is about 40 mm and percent passing of 75 μm is 8~13% and Grain-size distribution is well-graded.
Maximum dry density is 2.01~2.08 and Soaked CBR value is 15~18%.

Table 4-7 METHOD & NUMBER TESTED FOR PAVEMENT MATERIALS

Test Item	Methods	Quantity
Natural Water Content	AS 1289 B1. 1	8
Liquid Limit	AS 1289 C1. 1	12
Plastic Limit	AS 1289 C2. 1	12
Shrinkage Limit	AS 1289 C4. 1	8
Particle Size Distribution by Dry Sieving	AS 1141 Sect. 11	8
Compaction	AS 1289 E1. 1 and E2. 1	8
California Bearing Ratio	AS 1289 F1. 1 - 1977	10
Unconfined Compressive Strength of Compacted bound Materials	AS 1141 51	7
Bulk Density and Water Absorption of Coarse Aggregate	AS 1141 Sect. 6	4
Los Angels Abraison Loss	AS 1141 Sect. 23	3
Soundness - by use of Sodium Sulphate Solution	AS 1141 Sect. 24	4
Flakiness Index	BS 812	1

(2) Cement Treated Sandy gravel

Most of the sandy gravel test results do not meet the DOW specification requirements for the Plasticity index not more than 10% and the soaked CBR value not less than 25%. In order to improve on the plastic nature of these sandy gravels caused by containing some amount of silt and clay, the addition of cement to these sandy-gravels was tested. The addition of type A portland cement improved the soil nature as shown in Table 4-11* & 4-12*.

By adding of 1.0% cement to the dry aggregate, the Plasticity index is reduced from 40~38% to 6~3% and the soaked CBR is increased from 15% to 50%.
By adding of the 2.0% cement, the Plasticity index is reduced from 39~37% to 3~5% and the soaked CBR value is increased from 15% to 110%.

4.3.2 Base course materials

(1) Eboa quarry crushed stone

Rock sample were taken from Eboa quarry and crushed for base course aggregate size at the DOW Materials Testing Laboratory.

Specific gravity is 2.24, Water absorption is 4.5%. Los Angeles abrasion loss is 24% and this conforms to DOW specification requirements for the coarse aggregate for base course materials.

(2) Cement treated Malalaua sandy gravel

Since the test results of untreated sandy gravel did not meet DOW specification requirements for base course materials, cement stabilization tests for Malalaua pit-run sandy gravel were done, as shown in Table 4-13*.
By adding type A portland cement to the dry aggregate 2%, 3%, 4% and 5%, the unconfined compressive strengths at 7-day curing are nearly 6~10 kg/cm^2, 13~14kg/cm^2, 14~16kg/cm^2 and 20 kg/cm^2 respectively. The recommended criteria of unconfined compressive strength for cement treated base course by Road Note 31 is 2501b/cm^2 (18kg/cm^2).

4.4 Cover Aggregate for Bituminous Surface Treatment

Tests were carried out on rock samples from Eboa quarry and cobble size river gravel from Angabanga river and Tauri river.

4.4.1 Eboa quarry rock samples

Sample from the quarry surface :
Specific gravity is 2.24, water absorption is 4.5%, Los Angeles abrasion loss is 24% and Sodium Sulphate soundness is 9.1%. These test results conform to DOW specification requirements for cover aggregates for bituminous surface treatment, however the material quality is considered to be the minimum satisfactory level.

Sample from the boring core was brought to and tested in Japan.
Specific gravity is 2.33, Water absorption is 7.3%.
Sodium Sulphate is 100% and this does not conform to DOW specification requirements of not more than 12%. The material quality is considered to be unsatisfactory as shown in Table 4-14*.

4.4.2 Angabanga river cobble and Tauri river cobble

Angabanga River Cobble :
Specific gravity is 2.70, Water absorption is 1.0%, Los Angeles abrasion loss is 17% and Sodium Sulphate soundness is 1.5%. The test results conform to DOW specification requirements and the material quality is considered to be satisfactory for the crushed stone cover aggregates.

Tauri River Cobble :
Specific gravity is 2.60, 'Water absorption is 2.9%, Los Angeles abrasion loss is 24% and Sodium Sulphate loss is 5.7%. The test results conform to DOW specification and the material quality is considered to be satisfactory for the crushed stone cover aggregates.
Above results are shown in Table 4-15*.

4.5 Concrete Aggregate

Sampling for fine and coarse aggregate for concrete work were taken at the upper reaches of Angabanga river, Tauri river and Karama river respectively.
The test items and method are shown in Table 4-16.
The test results are shown in Table 4-17.

According to the results, it can be said that the materials from Karama river are not suitable for use as concrete aggregate due to the high content of organic impurities in the sand and unsoundness of the gravel.

Table 4-16 METHOD & NUMBER TESTED FOR CONCRETE AGGREGATE

Test Item	Method of Number		Quantity	KEY
Bulk Density and Water Absorption of Fine Aggregate	AS 1141	Sect. 5	3	BD,WA
Bulk Density and Water Absorption of Coarse Aggregate	AS 1141	Sect. 6	3	BD, WA
Particle Size Distribution by Dry Sieving	AS 1141	Sect. 11	3	PSD
Aggregate Crushing Value	AS 1141	Sect. 21	3	ACV
Los Angeles Value	AS 1141	Sect. 23	3	LA
Soundness (by Use of Sodium Sulphate Solution)	AS 1141	Sect. 24	C3 F3	SS
Organic Impurities Other than Sugar	AS 1141	Sect. 34	3	OI

Table 4-17 CONCRETE AGGREGATE TESTED

Test Item \ Location		ANGABANGA 88/367	TAURI 88/366	KARAMA 88/365	Suggested Limit
PSD	Gravel	56	80	66	66
	Sand	41	19	29	29
	Silt	3	1	5	5
Coarse	BD 1」	2.7	2.6	2.6	2.3
	WA	1.0	2.9	2.7	5
	ACV	15	21	20	
	LA	17	24	30	
	SS	1.5	5.7	24.0 2」	12
Fine	BD	2.7	2.6	2.6	2.3
	WA	1.6	4.2	3.9	5
	SS	3.9	11.0	27.1 2」	16
	OI	1	1.2	2	

Note : 1」 Key words be referred to Table 4-15.
2」 Test shows the material from Kamara is out side of DOW specifications.

CHAPTER V HYDROLOGICAL AND HYDRAULIC ANALYSIS

1. FLOOD ANALYSIS

1.1 Peak Flood Discharge

Flood analysis was carried out by applying the Regional Flood Frequency method (RFF)[1] and the Rational method[2] of the Flood Estimation Manual, DOW, March 1973.

RFF method was applied to four major river basins, namely the Miaru river, Kapuri river, Lakekamu river and Tauri river. The Rational method was applied to the residual basins. Fig. 5-1 shows the Project catchment area with the locations of available gauging stations for stream flow and rainfall.

From the study of hydrological data available for the Project area, the water year, bounded by the time of lowest average rainfall or runoff, was defined as beginning in August.

Table 5-1 shows calculation by RFF method varying RIX (Rainfall Intensity Index) value from 110 mm to 130 mm. Values of RIX, RSX (Rainfall Slope Index) and QFF (Discharge Frequency Function) are adopted referring to figures in the Flood Estimation Manual shown in Figures 5-2* - 5-4* in Appendix.

Se (equal area slope) of four major rivers are illustrated in figures of river profile as shown in Figures 5-5* - 5-8* of Appendix.
Figure 5-9* of Appendix shows the linear relationship between specific peak discharge and catchment area at logarithmic scales obtained from the above calculation results.

Note 1 : Regional Flood Frequency method may be used for all catchments greater than 20 km^2

2 : Rational method may be used for all catchments less than 100 km^2 in area.

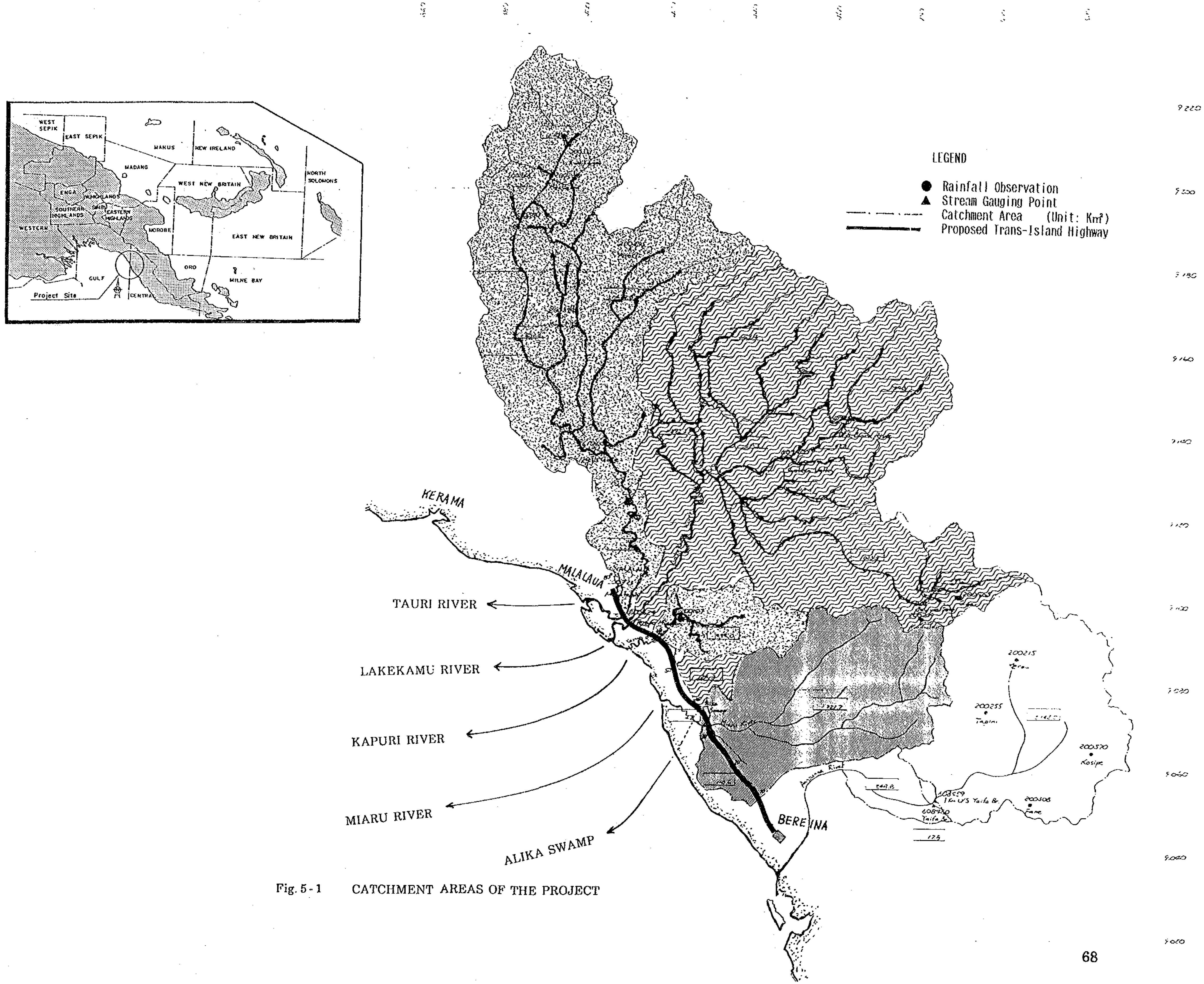

Fig. 5-1 CATCHMENT AREAS OF THE PROJECT

Table 5-1 PEAK FLOOD DISCHARGE OF MAJOR RIVERS BY REGIONAL FLOOD FREQUENCY METHOD

River	C.A. (km^2)	RIX (mm)	Q_2 (m^3/s)	RSX	Q_{10}/Q_2	QEF	Q_{100} (m^3/s)	Sp
Miaru	1721.7	110	891	1.45	1.51	2.15	1914	1.11
		120	953	do.	do.	do.	2048	1.19
		130	1014	do.	do.	do.	2179	1.27
Kapuri	494.0	110	433	1.45	1.65	2.48	1071	2.17
		120	450	do.	do.	do.	1114	2.25
		130	467	do.	do.	do.	1155	2.34
Lakekamu	5393.2	110	1972	1.45	1.39	1.88	3702	0.68
		120	2110	do.	do.	do.	3960	0.73
		130	2245	do.	do.	do.	4213	0.78
Tauri	4092.6	110	1628	1.45	1.42	1.94	3157	0.77
		120	1741	do.	do.	do.	3377	0.83
		130	1852	do.	do.	do.	3593	0.88

Where, Q_n : Peak discharge for return period of n years.

Q_2 for catchment area over 500 km^2

$$Q_2 = 0.1311 * A^{0.696} * RIX^{0.774}$$

Q_2 for catchment area from 20 to 500 km^2

$$Q_2 = 0.2148 * A^{0.911} * RIX^{0.453} * Se^{0.203}$$

where Se is equal area slope in %

$$Q_{10}/Q_2 = 1.672 * RSX^{1.143} * A^{-0.0706}$$

A : Catchment area in km^2

Sp : Specific flood discharge in $m^3/sec/km^2$

1.2 Design Peak Flood Discharge

Based on the water year, the probable peak flood discharge for several Average Recurrence Intervals (ARI) was calculated as shown in Table 5-2* of Appendix by Pearson III Method.
Estimated specific peak discharge for ARI of 100 years were plotted in Figure 5-9*. The value for Hells Gate on the Tauri river which has the most reliable data for 29 water years shows close relation to the line derived from the Regional Flood Frequency method.

Considering the catchment modification factor of 1.25 (Ref. Flood Estimation Manual, Figure 5-9*), the probable peak flood discharge of 100 years return period at Hells Gate was estimated as 2,748 m^3/sec and the specific peak discharge as 1.143.

As shown in Figure 5-9*, this modified peak discharge is close to the line derived from RFF method when RIX is 130 mm. Therefore the design peak flood discharge for the four main rivers was decided by reference to estimated results by RFF method (when RIX is 130 mm) as summarized in Table 5-3*.

Rainfall gauging stations are sparse in relation to the huge catchment area of the Project.
Along the proposed road alignment, there is only one reliable station with a continuous long term data series - Bereina station. Table 5-4* shows annual rainfall statistics in and adjacent to the Project area.

The design rainfall (the point rainfall) intensity curve was estimated by reference to the Flood Estimation Manual as illustrated in Figures 5-10* - 5-12*. Rainfall intensity, ($I_{tc.y}$) was estimated by following formula :

$$I_{tc.y} = \alpha \times REF \, [\, Y \, (RIX - R^{10min}_{2yrs}) + R^{10min}_{2yrs} \,] \, / \, t$$

Where, α : Conversion factor.

Return period (years)	;	2	5	≧ 10
Conversion factor	;	1.08	1.02	1.00

REF : Rainfall Frequency Function. (Fig. 5-13*)

Y : Value of rainfall duration factor. (Fig. 5-14*)

RIX : Rainfall index. (Fig. 5-2*)

R^{10min}_{2yrs} : 10 minute, 2 year rainfall (Fig. 5-15*)

To estimate R^{10min}_{2yrs}, mean annual rainfall was adopted as 1,500 mm from Fig. 5-16*

t : Duration. hour.

The estimated design peak flood discharge for the creek bridge sites proposed by Cardno & Davies Study except for the four main rivers are listed in Table 5-5.

Table 5-5 DESIGN DISCHARGE OF CREEK RIVERS BY RATIONAL METHOD

Item	Taiena creak	Agobino creek	Ungongo creek	Anina swamp	Alika swamp	Makara river	Divola creek	Sappaharo river	Opou swamp
Area (km^2)	9.2	9.3	61.4	4.1	124.3	1.8	0.4	2.8	2.2
Length (km)	7.2	5.7	15.5	4.3	24.6	1.8	0.8	3.0	2.0
se (%)	0.723	0.784	0.360	1.205	0.052	0.038	0.038	0.038	0.038
Tc (min)	225.3	175.2	461.0	131.7	1002.9	119.5	61.7	190.5	130.1
Ka	0.89	0.90	0.70	0.94	0.67	0.95	1.00	0.94	0.95
C	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45

Once in 100 years

Itc.y (mm/h)	46.9	56.8	28.9		15.0	95.3		68.4	
Q (m3/sec)	47.9	59.4	155.3		156.2	20.4		22.5	

Once in 50 years

Itc.y (mm/h)				69.5			129.8		81.9
Q (m3/sec)				33.5			6.5		21.4

Where,
- Se : Area equivalent slope
- Tc : Time of concentration
- Ka : Rainfall areal reduction factor
- C : Runoff coefficient
- $I_{tc.y}$: Point rainfall intensity

2. DETERMINATION OF HWL

2.1 HWL of Major Rivers

To estimate flood water level, the flood hydrograph was calculated by referring to shape parameters for typical hydrographs in the Flood Estimation Manual.
Figure 5-17* shows the relation between parameters

Based on the river cross section survey at the proposed bridge site, rating curves were estimated for the four main rivers. The flow condition was assumed to be uniform flow. Figure 5-18* shows uniform flow rating curves for the four main rivers.

According to the results of uniform flow estimation, the bank full capacity is smaller than the design peak flood or flood record at the gauging station obtained in the past. From the study on topographical map, flow capacity at upstream in the flood plain was judged almost same with or less than the flow capacity at bridge site. Therefore when the flood occurs, the flood will start to overflow from the point where the river leaves the mountainous area and enters the plain area.

Fig. 5-19* shows 24 hours observation of the four main rivers water levels at staff gauges installed near or at each bridge site. The figure shows that each river has a tidal affect. Especially the Kapuri, Lakekamu and Tauri rivers show remarkable tidal affects.

Flood simulation was carried out by combining routine and non-uniform calculation of floods considering sea water level changing by tide phenomena. This simulation made clear that existing rivers have limited capacity to pass flood discharges, it is hard to determine reliable flood peak water levels with the limited point information on such a huge flood plain, unless the topographical data to cover the flood plain are clear.

Finally design flood water levels were adopted as listed in Table 5-6 after referring to information obtained from local inhabitants during the field investigations.

Table 5-6 DESIGN FLOOD WATER LEVEL OF MAIN RIVERS

RIVER	FWL (m)	Flood height from ground (m)	ground height (m)
Miaru	5.0	(0.5) 2.5 - 3.0	(4.5) 2.0
Kapuri	1.4	0.9	0.5
Lakekamu	2.5	Not flooded (Terapo Side)	2.0
Tauri	2.5	0.7	1.8
Makara	2.1	Not flooded	2.1
Sappaharo	2.8	Not flooded	3.0

2.2 HWL of Creeks

Flood water levels at the creek bridge sites proposed in the Cardno & Davies Study except four major rivers were estimated by flood routine. Estimation formula is,

$$\frac{I_1+I_2}{2}\times T-\frac{O_1+O_2}{2}\times T=S_2-S_1$$

Where, I_i : Instantaneous inflow rate of discharge. (m^3/s)

O_i : Instantaneous outflow rate of discharge. (m^3/s)

S_i : The volume of temporary. (m^3/s)

Subscript i=1, 2 refers the start and end of a particular period.

T : the routine period.

Estimated design flood water level is tabulated in Table 5-7.

Table 5-7 DESIGN FLOOD WATER LEVEL OF CREEKS

LOCATION	FWL (m)	Drainage Treatment
Taiena creek	18.7	Bridge
Agobino creek	12.7	Bridge and Pipes
Ungongo creek	13.1	Bridge and Pipes
Anina swamp	10.7	Pipes
Alika swamp	4.2	Pipes
Divola creek	1.9	Pipes
Opou swamp	2.8	Pipes

Above flood routine analysis of creeks and swamp are shown in Table 5-8* to 5-13* in Appendix.

These selections on drainage treatment of creeks and swamp are discussed in Chapter VII.