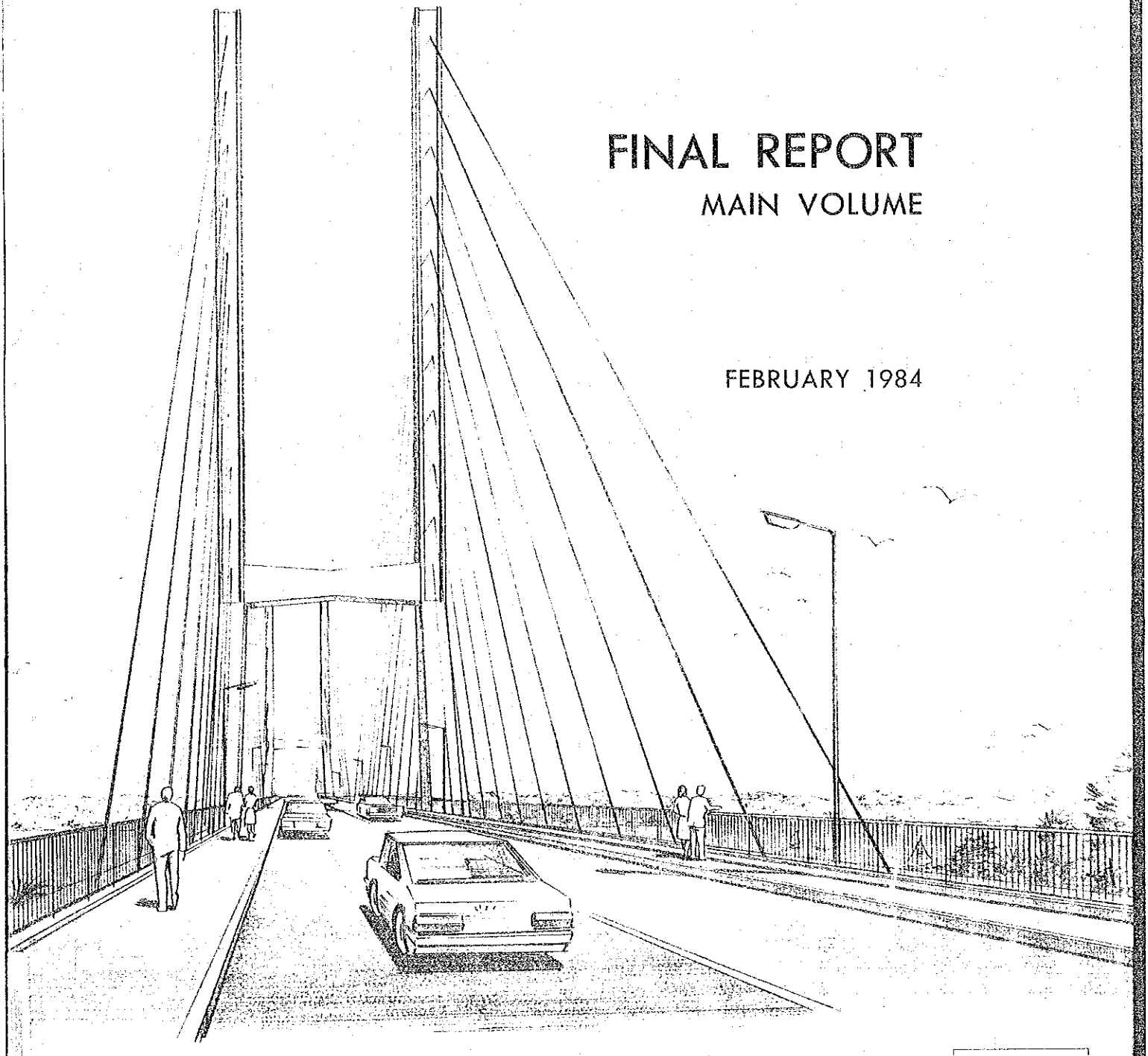
社会開発協力部報告書

No. 1

REPUBLIC OF KENYA
FEASIBILITY STUDY
ON
KILIFI BRIDGE CONSTRUCTION PROJECT



FINAL REPORT
MAIN VOLUME

FEBRUARY 1984

JAPAN INTERNATIONAL COOPERATION AGENCY

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84-020 (2/3)

REPUBLIC OF KENYA

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PREFACE

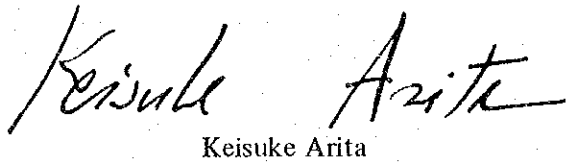
In response to the request of the Government of the Republic of Kenya, the Government of Japan decided to conduct a feasibility study on the Kilifi Bridge Construction Project and entrusted the study to the Japan International Cooperation Agency (JICA). The JICA sent to Kenya a study team headed by Mr. Mamoru Kikuno (Central Consultant Inc.) from February 1983 to August 1983 under the guidance of the Supervisory Committee chaired by Mr. Takeshi Nakayama, Honshu Shikoku Bridge Authority of Japan.

The team held discussions with the officials concerned of the Government of Kenya on the Project and conducted a field survey in Kenya. Subsequently, further studies were made in Japan and the present report has been prepared.

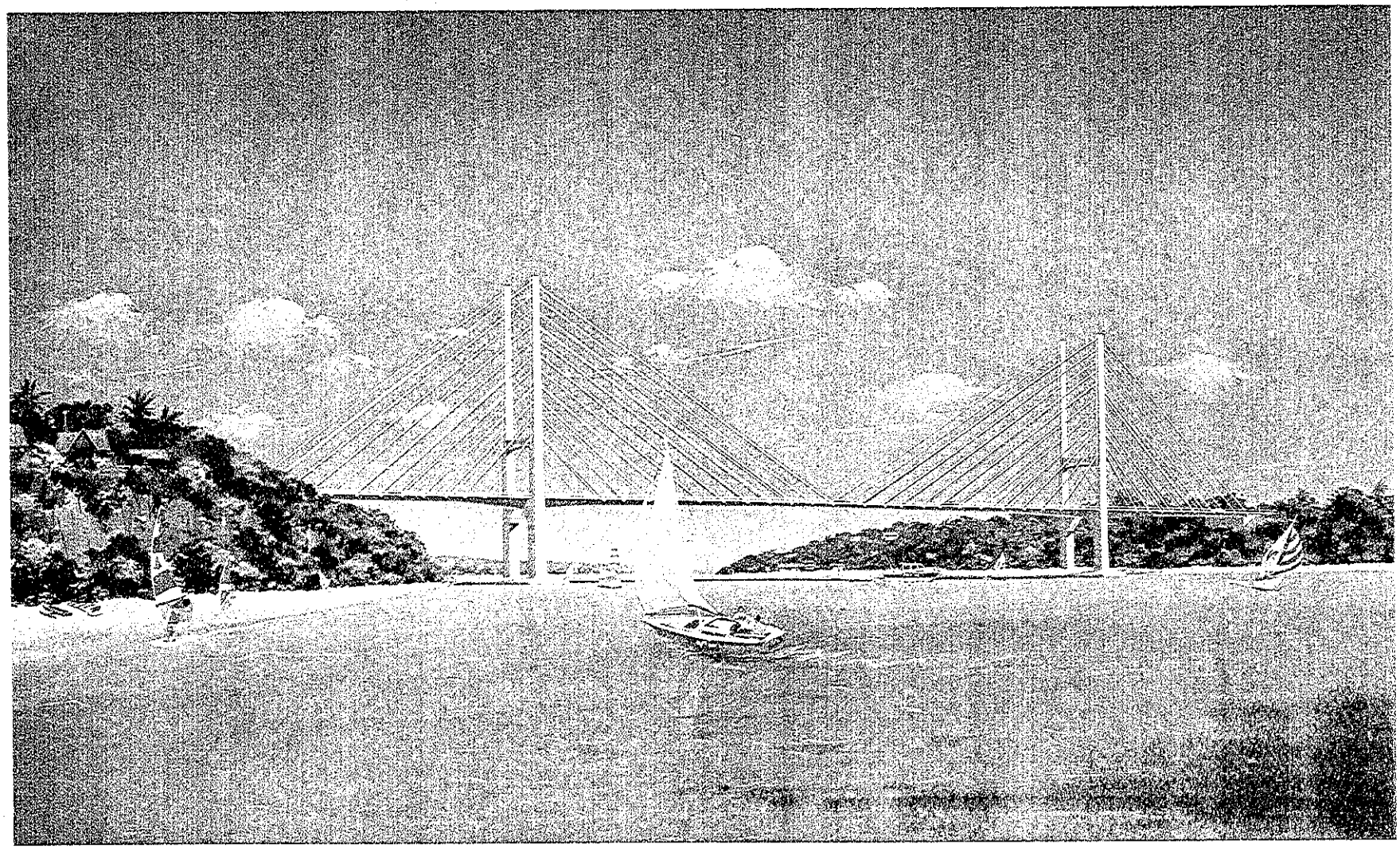
I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Republic of Kenya for their close cooperation extended to the team.

February 1984

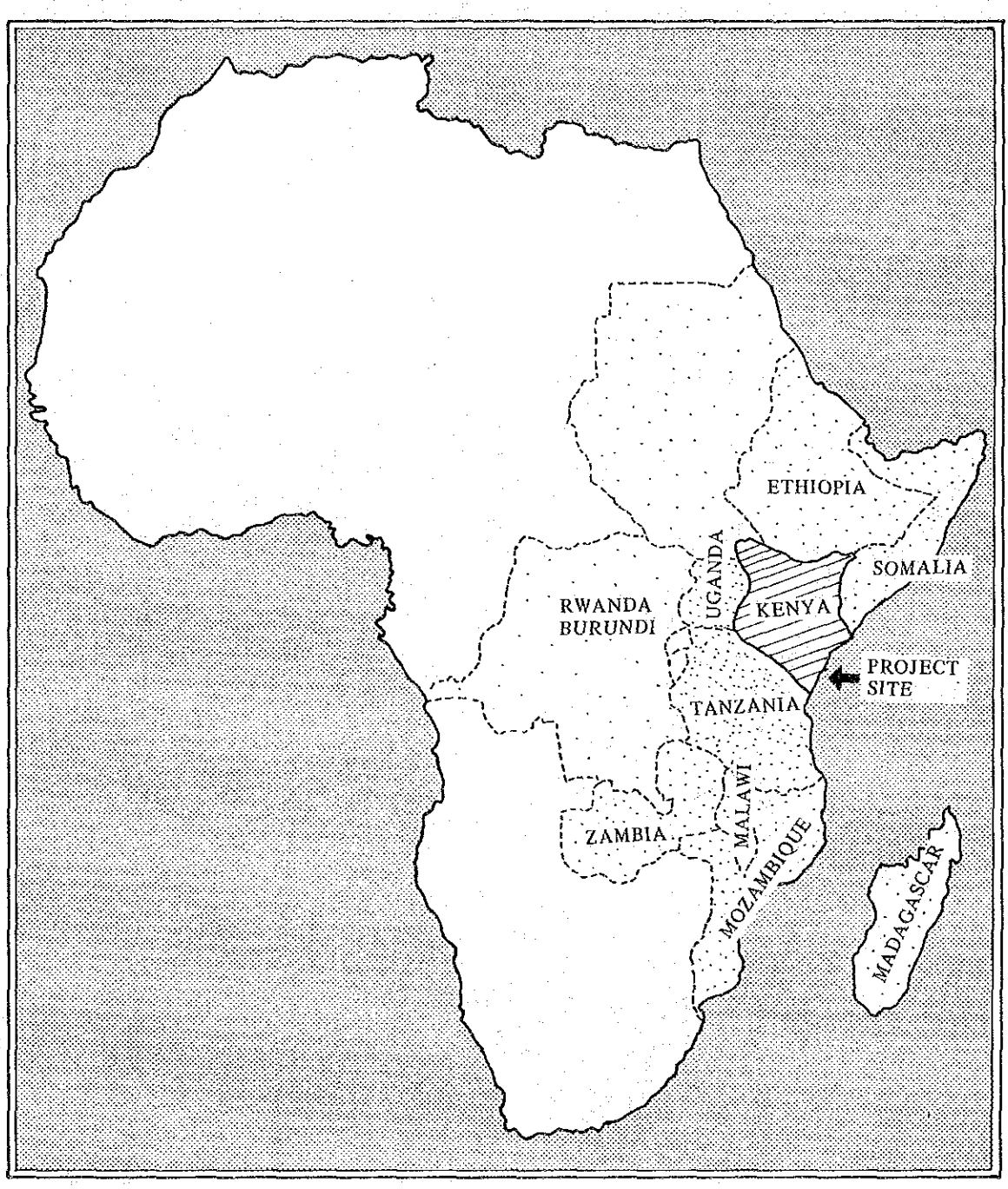


Keisuke Arita
President
Japan International Cooperation Agency

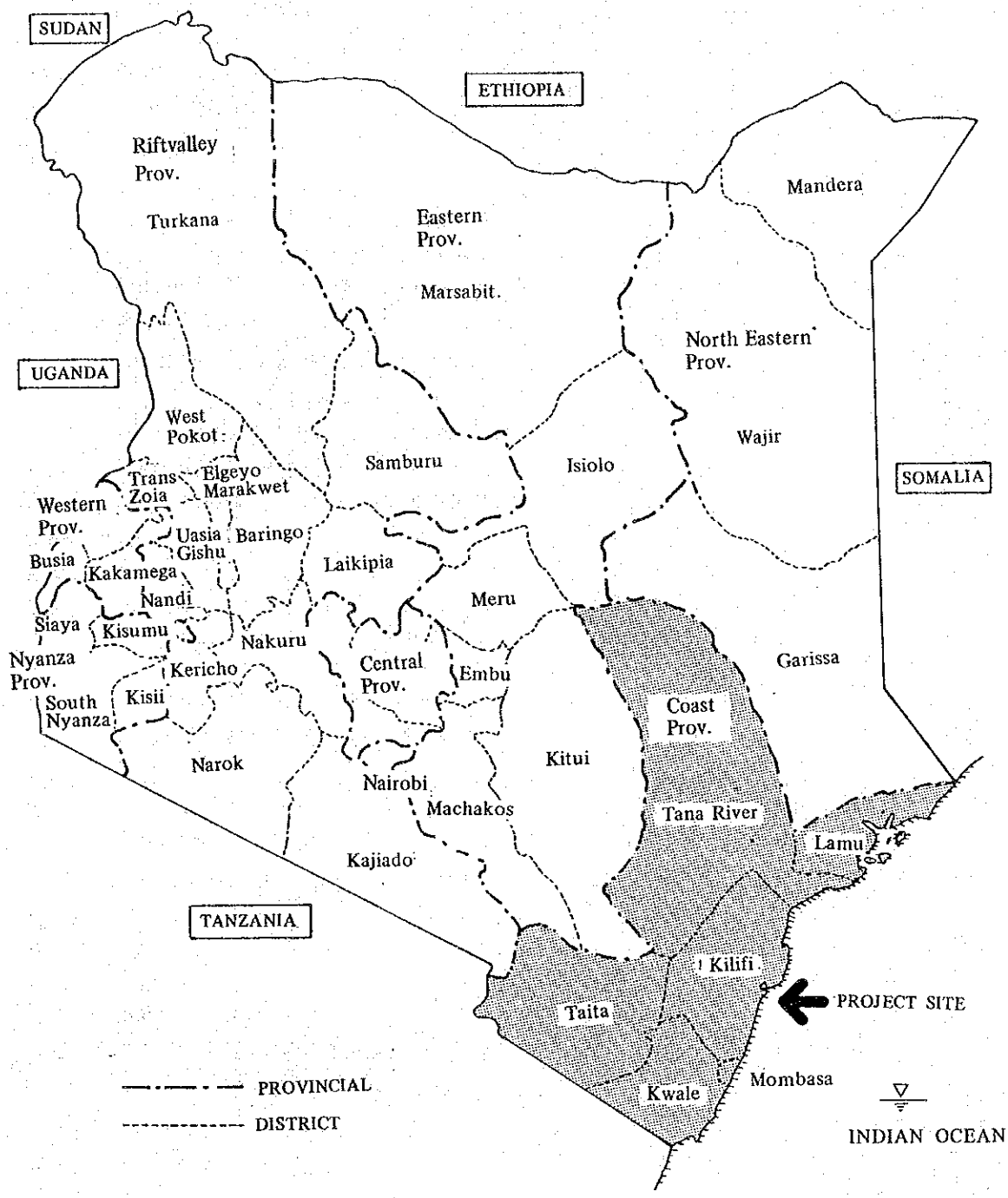


BIRD'S-EYE VIEW OF KILIFI BRIDGE

PROJECT LOCATION MAP–1



PROJECT LOCATION MAP–2



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A. CONCLUSION AND RECOMMENDATION

A.1 CONCLUSION

1. The result of the economic study shows that the Benefit Cost Ratio (B/C) is 1.088 and Economic Internal Rate of Return (EIRR) is 12.89%, hence this project can be considered as firmly profitable.

2. The project cost is estimated at 359,608,000 K.Shs. at 1983 prices. A major portion of which is for the construction of the bridge.

3. The selected crossing point of the bridge over the creek is at about 400 meters down stream from the existing ferry crossing (B-Route).

4. The selected bridge design is the cable stayed concrete girder type that has a total length of 420 meters and a central span of 250 meters.

A.2 RECOMMENDATION

1. This project is judged to be a very benefitial project from the Kenya national economy and social perspectives, its implementation at the earliest possible time is recommended.

2. Before the preparation of any detailed engineering design of the project, further investigation such as the topographic survey, the subsurface investigation, the material survey and the bathymetric survey should be carried out.

3. The technology for the construction of the cable stayed concrete bridge has made a remarkable progress in recent years. The proposed bridge in this study, having a central span of 250 meters would be one of the longest bridge of this kind in the world.

   Therefore, it is desirable that the new construction technology and the valuable knowledge of the experts will be employed and reflected in the design and the construction of this bridge.

SUMMARY

B . SUMMARY

B.1 BACKGROUND

The east coast of Kenya especially the coastal line has a high potential for development. The historical, meteorological, socio-economic and environmental conditions of this area are very promising. The B--8 road on which the Kilifi Bridge will be constructed and which passes through this high potential area is therefore a very important link in the transportation network of these area.

The development plans for Kilifi, Malindi, Tana River and Lamu were prepared by the Ministry of Urban Development and Housing Physical planning Department and be implemented gradually. Following their implementation, the traffic volume on the B–8 road will be expected to increase rapidly. The crossing on the Kilifi creek is currently done by selfpropelled pontoon ferries whose load capacity restrictions prohibit heavy trucks which are over 15 ton load. The crossing has for a long time been a major bottleneck on this important road and subsequently a constraint to development along the B–8 road. Taking into account the high development potential area and the problems of the crossing of the Kilifi creek, the Kilifi Bridge is required to be constructed as soon as possible. The construction of this bridge will mean that the traffic flow and the activities along the B–8 road will be supported.

B.2 TRAFFIC STUDY

B.2.1 Traffic Survey

The following traffic surveys were carried out in this project:

(a) Supplementary origin-destination survey for vehicles.

(b) Traffic counting survey of vehicles.

(c) Spent time survey at Kilifi Ferry.

(d) Passengers counting survey at ferries and bus/matatu stops.

B.2.2 Characteristics of Existing Traffic Flow

From the result of the traffic surveys, the following characteristics are arraived at;

(a) The main generative and attractive zones of trips passing through Kilifi Creek Crossing are Mombasa, Malindi and Kilifi. The ratio for all generated and attracted traffic volume is 87%.

(b) Peak hours in the morning and the evening can be seen at 7.00 to 8.00 and 17.00 to 18.00 from the hourly flow with Kilifi Ferry Census data.

(c) Average ferry waiting time of vehicles moving from north to south at 7.00 to 10.00 and 16.00 to 18.00 on 16th March, are found to be 11.9 minutes and 11.0 minutes respectively. An average waiting time for vehicle moving from the reverse direction at 7.00 to 10.00, 16.00 to 18.00 on 16th March, are 12.8 minutes respectively.

(d) It can be seen from the hourly pedestrians flow that the maximum number of pedestrians moving from north to south are 235 persons and the maximum number of pedestrians moving from south to north are 342 persons per day. Also the average pedestrians for 12 hours are 134 persons from north to south and 202 persons from south to north respectively.

B.2.3 Forecast of Future Traffic Volume

The following components are taken into consideration:

(a) Normal traffic

Normal traffic growth, i.e. the growth when the ferry service is retained and regularly expanded to maintain the present level of service is forecasted on the basis of the O-D Table.

(b) Induced traffic

Induced traffic volume is forecasted at 30 percent of the normal traffic volume based on the notable variation of traffic volume before and after the construction of the New Mtwapa bridge.

B.2.4 Future Traffic Volume

On the basis of the traffic survey, population and development analysis, the future traffic volume is forecasted as shown in Table B–1.

Table B–1 FUTURE TRAFFIC VOLUME

Year	Vehicle Type				Total Vehicles	Total P.C.U.
	Light	Medium	Heavy	Bus		
1983	589	201	93	100	983	1,617
1990	1,108	361	166	179	1,814	2,949
2000	1,913	574	266	284	3,037	4,847
2010	3,303	887	410	438	5,038	7,831

B.3 FIELD SURVEY

In order to gain knowledge of the physical conditions of the study area, the following surveys were conducted in June and July, 1983:

(a) Bathymetric Survey.

(b) Sub-surface Investigation.

(c) Topographic Survey.

The survey sites are illustrated in Fig. B–1.

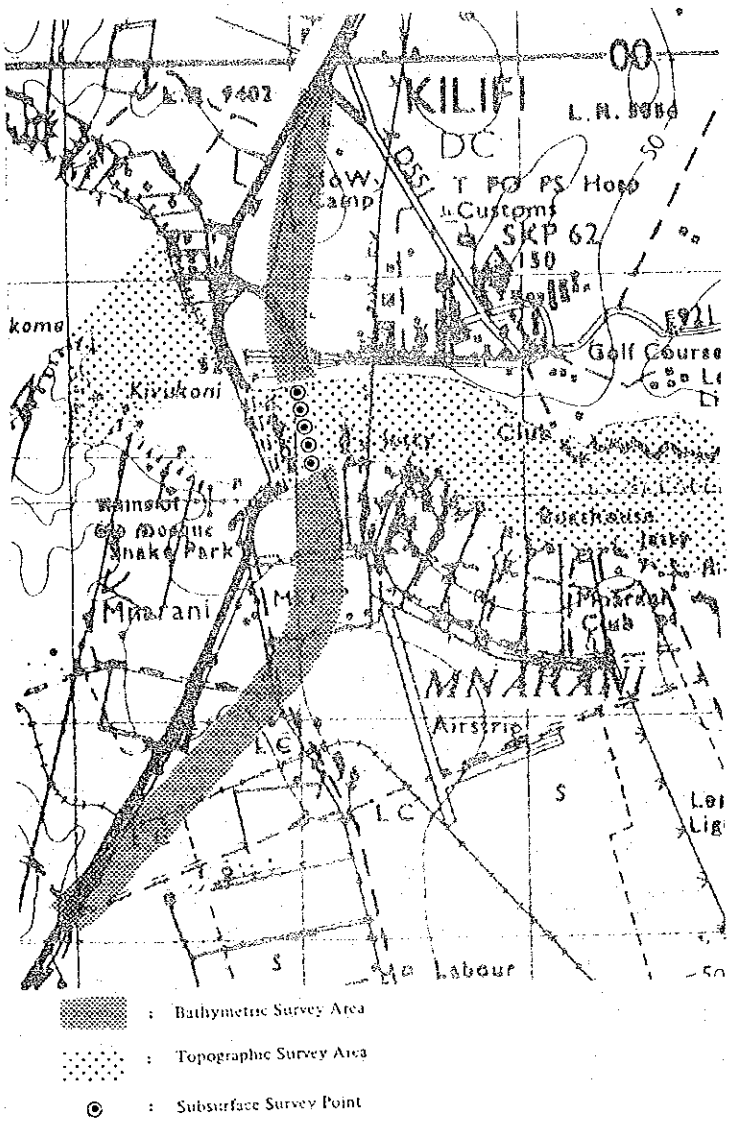


Fig. B–1 LOCATION OF SURVEY SITE

B.4 ALTERNATIVE ROUTE STUDY

B.4.1 Preparation of Alternative Routes

Taking into account the various considerations of route location, topographic feature, existing and future development situation, three alternative routes: route A, route B and route C are prepared as shown in Fig. B–2.

B.4.2 Description of Alternative Routes

(a) Alternative Route A:

This route A is selected with its creek crossing at the shallowest part of the Kilifi Creek, located at 450 meters upstream from the 132 KV electric power line and runs parallels to this electric power line.

(b) Alternative Route B:

Route B is selected with its crossing at the narrowest section of the Kilifi Creek at which the telephone and telegram communication line passes and is 400 meters downstream from the existing ferry operating line.

(c) Alternative Route C:

Route C is selected with its crossing at a comparatively narrow and comparatively shallow area of the Kilifi Creek. There is a ford which is located in front of the Kilifi Club, the depth of which is between 2 and 7 meters. This area is 150 meters off-shore.

B.4.3 Screening of Alternative Routes

Judging from the economic, technical and environmental perspectives, the alternative Route B is selected for preliminary design.

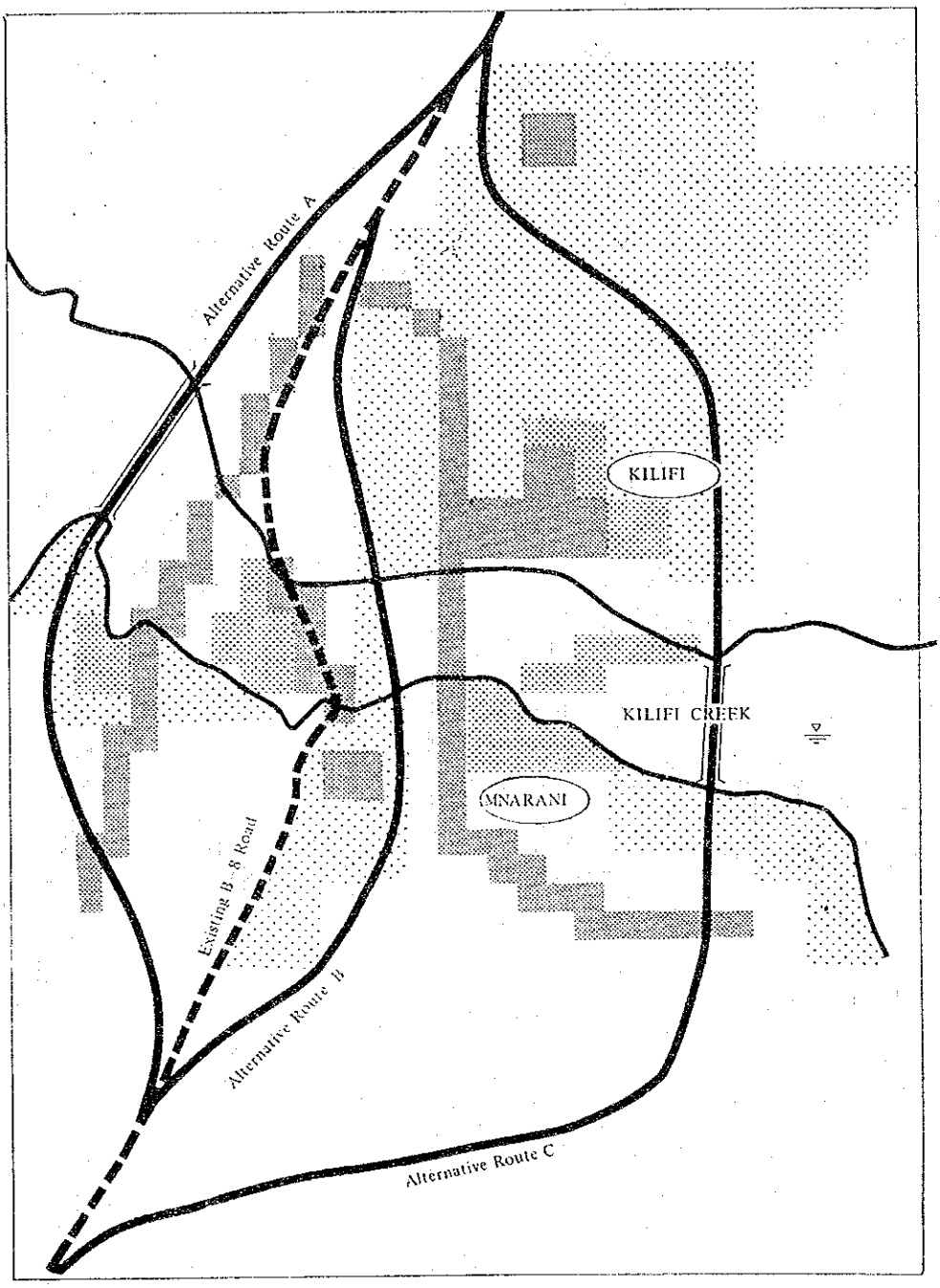


Fig. B–2 LOCATION OF PROPOSED ALTERNATIVE ROUTES

B.5 ALTERNATIVE BRIDGE STUDY

B.5.1 General

The alternative bridge study is carried out on the base of the topographic survey, subsurface investigation, bathymetric survey and sufficient reconnaissance survey.

A total bridge length of 420 meters is selected and design for the positioning of bridge piers is much dependent on the Kilifi creek condition.

Considering the positioning of piers are illustrated in Fig. B–3.

B.5.2 Superstructure Type

Judging the span length from case 1 to case 4, suitable superstructure types are examined. Drawing the knowledge and experience of the bridge engineer and the examination of the actual bridge construction in the past, the superstructure type is decided. Additionally, the input of the following planning perspectives are considered:

(a) Economic perspective.

(b) Technical perspective.

* Structural stability.
* Construction method and condition.
* Maintenance.

(c) Environmental Aesthetics.

With these considerations and perspectives, five (5) different superstructure types are arrived at:

(a) Cable Stayed Steel Girder.

(b) Steel Truss.

(c) Cable Stayed Concrete Girder.

(d) Concrete Girder with a hinge by free cantilevering method.

(e) Concrete Girder with three Hinges free Cantilevering method.

The prepared superstructure types are illustrated in Fig. B–4.

B.5.3 Foundation Structure Type

Taking into account the economical aspects, the construction difficulty, site condition and the construction materials situation, the Pile Bent Type is adopted.

B.5.4 Supplementory Bridge Alternative Study

The supplementary study is carried out to examine the effects of varying the central span length on alternative (3) on the construction costs.

The supplementary alternatives bridge type are as follows;

(a)	Alternative (3)–1	Central span length	250 meters
(b)	Alternative (3)–2	Central span length	280 meters
(c)	Alternative (3)–3	Central span length	300 meters

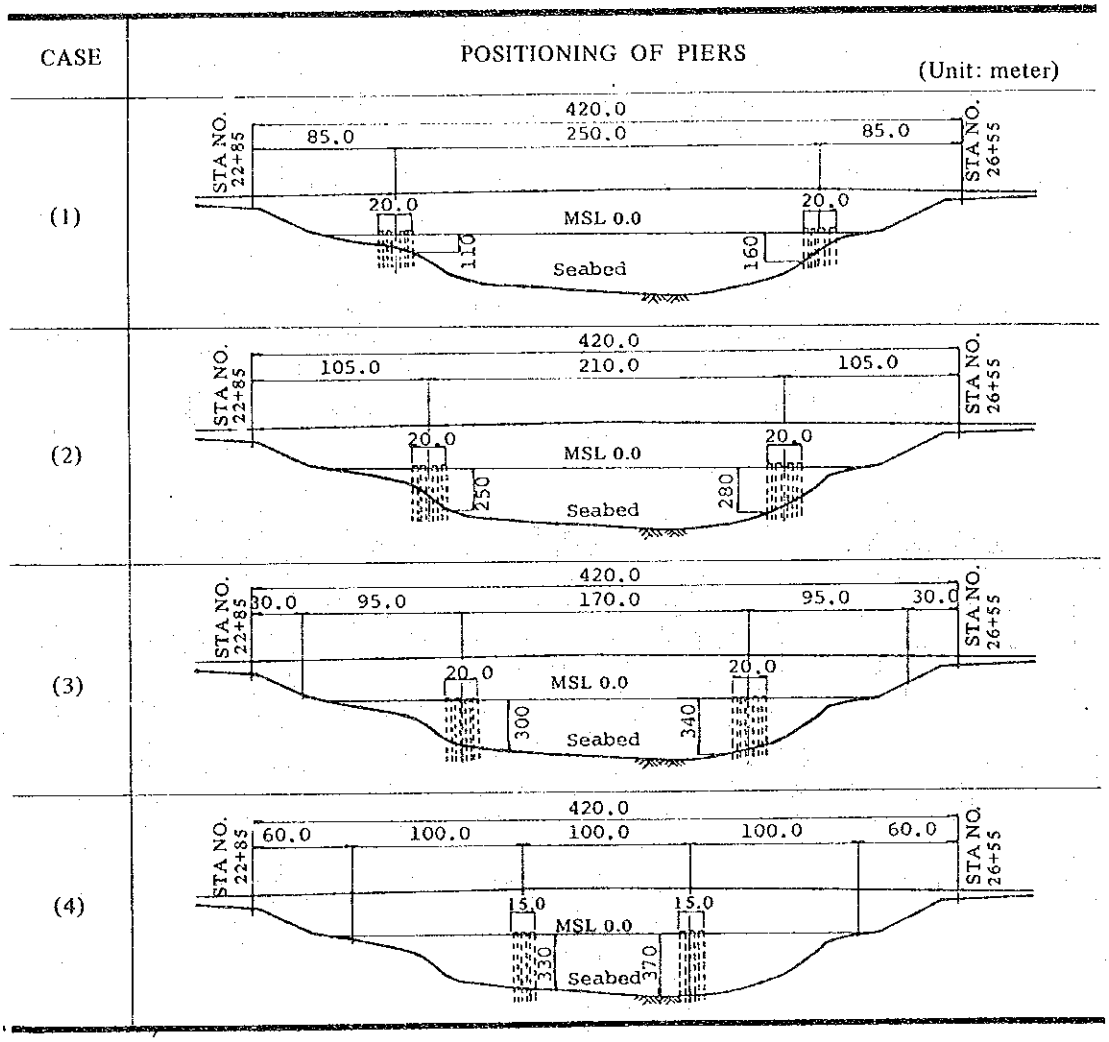
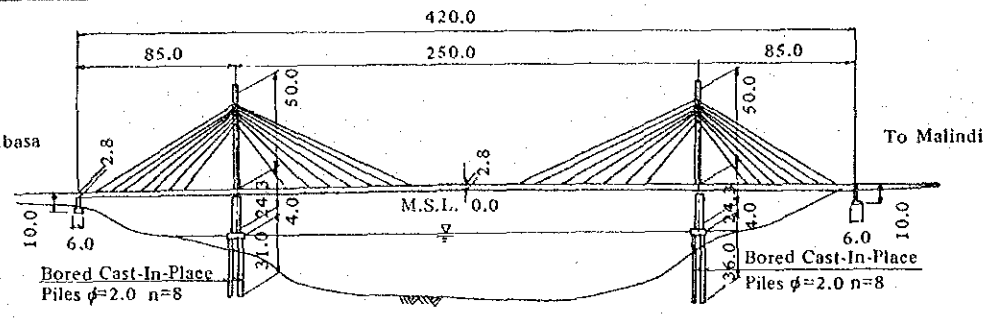


Fig. B–3 POSITIONING OF PIERS

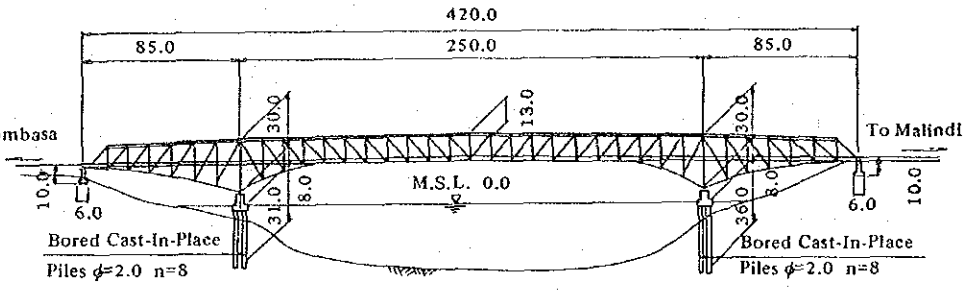
Profile of Bridge: (Unit: m)

Alternative (1)



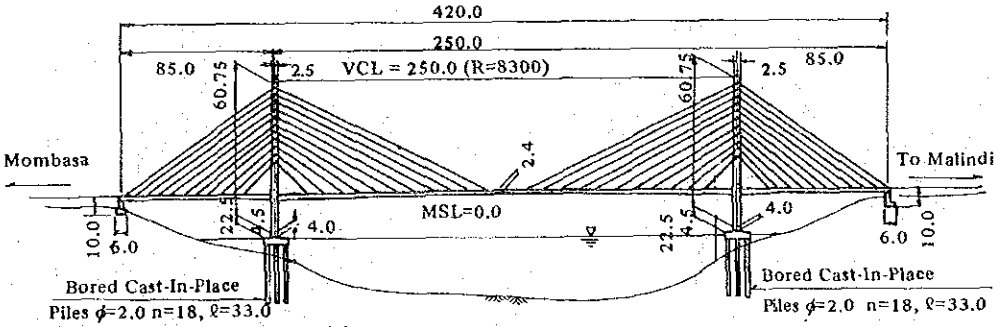
(Cable Stayed Steel Girder)

Alternative (2)



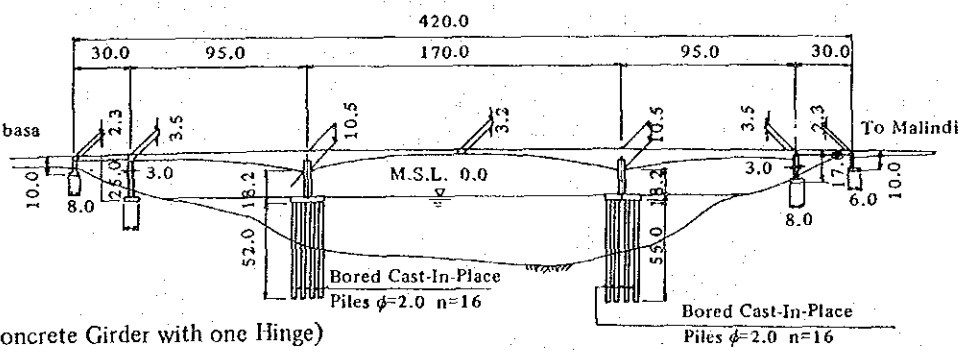
(Steel Truss)

Alternative (3)



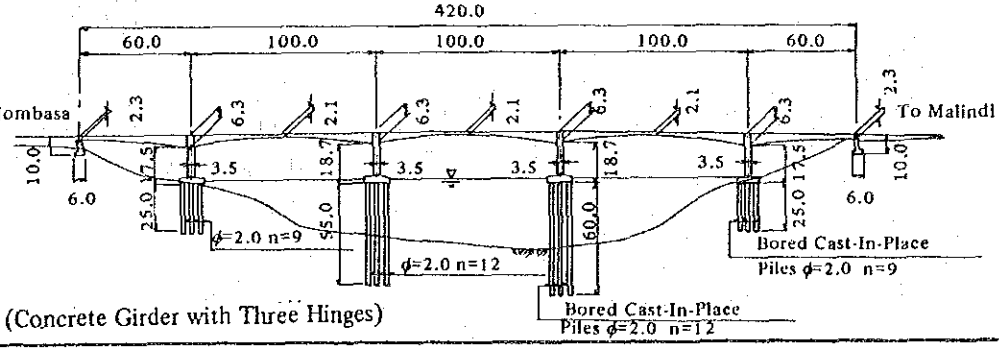
(Cable Stayed Concrete Girder)

Alternative (4)



(Concrete Girder with one Hinge)

Alternative (5)



(Concrete Girder with Three Hinges)

* Fig. B-4 ALTERNATIVE BRIDGE PLAN

B.5.5 Construction Cost

The construction costs for the bridge alternatives are shown in Table B–2.

Table B–2 CONSTRUCTION COST OF ALTERNATIVES

(Unit 1,000 K.Shs.)

Item	Alt.(1)	Alt.(2)	Alt.(3)				Alt.(4)	Alt.(5)
			(3)	(3)–1	(3)–2	(3)–3		
Bridge	296,889	282,292	282,655	264,164	303,739	336,967	283,877	274,697

B.5.6 Screening of Bridge Alternatives

The cable-stayed concrete girder bridge with a central span of 250 meters in length Alt. (3)–1 is selected for this feasibility study.

The reasons are as follows:

(a) The construction costs of Alt. (3)–1 is the minimum as shown in the alternative construction cost analysis.

(b) The construction workability of foundation for Alt. (3)–1 is superior from the others due to its location at shallower water.

(c) Alt. (3)–1 has a wide under-clearance, with ample rooms for the passage of ships both recreational and commercial. Moreover, the profile of this alternative is also compatible to the surrounding natural features.

B.6 PRELIMINARY ROAD DESIGN

B.6.1 Alignment Design

1) Horizontal Alignment

On the basis of the alternative Route B alignment, the horizontal alignment is planned.

In the project site, the arrangement between the alignment on the map and actual site is carried out by highway engineer and the final alignment is arrived.

2) Vertical Alignment

Taking into consideration the existing ground level, navigation clearance, and environmental aesthetics, a 1.5 percent grade on both sides of the bridge is adopted for the bridge.

B.6.2 Cross-Section Design

Using the Design Manual prepared by M.O.T.C., the following element of the cross-section are adopted.

(a) Lane width is 7.0 meter (2 lane road).

(b) Shoulder width is 2.50 meter for the road and 0.75 meter for the bridge.

(c) Pedestrianway width is 2.00 meters on both sides in urban areas.

B.6.3 Intersection Design

At grade intersections are planned for the intersections between the project road and the existing roads.

B.7 PRELIMINARY BRIDGE DESIGN

B.7.1 General

In this chapter, a more detailed study is carried out on the design of the cable stayed prestressed concrete girder bridge with a central span of 250 meters and a total bridge length of 420 meters which is proposed as the result of the alternative bridge study.

B.7.2 Design Criteria

The study is in accordance with the following design criteria.

1) Dimension

(a)	Design of bridge	Cable stayed presstressed concrete girder
(b)	Length of bridge	420 m
(c)	Length of spans	85 m + 250 m + 85 m
(d)	Width of bridge	
	Total width	12.5 m
	Width of carriageway	8.5 m
	Width of sidewalk	2 x 2.0 m = 4.0 m
(e)	Horizontal road alignment	Straight
(f)	Angle of bridge	Rectangular (90°)
(g)	Head Clearance	
	Carriageway	5.25 m above the top of the road surface
	Sidewalk	2.50 m above the top of the road surface

2) Design Loads

(a) Live loading (Traffic loads)

The live loading for the main structure shall be in accordance with the Specifications for Highway Bridges published by the Japan Raod Association to a carry TL–20 Loading.

(b) Wind load

A design wind speed of 30 m/sec shall be applied for the girder, tower and stayed cables. This is determined using the data recorded at the Mombasa Ras Serani Station which is the nearest station at Kilifi.

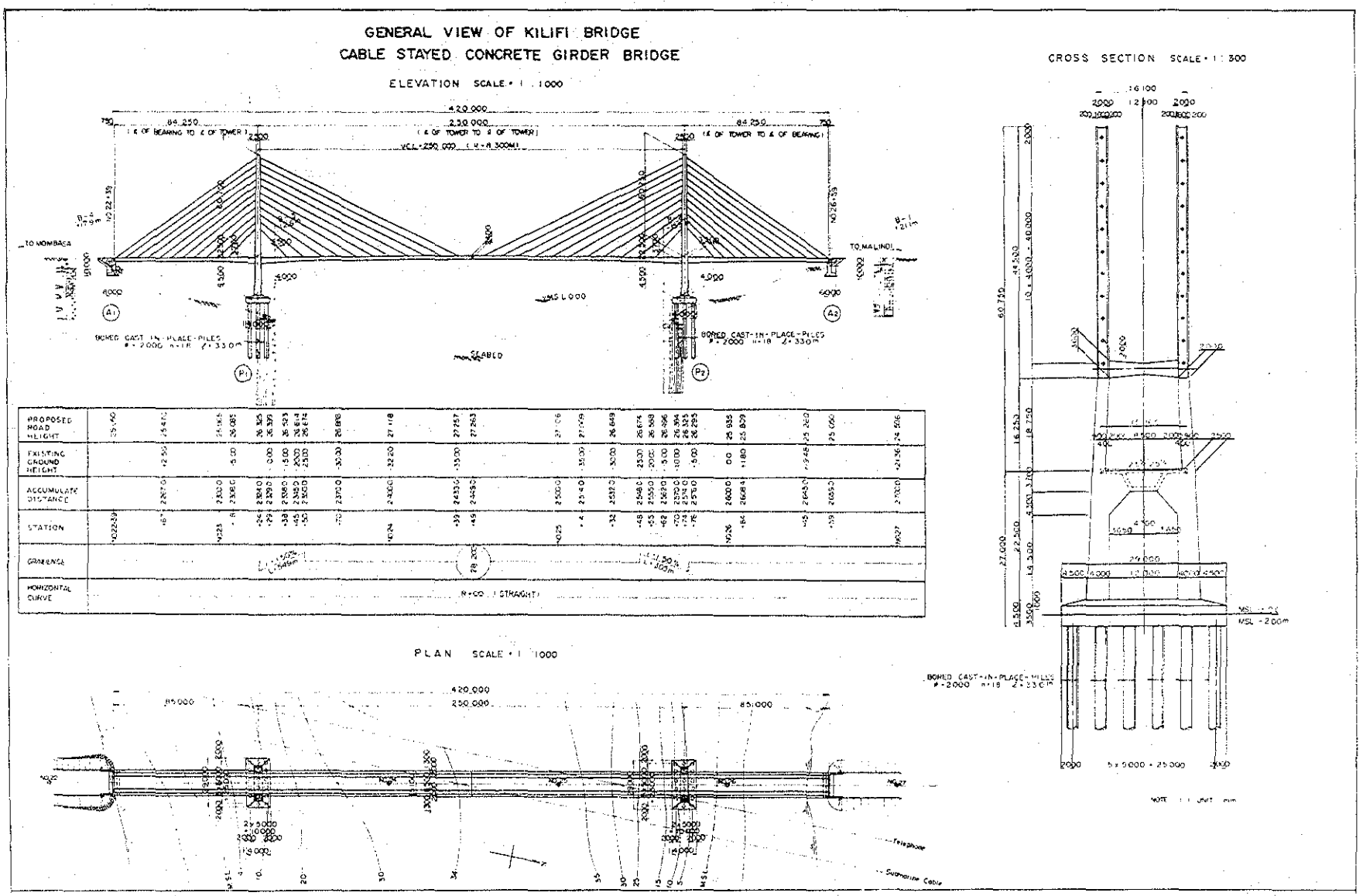


Fig. B–5 GENERAL VIEW OF KILIFI BRIDGE
(CABLE STAYED PRESTRESSED CONCRETE GIRDER BRIDGE)

(c) Effect of Temperature

The range of the effective bridge temperature shall be ±5°c and the effective temperature difference within the superstructures shall be 5°c. These are determined using the data recorded at three stations in Malindi, Kilifi and Mombasa.

B.7.3 Superstructure

B.7.3.1 Skeleton

1) Arrangement of cables

Arrangement of cables is designed as follows:

(a) Multi-cable design

The multi-cable design which has many cables stretched between the tower and main girder and arranged with relatively small intermediate supporting points is selected. This design is recommendable for such a bridge that has a relatively long span and must be constructed by cantilevering method.

(b) Harp-shaped pattern

The harp-shaped pattern which is considered to be the most rational for this bridge is adopted.

(c) Double-cable-plane arrangement

The double-cable-plane arrangement is adopted to avoid the carriage-way being divided into two and ensuring a higher utility of the road space.

2) Height of tower

The height of tower above the road surface is determined to be 60.75 meters. The ratio of the height of the tower to the central span is 1 : 4.1 and the angle of the top cable in the central span is placed at 27°.

3) Mechanical configuration

The mechanics configuration as shown in Fig. B–6 is adopted from the economical point of view.

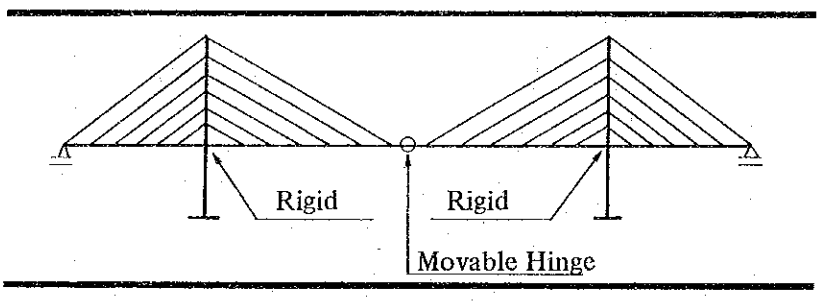


Fig. B–6 GENERAL VIEW OF KILIFI BRIDGE (PRELIMINARY BRIDGE DESIGN)

The main girder is rigidly connected with the towers. As a result of this design, a movable hinge is required at the centre of the central span to release the expansion and shrinkage caused by the temperature change.

B.7.3.2 Design of Cables

1) Kind of cable

The spiral wire strand is adopted for the stayed cable considering that this must be a popular one though it must be protected completely against corrosion.

Each strand has a diameter of 15.2 millimeters and is composed of wires each with a diameter of 5 millimeters. Each cable is inturn composed of 19 to 37 strands in demand to the design tensile strength.

2) Anchorage

For the ancorage of cables, the Fressinet anchor which is one of the more popular anchorages is applied.

B.7.3.3 Design of Main Girder

The cross-sectional configuration of the main girder is shown in Fig. B—7. As shown in the figure, the main girder has a mono-box configuration and the web of the box form an angle of 27° with the vertical (pitch 1 : 2) in due consideration of the aerodynamic stability.

The depth of the main girder is 2.40 meters except a portion near the tower where the main girder has a greater depth of 3.70 m to sustain the greater bending moment.

B.7.3.4 Design of Tower

The tower which is made of reinforced concrete has two pillars corresponding to the cables of double planes. The bottom part the pillar is connected directly with the footing on the foundation piles.

Two pillars are connected with thick beam which supports the main girder and strut which against such horizontal thrust as wind force, and make up a rigid frame.

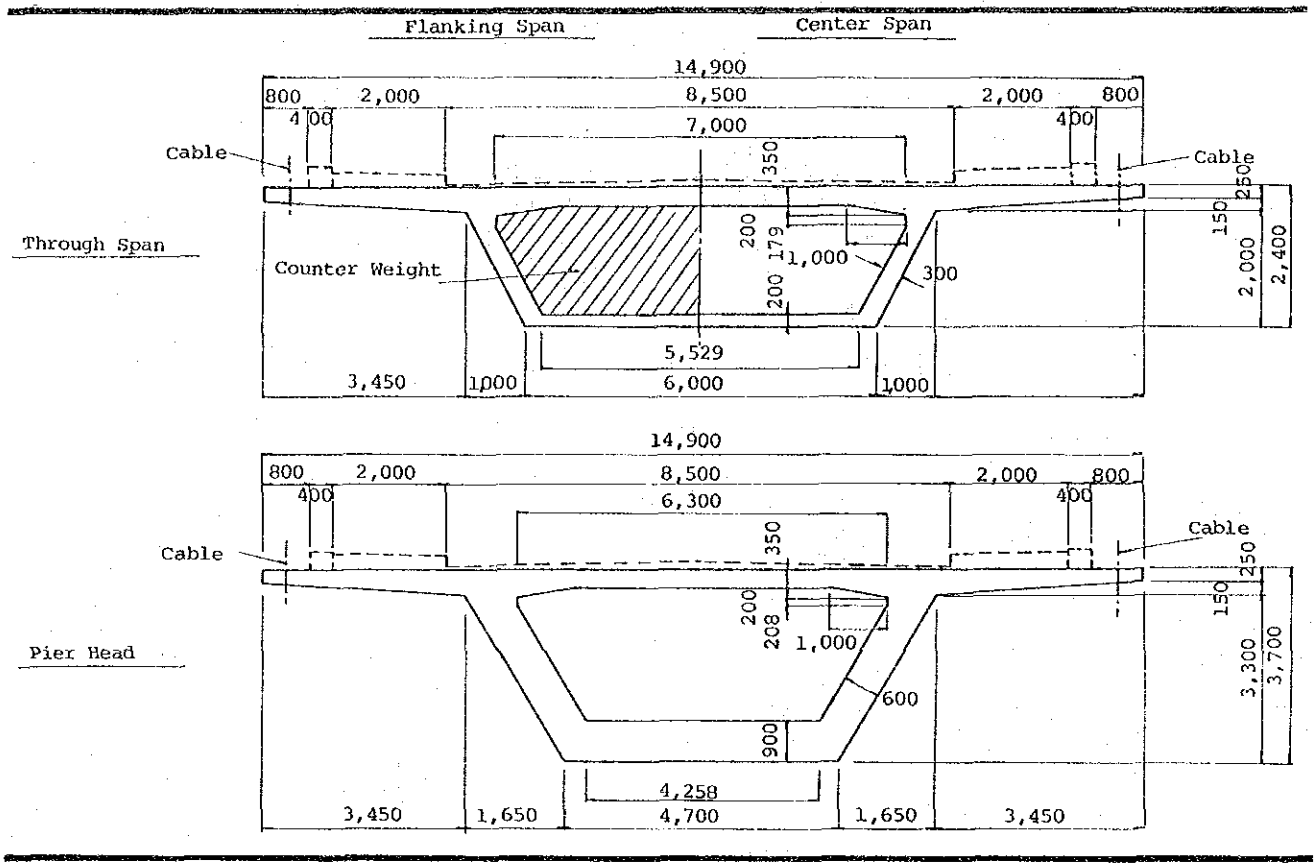


Fig. B–7 CROSS-SECTION OF MAIN GIRDER

B.7.4 Substructure

B.7.4.1 Design of Abutments

As known from the results of the geotechnical investigation, on either land side, the stiff coral limestone which is expected to be the bedrock is encountered within 3 meters to 5 meters deep below the ground surface.

The foundation of the abutment shall be the spread footing type that is to rest on this coral limestone layer.

The height of the abutment and the breadth of footing are 10 meters and 6 meters. These dimensions are the same on both Mnarani side and Kilifi side.

The negative force of 25 tons to 429 tons works from the superstructure to the abutment. In order to use the abutment as a counter weight, the main girder of superstructure is ancored to the abutment by P.C. strands.

B.7.4.2 Design of Tower Foundation

1) Foundation type

As described in the Alternative study, the pile foundation which is composed

of the cast-in-place piles by the reverse circulation method is adopted.

2) Diameter of pile

The design diameter of piles shall be 2.0 meters from the following reason;

The diameter generally used in the cast-in-place by the reverse circulation drilling method is 1.0 meters to 2.0 meters. In the case where the diameter of the pile is over 2.0 meters, the construction cost rises radically because a special drilling machine in needed. For diameter of 1.0 to 2.0 meters, the result of comparison indicates that the diameter of 2.0 meters is the most economical.

3) Penetration depth

As known from the results of the geotechnical investigation, the stiff silty sand is encountered within 2 meters to 4 meters below the seabed. Although most of this silty sand layer is very hard and compact with N-Value of over 60, relatively loose layer with N-Value of approximately 25 to 40 is encountered in 25 meters to 32 meters deep below MSL. At these points, the pile shall penetrate through this loose layer to a 35 meters depth below MSL.

4) Arrangement of piles

Number of piles of each foundation designed is eighteen (18). These are arranged in three rows in the direction of span each having six piles.

B.8 ESTIMATION OF PROJECT COSTS

1) The project costs consists of the construction cost, engineering fee, land acquisition, compensation and contingency.

2) Based on the preliminary engineering study, the quantities for main work items are calculated. Subsequently, the unit cost by main work items are analysed from the aspects of material cost, labour cost, construction equipment, etc. taking also into consideration the local condition in Kenya.

3) The project costs are split into two compornents, that is foreign currency and local currency.

4) The Project costs are culculated in 1983 prices.

5) The project costs are shown in Table B–3.

Table B–3 PROJECT COST

(In 1,000 K.Shs.)

Item \ Currency	F.C.	L.C.	T.C.
Bridge	219,582	46,071	265,653
Approach Road	13,618	10,849	24,467
Construction Cost	233,200	56,920	290,120
Engineering Fee	27,851	6,963	34,814
Land Aquisition	–	1,612	1,612
Compensation	–	370	370
Sub-Total	261,051	65,865	326,916
Contingency	26,105	6,587	32,692
Total	287,156	72,452	359,608

Note: 1) The project cost is expressed in July 1983 prices.
2) The price contingency is not considered.

B.9 ECONOMIC ANALYSIS

B.9.1 Premises

Basic premises for the economic analysis are as follows;

(a)	Construction period	Six (6) years, 1984 ~ 1989
(b)	Project cost	359,608,000 K.Shs. at 1983 constant price
(c)	Raise of project cost	Abroad (Soft Loan)
(d)	Projection of traffic volumes	in Chapter 2
(e)	Level of ferry survice	Keeping the existing level

B.9.2 Economic Cost

The economic cost is estimated considering the conversion factors of the main construction working items, materials, and labor cost. The total economic cost is 339,771,000 K.Shs., and detailed costs are shown in Table B–4.

Table B–4 ECONOMIC COST

(Unit: 1,000 K.shs. 1983 Constant/Economic Price)

At \ Year	1984	1985	1986	1987	1988	1989	Total
Financial Price	6,382	12,767	50,967	90,171	119,230	80,091	359,608
Economic Price	6,275	12,552	48,288	84,020	113,088	75,548	339,771
Economic Cost/Financial Cost							94.5

B.9.3 Traffic Cost Estimate

B.9.3.1 Time Value

The time values in 1983 estimated on the incomes of the vehicle users, waiting charge of heavy goods vehicle and numbers of persons whose time values are shown in Table B–5.

Table B–5 TIME VALUES PER HOUR IN 1983

(Unit: K.Shs./Hour, 1983 Price)

Type of Vehicle / At	Car	Light Goods Vehicle		Medium Goods Vehicle	Heavy Goods Vehicle	Bus
		Owner	Matatu			
Market Price	94	84	99			240
Economic Price	88	79	93	40	150	224

B.9.3.2 Vehicle Operation Cost

Taking into account the characteristics and the accuracy of the related information collected at Mombasa, sub-classifications and definitions of the vehicle operating costs are estimated as shown in Table B–6 and B–7.

Table B–6 VEHICLE OPERATING COST (VOC) PER KILO METERS

(Unit: K.Shs./Km, 1983 Economic Price)

Type of Vehicle / VOC Item	Car	Light Goods Vehicle		Medium Goods Vehicle	Heavy Goods Vehicle	Bus
		Owner	Matatu			
Variable Costs	0.901	1.397	1.397	2.284	4.189	2.533
Fuel	0.686	0.979	0.979	1.640	3.055	1.603
Engine oil	0.024	0.037	0.037	0.067	0.084	0.078
Repair	0.191	0.381	0.381	0.577	1.050	0.852
Fixed Costs	0.884	1.454	2.048	2.907	10.479	7.786
Depreciation	0.411	0.958	0.958	0.695	3.489	4.559
Interest Costs	0.258	0.271	0.271	0.442	0.070	0.966
Crew Costs			0.594	0.818	1.164	0.701
General Administration				0.584	1.168	0.758
Insurance Costs	0.215	0.225	0.225	0.368	2.588	0.802
Total	1.785	2.851	3.445	5.191	14.668	10.319

Table B–7 FIXED COST IN VOC PER OPERATING HOUR

(Unit: K.shs/Hour, 1983 Ecohomic Price)

Fixed Costs Item \ Type of Vehicle	Car	Light Goods Vehicle		Medium Goods Vehicle	Heavy Goods Vehicle	Bus
		Owner	Matatu			
Depreciation	6.58	26.09	26.09	18.35	74.54	48.70
Interest Costs	4.13	7.37	7.37	11.79	44.23	41.28
Crew Costs [3]			16.18	21.85	24.86	29.97
General Administration				12.48	24.96	32.39
Insurance Costs	3.44	6.14	6.14	9.83	55.29	34.40
Total	14.15	39.60	55.78	74.50	223.88	186.74

B.9.4 Result of Economic Analysis

On the basis of the future traffic volume, traffic cost and economic cost, the following results of the economic analysis are arrived.

(a) Net Present Values*

Economic cost	200,331,000 K.shs.
Economic benefit	217,882,000 K.shs.
NPV	17,551,000 K.shs.

Note * : in 1983
Annual discount rate 12%

(b) Benefit Cost Ratio (B/C) 1.088

(c) Economic Internal Rate of Return (EIRR) 12.89%

B.9.5 Sensitivity Analysis

The sensitivity analysis is carried out on the basis of the changing project cost and construction period. The results of the sensitivity analysis are shown in Table B–8.

Table B–8 RESULT OF SENSITIVITY ANALYSIS

(Unit: %)

Construction Period \ Project Cost	10% Increase	Base	10% Decrease
One Year Prolongation (7 years)	11.81	12.65	13.62
Base (6 years)	12.01	12.89	14.22
One Year Shortening (5 years)	12.08	12.97	14.02

B.10 FINANCIAL ANALYSIS AND IMPLEMENTATION PROGRAM

B.10.1 Implementation Schedule

Taking into account the results of the economic analysis, construction cost and the construction method on the project road, the implementation schedule is arrived as shown in Table B–9.

Table B–9 IMPLEMENTATION PROGRAM

Working Item			1984	1985	1986	1987	1988	1989
Engineering and Evaluation								
Land Acquisition and Compensation								
Temporary & Other Works								
Bridge	Foundations	P_1						
		P_2						
	Abutments	A_1						
		A_2						
	Towers	P_1						
		P_2						
	Superstructure							
	Surface and Facilities							
Roads	Approach Roads							
	Access Roads							

B.10.2 Investment Requirement

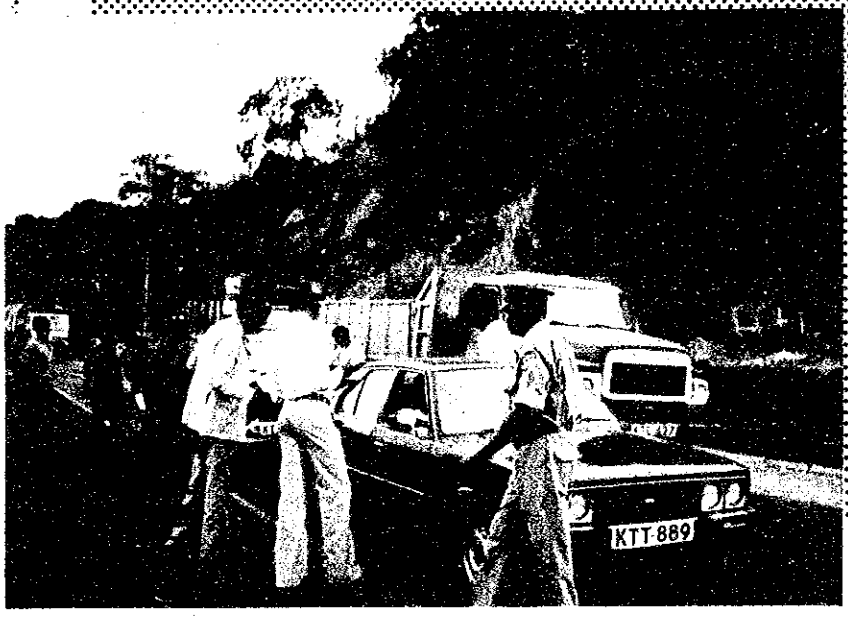
Based on the implementation schedule and financial analysis, the investment requirement on each year is estimated as shown in Table B–10.

Table B–10 INVESTMENT REQUIREMENT

(Unit: 1,000 K.shs, Current Price)

Year	Foreign Currency	Local Currency	Total
1984	5,642	1,424	7,066
1985	12,470	3,405	15,875
1986	54,209	16,240	70,449
1987	102,273	37,644	139,917
1988	162,784	44,305	207,089
1989	116,889	45,991	162,880
Total	454,267	149,009	603,276

MAIN VOLUME



MAIN VOLUME

1 . INTRODUCTION

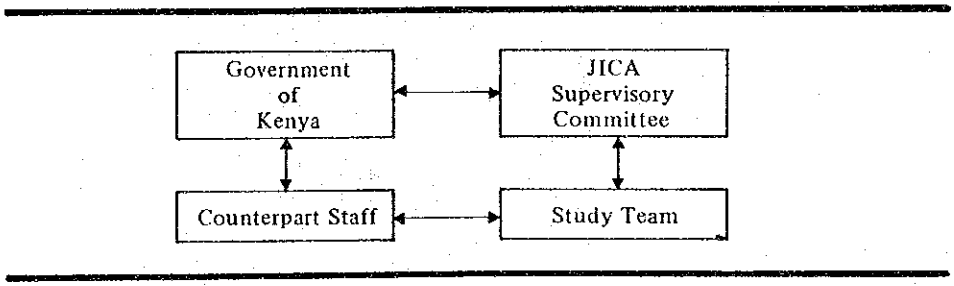
1.1 BACKGROUND

The east coast of Kenya especially the coastal line has a high potential for development. The historical, meteorological, socio-economic and environmental conditions of this area are very promising. The B–8 road on which the Kilifi Bridge will be constructed and which passes through this high potential area is therefore a very important link in the transportation network of these area.

The development plans for Kilifi, Malindi, Tana River and Lamu were prepared by the Ministry of Urban Development and Housing Physical Planning Department and be implemented gradually. Following their implementation, the traffic volume on the B–8 road will be expected to increase rapidly. The crossing on the Kilifi creek is operated by selfpropelled pontoon ferries whose load capacity restrictions prohibit heavy trucks which are over 15 ton load. The crossing has for a long time been a major bottleneck on this important road and subsequently a constraint to development along the B–8 road. Taking into account the high development potential area and the problems of the crossing of the Kilifi creek, the Kilifi Bridge is required to be constructed as soon as possible. The construction of this bridge will mean that the traffic flow and the activities along the B–8 road will be supported.

1.2 ORGANIZATION OF PROJECT

The project is being carried out jointly by JICA and the Government of Kenya, in collaboration with other related agencies. The organization for the Study is as follows.



1.3 STUDY APPROACH

1.3.1 Objectives of the Study

(1) To carry out a feasibility study for the construction of the Kilifi Bridge, including its approach roads.

(2) The Study is to act as a means of technology transfer from JICA to the counterparts of the Republic of Kenya.

1.3.2 Study Area

The study area covers the proposed bridge site at the Kilifi creek and its vicinity. The latter is necessary for the planning of the bridge approach roads. The study area is shown in Fig. 1-1.

1.3.3 Outline of the Study

The major study items are as follows:

(1) Traffic and Socio-Economic Study

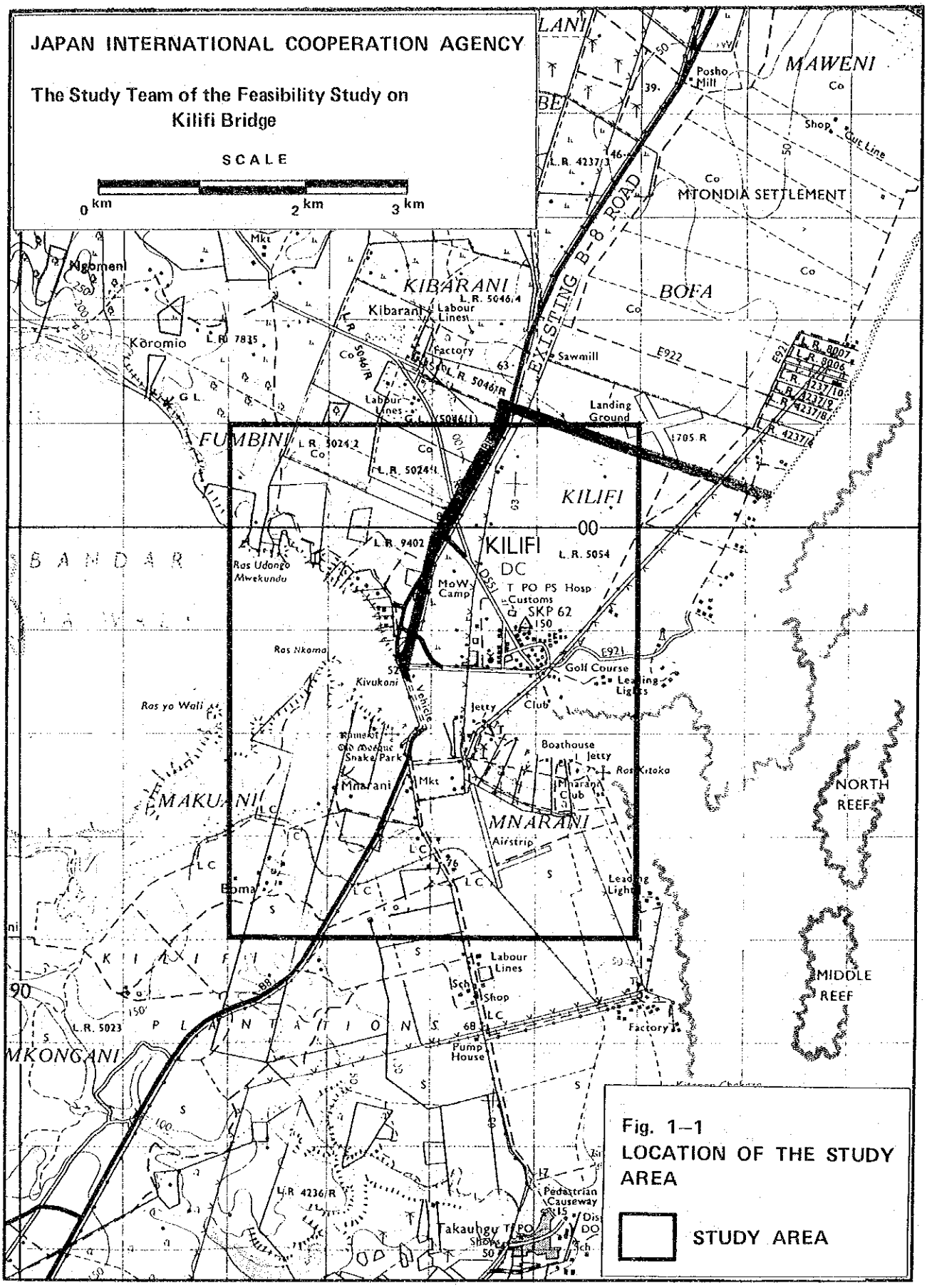
a) Traffic data collection, traffic survey and analysis
b) Collection and analysis of socio-economic data
c) Review of population and socio-economic conditions
d) Forecast of future traffic demand

(2) Engineering Study

a) Topographic map acquisition
b) Collection and analysis of engieering data
   b-1 soil and geological data
   b-2 hydrological and hydrographic data
   b-3 materials data
   b-4 meteorological data
c) Surveying
   c-1 bathymetric survey
   c-2 subsurface investigation
   c-3 topographic survey
d) Design criteria
   d-1 geometric design standards
   d-2 structural design standards
e) Engineering works
   e-1 design works
   e-2 quantity estimation
f) Construction program
   f-1 construction method
   f-2 construction schedule
g) Cost estimates
   g-1 right-of-way acquisition cost
   g-2 construction cost
   g-3 maintenance cost

(3) Economic Evaluation

a) Estimates of benefit
b) Estimates of NPV, IRR, and B/C
c) Sensitivity analysis


JAPAN INTERNATIONAL COOPERATION AGENCY
The Study Team of the Feasibility Study on
Kilifi Bridge
SCALE
0 km
2 km
3 km
EXISTING B 8 ROAD
MAWENI
MTONDIA SETTLEMENT
BOFA
KIBARANI
FUMBINI
KILIFI
KILIFI DC
BANDARINI
EMAKUNI
MNARANI
KILIFI PLANTATIONS
MKONGANI
Ngomeni
Kibarani Labour Lines
Factory
Sawmill
Landing Ground
Posho Mill
Shop
Cut Line
Ras Udongo Mwekundu
Ras Nkoma
Kivukoni
Ras yo Wali
MoW Camp
T PO PS Hosp
Customs
SKP 62
Golf Course
Leading Lights
Jetty
Club
Boathouse
Ras Kitoka
Pharana Club
Airstrip
Boma
Labour Lines
Shop
Pump House
Factory
Pedestrian Causeway
Takaungu T PO
NORTH REEF
MIDDLE REEF
Fig. 1–1
LOCATION OF THE STUDY AREA
STUDY AREA

(4) Budget and Financial Study

(5) Implementation Program

An implementation program be prepared based on the construction program and the budget and financial study.

1.4 PROGRESS TO DATE

(1) The Study was commenced on 23rd of February, 1983 when the meeting between the MOTC officials, the Supervisory Committee of JICA and the Study Team was held to discuss the Inception Report to be executed in the study.

(2) In March, the reconnaissance survey, data collection and various traffic surveys were carried out.

(3) In April, analysis of the collected data, identifications of the design criteria and preparation of the alternative routes were carried out and on the 15th of April, a meeting between the Study Team and MOTC was held to discuss the basic technical matters.

(4) In May, examinations of the technical problems for design and selection of the alternative routes were carried out and on these basis the Progress Report was prepared.

(5) On the 31st of May, 1983 a meeting between the Supervisory Committee of JICA, the MOTC officials and the Study Team was held to discuss the Progress Report to be executed in the Study. The Progress Report was submitted to the MOTC officials.

(6) In June and July, the subsurface investigation, bathymetric survey, topographic survey, the examination of the bridge type, cost estimation and preliminary economic study were carried out.

(7) On the 25th of August, 1983 a meeting between the Supervisory Committee of JICA, the MOTC officials and the Study Team was held to discuss the Interim Report. The Interim Report was submitted to the MOTC officials.

(8) In September, October and November, the preliminary design was carried out and the Draft Final Report was prepared in Japan.

(9) On the 14th of December, 1983 a meeting between the Supervisory Committee of JICA, the MOTC officials and the Study Team was held to discuss the Draft Final Report. The Draft Final Report was submitted to the MOTC officials.

2. TRAFFIC STUDY

2.1 GENERAL

(1) The Kilifi creek crossing is situated on the national trunk road B–8 between Mombasa and Malindi, approximately 55 kilometers north of Mombasa. The present crossing transportation facilities consist of a 24 hours ferry service operated by the Ministry of Transport and Communications. The ferry is free of charge to the road-users.

(2) Several traffic surveys are conducted upon an examination of the existing traffic data. The surveys are to obtain the information of vehicles using the ferry on Kilifi creek crossing.

(3) The results of these surveys are used for the future traffic projection after the construction of the Kilifi bridge.

The survey that is carried out consists of the following:

a) Supplementary origin-destination survey for vehicles

b) Traffic counting survey for vehicles

c) Spent time survey for Kilifi ferry transportation

d) Passengers counting survey in ferries and at bus/matatu stops

2.2 CHARACTERISTICS OF EXISTING TRAFFIC

2.2.1 Traffic Flow

Based on the origin-destination (O–D) survey data, the traffic flow can be recognized as follows.

(1) The main traffic flow passing through the Kilifi creek crossing is composed of trips between Mombasa and Malindi. This traffic accounts for 50 percent or more of all vehicles.

(2) The ratio accounted by the main O–D pairs (Mombasa – Malindi, Mombasa – Kilifi, Kilifi – Central and Mombasa – Tana River, Lamu, Garrissa) is approximately 90% of the total traffic volume on Kilifi creek crossing.

(3) The main generation and attraction places of trips passing through Kilifi creek crossing are Mombasa, Malindi and Kilifi. The ratio for all the generated and attracted traffic volume is 87%.

2.2.2 Traffic Volume

Based on the traffic volume counting survey data and O–D survey data, the traffic volume by purpose on the Kilifi creek crossing for a period of 12 hours (7 a.m – 7 p.m) is shown in Table 2–1.

Table 2–1 TRAFFIC VOLUME

(V/12H)

Purpose \ Place	Kilifi	Central	Malindi	Northern	Southern	Mombasa	Tana River Lamu Garissa	Nairobi	Total
Going to work	25	10	17	–	1	51	2	–	106
Business	68	17	139	7	15	191	13	2	452
Going home	9	1	12	–	–	9	1	–	32
Tourism	3	2	20	–	–	37	0	3	65
Personal	3	0	4	–	–	1	–	–	8
Others	2	–	5	–	–	1	–	–	8
Total	110	30	197	7	16	290	16	5	671

2.2.3 Vehicle Composition

The vehicle composition on the Kilifi creek crossing is shown in Table 2–2.

Table 2–2 NUMBER OF VEHICLES BY VEHICLE TYPE
(converted to passenger car unit)

Date \ Vehicle Type	Car	Light	Medium	Heavy	Bus	Motor Cycle	Total
16th/3	156 (14.3)	257 (23.5)	470 (43.0)	59 (5.9)	138 (12.6)	12 (1.1)	1,092 (100.0)
17th/3	149 (14.1)	262 (24.8)	417 (39.5)	59 (5.6)	162 (15.3)	7 (0.7)	1,056 (100.0)
Average	153 (14.2)	260 (24.2)	445 (41.4)	59 (5.5)	150 (13.9)	9 (0.8)	1,076 (100.0)

Note: the upper: No. of vehicles/12hrs PCU
the lower: percentage (%)

2.2.4 Fluctuation of Traffic Volume

(1) Monthly Variation

A monthly variation correction factor, expressed as the Average Monthly Daily Traffic divided by the ADT (Average Annual Daily Traffic), has been calculated for each month in 1982 and is given in Fig. 2–1. Fig. 2–1 shows that January, April and December are the peak months and May, June, July, October and November are the low months, while February, March, August and September have average daily traffic flows close to the annual average.

(2) Daily Variation

The daily variation pattern is given in Fig. 2–2, which indicates that Tuesdays and Saturdays are the peak days while Sundays are the low days. The vehicular composition on Sundays is observed to differ from other days.

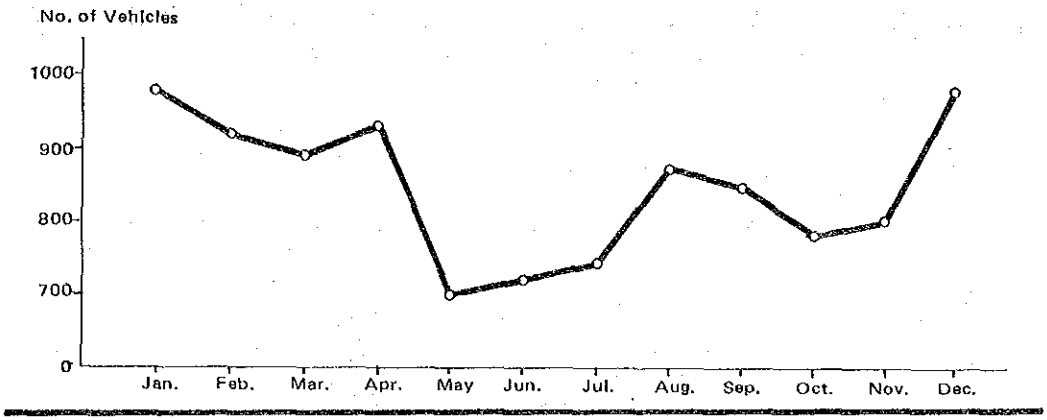


Fig. 2–1 MONTHLY VARIATION

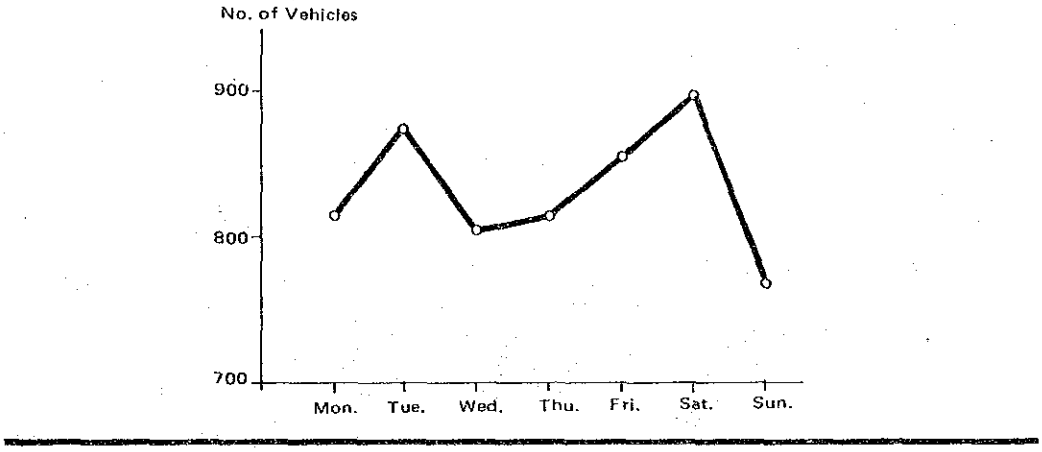


Fig. 2–2 DAILY VARIATION

(3) Hourly Variation

The hourly fluctuation is shown in Fig. 2–3 which shows that 7:00 to 10:00 and 15:00 to 18:00 are the peak hours. The peak hour ratios are 11.0% at 15:00 to 16:00 on 16th March and 9.2% at 16:00 to 17:00 on 17th March, 1983. The ratio of 24 hours to 12 hours is 1.18 which coincides with the result of Traffic Census.

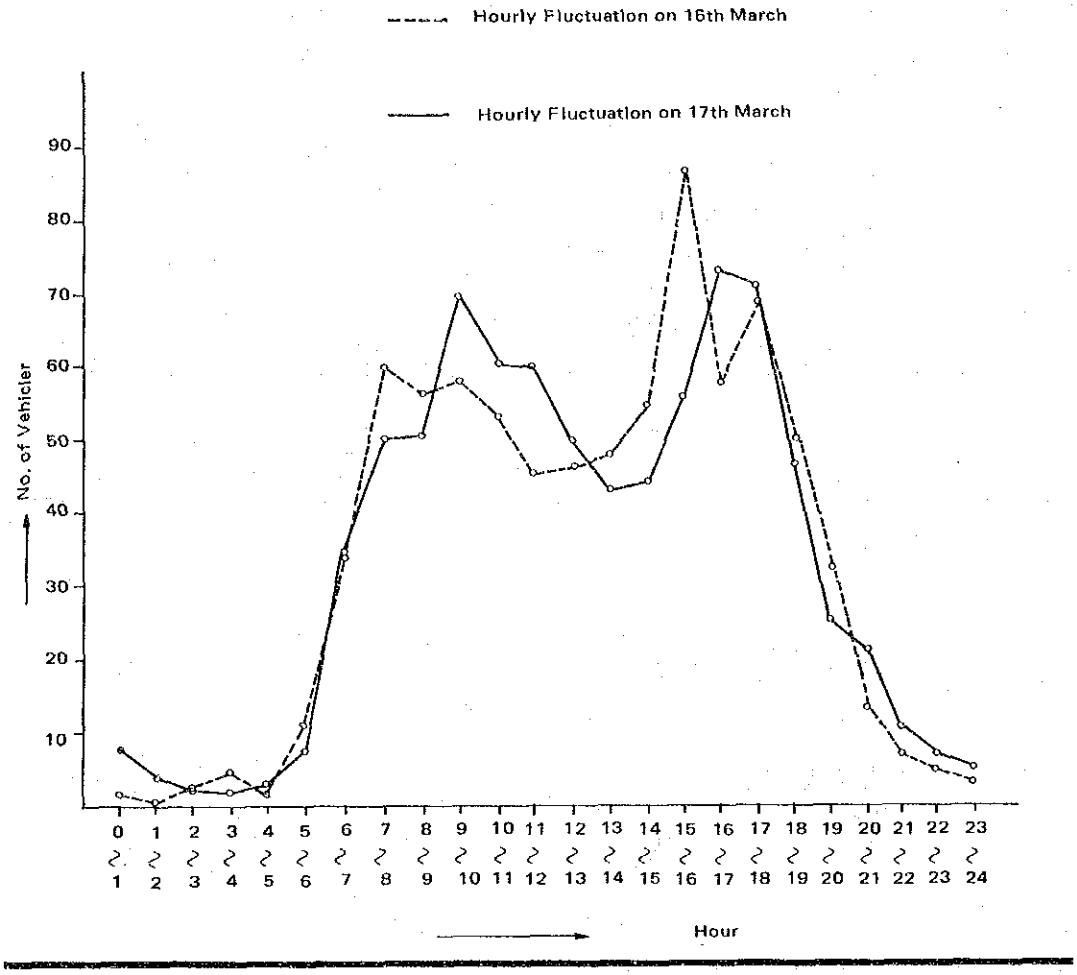


Fig. 2–3 HOURLY FLUCTUATION

2.3 FRAMEWORK FOR TRAFFIC PROJECTION

2.3.1 Procedure

On the basis of the various traffic surveys which were carried out in March, 1983, examination of population trend, analysis of the hotel bed occupancy, consideration of the development pressure and analysis of the related traffic data, the projection of the future traffic volume is carried out. The general flow chart of the traffic projection procedure is shown in Fig. 2–4.

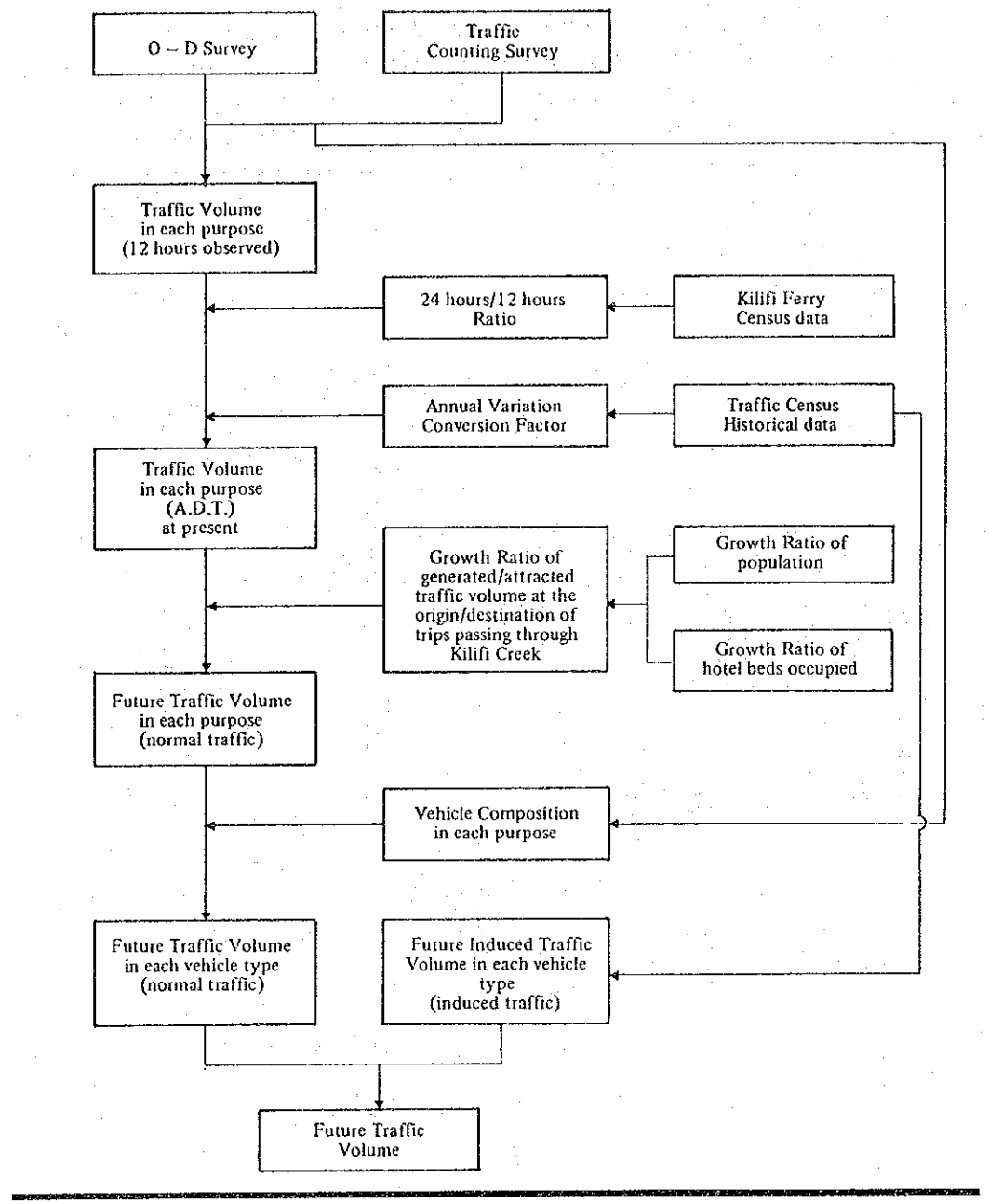


Fig. 2–4 GENERAL FLOW CHART

2.3.2 Traffic Zoning

Based on the result of the O–D survey, the existing road network, existing and future landuse pattern and characteristics of the areas, the traffic zoning is decided. Basically, the traffic zones are divided equally by each division in the Kilifi district. The traffic zoning is illustrated in Fig. 2–5.

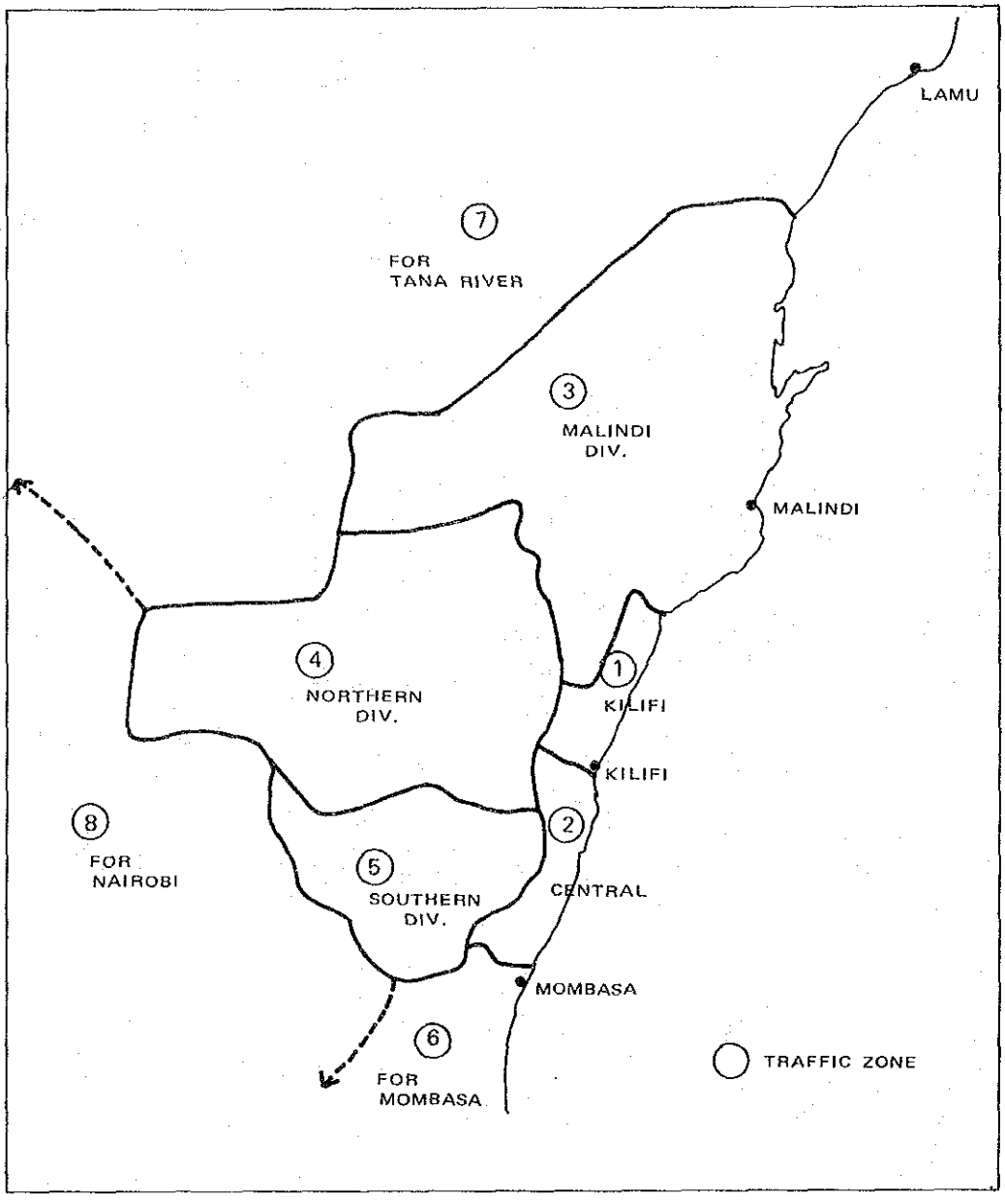


Fig. 2–5 LOCATION OF TRAFFIC ZONES

2.3.3 Development Outline

This section contains the summary of development outline which complies with the "District Development Plan" 1979–83 (January 1980) for the coastal area consisting of Kilifi, Tana River, Lamu and Garissa districts.

Generally, these areas are regarded as high potential areas with respect to the growth of population and the agriculture sector. However, the present road network is not adequate to (facilitate the flow of goods between) the centres of production and marketing as well as the movement of labour power.

The principal programmes and projects are depicted in Table 2–3.

Table 2–3 PRINCIPAL PROGRAMMES OF DEVELOPMENT PLAN (1979–83)

				Kilifi (Coast Pr)	Tana River (Coast Pr)	Lamu (Coast Pr)	Garissa (Eastern Pr)	Total
Population	1969 Sensus			307,563	50,696	23,961	64,521	446,741
	1979 Sensus			430,986	92,401	42,299	128,867	694,553
	(Annual Growth Ratio)			(5.3%)	(6.2%)	(6.5%)	(7.2%)	(4.5%)
	1983 Projected			507,100	N/A	N/A	N/A	N/A
	2000 Projected			1,058,800	N/A	N/A	N/A	N/A
Agriculture	Product Increase Rate (%)	1983 1979	Cashewnuts	9	18	72	N/A	
			Coconuts	67	1	295	N/A	
			Mangoes	N/A	81	371	N/A	
			Simsim	88	71	222	N/A	
			Cotton	9	63	162	N/A	
	Devp. Expenditure (Shs. million)		Integrated Agriculture Development Programme	15	9	0	9	33
			Tractor Hire Service	2	2	0	2	6
			Small-Scale Irrigation Programme	4	0	2	1	7
			Total	21	11	2	12	46
Livestock Development Expenditure (Shs million)				36	25	19	4	84
Water Devp.	Expenditure (Shs. million)		Rural Water Supplies	11	1	9	2	
			Water Conservation	8	N/A	3	N/A	
			Minor Water Programme	4	1	1	1	
			Minor Irrigation	1	N/A	N/A	1	
			Livestock Water Development	N/A	30	N/A	51	

2.3.4 Population

The projected future population in each zone is shown in Table 2–4. The future population is forecasted by the growth rate method based on Population Census data with reference to the District Development Plans.

Further, this projected future population in each zone is adjusted to fit the estimated future population in each province that was projected in the National Transport Study in 1983.

Table 2–4 PROJECTED POPULATION BY AREA, (1979 to 2010)

Zone	1969	1979	1983	1985	1990	1995	2000	2005	2010
TEZO/ROKA (KILIFI)	10,797	42,605 (7.44)	58,100	67,100	95,800	135,800	191,300	260,100	351,100
CENTRAL (Excluding) TEZO/ROKA)	33,425	42,732 (2.48)	48,200 1.0	50,700 1.052	57,200 1.187	64,100 1.330	71,300 1.479	76,500 1.587	81,600 1.693
MALINDI Div.	71,956	124,476 (5.83)	158,600 1.0	177,100 1.117	232,400 1.465	302,800 1.909	391,800 2.470	489,600 3.087	807,300 3.829
NORTHERN Div.	47,239	65,983 (3.40)	77,200 1.0	82,500 1.069	97,200 1.259	113,800 1.474	132,400 1.715	148,600 1.925	165,700 2.146
SOUTHERN Div.	112,493	149,749 (2.90)	171,800 1.0	182,100 1.060	209,500 1.219	239,500 1.394	271,900 1.583	29,800 1.735	324,300 1.888
KILIFI District	307,568	433,510 (3.49)	513,900 1.0	559,500 1.089	692,100 1.347	856,000 1.666	1,058,800 2.060	1,272,800 2.477	1,530,000 2.977
MOMBASA	247,073 (4.70)	341,148 (3.30)	388,500 1.0	414,500 1.067	487,600 1.255	573,500 1.476	674,600 1.736	793,500 2.042	933,400 2.403
TANA RIVER	50,696	92,321 (8.20)	117,400 1.0	132,400 1.128	178,900 1.524	241,700 2.059	326,500 2.781	441,100 3.757	595,900 5.076
LAMU	22,401	42,000 (8.50)	54,000 1.0	61,300 1.135	84,000 1.556	115,000 2.130	157,600 2.919	215,900 3.998	295,800 5.478
GARISSA	84,521	129,000 (7.20)	147,500 1.0	157,700 1.069	188,300 1.263	220,300 1.494	260,300 1.765	307,700 2.086	363,700 2.466
NAIROBI	509,000 (5.60)	828,000 (5.00)	1,018,000 1.0	1,128,000 1.108	1,434,000 1.409	1,803,000 1.771	2,293,000 2.252	2,916,000 2.864	3,709,000 3.643

Note: The future population in each zone was forecasted based on population Census data.
The growth rate of population in each zone is prepared as the following:

KILIFE	District = 4.3% (1983–2000), 3.75% (2000–2010)
MOMBASA	District = 3.3%
TANA RIVER	District = 6.2%
LAMU	District = 6.5%
GARISSA	District = 3.4%
NAIROBI	District = 5.3% (1983–1985), 4.9% (1985–2010)

2.3.5 Tourism

Data of hotel beds occupancy from 1972 to 1981 at the Coastal-Beach area is prepared for the forecasting of tourist traffic. The time series data is shown in Table 2–5.

A hotel bed-nights data is analysed and a future annual growth rate of 8.5 percent is obtained.

Table 2–5 HOTEL BEDS OCCUPANCY AT COASTAL – BEACH AREA

(Unit: 1000 Bed-nights)

Average	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Coastal Beach	763.2 (100)	812.5 (108)	950.9 (125)	1,149.4 (151)	1,354.4 177)	1,543.6 (202)	1,654.0 (217)	1,809.8 (237)	2,055.3 (269)	2,039.1 (267)
KENYA	2,474.7 (100)	2,783.8 (112)	2,979.0 (120)	3,208.8 (130)	3,573.7 (144)	3,887.9 (155)	3,982.3 (161)	4,338.1 (175)	3,717.3 (191)	4,691.0 (190)

Annual Growth Rate:	Coastal – Beach	1972 – 1981	11.5%
		1976 – 1981	8.5%
		(1970 – 1980)	(14.8%)
	KENYA	1972 – 1981	7.4%
		1976 – 1981	5.6%
		(1970 – 1980)	(9.5%)

2.4 TRAFFIC PROJECTION

2.4.1 General

It is assumed that service at the Kilifi creek crossing should not be allowed to deteriorate in the future. The following components must hence be taken into account in the traffic forecast.

a) Normal traffic growth, i.e. the growth when the ferry serviceis retained and regularly expanded to maintain the present level of service.

b) Induced traffic due to the construction of a bridge. The traffic forecast in this study is mainly based on the results of traffic survey and analysis of past trend from the traffic census data.

2.4.2 Normal Traffic

A guture traffic volume is forecasted on the basis of the present O–D table which is conducted by an O–D survey. A formulation for the future traffic volume estimation is as follows.

a) For work, Business and Personel trip and others.

$$nTk = \sum_{i=1}^{8} nG_i^k = \sum_{i=1}^{8} \left({}_{83}G_i^k \times \frac{nPi}{{}_{83}Pi} \right)$$

nTk ; Traffic volume in total zone in year (n)

nG_i^k ; Traffic volume in (i) zone in year (n)

${}_{83}G_i^k$; Traffic volume in (i) zone in year 1983

nPi ; Number of population on (i) zone in year (n)

b) For home bound trip

$$nTk = \sum_{i=1}^{8} nG_i^k = \sum_{i=1}^{8} \cdot \sum_{j=1}^{8} n\,OD_{ij}^k$$

nOD_{ij}^k ; Traffic volume from (i) zone to (j) zone in year (n)

c) For tourist traffic

$$nTk = {}_{83}Tk \times \frac{nH}{{}_{83}H} = {}_{83}Tk \times (1+r)^{n-1983}$$

nH ; Number of hotel bed night in year (n)

r ; Average growth rate of the hotel bed night in year 1976–1981

d) Future traffic volume

$$nTT = \sum_{k=1}^{8} \cdot nTk$$

nTT ; Total traffic volume in year (n)

nTk ; Total traffic volume of (i) purpose in year (n)

2.4.3 Induced Traffic

Construction of a bridge could be expected to induce some extra traffic across the Kilifi creek, in addition to the traffic which would have used the ferries anyway. However, it is difficult to make any firm estimates of such induced traffic volume.

In this forecast, it is assumed that the induced traffic would account for 30% of the normal traffic in the first year of the operation of the bridge. This estimate is based on the notable variation of traffic volume before and after the construction of the New Mtwapa bridge.

2.4.4 Future Traffic Volume

The results of forecast of the future traffic volume are shown in Table 2–6 and Table 2–7. The number of the total vehicles in above mentioned Table is including normal and induced traffic volume and these numbers are illustrated in Fig. 2–6. Annual growth rates are 5.1 percent, 5.3 percent and 5.2 percent during the periods of 1983 to 1990, 1990 to 2000 and 2000 to 2010 respectively.

Table 2–6 ESTIMATED FUTURE TRAFFIC VOLUME BY YEAR AND BY PURPOSE

(Vehicle/day)

Year	PURPOSE						Total Vehicles
	Going to work	Business	Going Home	Tourism	Personal	Others	
1983	156 (15.9)	665 (67.7)	46 ((4.7)	94 (9.6)	11 (1.1)	11 (1.1)	983 (100.0)
1990	279 (15.4)	1,194 (65.8)	82 (4.5)	216 (11.9)	22 (1.2)	21 (1.1)	1,814 (100.0)
2000	448 (14.8)	1,901 (62.6)	122 (4.0)	489 (16.1)	39 (1.3)	38 (1.2)	3,037 (100.0)
2010	700 (13.9)	2,930 (58.2)	178 (3.5)	1,105 (21.9)	64 (1.3)	62 (1.2)	5,038 (100.0)

Table 2–7 ESTIMATED FUTURE TRAFFIC VOLUME BY YEAR AND BY VEHICULAR TYPE

(Vehicle/day)

Year	Vehicle Type				Total Vehicles	Total P.C.U.
	Car Light	Medium	Heavy	Bus		
1983	589 (59.9)	201 (20.4)	93 (9.5)	100 (10.2)	983 (100.0)	1,617
1990	1,108 (61.0)	361 (19.9)	166 (9.2)	179 (9.9)	1,814 (100.0)	2,949
2000	1,913 (63.0)	574 (18.9)	266 (8.8)	284 (9.4)	3,037 (100.0)	4,847
2010	3,303 (65.6)	887 (17.6)	410 (8.1)	438 (8.7)	5,038 (100.0)	7,831

Note: The following P.C.U. conversion factor is used:

Type	Passenger Car Light Goods	Medium Goods	Heavy Goods	Buses
Conversion factor	1.0	2.5	3.5	2.0

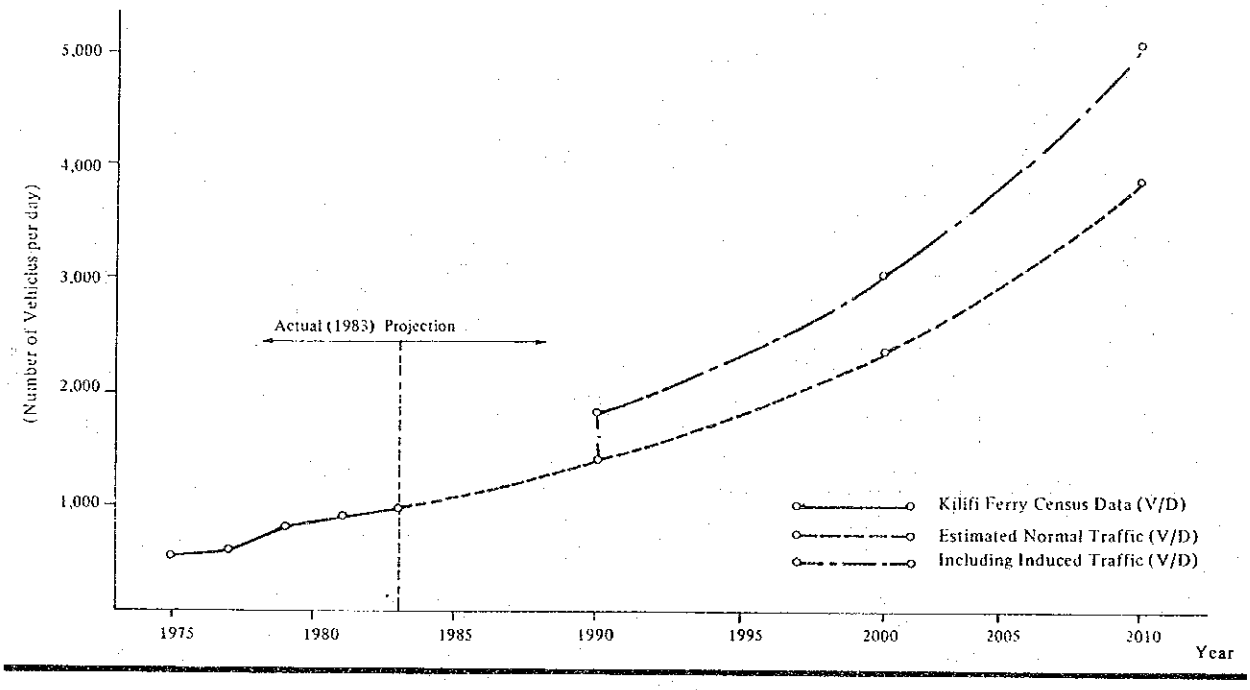


Fig. 2–6 ESTIMATED FUTURE TRAFFIC VOLUME

3. CHARACTERISTICS OF THE STUDY AREA

3.1 NATURAL CONDITION

3.1.1 Temperature

The average monthly temperature in Kilifi is shown in Fig. 3–1.

3.1.2 Rainfall

Annual rainfall in Mombasa is 1,163 mm (1931 – 1960). Histogram of the average monthly rainfall is shown in Fig. 3–2.

3.1.3 Wind

The seasonal wind blows in the south-west direction between April and October, and north-east between December and March. The former is generally stronger than the latter, but this seasonal wind is generally mild, i.e. the maximum instantaneous wind speed does not exceed 40 knots (= 20 m/sec).

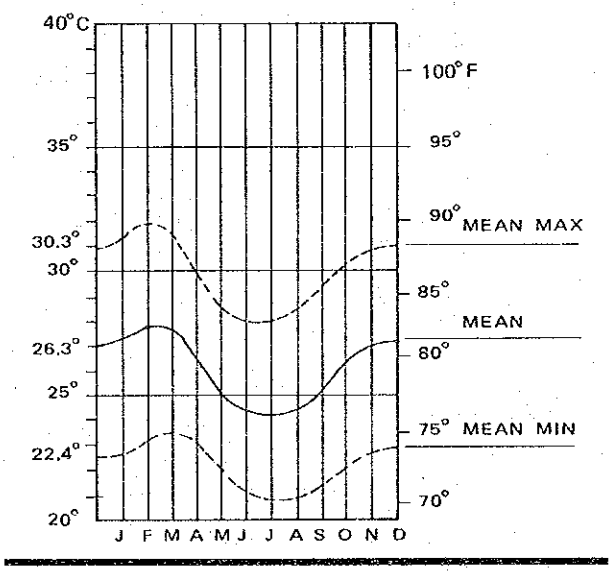


Fig. 3–1 AVERAGE MONTHLY TEMPERATURE

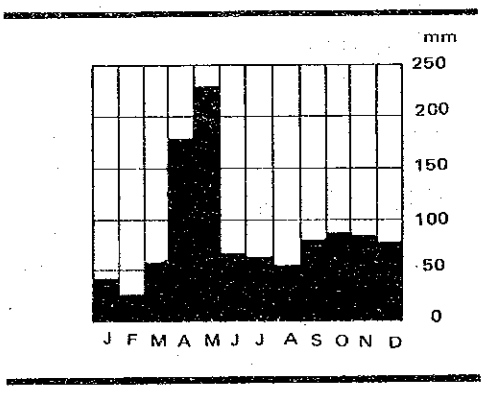


Fig. 3–2 AVERAGE MONTHLY RAINFALL

3.1.4 Tide

(1) Tidal Range

According to the tide table of Kenya Ports Authority, the maximum tidal range in Kilindini (Mombasa) is 3.98 m, that is between + 3.93 m and – 0.05 m.

(2) Tidal Current

According to the chart of Kilifi creek (surveyed in 1880), the maximum tidal current velocity in the creek is 1.5 knots, that is 0.75 m/sec.

(3) Effect of Flood

At the up-stream of the Kilifi creek, several rivers, for example Rave and Ndzovuni, flow into the Kilifi creek. But as the basins of these rivers are rather small while the opening of the creek is comparatively wide, any extreme rise of water level at or after heavy rainfall does not appear. In fact the ground near the Kilifi creek on which the present MOTC Provincial Office building is standing, is only slightly higher than the normal high-tide level but has never been submerged.

(4) Datum Line

The datum line of the survey of kenya is used for this study. This is the mean sea level of mombasa port and is 1.85 m above the admiral chart datum (Fig. 3–3).

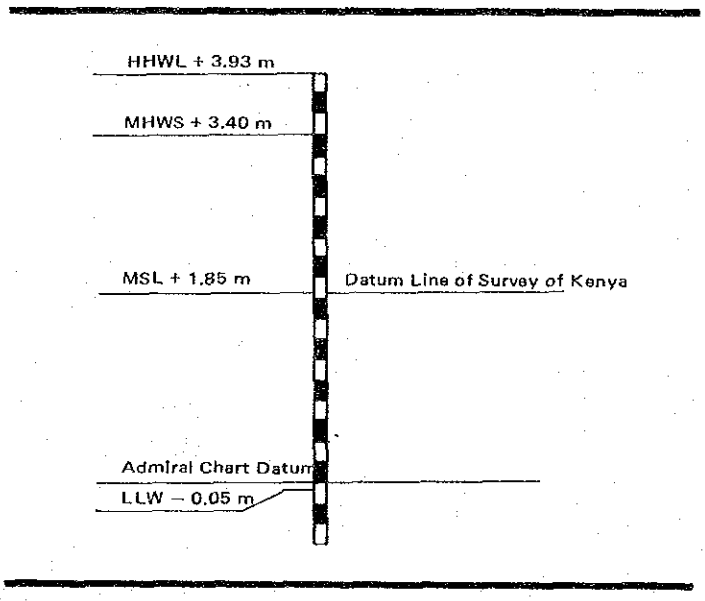


Fig. 3–3 DATUM LINE OF THE STUDY

3.1.5 Earthquake

There are some earthquakes data namely the Modified Mercalli Scale of 1931 (Wood and Neumann 1981), supplemented by Richter's version (1956) and the Code of Practice for the Design & Construction of Buildings & other Structures in relation to Earthquakes (1973).

According to the above mentioned reports, a total of five hundred (500) earthquakes with intensity high enough to effect to the people have occured between the year 1892 and 1969. These earthquakes occured mainly along the Rift Valley.

In the study area, some minor earthquakes have occured but they are very scanty. The effects to the bridge structure by earthquakes in the study area seem very unlikely.

3.2 FIELD SURVEY

3.2.1 Conducted Survey

In order to study the physical conditions of the study area, the following surveys were conducted in June and July, 1983:

a) Bathymetric survey
b) Sub-surface investigation and
c) Topographic survey

The above mentioned survey areas or survey points are illustrated in Fig. 3–4.

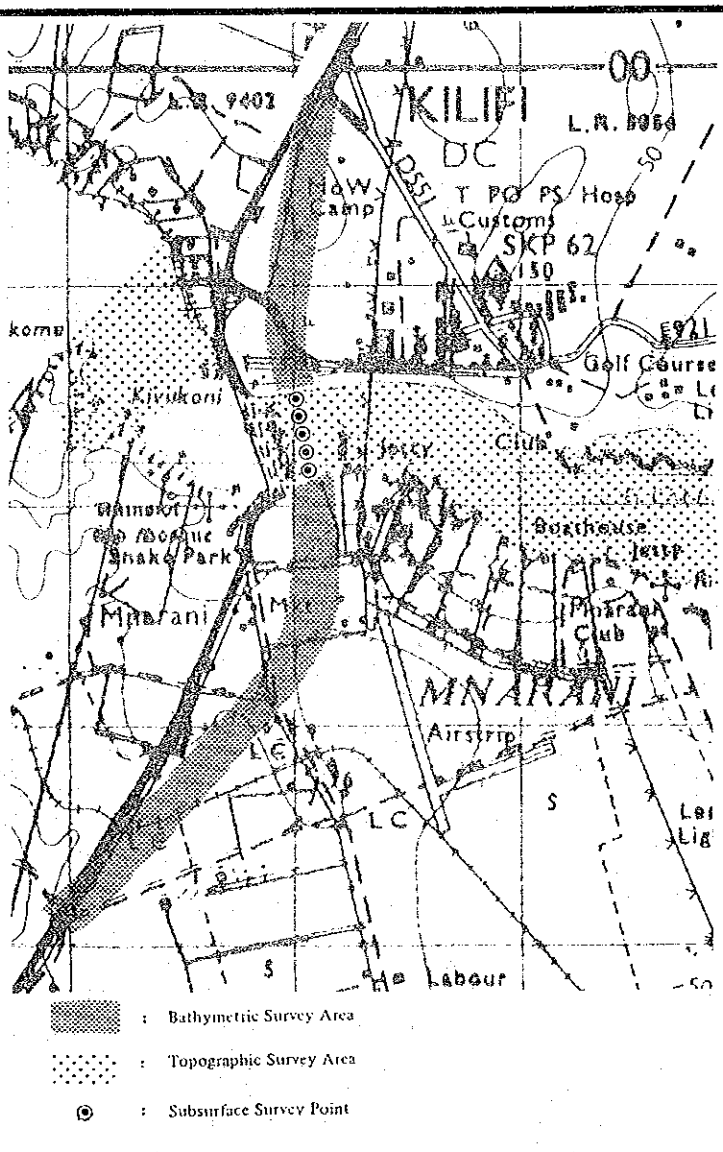


Fig. 3–4 SURVEY SITE LOCATION

3.3 SUBSURFACE INVESTIGATION

3.3.1 General

In compliance with the proposed location of Kilifi Bridge, the subsurface investigation for the design of substructure foundations was performed along the centre line of the Kilifi Bridge between 16th June, 1983 and 15th August, 1983. In addition, the aggregate materials investigation for construction was performed in and around the Kilifi region.

Two onshore exploratory borings were sunk to 30 m deep at the expected two abutments on both the banks of Kilifi creek. Two offshore borings were sunk to 40 m and 50 m deep respectively from the bottom of creek near the proposed two locations of piers.

The representative soil samples were tested in the laboratory on physical and mechanical properties necessary for the analyses of the subsurface ground conditions.

The actual field work was carried out by Consolidated Marine Engineering Constractors Limited under our supervision. The laboratory soil and material tests were carried out by Central Testing Laboratories Limited under our direction.

3.3.2 Outline of Physiography and Geology

Physiography and geology of the Kilifi region is outlined below for a better understanding of the subsurface ground conditions.

(1) The coastal belt of the Kilifi area can be described as a series of four parallel zones. These four zones are the (I) Coastal Plain, which is typified by Pleistocene deposits, (II) Foot Plateau, which is practically coincidental with the Jurassic outcrop, (III) Coast Range, which comprise the Jibana and Simba hills, and (IV) Nyika, which embraces the ground covered by the Duruma Sandstone Series. All four zones, as shown in a Physiographical Map of Kilifi – Mazeras Area, in Fig. 3–5 can be found in the Kilifi region.

(2) The Kilifi area falls on the (I) Coastal Plain which varies from 2 to 5 miles (3 to 8 kms) in width and generally lies below 100 ft in elevation. Its seaward margin is composed of a Pleistocene coral reef and this is backed by a series of variable sands, also of Pleistocene age. Under natural conditions, the coastal plain supports thick bush, but throughout most of the Kilifi area the bush has been cleared and the ground is presently being cultivated for large sisal plantations, e.g. the Vipingo Estates and Kilifi Plantations.

The geology of the Kilifi-Mazeras area is shown in a Geological Map in Fig. 3–6.

(3) The rocks of the Kilifi-Mazeras area are of wholly sedimentary origin, and range in age from Triassic to Recent. Generally, these rock formations descend gradually seaward from west to east.

The general geologic structure of the coast follows a linear north-south pattern as shown in Fig. 3–6. Fluctuating sea levels over extended periods

have lead to the formation of narrow parallel bands of sands, clays, coral, coral limestone, shale, limestone, and sandstone. This can be clearly seen on the geological map. Kilifi is one of the few areas where the linear north-south structure is traversed and replaced by an east-west structure. The wide creek has cut through a whole range of coastal geology and soils perpendicular to the coastline.

(4) The site reconnaisance survey was made between 14th March and 24th March, 1983. The present physical geography of the major study area is sketched in Fig. 3–7 and based on outcrops, microclimate and microsoil variations, which account for changes in vegetation. A typical cross-section for the south side of the creek is shown in Fig. 3–8, this being not much different from the north side of the creek. However, it is observed that the dry slope for the northern side of the creek is steeper and less vegetation exists than on the southern side of the dry slope. From Fig. 3–8 it can be seen that there are coral limestone boulders and cobbles spreading along the foot of both dry slopes and consist mainly of coral limestone and marls. In some sections, coral covers the areas along the shoreline near the mangrove sand beach.

3.3.3 Results of Subsurface Ground Conditions

Two offshore boreholes were drilled down to 40 and 50 m in depth respectively from the creek-bed near the expected two locations of piers by one Pilcon hydraulic rotary drill rig mounting aboard the 270-tonnage ship, Venture. Two onshore boreholes were sunk to 30 m deep by one Crealius D750 Drill rig at the expected two abutments on both the banks of Kilifi Creek. The results of subsurface ground conditions are shown in a Soil Profile along Kilifi Bridge in Fig. 3–9.

The stratigraphy of the subsurface is classified into 5 layers as shown in Fig. 3–9. Descriptions of each layer, i.e. type of soil, relative density, characteristics and geologic period are tabulated in Table 3–1. It is observed that each of the 5 layers is developed horizontally at the site. It is also found that no geological faults exist around the site. The laboratory soil and material tests were performed after British Standard. Grading mixture of each borehole is shown in Fig. 3–10.

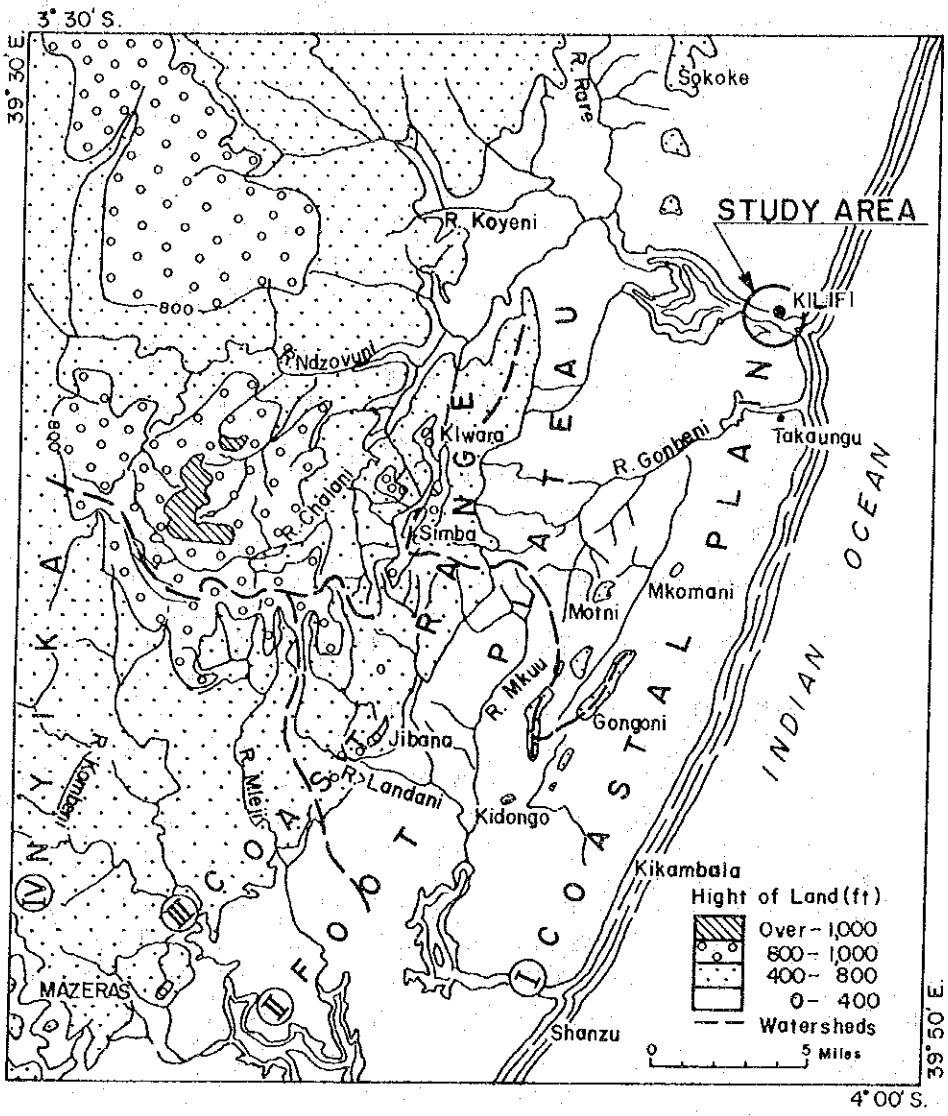


Fig. 3–5 PHYSIOGRAPHICAL MAP OF KILIFI–MAZERAS AREA

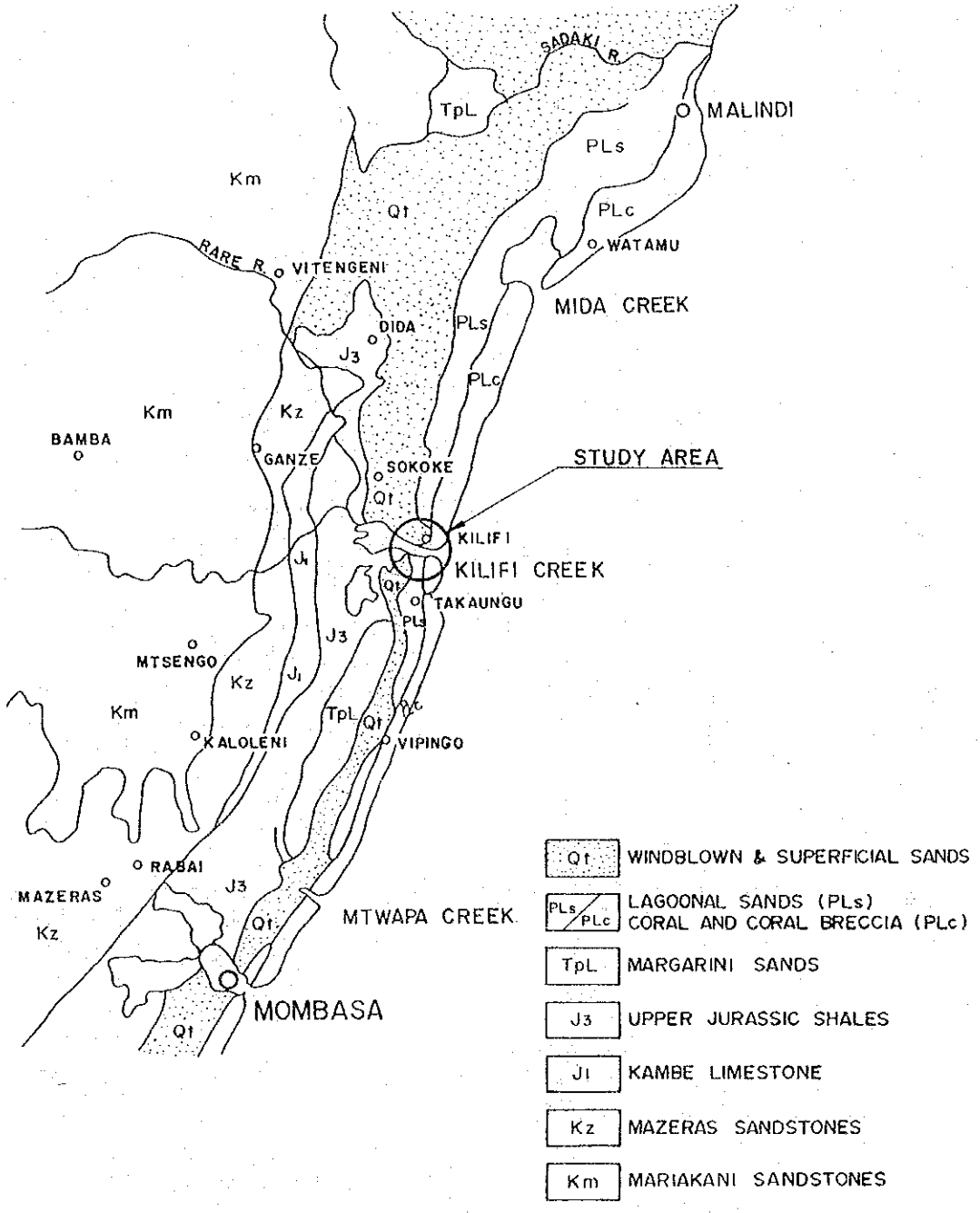


Fig. 3–6 GEOLOGICAL MAP

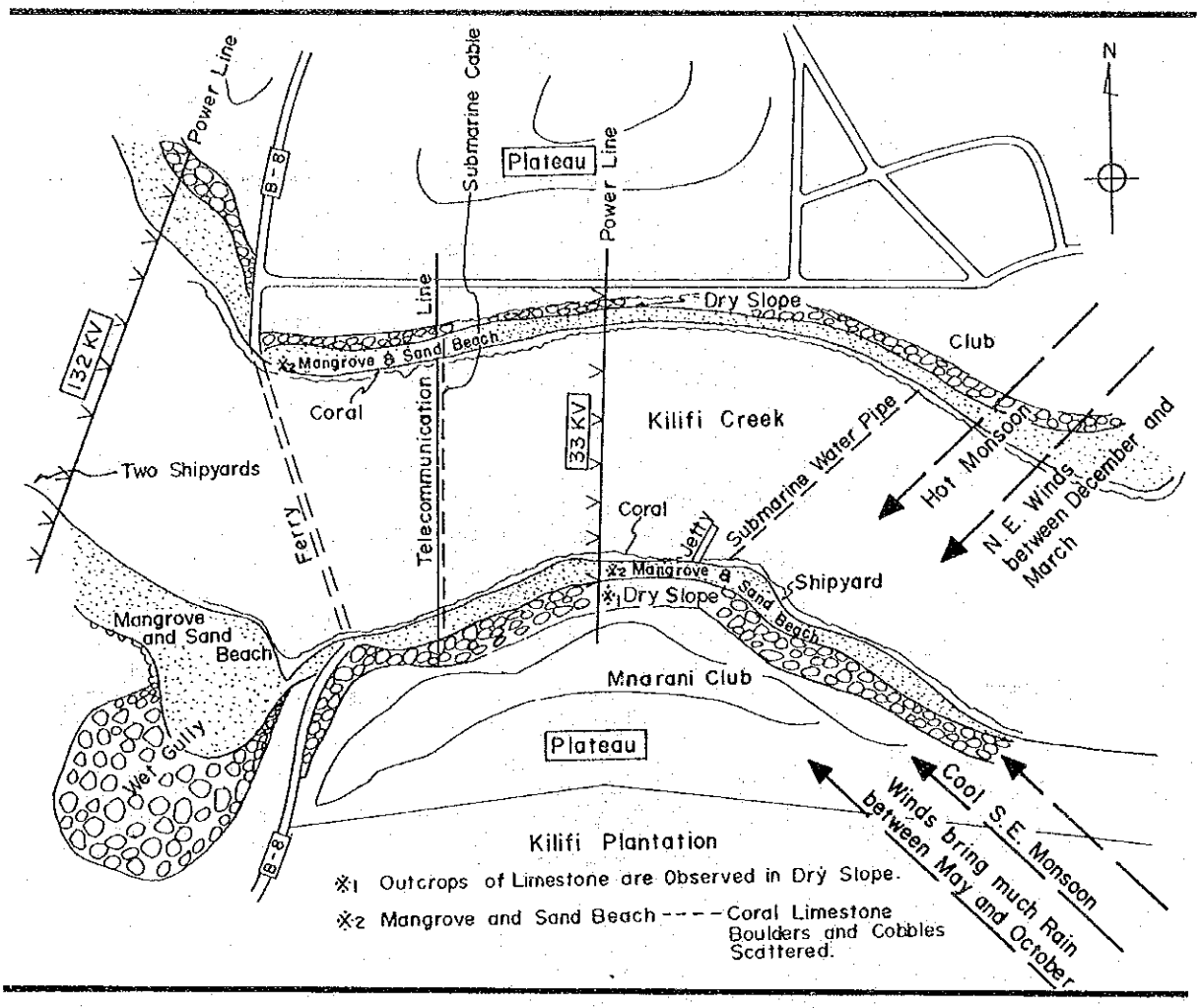


Fig. 3–7 PHYSICAL GEOLOGY OF THE STUDY AREA, SCALE = 1/10,000

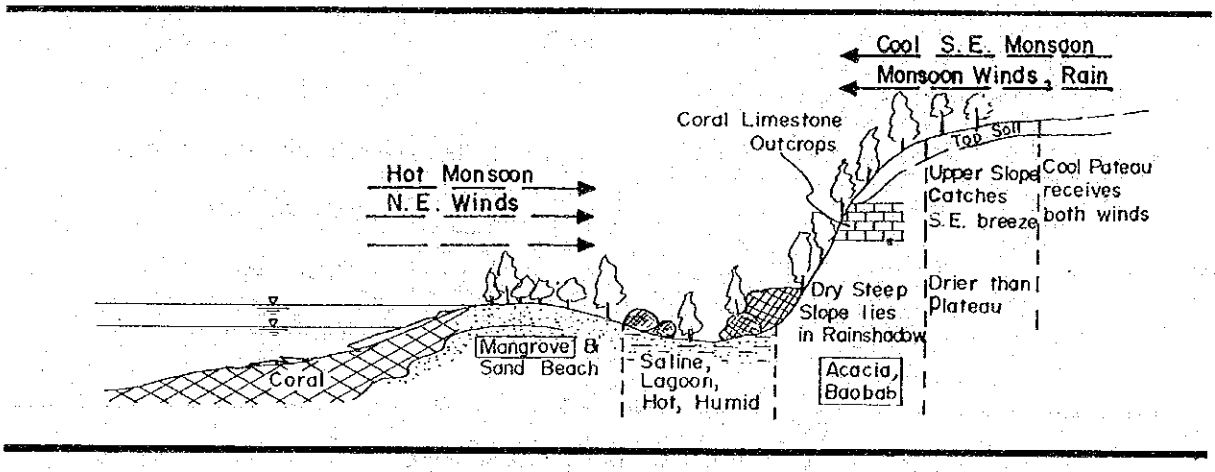
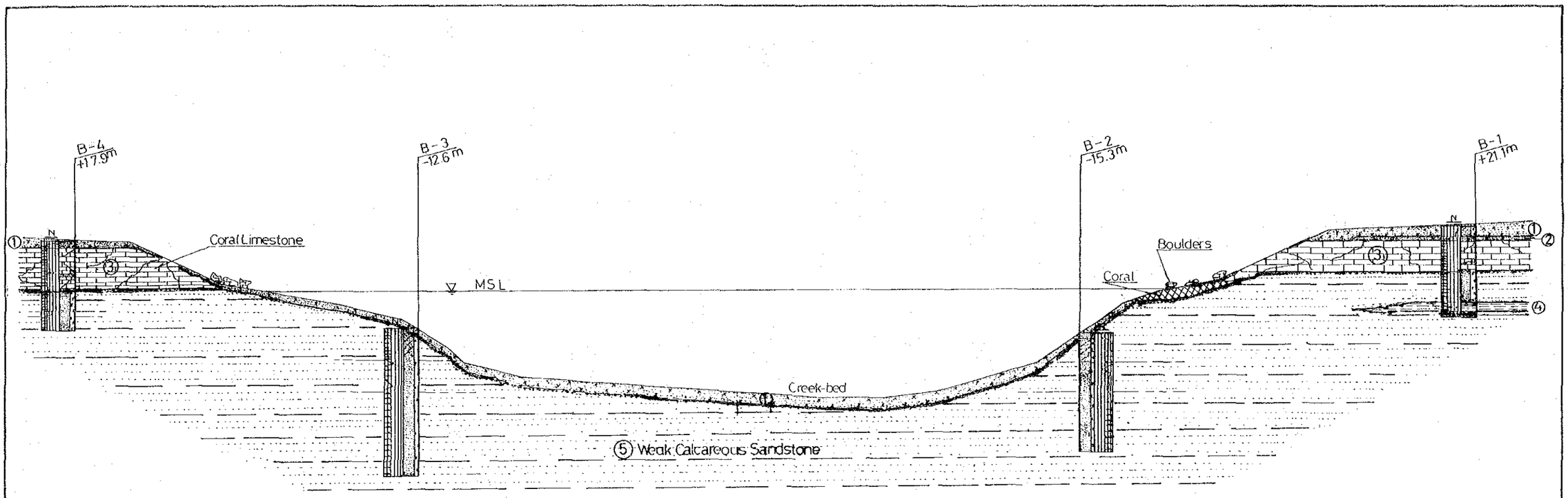
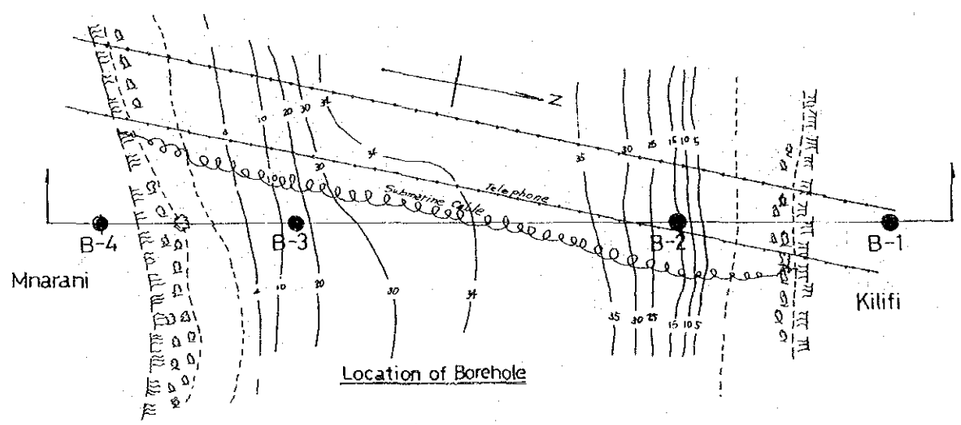


Fig. 3–8 TYPICAL CROSS-SECTION FOR SOUTH OF CREEK (MICRO-CLIMATE & VEGETATION)





No.	Legend	Type of soil	Description
①		Silty Sand	Brown to reddish brown loose silty sand, N = 5 – 10 Greyish brown to greyish black loose silty fine sand in the creek-bed, N = 3 – 10
②		Fine to Coarse Sand	Compact to dense coral sand with pebbles consist of coral pieces, quarts, biotite and mica, decomposed coral limestone, N = 30 – 40
③		Coral Limestone	Very hard yellowish white coral limestone, pores and some cracks which exist in the stratum are filled with gravelly sand, decomposed coral limestone in some sections, low recovery of coring.
④		*Limy Silty* Clay	*Very stiff to hard silty clay* with occasionally coral pebbles ϕ 10 – 40 mm, N = 20 – 50
⑤		Weak Calcareous Sandstone	Compact to very dense (N = 20 – greater than 50) yellowish to greyish brown silty sand, loosely consolidated sandstone some sections of this stratum are loosely cemented, with calcium, guarts, biotite and mica.

Fig. 3–9 SOIL PROFILE ALONG KILIFI BRIDGE LINE

Table 3–1 DESCRIPTIONS OF LAYERS

Layer	Type of Soil	Description	Geologic	
			Epoch	Period
1	Silty Sand	*Brown to reddish brown loose silty sand, N = 5 ∿ 10* Greyish brown to greyish black loose silty fine sand in the creek-bed, N = 3 ∿ 10	Recent	
2	Fine to Coarse Sand	Compact to dense coral sand with pebbles consist of coral pieces, quarts, biotite and mica, decomposed coral limestone, N = 30 ∿ 40	(Recent) Pleistocene	Quaternary
3	Coral Limestone	Very hard yellowish white coral limestone, pores and some cracks which exist in the stratum are filled with gravelly sand, decomposed coral limestone in some sections, low recovery of coring.	Pleistocene	
4	Limy Silty Clay	Very stiff to hard silty clay with occasionally coral pebbles ϕ10 ∿ 40 mm, N = 20 ∿ 50	Pleistocene	
5	Weak Calcareous Sandstone	*Compact to very dense (N = 20 ∿ greater than 50)* yellowish to greyish brown silty sand, loosely consolidated sandstone, some sections of this stratum are loosely cemented, with calcium, quarts, biotite and mica.	Pliocene	Tertiary

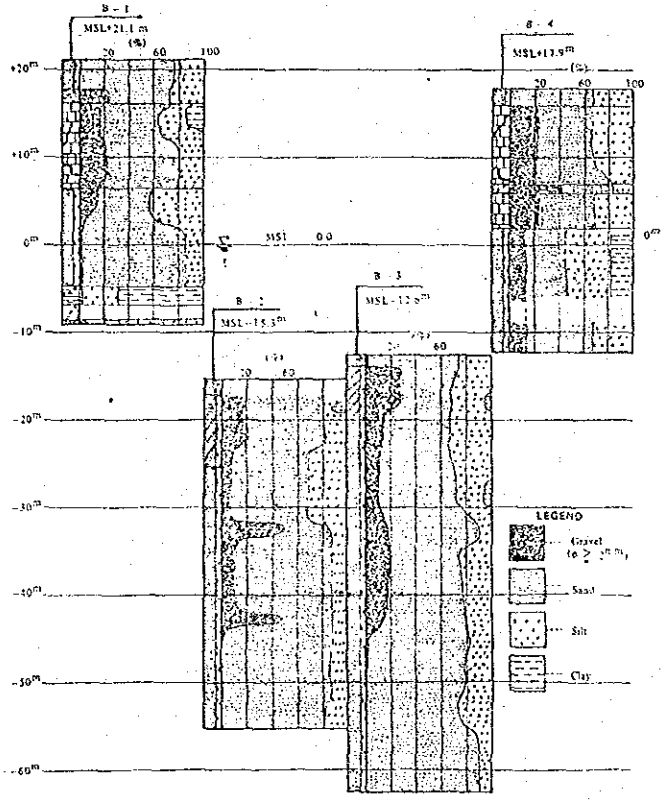


Fig. 3–10 SUMMARIZED GRADING MIXTURE

3.3.4 Some Comments on Coral Limestone and Weak Calcareous Sandstone

(1) Coral Limestone

From the engineering viewpoint, the marine coral limestones developed in the tropical region are distinguished from other rocks by two characteristics:

a) Solubility in water that produces enlarged pores and cavities, and

b) Blanketing by nonsoluble sediments or residual soils in the cavities. The tropical marine coral limestone is essentially a soil, rather than a rocklike material. The tropical marine coral limestone and decomposed coral limestone deposits are encountered between MSL + 16M and MSL + 2m in elevation. The coral limestone has a primary porosity solution as shown in Fig. 3–11 and Fig. 3–12 in its materials. It is observed that some secondary porosities as shown in Fig. 3–11 and Fig. 3–12 exist in the coral limestone layer according to the outcrops in the slope of cliff and the core samples obtained from borings.

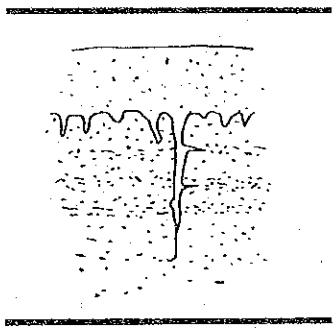


Fig. 3–11 PRIMARY POROSITY SOLUTION ENLARGEMENT

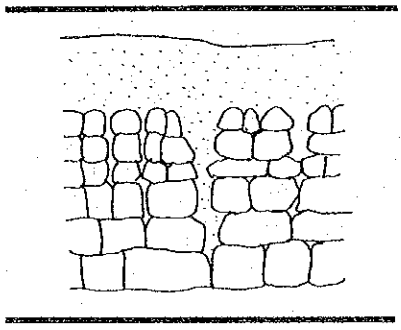


Fig. 3–12 SECONDARY POROSITY ENLARGED

It is found that the young poorly consolidated coral limestones in the Kilifi area have a relatively high void ratio and exhibit a soft chalky fabric in some sections. It is believed that the strengths of the chalky phase range from 3,500 KN/M² to 3,000 KN/M² (350 t/m² – 300 m t/m²). Therefore, it can be estimated that the whole coral limestone bearing capacity is 3,000 KN/M², as a conservative value. It is recommended that plate loading tests on the proposed depth of abutments be carried out to ascertain the required bearing capacity for confirmation at the construction stage. When some sinkholes and/or some cracks are encountered in excavation at the proposed bottom of foundations, some minor modifications of footing widths/depths and/or concrete grouting shall be required at the construction stage. It is also recommended that some slope protection, i.e. concrete gridworks be placed in front of both the abutments.

(2) Weak Calcareous Sandstone

Loosely consolidated weak calcareous sandstone layer below coral limestones is developed predominantly in the Kilifi creek. Major characteristics

of the weak calcareous sandstone are summarized below:

a) Compact to very dense (N = 20 – greater than 50)

b) Some sections of this layer are loosely cemented with calcium, quarts, biotite and mica

c) Grading mixture consists of fairly well graded silty fine to coarse sand with little coral and calcareous gravels.

d) No boulders/cobbles exist in this layer

Based on the above characteristics, the following pile foundations for the proposed piers are considered below:

i) Concrete pile and/or steel pipe pile
ii) Cast-in place concrete pile

It is anticipated that driving concrete and/or steel piles in deep water are considered to be difficult to penetrate through to the required depth of around MSL – 40 m. Therefore, it is expected that cast-in-place concrete piles by using a reverse circulation drill is preferable than driving pile methods.

It is recommended that drilling bits, i.e. tricon bits and rock crushing bits be used in the drilling.

3.3.5 Aggregate Materials Investigation

Fine to coarse aggregate materials investigation for construction was carried out in and around the Kilifi region.

Potential sources of aggregate materials are summarized in Fig. 3–14.

Results of grading analysis for each aggregate material are shown in Fig. 3–13.

From the results of grading analysis, Tiboni sand is more suitable as the fine aggregate for concrete mixture than the Sabaki River sand. Available amount of Rare River sand is limited for the required amount in the project. Mkongani materials are also suitable for the borrow materials.

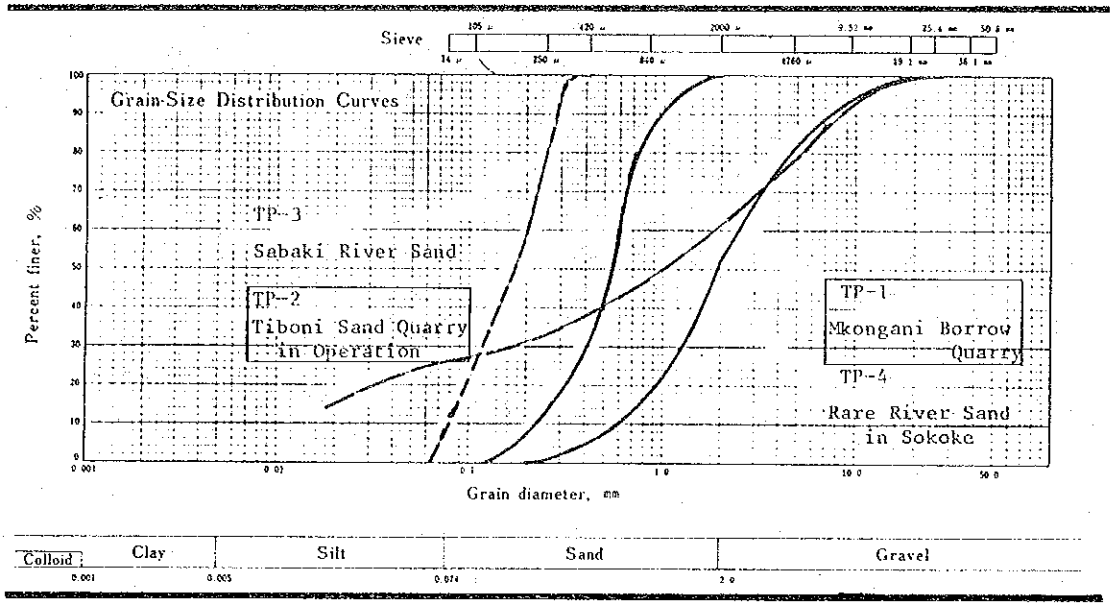


Fig. 3–13 GRADING OF AGGREGATE MATERIAL

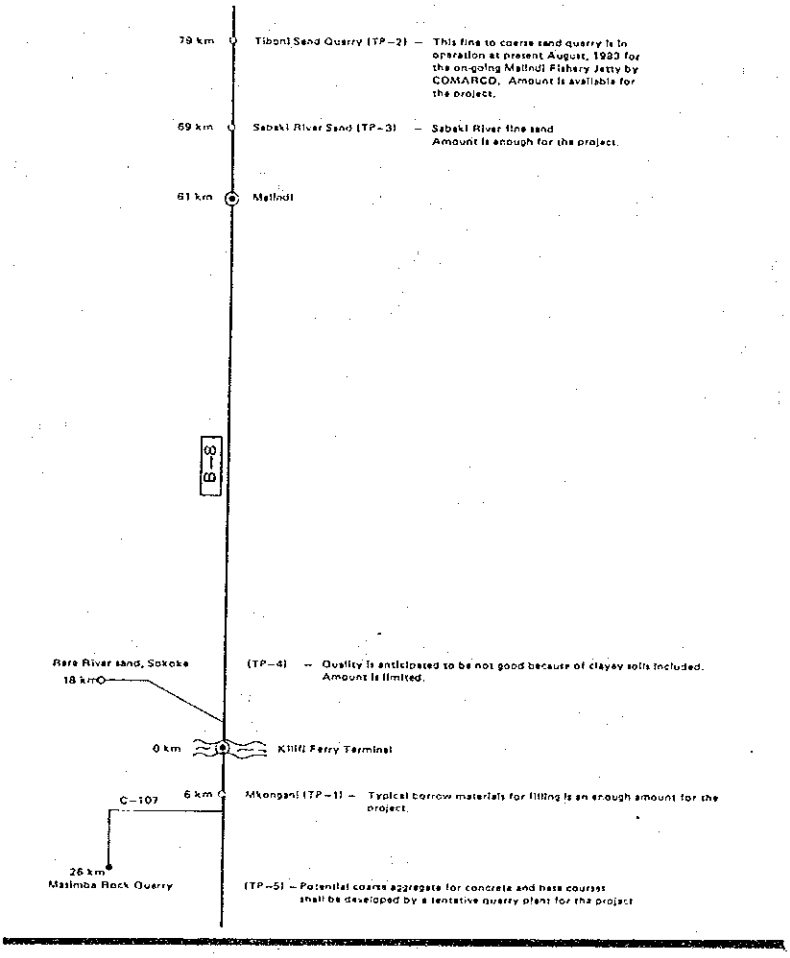


Fig. 3–14 LOCATION OF POTENTIAL SOURCES OF AGGREGATES

Photo 1

The existing B–8 road near the ferry terminal at Kilifi side. The width of the pavement is about 6.0 meters and a 1.5 meters soft shoulder is provided on both sides of the road.

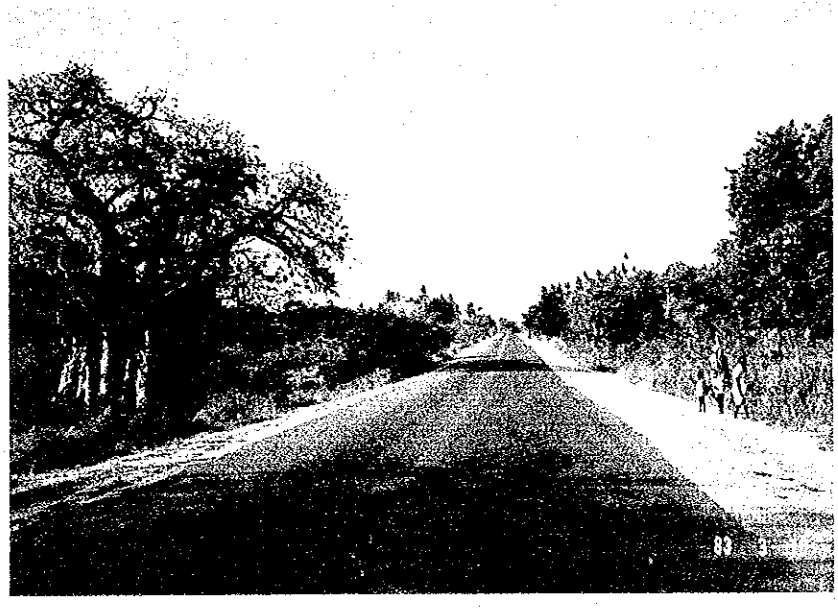


Photo 2

The existing B–8 road at the Manarani side. The horizontal alignment is almost in a straight line and the widths of the pavement and schoulders are 6.0 meters and 1.5 to 2.0 meters respectively.

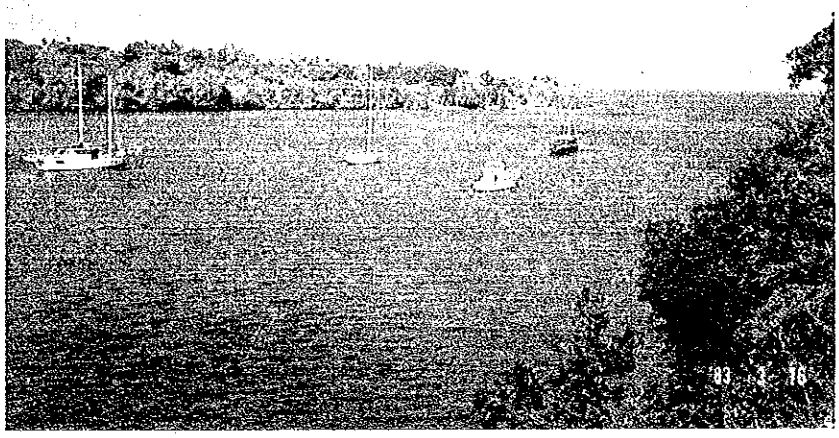


Photo 3

General view of the Kilifi creek crossings. A view towards the Kilifi side.

Photo 4

General view of the Kilifi creek crossing. This photograph is taken from the proposed bridge construction site in Kilifi to the Mnarani Club.

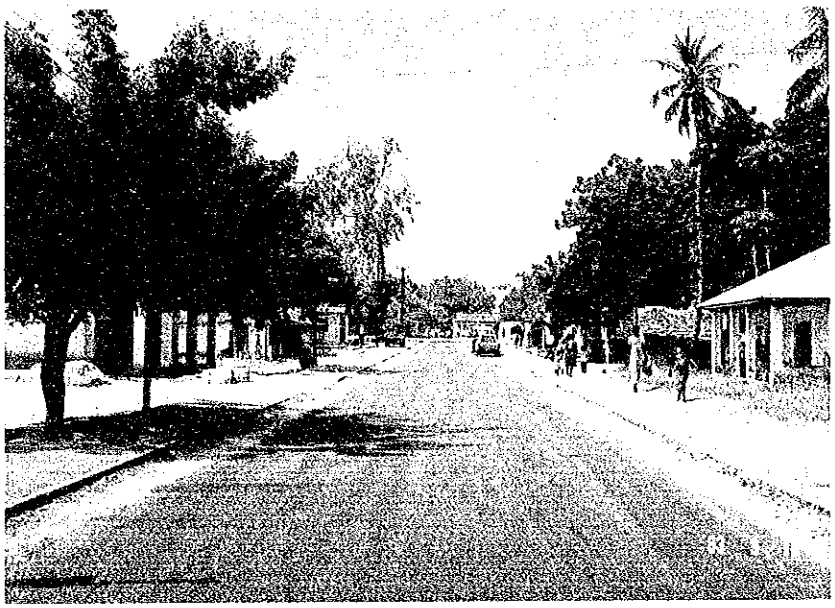


Photo 5

Main street of the Kilifi township. Both the commercial and residential areas are located along this road.

Photo 6

The existing E921 road. The widths of the pavement and pedestrian way are about 6.0 meters and 1.5 meters respectively.

Photo 7

Residential areas in the Kilifi township. The proposed road is to avoid disrupting such established settlement.

Photo 8

The town center at the Mnarani side. There are some residences in this area. The proposed road project is to preserve such areas.

Photo 9

The outskirts of the central area in the Mnarani side. The proposed road is located to pass into this area.

Photo 10

The livestock farming area in the Mnarani side. A part of the proposed road will pass through this area.

3.4 DEVELOPMENT FEATURES OF STUDY AREA

3.4.1 Existing Landuse Pattern

The study area consists of the Kilifi side and Mnarani side with the Kilifi creek inbetween. The population of Kilifi township and Mnarani is about 42,600 and 626 respectively (1979 population census). The commercial area is located along the D551 road and some parts of the E921 road. Along the seashore of the Kilifi creek, housing area and government utility are located on the Kilifi townside. Residential areas are located on both sides of the creek with their adjacent areas and the hinderland as open spaces left for crop and livestock farming. The existing situations of the study area are shown in the photo 1 to photo 10.

3.4.2 Existing Road Condition

The B–8 road passes through the side of Kilifi township and the D551 and E921 roads pass through the Kilifi township. The number of lanes of the B–8, D551 and E921 roads are two (2) lanes and the width of the pavement of the above roads are 7.0 m, 6.0 m and 5.5 m respectively. The pavement condition is comparatively good but the boundary between the pavement and the shoulder is at a different level due to heavy rainfall and other reasons. In the night time, a driver can easily misjudge the difference in level. This is one of the causes of many traffic accidents.

3.4.3 Existing Institution

(1) Public Utilities

There are two (2) schools, one national hospital, two (2) mosques and one church in the Kilifi township. There are also two (2) hotels; one at Kilifi township and one on the Mnarani side.

(2) Electric Power Line

Two (2) electric power lines run across the Kilifi creek; one is 132,000 V (132 KV) and the other is 33,000 V (33 KV). From the discussions with the East African Power and Lighting Company, it was learnt that the shifting of these lines to other places would be very difficult. To shift the lines would necessitate a reconstruction of the tower, involving a new electric line planning. Therefore it will be necessary, when locating the route, to avoid these electric power lines.

(3) Telephone and Telegram Communications Line

One telephone line passes through the Kilifi creek and the post that supports this telephone line is made of wood. The telephone line is light compared with the electric line. Therefore it is comparatively easy to shift the telephone line to another place.

(4) Ferry

Two (2) ferry boats are operating at a 24 hours service on Kilifi creek with one (1) ferry boat as a standby. The capacity of the existing ferry boat is