REPUBLIC OF KENYA

MINISTRY OF PUBLIC WORKS

DETAILED DESIGN STUDY
ON
THE NAIROBI BYPASS PROJECT

ENGINEERING REPORT

SEPTEMBER 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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SEPTEMBER 1992

Japan International
Cooperation Agency

The Permanent Secretary
Ministry of Public Works
P.O.Box 30260
NAIROBI

The Chief Engineer (Roads)
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PREFACE

In response to a request from the Government of the Republic of Kenya, the Government of Japan decided to conduct a detailed design study on the Nairobi Bypass Project and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Kenya a study team headed by Mr. K. Kuwata, Japan Engineering Consultants Co., Ltd., between November 1989 and June 1992.

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

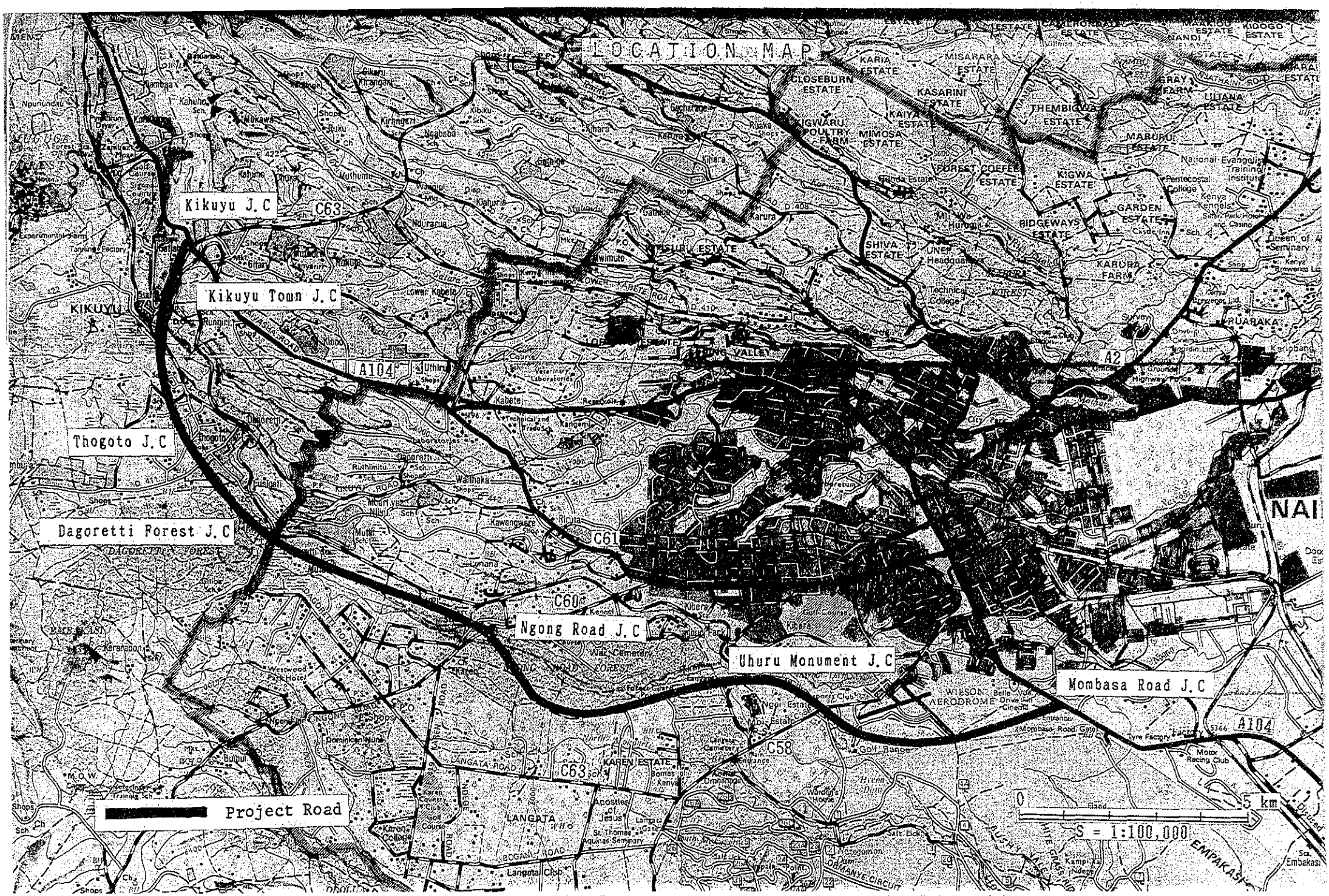
I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

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

September, 1992

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency


LOCATION MAP
Kikuyu J.C
Kikuyu Town J.C
Thogoto J.C
Dagoretti Forest J.C
Ngong Road J.C
Uhuru Monument J.C
Mombasa Road J.C
Project Road
0
5 km
S = 1:100,000
C63
C61
C60
C58
A104
A2
KIKUYU
KAREN ESTATE
LANGATA
NAIROBI

CONTENTS

1. INTRODUCTION

1.1 TERMS OF REFERENCE

In response to the request of the Government of Kenya (GOK), the Government of Japan agreed to provide technical expertise in conducting the Detailed Design Study for the Nairobi Bypass Project. Accordingly, the Japan International Cooperation Agency (JICA) sent a preliminary survey technical team, headed by Mr. Y. Adachi of Ministry of Construction of Japan, to Kenya in February 1989 for discussion on the Scope of Work of the Study with the officials of Kenya's Ministry of Public Works (MOPW) and other relevant authorities.

Based on the agreement, mentioned above, the JICA Study Team submitted an Inception Report in October, 1989 and the preliminary design study was carried out for the proposed Nairobi Bypass and other relevant roads, as well as intersections of roads (see location map). Principally, the work of the study, carried out prior to the detailed design, was conducted in Kenya in close cooperation between the Japanese expert staff and the counter-part staff of Kenya.

In accordance with the change of social conditions and increase of traffic accidents since the Feasibility Study stage, the whole route of the Bypass was planned to have adequate grade separated crossings to cater for vehicular and pedestrian traffic crossing the Bypass (Expressway with limited access).

Some sections of the project route in the Ngong Forest have been sifted to the edge of the forest to conserve the indigenous part after the Preliminary Design in response to a request made by the Government of Kenya.

1.2 LOCATION OF THE NEW ROAD

The proposed new dual carriageway is a class A international trunk road, approximately 29.2 km long, situated in the City of Nairobi and in the Kikuyu Division of Kiambu District, Central Province. It starts from Mombasa Road (A104) near the eastern gateway of Nairobi National Park and terminates on Nairobi-Nakuru road (A104) on the western outskirts of Kikuyu Town.

1.3 TOPOGRAPHY

Kenya consists of four major regions, namely the Costal Region, the Rift Valley, its associated highlands, and the Lake Victoria Basin.

Nairobi and its environs are located on the east-side highland of the Rift Valley. Nairobi's western and northern parts are hilly land which are located about 2,000 m above sea level. The southern and eastern parts of Nairobi are spread on the Athi and Kapiti Plains 1,890 m above sea-level. From west to east, the topography inclines gently.

Rocky mountains lie in Machakos District about 50 - 60 km south-east of Nairobi. Highland regions to the west and north of Nairobi are mainly used as farm land and except for town streets, unused land is covered with trees. The surface of the Athi plains is covered with black cotton soil which is very cohesive.

This area belongs to the Athi River Drainage System and is crossed by many rivers (Motoine River, Mokoyoti River, Nairobi River etc.) which flow from the eastern highlands of the Rift Valley towards the east forming alluvial deposits in places.

1.4 CLIMATE

The proposed route of the Bypass will be a section of the Trans-African Highway, and it is located almost at the equator.

The project area is located on a highland in the central area of Kenya at altitudes which range from 1,700 to 2,000 m. It is about 500 km from the eastern cost of Kenya, which faces the Indian Ocean, so the project area is not affected by the trade wind and is dry and calm except during the two rainy seasons from March to June and from the end of October to December.

(i) Temperature

Changes in temperature have been minimal over the years. The past average temperatures, according to records at four meteorological stations in the project area, are as follows:

STATION NAME	MEAN TEMPERATURE		
	MAX	MIN	ALTITUDE
Nairobi (J.K.A.)	24.4°	12.3°	1,624m
Wilson Airport	24.8°	13.1°	1,683m
Dagoretti	23.4°	11.9°	1,798m
Muguga K.A.R.I.	20.9°	10.8°	2,096m

(ii) Wind

Generally, wind blows calmly in the project area throughout the year. From May to September, there is a frequent mild wind. From October to April, the wind at noon blows comparatively stronger than in the morning. The maximum wind speed is around 6.5 m/sec.

The average wind speeds at the four meteorological stations are as follows:

STATION NAME	WIND SPEED	
	0600 G.M.T	1200 G.M.T
Nairobi (J.K.A)	6 knots	10 knots
Wilson Airport	*6 knots*	*10 knots*
Dagoretti	5 knots	9 knots
Muguga K.A.R.I	-	-

(iii) Precipitation

Annual rainfall in the project area ranges from 800 mm to 1,100 mm. Most rain falls during the main rainy season (March to June) and the lesser rainy season (October to December) similar to other areas of Kenya.

1.5 LAND USE

Present land use has been assessed and summarized by each link as follows:-

(1) Link 1: A104 (Mombasa Road) - C58 Uhuru Monument Junction (C58)

a) Area : 4.2 km^2

b) Main Figures : New Residential quarters, Nairobi National Park, Wilson Airport, Independence Monument

c) Present Land : Low density residential area with open space

d) Development Potential : High density residential area and institutional area

(2) Link 2: Uhuru Monument Junction (C58) - Ngong Road Junction (C60)

a) Area : 6.0 km^2

b) Main Figures : Nairobi Dam, New Residential Quarters, Langata Prison, Army Quarters, Moi Estate, Langata Cemetery, Karen Estate, Ngong Road Forest

c) Present Land : High density residential area
Reserved for forest

d) Development Potential : Residential area

(3) Link 3: Ngong Road Junction (C60) - Dagoretti Road Junction (C63)

a) Area : 6.6 km^2

b) Main Figures : Karen Estate, Motoine Stream, Mutuini Primary School, Railway

c) Present Land : High income low density residential area
Reserved for forest

d) Development Potential : Medium density residential area with water pipeline installations and sub-divisions of land

(4) Link 4: Dagoretti Road Junction (C63) - Thogoto Junction A104 (Naivasha Road)

a) Area : 7.0 km^2

b) Main Figures : Railway, Dagoretti Forest, D411 (Feeder Road), Kikuyu DNK High School, Alliance Boys High School, Alliance Girls High School, Nairobi University, Church University, Thogoto Technical College, Kikuyu Hospital, Ondiri Swamp, Route E422

c) Present Land : Medium income residential area, use Education Institutes

d) Development Potential : *High density residential area, Educational (Thogoto) and Commercial (Kikuyu) zone*

1.6 REVIEW OF THE FEASIBILITY STUDY

Review of the Feasibility Study (especially traffic forecast and traffic planning) and the Study of Possibility of Stage Construction for Nairobi Bypass were carried out in close consultation with the relevant engineers of Development Planning Division and Road Department (Design) of the MOPW.

During all stages of the study work, the JICA study team carried out their work based on the discussions and agreements between the team and the relevant engineers of the MOPW.

The review study report was submitted by the team in November 1989 and it was approved by the Chief Engineer (Roads).

A detailed description of the review of the Feasibility Study is given in "The STUDY REPORT-1, on REVIEW OF TRAFFIC DEMAND FORECAST AND TRAFFIC PLANNING, POSSIBILITY OF STAGE CONSTRUCTION".

2. OUTLINE OF THE DETAILED DESIGN STUDY

2.1 GENERAL

All geometric design work was carried out based on the "Road Design Manual Part I" and discussions between the MOPW and the JICA study team.

The following is a brief description of the project road.

(1) Length of Road : Approximately 29.2 km

(2) Road Standard : Class A international trunk road (Express way)

(3) *Section (see location map)*

Starting point : 400 m from crossing of Mombasa Road (A104) Road.

Ending point : Kabete Limuru Road (A104)

(4) Design Speed : 80 - 100 km/hr

(5) Number of lanes : 4 lanes (dual carriageway) of 7 meters carriage way and 1.5 meters shoulders

(6) Number of junctions : 7

Mombasa Road Junction
Uhuru Monument Junction
Ngong Road Junction
Dagoretti Forest Junction
Thogoto Junction
Kikuyu Town Junction
Kikuyu Junction

(7) Number of Main Structures

Mombasa Road Junction Bridge	:	One (1)
Uhuru Monument Junction Bridge	:	One (1)
Railway Bridge	:	One (1)
Pedestrian Bridge	:	Two (2)
Vehicle Over Bridge	:	Two (2)
Box Culverts	:	Sixteen (16)

(8) Bus Stops

	No. of Bus Stops
Mombasa Road Junction	2
Uhuru Monument Junction	2
Ngong Road Junction	2
Mutuini	2
Dagoretti Road Junction	2
Thogoto Junction	2
Alliance High School	2
Kikuyu Town Junction	2
Total:	16

2.2 DESIGN CRITERIA

(i) Plan and Profile of Main Road (Scale 1:1000)

The horizontal alignment and vertical profile of the main road was designed on a map of scale 1:1000.

(ii) Junctions

After a reconnaissance and a review of the Feasibility Study, junctions were designed based on discussion with the MOPW, and finally all the junction types were agreed upon.

(iii) Construction Quantities and Cost Estimates

The construction quantities and costs were estimated based on the plan for package construction (4-lanes).

(iv) Typical Cross Section

Typical cross sections of main roads, slip roads of junctions, approach roads, bridges and box culverts were decided based on the "Road Design Manual Part I" and discussion with the MOPW.

(v) Pavement Structure

The pavement structures were designed based on geological survey, soil tests in accordance with the "Road Design Manual Part III" and checked using "Road Note No. 29" and the AASHTO Guide in Consultation

with the Department of Soil and Material Research of the MOPW.

(vi) Structures

Type, location, and width of both of bridge and box culvert were discussed with the MOPW and Kenya Railways.

(vii) Geological Soil and Material Surveys

Surveys concerning geology, soil, and material were conducted based on discussion with the Department of Soil and Material Research of the MOPW as follows:

- Survey of Side Slope at Existing Road
- Survey of the Earthwork
- Survey of Structural Foundation Bed Rocks
- Survey of Road Bed Soil
- Survey of Crushed Stone, Aggregates for Pavement, and Cement Stabilized Material
- Survey of Hardstone and Gravel Quarries

(viii) Hydrological and Drainage Survey

Hydrological and Drainage Surveys were done on site and the drainage system of the road was designed based on collected data from the concerned authorities.

(ix) Survey of Public Utilities

Information on Public Utilities concerning the Nairobi Bypass were collected from the relevant authorities, and the results are reflected in the design.

(x) Others

Prior to the detailed design work, the following studies were carried out from 1989 to 1991.

1. The review of the Feasibility Study

2. Study of possibility of stage construction for the Nairobi Bypass

3. Topographical Survey by air and mapping

4. Preliminary Design

3 TOPOGRAPHICAL SURVEY

3.1 WORK IN FIRST PHASE AT FIELD

Field survey works in the first phase commenced on 27th November, 1989, and were completed on 9th January, 1990 by GEOMAPS (P.O. Box 61071, Nairobi, Kenya). The Aerial Photography work was carried out in December 1989 by PHOTOMAP (P.O. Box 43850, Nairobi, Kenya). The respective works were commissioned by the JICA study team.

3.1.1 Premaking of Photo Control Points

Prior to the aerial photography, of the Project Area, a total of 50 GPS and polygons points were provided and monumented in concrete. The locations of these points are shown in Fig. 3.1.

3.1.2 Aerial Photography

Aerial Photography started in 11th December, 1989, immediately after provision of premarks and was completed on 18th December, 1989.

A total of 7 course at a scale of approximately 1/6,000 for a total of 98 sheets photos, and a total of another 7 course at a scale of approximately 1/4,000 for a total of 80 sheets photos covering the proposed road and interchange areas were flown respectively, and were processed. The flight lines are shown in Fig. 3-2.

All of the shootings were checked for photo quality and coverage of the areas using contact prints for mapping purposes. One set of two-times enlargement prints were handed over to GEOMAPS for the ground survey works to be conducted course by course immediately after processing.

3.1.3 Ground Control Survey

The objective of the survey was to establish adequate and accurate horizontal and vertical control for the photogrammetrical mapping necessary for the detailed design and setting out of the Nairobi Bypass Road.

In this project area, one third of the area is located in high tree forests while the rest is close to the residential area. It would involve enormous time and cost to use a conventional method of triangulation of polygons in obtaining sight lines. Consequently, for this survey, satellite geodesy was adopted by means

of the Global Positioning System (GPS), which does not require sight lines between points to be measured to make positioning with high accuracy in short time possible.

3.1.4 Reconnaissance

Reconnaissance entailed six aspects, as follows:-

a) Physical checking of the existing Survey of Kenya control points and their relative positions to determine their suitability as GPS base points, including receipt of their existing data from the Survey of Kenya. Two of the SK points, named 148-S1 (Gitunguli) and 149-S3 (Lukenya), were accepted and used as horizontal control for this project, and another SK point, named SKP208 (Ngong Hill), and one of the MOPW's points (Roof top of the MOPW main office, in Nairobi) were checked for their relative accuracy.

b) Physical checking of existing Bench Marks including retrieval of their levels from the Survey of Kenya was done. BM IV/70 and VA/10 were adopted. Sixteen new Bench Marks were established along the proposed route and their positions marked in red paint for ease of identification.

c) A total of 31 of the new GPS points were selected, monumented and pre-marked. The positions of all the points were marked with white paint for ease of identification. The extra GPS point, named GM31, was placed near GPS28 to be used for traverse closing. This point was not pre-marked.

d) Polygon points were established all through, along the proposed way leave. Due to thick natural forests however, it was not possible to stick to the wayleave in a few places so alternative routes were selected as close as possible to the wayleave. All points were monumented and positions marked with white paint for ease of identification. The points were placed approximately 150 meters apart except in the forest where they were placed at shorter intervals.

e) Inspection plus adoption and/or alteration of major and minor leveling routes.

f) Selection of positions to place additional photo control points. Twenty points were established (called PP1-PP20), monumented and pre-marked. Their positions were also marked with white paint for ease of identification.

3.1.5 Polygon Survey

Traverse observations were carried out in two loops (named GA and GB) and broken down to shorter traverse between GPS stations that are within the periphery of the proposed wayleave. The co-ordinates of the polygon points including GPS points are listed in Table 3-1, 2, 3, 4, 5, and 6.

Traverse observations lines between GPS stations and their observed accuracies achieved after adjustments were as follows:-

TRAVERSE LINE	CONTROL Start	POINT Close	LENGTH (m)	ACCURACY
TR1	GPS01	GPS08	7,279,583	1: 363,988
TR2	GPS08	GPS010	1,827,537	1: 19,694
TR3	GPS10	GPS13	6,183,156	1: 89,722
TR4	GPS13	GPS14	1,601.744	1: 23,722
TR5	GPS14	GPS15	1,880.118	1: 132,110
TR6	GPS15	GPS18	3,636.849	1: 102,349
TR7	GPS18	GPS25	7,566.902	1: 16,241
TR8	GPS25	GM31	4,101.550	1: 57,464
TRP8	GB56	PR8	32.846	Polar
TRG04	GA15	GA23	3,835.624	1: 61,627
TRG07	GA29	GPS7	155.428	Polar
TRG30	GPS28	GPS29	2,842,315	1: 17,634

3.1.6 Leveling Observations

The two benchmarks used for vertical control (IV/10 and VA/19) for major leveling are near the both end of the proposed road and the BM to BM loops were leveled from both directions meeting near the middle. The net misclosure from datum to datum was 0.098 m in about 45 km. This was adjusted accordingly to 0.049 m in one half each.

The elevation values of the Bench Marks are as follows:-

NAME	ELEVATION (m)	NAME	ELEVATION (m)	NAME	ELEVATION (m)
BM1	1,648,421	BM7	1,808,321	BM13	1,992,390
BM2	1,659,400	BM8	1,813,900	BM14	1,993,366
BM3	1,681,516	BM9	1,828,938	BM15	2,020,891
BM4	1,706,623	BM10	1,857,014	BM16	2,036,587
BM5	1,759,279	BM11	1,881,356		
BM6	1,791,323	BM12	1,889,368		

Minor leveling was carried out throughout routes and pricking enlarged photographs was done for vertical control of aerial mapping.

These routes include heightening of GPS points which may not have been part of the major leveling routes. Fly leveling was done between Bench Marks through all the polygon points which include the PP points. The leveling routes are shown in Fig. 3-3.

3.2 WORK IN FIRST PHASE IN JAPAN

3.2.1 Aerial Triangulation

A total of 7 strips and 76 models of photography along the proposed road were used for photo co-ordinate measurement for a scale of 1/1,000 stereo plotting, and another 7 strips and 60 models of photographies covering the proposed interchanges and junction, and valley areas were used for a scale of 1/500 plotting. As for the pass, points five were taken at both sides of a line orthogonal of strips.

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

The software used for adjustment of strips based on the independent model method was 'PAT-M43' block adjustment program.

The accuracies were given in terms of mean square errors for the results of weighted model points, projection center and control point.

3.2.2 Stereo Potting 6 Compilation

The plotting equipment used was AUTOGRAPH A8 (Wild) and STEREO METROGRAPH (Zeiss, Jena).

Photogrametric orientation was based on pass-points, tie-points premarked points, and pricked level points. The allowable errors of orientation at each point were within 0.55 mm on map for horizontal locations and within 1/3 of contour interval for elevations. The results for each model were within those tolerance limits.

Spot height points as well as control points were spaced at 5 cm intervals of the map. Each of these points was measured twice in units of 0.1 m and their mean values were adopted as the final values.

To contour lines of both scaled plotting for 1/1,000 and 1/5,000, the intermediate contours represented in orange are to be delineated at 1 m and 0.5 m intervals, and the index contours in black at 5 m and at 2.5 m intervals. However, where the terrain was very flat, half contours were delineated at 0.5 m and at 0.25 m intervals. The boundaries of vegetation and water are represented in green and violet respectively so that their bounds could be clearly shown during the fair drawing stage. Maximum width of 2.5 m of 17 polyester base roll sheets were used for plotting work for the approximately 30 km of proposed road corridor area, and AO size of 20 polyester base sheets were used for interchanges, junctions and valley areas.

For compilation, the sheet using one and the same material as plotting sheet were overlaid on the plotting sheet, and necessary features were edited and represented according to the map symbols and systems of representation adopted by the MOPW.

The manuscripts of 1/1,000 and 1/500 scaled maps were completed by the middle of May 1990, and were presented to the MOPW when a supplementary survey commenced as the Second Phase.

The adjoining sheet index of compiled maps is shown in Fig. 3-4.

3.3 WORK IN SECOND PHASE

3.3.1 Supplementary Survey

A total of 46 sheets of 1/1,000 scaled transparently duplicated maps covering

the proposed road corridor, and a total of 32 sheets of 1/500 scaled transparently duplicated maps covering sites for proposed interchanges and junctions, and valley areas were prepared, sheet by sheet, in A1 size from original compiled maps for supplementary survey work.

Blue paper prints were prepared for all the sheets duplicated and these were used in the field for physical checks of all features. Where details have been omitted or new developments have come up, these were indicated by red pen on the field sheets.

It was deemed necessary to take spot levels in Ngong Road Forest area. These were done by Wild T2 theodolites, telescopic slaves, and ground distances measured by steel tapes. Open short traverses were run from existing concrete polygon points which were placed during the control survey in the First Phase. These short traverses were run for approximately 200 m at right angles to the proposed center-line in both directions. Horizontal and vertical angles were read on the theodolite, distance taped, and center hair read on the stave so as to obtain the height of forward point. A few levels near GA60 were taken directly by an automatic level.

After reduction of the levels for the spot heights, these were plotted on the field sheets and interpolation of contours done independently.

3.3.2 Fair Drawings of the Maps

In June and July 1990, the features, spot heights, and contouring on both scaled maps were reviewed in Japan based on the findings of the supplementary survey at the project sites, and on fair drawings by inking methods made to finalize products. The adjoining sheet index of the fair drawings and the compiled manuscripts sheet index are shown in Fig. 3-4.

Duplicates of the final maps, with the proposed road center-line, were handed-over to the JICA design team in the middle of July, 1990.

3.3.3 Center Line Staking & Profile Survey

On the basis of the tentative main route alignment, the chainage points and principal points were staked out between January and March, 1991. In addition, a longitudinal profile survey on the alignment was conducted during the same period. All principal points on the alignment were replaced by concrete monuments.

3.4 WORK IN THIRD PHASE

3.4.1 Work Aspects

The works in third phase entailed the following aspects.

a) Staking out the chainage pegs of the center-line for all interchanges.

b) Setting out the principal points along the center-line of all the interchanges including monumentation.

c) Carrying out items a) and b) above for the changed main route in the Ngong Road Forest.

d) Longitudinal profile survey for the routes in item a), b) and c) above.

e) Longitudinal profile chart drawing for item d) above.

f) Cross-section survey and chart drawing for the entire main route and interchanges.

g) Staking out right of way pegs including beaconing of witness marks for the monuments along main route and interchanges.

h) Point descriptions for all the monuments established.

i) Preration of Land acquisition drawings along the entire route.

3.4.2 Implementation

a) Short minor traverses were run in areas where the center-line could not be set directly due to obstruction. In cases where center-line fell in inaccessible locations temporary polar points were established to the survey work.

b) The setting out data was computed using an In house program on Sharp Pocket Computers PC-1360. These were also used in the field for setting of temporary pegs in inaccessible areas. Since these pocket computers have detachable printers, the printout was used in the field to check the points actually placed on the ground and then a check measurement was made on closing to the next control point.

c) Six survey teams from GEOMAPS were deployed during this project on, a full time basis. Each had a complete set of EDM equipment, automatic level, pocket computer, and peripheral equipment for the survey operations.

Due to the intensity of bush clearing and manual labor related requirements, e.g. monumentation, a lot of casual laborers were engaged to clear the forest and also to carry cement, water, pegs, etc. However, all the monumentation was done under the direct supervision of the surveyors.

d) The entire control used during this phase of survey was the control established during phases I and II of the project. All the leveling for profiling was closed accurately to this older control.

e) The cross-section surveys were all done by EDM-theodolite and computed in the office and checked for computation errors. The data was keyed in the computers and transferred to floppy disk. The drawings were prepared and traced by GEOMAPS in Nairobi. Marginal neat lines and datum lines were plotted using a WILD TA10 electronic table, data plotted along the datum lines manually by the draughtsmen and traced.

f) Monuments at the principal points were photographed and their descriptions prepared.

One major problem with descriptions of interchange monuments was that they bear the same naming structure. We therefore specified that the names include a notation of each interchange and each line e.g. for Mombassa road junction monuments, we add M after the monument name and then (A) for line A and (b) for line B etc. Points falling on existing tarmac roads could not be monumented for obvious reasons, but were set out and marked by survey nails.

g) The right of way pegs were placed using theodolite and tape with corrections made for slope. The witness beacons were placed using EDM-theodolite from the established monuments. Position of right of way pegs were plotted on 1:1,000 scaled topographical alignment maps as Land acquisition drawings.

h) The cad astral data available from the survey of Kenya was collected and reduced or enlarged by photocopier to scale 1:1,000 since the plans are at different scales. These were compiled into a mosic along the main route and adjusted to fit the alignment sheets. The boundary positions were then traced in red and plot numbers indicated.

Most of the route falls on government land up to sheet 28 except for only private property at Ngong road junction. The rest of the route is mostly on private land as indicated on the plans. Care should be taken during compensation since there is big possibility of plots having been sub-divided and the plans in the survey office not yet amended to reflect the sub-divisions.

3.5 RESULTS TO BE DELIVERED

The topographical and line survey results which were submitted by the study team to the JICA Head Office in Tokyo are as follows:-

a) Aerial Photographs

Contact prints	scale 1:6,000.....	1 set
	scale 1:4,000.....	1 set
Enlarged prints	scale 1:3,000.....	1 set
Negative rolls.....		1 set

(submitted to the MOPW)

b) Aerial Triangulation Results

Computation result	for 1:1,000 plotting.....	1 Vol.
	for 1:500 plotting.....	1 Vol.
Contact prints and dia-positive films		
	scale 1:6,000.....	1 set
	scale 1:4,000.....	1 set

c) Topographical maps with road center-lines

	scale 1:1,000.....	1 set
	scale 1:500.....	1 set

d) Longitudinal profile charts..... 1 set

e) Cross-sections profile charts..... 1 set

f) Land acquisition maps..... 1 set

g) Survey data book Vol. I, Vol. II and Vol. III..... 20 Vol.

4. TRAFFIC STUDIES

Prior to starting the Detailed Design (including the Preliminary Design) the JICA study team carried out a review of the Feasibility Study (the traffic survey, traffic forecast) and a study of the possibility of a stage construction in December of 1989. The results of these investigations have been accepted by the Chief Engineer (Roads), MOPW. Therefore, the future traffic volume for the road design work was depended on the traffic forecast in the Feasibility Study of the Nairobi Bypass Construction Project.

In 1991, an oil pipeline project started between Nairobi and Kisumu/Eldoret. Oil transportation was scheduled to start in 1993. Traffic volume (P.C.U) of oil tankers, however, has been forecasted at 2 or 3 % of total traffic on the Nairobi Bypass in the year 2000 referring to the Feasibility Study, and percentage of oil-tankers in heavy vehicles is about 33 % according to the Material Branch Report No. 333. This trend is not changed by the recent traffic survey.

Therefore, the reduction of oil-tanker traffic due to the opening of the pipeline, will not be a major influence on the road design.

4.1 TRAFFIC FOR PAVEMENT DESIGN

A major factor in pavement design is the cumulative number of equivalent standard axles (ESA) in the design period. The cumulative number of equivalent standard axles during the design period was calculated from the forecast of future traffic in the feasibility study which was reviewed by the JICA study team and which was accepted by the Planning Department of the MOPW in the end of 1989.

(1) Cumulative number of equivalent standard axles during the design period

1) Initial daily number of equivalent standard axles (ESA) in the opening year 1997 :

The initial daily number of ESA in the opening year of the by pass were obtained from the number of medium goods vehicles (M.V.), heavy goods vehicles (H.V.), oil tankers (O.T. and buses (B) in Table VI-4-4 "Future Traffic Growth of the Bypass by Links" in the Feasibility Study Report. However, the number of oil-tankers

FUTURE TRAFFIC GROWTH OF THE BYPASS BY LINK

Link		LINK-1				LINK-2				LINK-3				LINK-4			
		pcu rate	AADT	AADT in pcu	AGR(%)	AADT	AADT in pcu	AGR(%)		AADT	AADT in pcu	AGR(%)		pcu rate	AADT	AADT in pcu	AGR(%)
1986	C/T	1.0	898	898	21	1,208	1,208	18		3,468	3,468	10		1.0	3,812	3,812	8
	L.V	1.0	414	414	24	934	934	19		1,675	1,675	11		1.0	1,846	1,846	10
	M.V	2.0	588	1,176	4	575	1,150	3		224	448	4		3.8	295	1,112	4
	H.V	2.0	491	982	6	465	930	6		374	748	7		3.8	412	1,583	5
	B	2.0	313	626	-1	172	344	-4		104	208	-9		3.8	112	429	-8
		pcu rate	AADT	AADT in pcu	CRV(%)	AADT	AADT in pcu	CRV(%)		AADT	AADT in pcu	CRV(%)		pcu rate	AADT	AADT in pcu	CRV(%)
2000	C/T	1.0	12,750	12,750	50	8,780	8,780	48		9,371	9,371	49		1.0	10,921	10,921	48
	L.V	1.0	8,272	8,272	32	6,547	6,547	33		5,220	5,220	32		1.0	6,588	6,588	29
	M.V	2.0	965	1,930	8	771	1,542	8		659	1,318	8		3.8	683	2,050	9
	H.V	2.0	1,066	2,131	8	999	1,998	9		1,027	2,054	11		3.8	1,101	3,138	13
	B	2.0	255	510	2	37	74	2		41	82	0		3.8	48	134	1
				25,594			18,941				18,045					22,831	

Note: C/T = Car, Taxi L.V = Light goods vehicle M.V = Medium goods vehicle H.V = Heavy goods Vehicle
B = Bus
AGR = Annual growth rate by vehicle types
CRV = Composit ratio by vehicle types

classified in the heavy vehicles class category was estimated by referring to "MATERIALS BRANCH REPORT NO.333 AND NO. 455".

2) Ratio of Heavy Goods Vehicles to Oil Tankers

According to "Summary Chapter 16, page 13, Material Branch Report No. 333" and "Table 9.2.11 (a) *Nairobi / Kisumu / Mal aba* Roads (A104, B1, A1) 12 hr ADT. Daytime Number of Vehicles by class listed Time and Road Section", the ratio of heavy goods vehicles and oil-tankers is 2 : 1.

This ratio applies to the number of heavy vehicles including oil tankers in the heavy vehicles category.

3) Commercial vehicles distribution on the Bypass

The commercial vehicles distribution by section (link) is as follows;

AADT (Both Directions), 1986

Section	1	2	3	4
M.V.	588	575	224	295
H.V.	327	310	249	275
O.T.	164	155	249	275
B.	313	172	104	112

AADT (Both Directions), 2000

Section	1	2	3	4
M.V.	965	771	659	683
H.V.	711	666	658	734
O.T.	355	333	342	367
B.	255	37	41	48

4) Equivalence Factors of Vehicles

Referring to Table 9.2.1 Mean Equivalence Factors, (Material Branch Report No. 455), the Equivalence Factors on A104 near Nairobi City are as follows.

Vehicle	Equivalence Factor
M.V	0.9
H.V	8.57
O.T	12.8
Bus	0.45

5) The average daily number of Equivalent Standard Axles (ESA) in the base years 1986 and 2000

Average daily number ESA in 1986

EF	1		2		3		4	
	AADT	ESA	AADT	ESA	AADT	ESA	AADT	ESA
M.V. 0.9	588	529	575	517	224	201	295	265
H.V. 8.57	327	2802	310	2656	249	2133	275	2356
O.T. 12.8	164	2099	155	1984	125	1600	137	1753
B. 0.45	313	140	172	77	104	46	112	50
Total:		5570		5234		3980		4424

Average daily number ESA in 2000

EF	1		2		3		4	
	AADT	ESA	AADT	ESA	AADT	ESA	AADT	ESA
M.V. 0.9	965	868	771	694	659	593	683	615
H.V. 8.57	711	6090	666	5708	685	5870	734	6290
O.T. 12.8	355	4548	333	4262	342	4378	367	4698
B. 0.45	255	114	37	17	41	18	48	22
Total:		11620		10681		10859		11625

6) Annual growth rate of ESA (1986 - 2000)

$t_{2000} = t_{1986} \times (1+i)^{14}$

$i = (t_{2000}/t_{1986})^{1/14} - 1$ ..... Annual growth rate

Section	1	2	3	4	
	5570	5234	3980	44424	1986
	11620	10681	10859	11625	2000
i (%)	5	5	7	7	

7) Daily number of standard axles in the Bypass opening year, 1997.

$t_{1997} = t_{1986} \times (1 + i)^n$

where,

t = The average daily number of ESA in the base year (1988)

i = Annual growth rate

n = years (1997-1986)

Section	T_{1986}	i (%)	n	ESA/day in 1997
1	5570	5	11	9526
2	5234	5	11	8951
3	3980	7	11	8377
4	4424	7	11	9311

8) Numbers of oil-tankers which are equivalent to the volume of oil transport by pipeline:

The volume of oil transport by pipeline was planned by KPC is as follows;

1993 $1{,}080{,}000^{kl} / _{year}$

2008 $1{,}815{,}000^{kl} / _{year}$

Equivalent number of oil-tanker to the oil transport by pipeline is;

1993 $1{,}080{,}000^{kl} \div 20^{kl} / _{UNIT} = 54000^{kl}$ UNIT/year

2008 $1{,}815{,}000^{kl} \div 20^{kl} / _{UNIT} = 90750^{kl}$ UNIT/year

As: Capacity of an oil-tanker is 20 kl

Number of ESA (Oil-tankers)

1993 $54,000 \times 12.8 = 691,200/_{year}$

2008 $90,750 \times 12.8 = 2,161,600/_{year}$

Average daily number of ESA (Oil-tankers)

1993 $691,200 \div 365 = 1,893$

2008 $1,161,600 \div 365 = 3,182$

Decrease rate of ESA (1993 ~ 2008) of oil-tankers : i

$$i = (3,182/1,893)^{1/15}-1$$

$$= 3.5\%$$

Decrease number of ESA/day (Oil-tankers) in 1997 (Opening year of the Bypass)

$$t_{1997} = 1,893 \times (1+0.035)^4$$

$$= 2,172$$

Decrease number of ESA/day (Oil-tanker) in 2000

$$t_{2000} = 1,893 \times (1+0.035)^7$$

$$= 2,408$$

9) Cumulative number of Equivalent Standard Axles (ESA) during the design period (T).

Average daily number of ESA (t_1)

Section	1997	2000
1	19,526	11,028
2	28,951	10,363
3	38,377	10,263
4	9,311	11,407

Cumulative number of Equivalent Standard Axles (ESA) during the design period (T) is obtained in accordance with the MOPW method as follows:

$$T = 365 \times t1 \times \frac{(1+i)^n - 1}{i}$$

where:

t1 : The average daily number of standard axles in the first year.

i : The annual growth rate expressed as a decimal fraction

n : Design period: 3 years from 1997 to 2000

7 years from 2000 to 2007

Cumulative decrease number of Equivalent Standard Axles (ESA) of Oil-tankers during the design period (1997~2007)

1997 - 2000 (3 years)

$$T_1 = 365 \times 2,172 \times \frac{(1+0.035)^3 - 1}{0.035} = 2.4 \times 10^6$$

2000 - 2007 (7 years)

$$T_2 = 365 \times 2,408 \times \frac{(1+0.035)^7 - 1}{0.035} = 6.8 \times 10^6$$

Cumulative number (T) of ESA by section (Link)

1997 - 2000 (3 years)

Section	T_{1987}	i (%)	T	$(T/2-T_1)x0.8$
1	9,526	5	10,961,210	2.4×10^6
2	8,951	5	10,299,580	2.1×10^6
3	8,377	7	9,829,894	1.9×10^6
4	9,311	7	10,925,885	2.4×10^6

2000 - 2007 (7 years)

Section	T_{2000}	i (%)*	n	$(T/2-T_2)\times 0.8$
1	11,028	3	30,843,096	6.9×10^6
2	10,363	3	28,983,224	6.2×10^6
3	10,263	5	30,499,922	6.7×10^6
4	11,407	5	33,899,700	8.1×10^6

* : Growth rate is reduced after the year 2000 refering to Traffic Demand Forecast in the Feasibility Study Report. (Table VI-2-2)

Cumulative ESA (1997 - 2007)

Section :

1	2.4 + 6.9 =	9.3×10^6
2	2.1 + 6.2 =	8.3×10^6
3	1.9 + 6.7 =	8.5×10^6
4	2.4 + 8.1 =	10.5×10^6

5. SOIL AND MATERIAL INVESTIGATIONS

5.1 OUTLINE OF INVESTIGATIONS

Primary soil and material investigations along the proposed alignment were conducted between June 20th and October 30th, 1990, taking the findings of the Feasibility Study into consideration. Following the decision to change the alignment, an additional investigation was conducted between September 20th and October 30th, 1991. These investigations actually consisted of drilling investigation at 9 sites, test pit investigation at 47 sites and general soil tests, etc. The specific soil test on black cotton soil (expansive clay) was also carried out.

The main component of the material investigation was examination of gravel materials and hard stone materials in relation to their use as subgrade, aggregate for surfacing and concrete. While it was originally planned to purchase the materials to be investigated from existing quarries, the capability of these quarries to guarantee a stable supply was judged to be doubtful. In order to find promising new quarry sites, drilling investigations were conducted at 5 sites, test pit investigations at 96 sites and various material tests were also done. The detailed investigation results are given in the Material Report and are summarized below.

5.2 SOIL INVESTIGATION RESULTS ALONG THE ALIGNMENT

Based on the soil characteristics, the areas along the proposed alignment are classified into 5 areas, i.e. black cotton soil area, red soil area, pyroclastic tuff area, trachyte area and other area. Black cotton soil areas are scattered in Nairobi National Park and Ngong Road Forest where black cotton soil (expansive clay) of some 0.3 - 1.0 m in thickness lies on top of weathered bedrock. These areas are problematic as the extremely low CBR value and the possible repetition of expansion and contraction make black cotton soil and inferior base, necessitating its replacement by better soil. Red soil areas dominate areas along the alignment and are made up of hard clayey soil which is weathered residual soil. While red soil provides a generally favorable base, it is liable to erosion when dry. Careful attention should be paid to the prevention of slope erosion. Pyroclastic tuff areas are found near the Moi Otiende Estate in Langata and near Ngong Road Forest. A pyroclastic tuff is classified somewhere between soft rock and medium hard rock, ripper work is required during cutting work. This requirement was taken into consideration

in the decision on the longitudinal slope of the road. Trachyte areas are found in the area between the Carnivore Restaurant and the Moi Otiende Estate and parts of Dagoretti Forest. It is of a sedimentary state around Kikiyu due to strong weathering and is covered by red soil. However, the trachyte found along the alignment is generally fresh and is classified as hard rock, necessitating blasting work as part of the cutting work. Other areas include a site near Langata Prison where rubbish is scattered due to the use of the site for tipping purposes. Alluvial deposits are found near Ngong Road Junction, Dagoretti and Ondiri Swamp. While alluvial deposits are generally hard, a very soft peat layer exists near Ondiri Swamp although it is rather thin (1.5 m). Banking material for C63 Road is found around Kikuyu.

In general, the ground along the alignment provides a favorable foundation for a bridge. Weathered red soil and strongly weathered trachyte are found around Kikuyu Town Overbridge and the N value is low (4-24) upto 9 m below the ground surface.

The banking materials to be used are mainly red soil and weathered rock, both of which are reasonably good but which require water sprinkling to regulate the water content. The design bulking factor (C) is 0.85 for soil, 1.0 for soft rock and 1.2 for hard rock.

Previous investigations on cut and banked slopes indicate a predominance of red soil which is liable to erosion. Therefore, it was decided that the appropriate stable gradient was 37° for cutting and 30° - 35° for banking. The study on the stability of high banking near Alliance Boys High School found that the slope was stable with a gradient of 1:1.5 and subsidence was minimal.

The CBR value for subgrade is 10 - 30 < which is classified into S4 - S6 based on the MOPW soil class criteria.

5.3 RESULTS OF MATERIAL INVESTIGATION

The distribution of lateritic gravel along the alignment was confirmed but its thin layer cannot provide sufficient quantity to meet the demand. The anticipated poor quarrying efficiency is an additional disadvantage. Quality improvement is also necessary for its use as a subgrade material.

In regard to rocks, the trachyte along the alignment is much weathered and its use as gravel is questionable in terms of quality.

The Kitengela Site by Namanga-Arusha Road (A104), located some 2 km from Athi River Town, appears to be a good quarry site for phonolite which is mostly of good quality except that the FI value is a little bit above the standard value and can be used for surfacing and as an aggregate material.

No sand deposits are available along the route and sand must, therefore, be purchased. The water required for construction work can be easily obtained from Motoine River which runs along the proposed alignment.

6. HYDROLOGICAL SURVEY AND DRAINAGE DESIGN

6.1 GENERAL

Hydrological and drainage survey were carried out to obtain data to assist in planning and designing the drainage system to avoid flooding the road.

6.2 HYDROLOGICAL SURVEY

Hydrological Survey was carried out to review and check rainfall data in feasibility study stage.

To collect the date from Meteorological Department a station which controls and observes all rainfalls in Kenya is shown as following;

(1) "The Rainfall Frequency Atlas of Kenya (January, 1978)"

(2) Rainfall data at Dagoretti Head Quarter

(January, 1978 to May, 1990)

(3) Rainfall data at Wilson Airport Station

(February, 1980 to May, 1990)

The nearest rainfall observation stations for this project were Wilson Airport Station and Dagoretti Head Quarter. In this stage, maximum rainfall data of Dagoretti Head Quarter (Figure C.1) was used.

The rainfall frequency Atlas of Kenya (January, 1978) was used to obtain rainfall data at feasibility study stage. These data was used in the preliminary design stage after it was compared with above mentioned data (1) and (3).

6.3 DRAINAGE SURVEY

Drainage Survey was carried out to determine the various places where the surface run-off could be discharged. Efforts were made to avoid discharging water into people's land without channelising it. The surface run-off was discharged into Nairobi Dam, a pond within the national park and existing drainage wayleaves. In one place at around Thogoto College, the water was directed into a proposed drainage pond. The drainage system along the alignment was divided into eleven (11) sections as follows;

(1) CH. 0 + 00 to CH. 5 + 280
Discharge into a tributary of Ngong river.

(2) CH. 5 + 280 to CH. 6 + 660
Discharge into a pond within the National Park.
The pond is about 750 m from the road.

(3) CH. 6 + 660 to CH. 8 + 180
Discharge into Nairobi Dam.

(4) CH. 8 + 180 to CH. 22 + 380
Discharge into Mutoine River.

(5) CH. 22 + 380 to CH. 23 + 640
Discharge through an existing twin pipe culvert under railway.

(6) CH. 23 + 640 to CH. 24 + 890
Discharge into a drainage pond

(7) CH. 24 + 890 to CH. 26 + 200
Discharge through an existing pipe culvert

(8) CH. 26 + 200 to CH. 27 + 320
Discharge into Odiri Swamp.

(9) CH. 27 + 320 to CH. 27 + 800
Discharge through existing twin pipe culvert under railway.

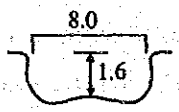
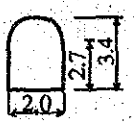
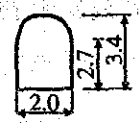
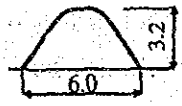
(10) CH. 27 + 800 to CH. 28 + 080
Discharge through existing twin pipe culvert under railway.

(11) CH. 28 + 080 to End
Discharge into a valley along C63.

6.4 DRAINAGE DESIGN

Catchment areas have been taken from 1/50,000 and 1/5,000 scale maps and field inspection. The adequency of existing culverts, bridges and channels have been assessed wherever possible by interviewing local residents about frequency and maximum water levels observed and comparing these observations with calculated floods. Peak floods have been estimated using the "The TRRL (EA) flood mode" and "The rainfall Frequency Atlas Method for 25 years return period.(refer to Appendix-D)

Table 6.1 Summary of Box Culvert for Drainage

Chainage	Existing Structure	Design Flood	Return Period	Proposed Structure	Design Surcharge
CH.13 + 978		26.1	25	3.0 x 3.0	65.5
CH.14 + 943		30.6	25	2.0 x 3.0	33.9
CH.15 + 560		38.4	25	3.5 x 3.0	93.3
Ngong Rd J/C B-RAMP CH.0 + 157		38.4	25	3.5 x 3.0	100.1
CH.26 + 335		101.4	25	2-3.5 x 3.5	358.3

(1) CH. 13 + 978

The sectional area of this box culvert is decided by existing timber bridge.

(2) CH. 14 + 943

The sectional area of this box culvert is decided by existing natural channel.

(3) CH. 15 + 560/Ngong Rd J/C B-RAMP CH. 0 + 157

The size of these box culverts increased due to overtopping in 1985.

(4) CH. 26 + 335

The size of this culvert increased to avoid making a temporary dam upstream during the rainy season.

For minor crossings and cross carriageway a minimum of 900 mm diameter concrete pipe culverts are proposed except for special case.

All minor drainage have been checked using the "Rational Design Method" taking areas from 1/2,000, 1/5,000 scale maps, study of the stereo photographs and checking slope and run-off parameters in the field. Drainage capacities have been checked using "the Manning Formula".

6.5 DRAINAGE POND

Between Thogoto College and Ondiri Swanp there exists a valley. In this valley there is no stream or river where the surface run-off can be drained. From the history of the area, ponding has been experienced. However, after the road is constructed, the run-off is expected to be increased. To alleviate this problem, it was proposed to construct a pond for drainage at the valley and then channelize the run-off from the road in this stage.

In Preliminary Design Stage, it was proposed to construction a soak pit. The reason was that soak pits for sewerage under construction near here and it was judged that soil of the location had enough coefficient of infiltration. But it was found that soil of the location is not enough coefficient of infiltration after boring survey and soil test.

In this stage, a drainage pond was designed as substitute plan of soak pit. (refer to Appendix-C)

7. UTILITIES SURVEY

7.1 GENERAL

Relocation of existing utilities is one of the most awkward aspect in constructing roads in urban areas due to involvement of many authorities having different policies, technical standards, development plans and their implementation schedule.

Data on existing utilities were collected from the following authorities;

(i) Water and Sewerage Department of Nairobi City Commission.

(ii) Water Department of Ministry of Water Development.

(iii) Kenya Posts & Telecommunications.

(iv) Kenya Power & Lighting Co., Ltd.

(v) Kenya Railways Corporation

(vi) Kenya Wildlife Service

(vii) City Engineer's Dept., Highway

(viii) Kenya Rifles Ministry of Defense

MOPW should discuss about the relocation of existing utilities budgetary requirements, relocation/replacement methods and scheduling with the relevant authorities after detailed design. However, during this stage, estimate envisaged were obtained from the affected authorities.

Site investigations were also carried out along the whole length on Nairobi Bypass.

7.2 EXISTING UTILITIES

Inventories of existing utilities along Nairobi Bypass corridor are shown in Table 7.1.

Table 7.1 Existing Utilities

Chainage	Utility	Capacity or Size	Aerial or Underground
CH.0 + 000	Water Line	DN 600S	Aerial
to CH.0 + 500	Telecommunication Line		Aerial
(Mombasa Road J/C)	Electric Line	2 x 66 KV	Underground
	Telecommunication Line		
	Electric Fence		
CH.5 + 900	Electric Line	66 KV	Aerial
CH.6 + 650	Telecommunication Line		Underground
to CH.7 + 500	Telecommunication Line		Aerial
(Uhuru Monument J/C)	Electric Line	66 KV	Aerial
	Street Lighting		
	Sewerage Line	Dia. 300 mm	Underground
	Fence		
CH.7 + 150	Sewerage Line	Dia. 535 mm	Underground
CH.7 + 475	Sewerage Line	Dia. 535 mm	Underground
CH.7 + 910	Water Line	DN 250 UPVC	Underground
CH.8 + 660	Telecommunication Line		Aerial
CH.8 + 820	Electric Line	66 KV	Aerial
CH.9 + 400	Water Line	DN 400S 16"S	Underground
	Water Line	8" PVC	Underground
	Water Line	4" GI	Underground
CH.11 + 160	Electric Line	66 KV	Aerial
to CH.13 + 800			
CH.15 + 500	Telecommunication Line		Underground
(Ngong Rd J/C)	Telecommunication Line		Aerial
	Electric Line	2 x 11 KV	Aerial
CH.16 + 160	Electric Line	11 KV	Aerial
CH.19 + 550	Electric Line	66 KV	Aerial
CH.20 + 850	Telecommunication Line		Aerial
to CH.21 + 240	Electric Line	11 KV	Aerial
(Dagoretti Forest J/C)	Water Line	500 mm INLET	Underground
	Telecommunication Line		Underground
CH.22 + 390	Water Line	3/4"	Underground
CH.22 + 640	Water Line	3/4"	Underground
CH.22 + 680	Electric Line	66 KV	Aerial
CH.22 + 880	Water Line	3/4"	Underground
CH.22 + 960	Water Line	1/2"	Underground
CH.23 + 010	Water Line	1/2"	Underground
CH.23 + 020	Water Line	3/4"	Underground
to CH.23 + 160			
CH.23 + 160	Water Line	2 1/2"	Underground
CH.23 + 170	Water Line	2 1/2"	Underground
CH.23 + 180	Telecommunication Line		Aerial
to CH.23 + 500	Electric Line	66 KV, 11 KV	Aerial
(Thogoto J/C)	Electric Line	11 KV	Aerial
	Electric Line	11 KV	Aerial
	Electric Line	66 KV	Aerial

Table 7.1 Existing Utilities

Chainage	Utility	Capacity or Size	Aerial or Underground
CH.23 + 560	Electric Line	11 KV	Aerial
CH.23 + 800	Sewerage line	Dia. 225 m	Underground
	Electric Line	11 KV	Aerial
CH.24 + 580	Electric Line	11 KV	Aerial
CH.24 + 720	Electric Line	11 KV	Aerial
CH.24 + 800	Electric Line	11 KV	Aerial
	Water Line	1 1/2"	Underground
CH.24 + 810	Water Line	1 1/2"	Underground
	Telecommunication Line	3/4"	Aerial
CH.24 + 900	Water Line	11 KV	Underground
CH.24 + 950	Electric Line	11 KV	Aerial
CH.25 + 020	Water Line	1/2"	Underground
	Electric Line	11 KV	Aerial
CH.25 + 120	Electric Line	66 KV	Aerial
CH.25 + 260	Electric Line	11 KV	Aerial
CH.25 + 380	Telecommunication Line		Aerial
CH.25 + 420	Water Line	1 1/2"	Underground
CH.25 + 480	Electric Line	66 KV	Aerial
CH.25 + 480	Water Line	1 1/2"	Underground
CH.26 + 660	Water Line	6"	Underground
	Water Line	2 x 2 "	Underground
CH.26 + 680	Telecommunication Line		Aerial
CH.26 + 700	Water Line	1"	Underground
CH.26 + 570	Water Line	3/4"	Underground
	Electric Line	11 KV	Aerial
CH.26 + 560	Telecommunication Line		Underground
to CH.26 + 960			
CH.26 + 860	Water Line	1/2"	Underground
CH.26 + 860	Electric Line	11 KV	Aerial
CH.26 + 900	Water Line	3/4"	Underground
CH.26 + 960	Telecommunication Line		Aerial
to CH.27+ 360			
CH.27 + 020	Railway		
CH.27 + 240	Water Line	1"	Underground
CH.27 + 300	Water Line	1"	Underground
CH.27 + 300	Water Line	2"	Underground
to CH.28 + 400			
CH.27 + 360	Telecommunication		Aerial
to CH.27 + 780			
CH.27 + 420	Electric Line	11 KV	Aerial
CH.27 + 240	Electric Line	11 KV	Aerial
to CH.27 + 720			
CH.27 + 680	Water Line	1"	Underground
CH.27 + 720	Water Line	1"	Underground
CH.27 + 960	Electric Line	11 KV	Aerial
to CH.28 + 020			
CH.28 + 220	Water Line	3/4"	Underground

8. ROAD DESIGN

8.1 GENERAL

Road design was carried out based on the Preliminary Design, which was conducted in close consultation with the relevant engineers of the MOPW, reference to the ROAD DESIGN MANUAL issued by the MOPW.

8.1.1 Geometric Design Standard

The geometric design of the road, which is the basis of road design work, is based on the Road Design Manual Part I. Issues not referred in the Manual, were discussed and the design specification were decided based on recommendations made by the JICA Team to the MOPW.

(1) Geometric Design Standard for Main Road

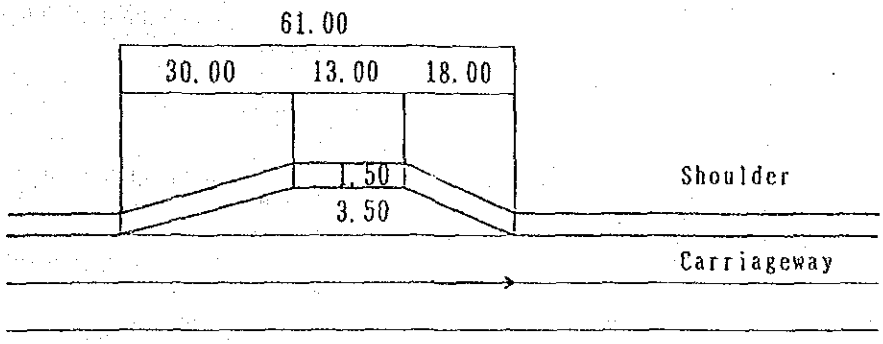
Road classification	Class A
Design Speed	
Mombasa junction - Uhuru monument junction	100 km/hr
Uhuru monument junction - Kikuyu junction	80 km/hr
Lane width	3.50 m
Lane number	4 lanes
Shoulder width	
Right	1.00 m
Left	1.50 m
Central Reserve	
Mombasa junction - Uhuru monument junction	11.00 m
Uhuru monument junction - Kikuyu junction	3.50 m
Superelevation	2.50 %
Maximum Gradient	5.00 %
Minimum Horizontal Curve Radius	600 m
Right of Way	60 m
Vertical Clearance	5.50 m
Horizontal Clearance (from the edge of shoulder)	1.50 m

(2) Geometric Design Standard for Intersections

Design Speed	40 km/hr - 50 km/hr
Lane width One way	4.00 m
Two way 6.00 (Thogoto J, C) -	8.00 m

Shoulder width		
Right	*One way 1.00 (Thogoto J, C)* -	1.50 m
Left		1.00 m
Two way		1.00 m
Superelevation		2.50 %
Minimum Horizontal Curve Radius		30.00 m
Maximum Gradient		7.00 %
Speed change lane (including length of taper)		
Design speed of main road	80 km/hr	100 km/hr
Acceleration lane	160+40=200 m	180+50=230 m
Deceleration lane	50+40= 90 m	70+50=120 m

(3) Geometric Design Standard for Bus Stops



(4) Service roads

Design Speed		20 km/hr - 30 km/hr
Lane width	One way	4.00 m
Two way	6.00 m	

8.2 HORIZONTAL ALIGNMENT

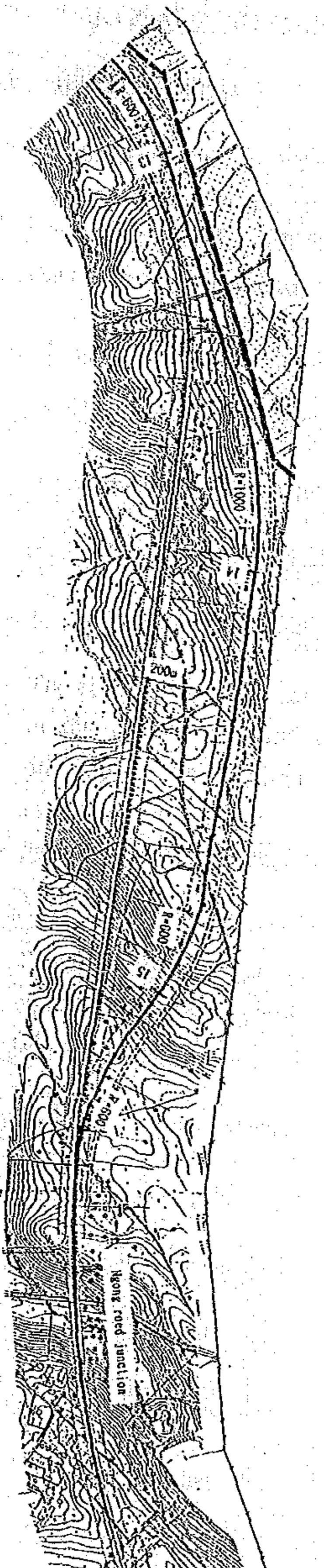
The horizontal alignment largely reflects the locations suggested by the Feasibility Study and strict control is exercised at the following sections.

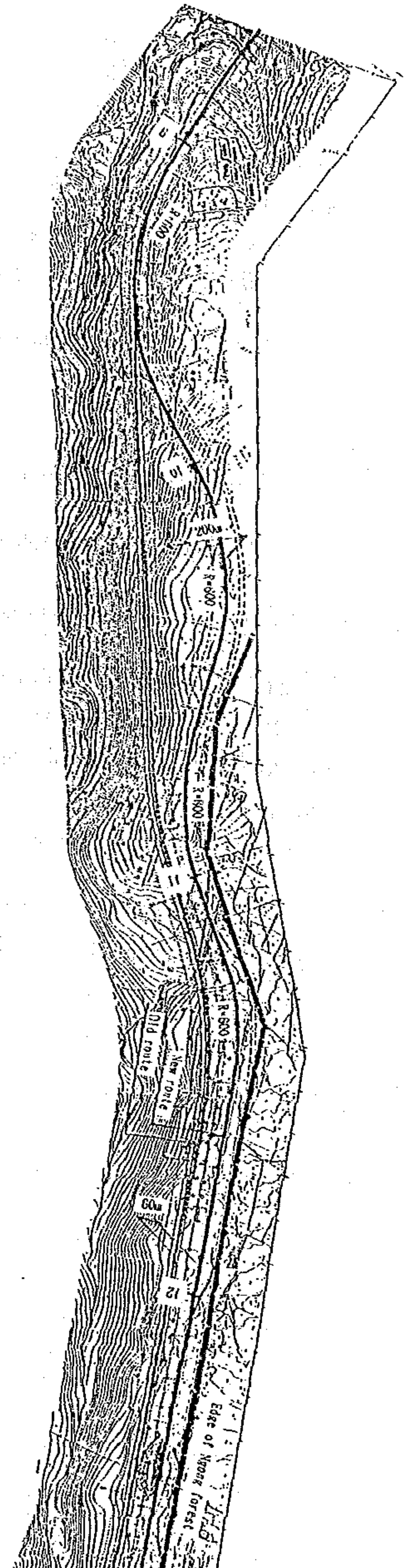
- Mombasa Road Junction - Uhuru Monument Junction (CH.0 + 000 to CH.7 + 300)

  The center-line is introduced in this section at the center of the 60 m wide zone near the urbanized area (right-hand side) of the 120 m wide road reserve which includes the Trans African Highway and the railway tracks.

- CH9+500 - CH15+300 (Ngong Road Junction)

  This section transverses the Ngong natural forest. The road location was changed to the edge of the Ngong forest after the completion of the Preliminary Design in response to a request made by the Government of Kenya in order to minimize damage to the environment.


R=1000
200m
R=800
Ngong road junction


200m
R=800
Old route
New route
60m
Edge of Ngong forest

8.3 VERTICAL ALIGNMENT

8.3.1 Basic Principles

In principle, the vertical alignment involves grade separation vis-a-vis all roads crossing the Bypass with a vertical clearance of 5.5 m being secured. The maximum gradient of the main road is set at 5 %. The following conditions are generally taken into consideration in deciding the vertical alignment.

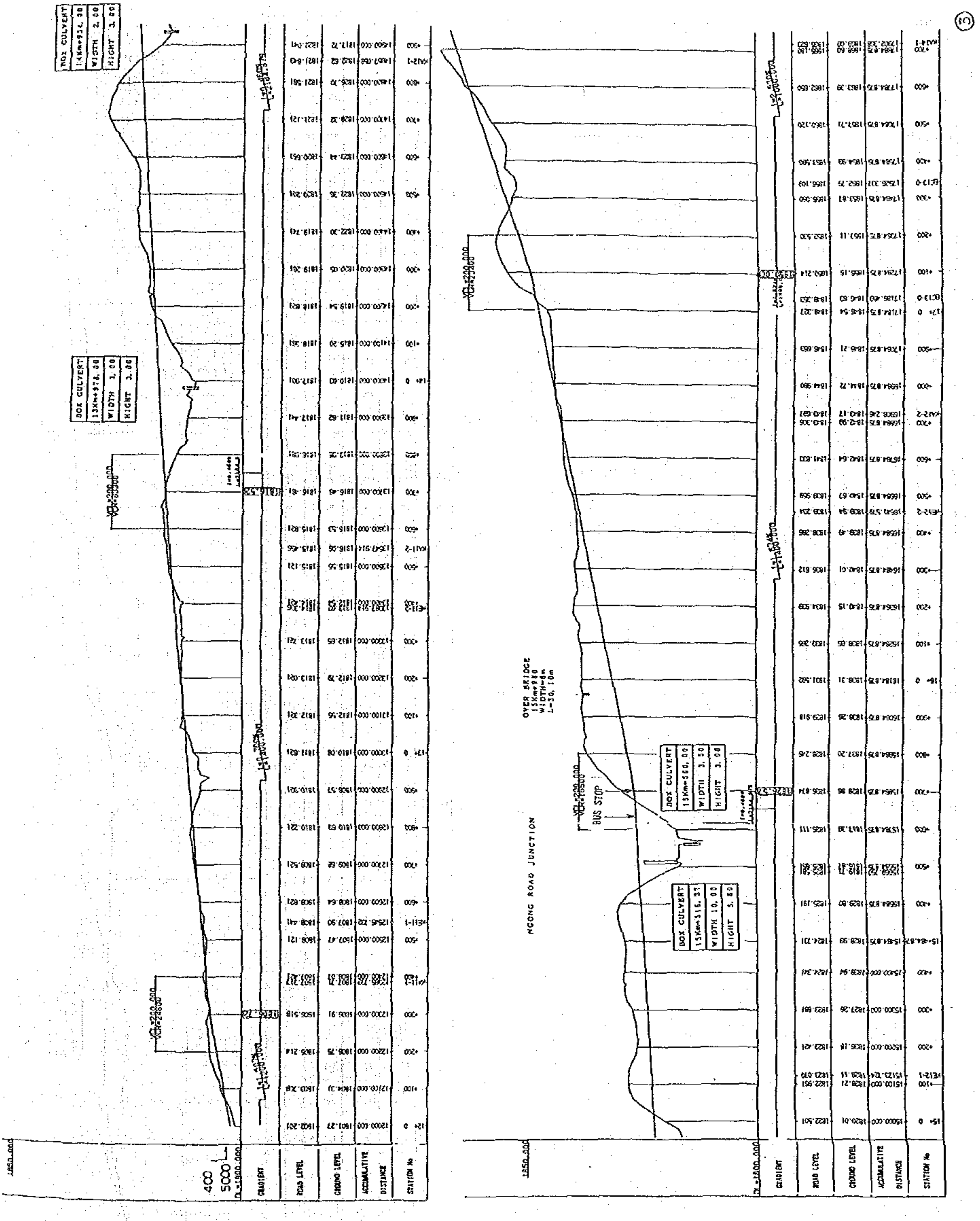
- Crossing or underpassing by roads or other facilities
- Crossing by road drainage facilities
- Balance between cutting and embankment volumes
- Balance between vertical alignment and horizontal alignment
- Desirable length and location of particular gradient

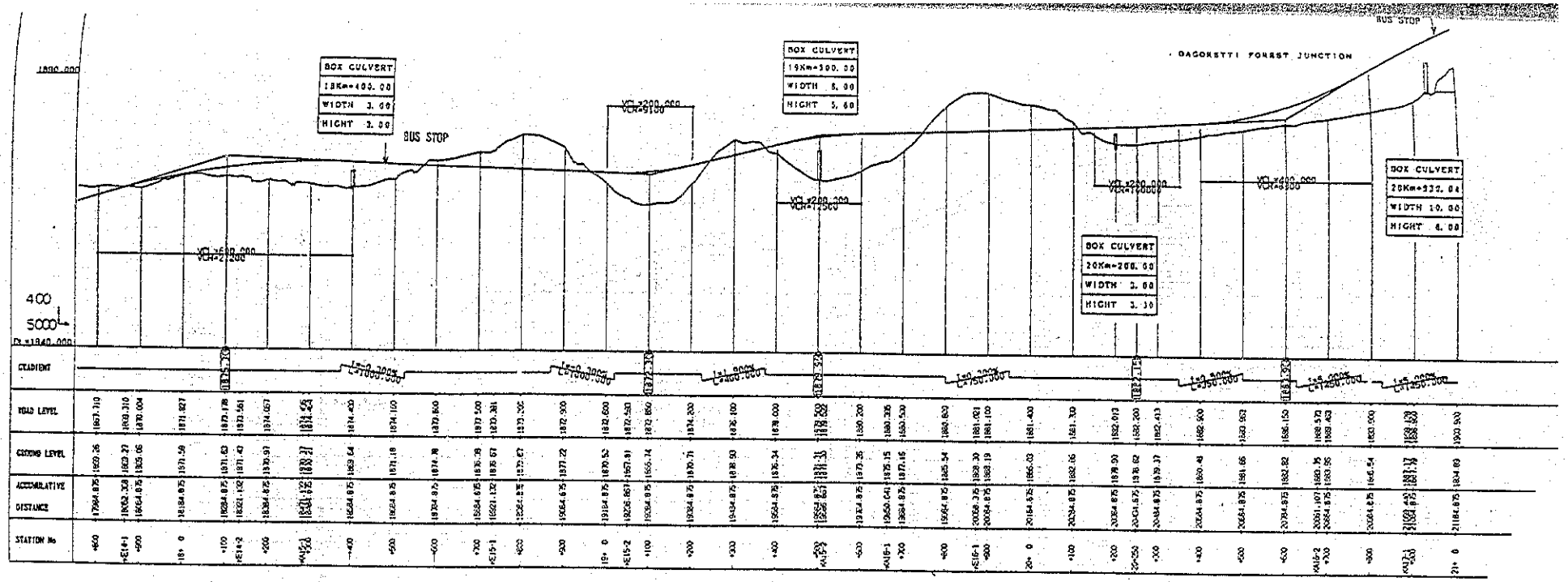
The above conditions, particularly the extent of earth work, play a crucial role in determining the construction cost. The adoption of a gentle gradient is preferable to facilitate smooth traffic flow although it leads to an increase in the initial investment cost. In the long run however, a road with a gentle gradient has a lower running cost as well as a lower maintenance cost than a road with a steep gradient.

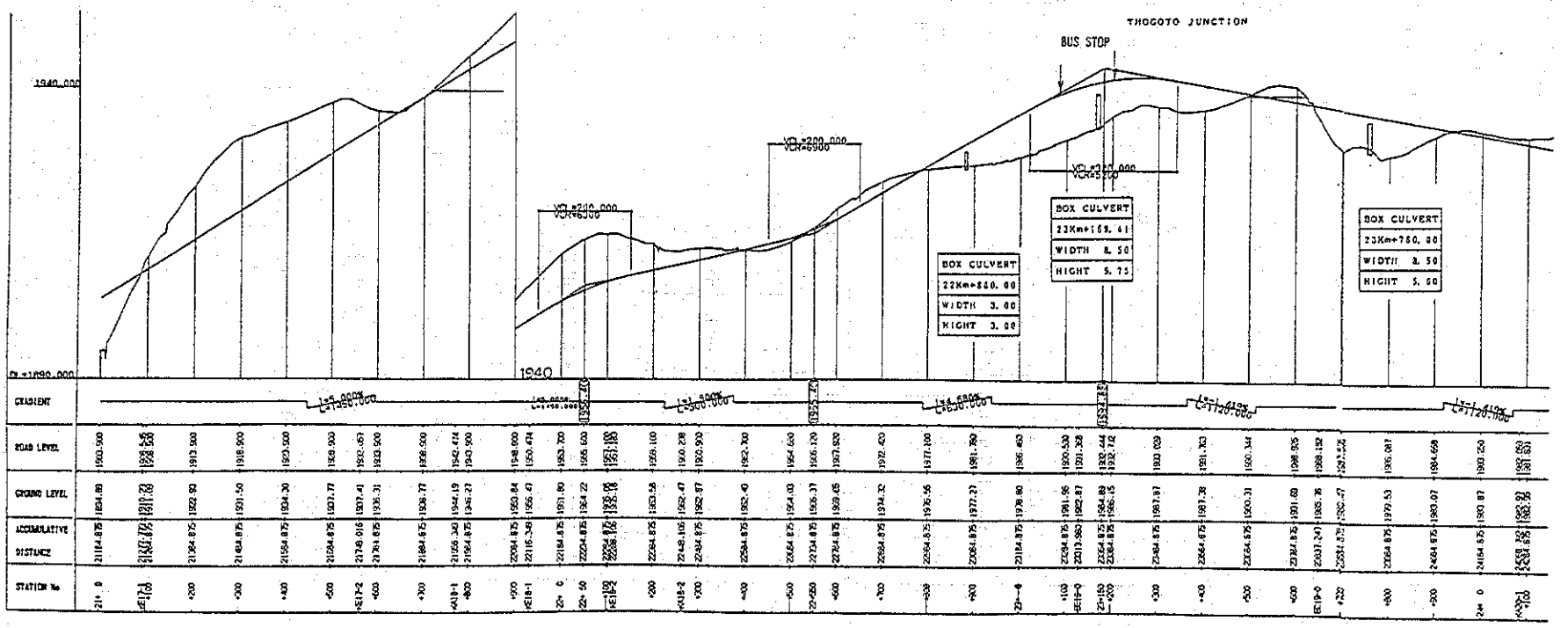
The final road design was carried out by taking all the above-described conditions into consideration. The profile of the main road is shown on the following sheets.

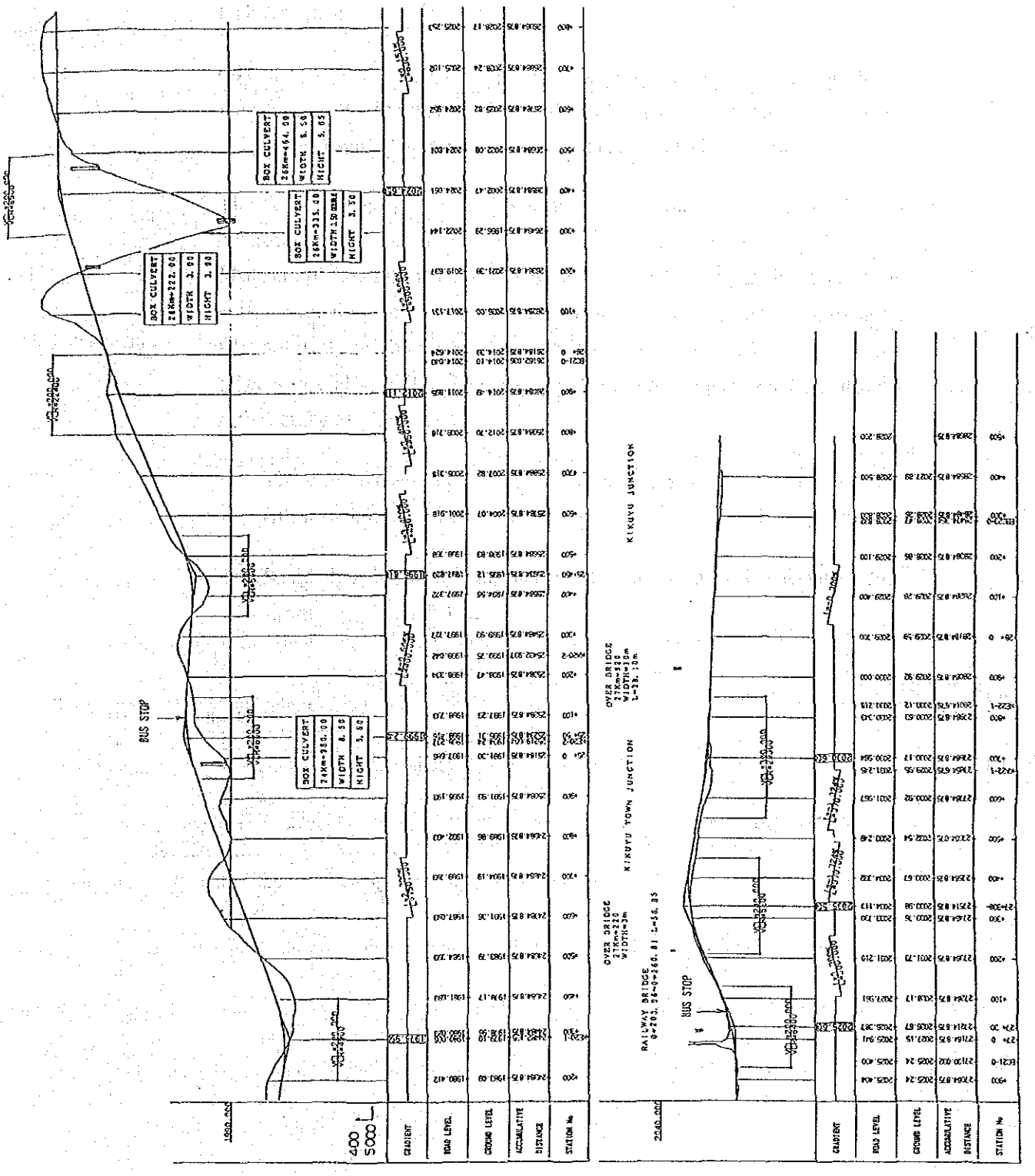
MOMBASA ROAD JUNCTION
MOMBASA ROAD JUNCTION BRIDGE
0+251.10~0+426.10 L=51.00m
OVER BRIDGE
1Km=100
W(OTH=34
BUS STOP
STATION No
ACCUMULATIVE DISTANCE
GROUND LEVEL
ROAD LEVEL
GRADIENT

UHURU MONUMENT JUNCTION
UHURU MONUMENT JUNCTION BRIDGE
BUS STOP
STATION No
ACCUMULATIVE DISTANCE
GROUND LEVEL
ROAD LEVEL
GRADIENT


BOX CULVERT
NGONG ROAD JUNCTION
BUS STOP
OVER BRIDGE


BUS STOP
DAGORETTI FOREST JUNCTION
BOX CULVERT
18Km+400.00
WIDTH 3.00
HIGHT 3.00
BOX CULVERT
19Km+300.00
WIDTH 6.00
HIGHT 5.60
BOX CULVERT
20Km+200.00
WIDTH 3.00
HIGHT 3.30
BOX CULVERT
20Km+920.84
WIDTH 10.00
HIGHT 6.00
VCL=2200.000
VCR=2200
VCL=2200.000
VCR=5100
VCL=2200.000
VCR=12500
VCL=2200.000
VCR=16000
VCL=2400.000
VCR=6500
VCL=2400.000
VCR=6500
400
5000
GRADIENT
ROAD LEVEL
GROUND LEVEL
ACCUMULATIVE DISTANCE
STATION No


THOGOTO JUNCTION
BUS STOP
BOX CULVERT
22Km+860.00
WIDTH 3.00
HIGHT 3.00
BOX CULVERT
23Km+169.41
WIDTH 8.50
HIGHT 5.75
BOX CULVERT
23Km+780.00
WIDTH 8.50
HIGHT 5.50
VCL=2200.000
VCR=6000
VCL=2200.000
VCR=6900
VCL=2200.000
VCR=5200
1940
GRADIENT
ROAD LEVEL
GROUND LEVEL
ACCUMULATIVE DISTANCE
STATION No


BUS STOP
BOX CULVERT
24Km-222.00
WIDTH 3.00
HIGHT 3.50
BOX CULVERT
24Km-454.00
WIDTH 5.50
HIGHT 3.65
BOX CULVERT
24Km-335.00
WIDTH 5.50
HIGHT 3.50
BOX CULVERT
24Km-950.00
WIDTH 8.50
HIGHT 3.60
OVER BRIDGE
27Km+220
WIDTH=9m
L=29.10m
KIKUYU JUNCTION
KIKUYU TOWN JUNCTION
RAILWAY BRIDGE
0+280.86~0+368.81 L=56.85
OVER BRIDGE
27Km+220
WIDTH=9m
BUS STOP
GRADIENT
ROAD LEVEL
GROUND LEVEL
ACCUMULATIVE DISTANCE
STATION No

⑤

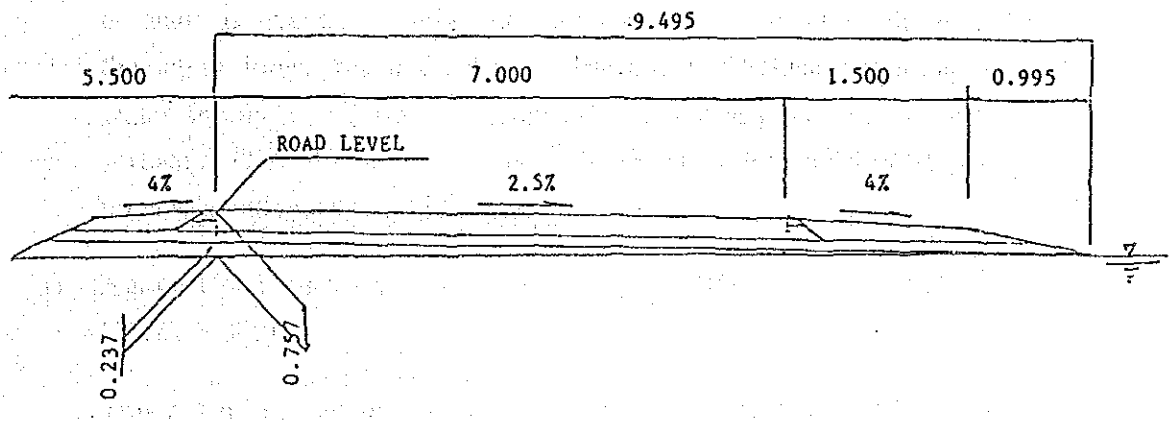
8.3.2 Outline of Each Section

(1) Mombasa Road Junction - Uhuru Monument Junction (CH.0 + 000 to CH.7 + 300)

Given the clover-leaf configuration of this junction which produces weaving on the main road, the vertical alignment (vertical curve) of the main road should be gentle enough to ensure sufficient visibility.

The section, approximately 6 km in length, which traverses the Nairobi National Park between the Mombasa Road Junction and Uhuru Monument Junction is covered by a 50-70 cm thick layer of black cotton soil. Since this soil is unsuitable for filling, it must be replaced by good fill material which can be obtained from a borrow pit located between CH9 and CH10+400. The following two conditions must be met for satisfactory earth work.

- The embankment height should be kept to a minimum to reduce the filling volume
- Read level should be raised up to keep out subbase from submergence by flood.



(2) Around Uhuru Monument Junction

There are outcrops of very hard rock around the Uhuru Monument Junction, necessitating the use of explosives to excavate the area. The existence of residential areas, including the Uhuru Garden Estate, in the vicinity adds an additional complication to earth work in this area. As a result, it was decided that filling will be used in the construction of the Uhuru Monument Junction as an underpath. The use of explosives for excavation is not considered to be an option.

(3) Uhuru Monument Junction - Ngong Road Junction (CH.7 + 300 to CH.15 + 800)

In order to conserve the natural forest in this area, the horizontal alignment of this section has been changed and the Bypass will run along the edge of the Ngong forest which lies between CH9+400 and CH15+300. As a result, a maximum gradient of 5 % has been introduced for the section between CH9+400 and CH10+300. The section between CH10+300 and CH11+100 has been designated a cutting area to obtain filling material for the section between the Mombasa Road Junction and the Uhuru Monument Junction. The pavement height for the section between CH11+100 and CH15+300 will be made as level as possible with the present ground level to minimize the natural forest area affected by the Bypass. The field survey found a water supply pipe (400 mm diameter) laid 1.2 m below the ground surface at CH9+400 and the vertical alignment envisages filling at this point to avoid relocation of the pipe.

(4) Ngong Road Junction - Dagoretti Forest Junction (CH. 15 + 800 to CH.21 + 000)

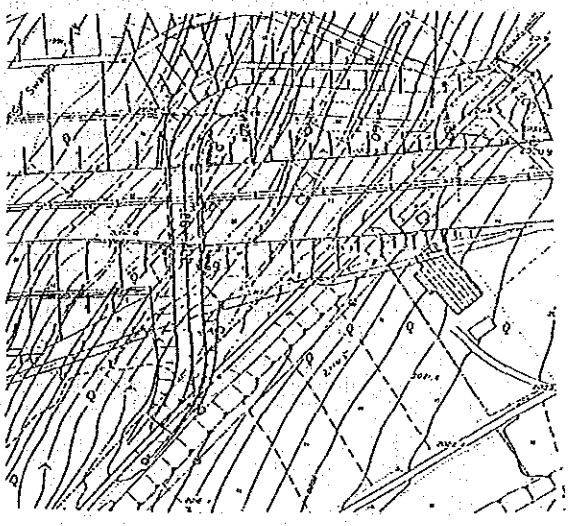
This 5 km long section, with an elevation changing from 1,820 m to 1,880 m, has a gentle average gradient of 1.2 % with a succession of cutting and embankment sections. The alignment control conditions include excavation of some 7 m in depth to reach the soft rock layer in the cutting sections to balance out with the volume of earth required for the embankment sections. The latter is adjusted by controlling box culverts across the embankment sections.

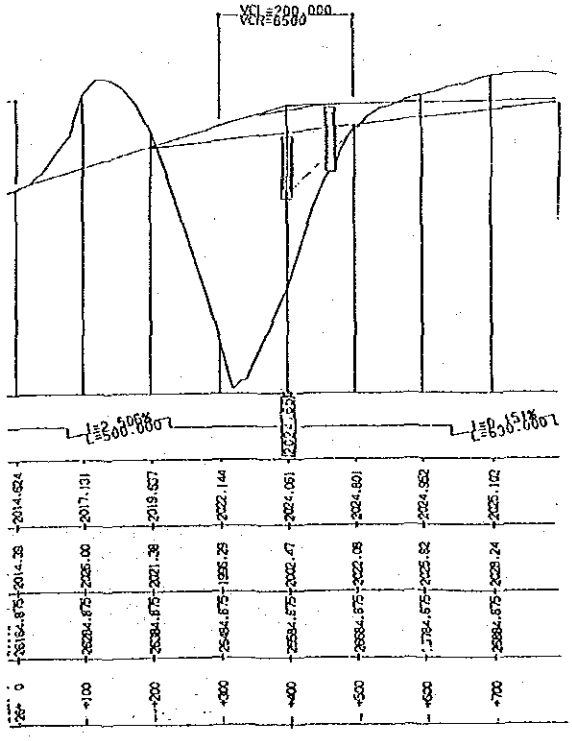
(5) Dagoretti Forest Junction - Thogoto Junction (CH.21 + 000 + CH.23 + 180)

The elevation difference of 115 m (between 1,800 EL and 1,995 EL) in 2,800 m makes this the steepest section of the Nairobi Bypass with an average gradient of 4.1 %. Topographically, this section is located in the border area between flat and mountainous areas. The cutting depth is 12.5 m, the deepest of all the sections, requiring the largest cutting work in the Bypass, as hard rock spreads from CH21+100 to CH21+500.

(6) Thogoto Junction - Kikuyu Town Junction (CH.23 + 200 to CH.28 + 416)

The design road height for this section is determined both by the balance between the cut volume and filling volume and by the design box culvert height. The desirable road height at the Ondri swamp section is subject to two factors, i.e. the box culvert height for a crossing road and the height of the approach to the C63 from the slip road of the Kikuyu Town Junction. An embankment height of 32 m has been proposed. While it is possible at this point to relocate the box culvert, as shown in Fig. 8.3, to lower the main road height by some 3 m, in order to reduce the required filling volume, it has been decided through consultations with the MOPW to construct the box culvert on the present road to avoid the possible subsidence of the box culvert if it is located on top of the new embankment.





(7) Kikuyu Town Junction - Kikuyu Junction

This section will form the replaced section of the C63. The design road height is identical to that of the existing road.

8.4 EARTH WORKS

8.4.1 Design of Slopes

The various slopes were obtained from the MOPW Design Manual Part I. However, after investigations, the cut slope for red soil was altered. The values of the slopes adopted are tabulated in Table 8.4.1 and 8.4.2.

Table 8.4.1 Values of cut slopes

Type	Factor
Soil	1 : 1.4
Weathered Rock	1 : 0.5
Hard Rock	1 : 0.2

Table 8.4.2 Values of Embankment Slopes

Type	Factor
h < 3 m	1 : 2
3 < h	1 : 1.5

where h is height of embankment

In cut areas with height exceeding 5.0 m, berms with a width of 2.0 m shall be constructed. The top of the slope must be rounded as shown in figure below.

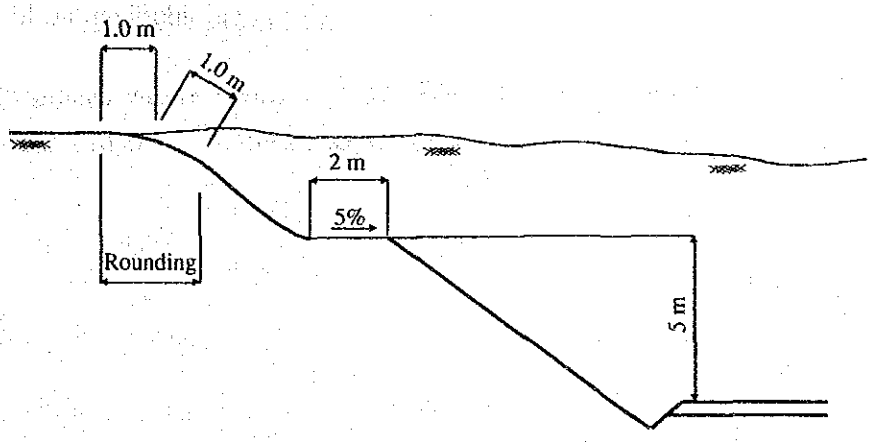


Figure 8.4.1 Cross Section in Cut Area

8.4.2 Site Clearance and Topsoil Stripping

As shown in Fig. 8.4.2 site clearance shall be conducted in the cutting and embankment section within the road reserve. Top-soil shall be removed from the whole area of the construction to a depth of 10 cm as shown in Fig. 8.4.2.

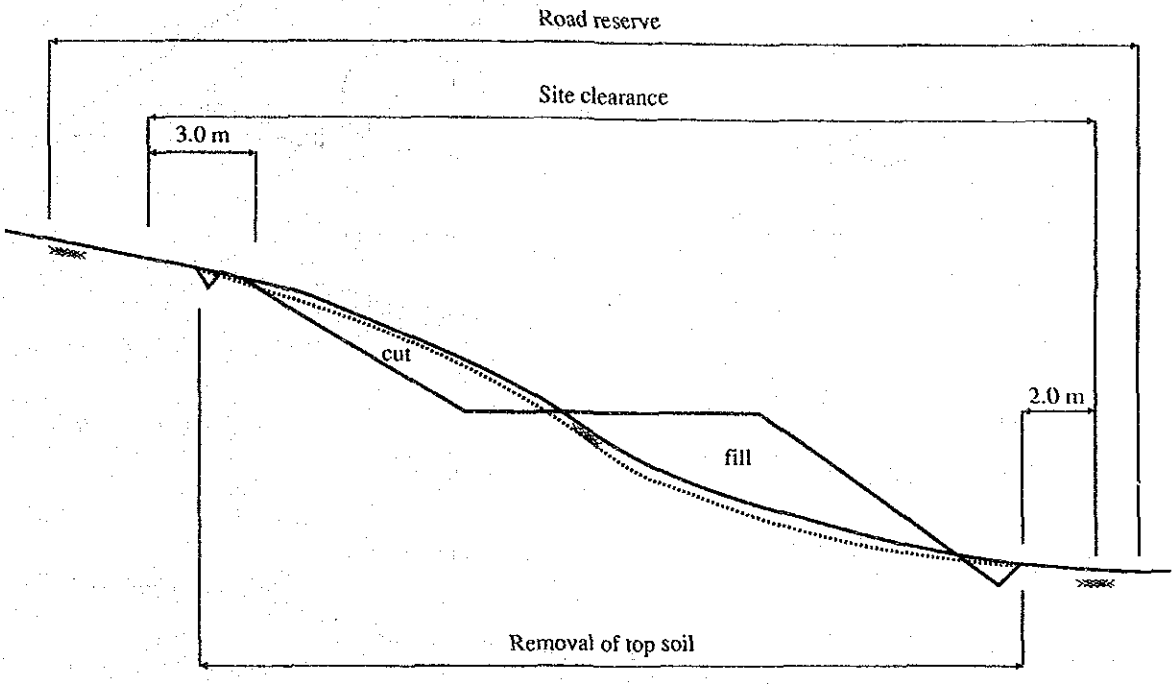
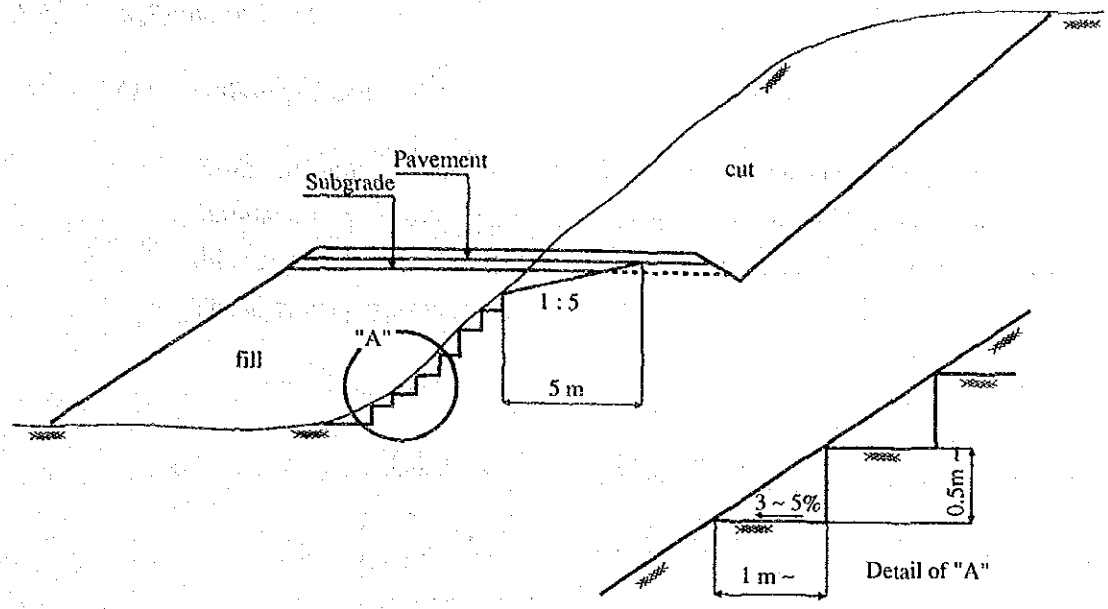


Figure 8.4.2 Extent of Site Clearance and Removal of Topsoil

8.4.3 Fill on the including ground

In places where filling is required on inclined ground having a side slope greater than 1 in 5, the stepping shall be carried out as shown in Fig. 8.4.3.



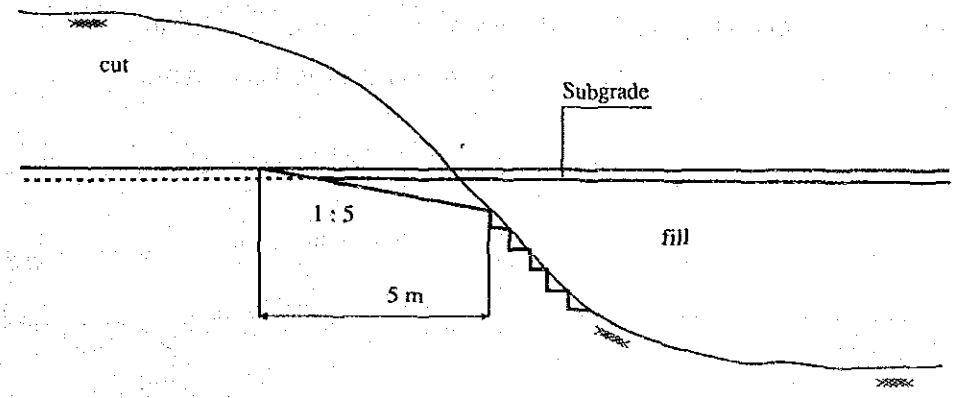


Figure 8.4.3 Stepping on the inclined Ground

8.4.4 Scheme of Haul

(1) Bulking of Soil

After comparing the bulking factors of Kenyan and Japanese road manuals, it was found that the Japanese Manual had higher factors. For this reason, it was decided to adopt the values in the Japanese Manual. These values are given in Table 8.4.3.

Table 8.4.3 Bulking Factors

Type	Factor (c)
Soil	0.85
Weathered Rock	1.00
Hard Rock	1.20

(2) Borrow Area

Fill material required, in addition to that provided by the excavation of cuttings, shall be obtained from the widening of cuttings within the road reserve as shown in Fig. 8.4.4. (Here in after called Side Borrow)

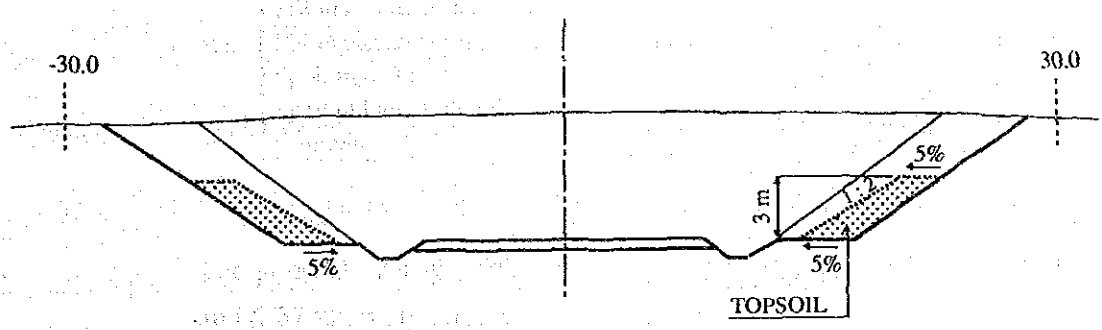


Figure 8.4.4 Standard Cross Section of Side Borrow Section

At the detail design stage, side borrow section through CH9+800 to CH10+260 was selected, taking into account the following considerations:

- Preservation of the natural forest
- Avoidance of black cotton soil
- Avoidance of hard materials
- Location to be as close as possible to the Mombasa Road Junction

Fill material which will be obtained from the excavation of the drainage pond located at CH24+380 shall be used for the filling of the road.

(3) *Mass Haul Diagram*

After drawing the mass haul diagram, the total volume of fill, spoil and overhaul were realized as shown in Table 8.4.4.

Table 8.4.4 Volume of Fill, Soil and Overhaul

Item	Unit	Quantity
Fill in soft material	m^3	1,458,000
Fill in hard material	m^3	105,000
Spoil in soft material	m^3	(241,800)
Spoil in hard material	m^3	0
Overhaul	$m^3 \cdot km$	3,432,000

The general average freehaul and overhaul distance comes to 0.64 km and 5.67 km respectively.

(4) Spoil Area

Removal of top soil and unsuitable materials are shown in Table 8.4.5.

Table 8.4.5 Rough Quantity of Unsuitable Material and Removal of Top Soil

Item	Section	Quantity (m^3)
Removal of Top Soil (*)		52,300
Unsuitable material		
Black Cotton Soil	CH0+000 - 5+600	152,500
Black Cotton Soil	CH11+000 - 11+280	4,500
Black Cotton Soil	CH11+420 - 11+640	2,500
Black Cotton Soil	CH11+800 - 12+200	8,600
Black Cotton Soil	CH12+760 - 13+50	1,100
Black Cotton Soil	CH13+740	200
Black Cotton Soil	CH16+240 - 16+980	10,300
Rubbish	CH8+850 - 9+30	9,800
Total		241,800

(*) Total Volume of top soil removal comes to 106,700 m^3, but since the required top soil volume is only 54,400 m^3, the remaining 52,300 m^3 will be spoiled.

The remaining top soil (52,300 m^3) shall be spoiled neatly around the road. But, because black cotton soil and rubbish are not useful, and it is unacceptable to dump them, spoil area is required. Consequently, spoil areas are determined as follows.

- Black cotton soil located from CH0+000 to CH5+600, shall be spoiled neatly inside the loops at the Mombasa Road Junction.
- Black cotton soil located from CH11+000 to CH11+280, and the others black cotton soil shall be spoiled neatly on grass land covered by black cotton coil beside the road.
- Rubbish materials located from CH8+850 to CH9+030 shall be spoiled inside the loops at the Mombasa Road Junction.

The surface of the black cotton soil and rubbish spoiled will be covered neatly with top soil and grass according to Section 8.4.5.

8.4.5 Grassing and Top Soiling

Grassing shall be carried out under the following conditions.

- Where the slope is less than 1 : 0.5, grass should be planted.
- Indigenous "runner" type grass should be used.

Top soil should be used in the following places.

- Embankment slopes where top soil is required:

  It should be laid to a thickness of 75 mm.

- Side borrow sections:

  After side borrow work is finished, top soil shall be placed as shown in Fig. 8.4.4.

- Spoil banks of black cotton soil:
- Spoil banks of black cotton soil, beside the road and around the Mombasa Road Junction require top soil with thickness 200 mm.
- Rubbish dumps (from CH8+850 to CH9+30):

  Dumps within the road reserve require top soil to thickness 600 mm.

- Traffic islands at junctions and the Central reserve of Langata Road.