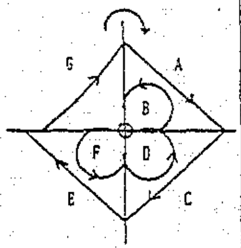
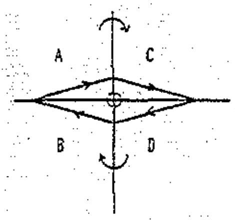
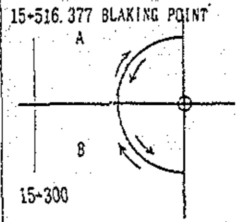
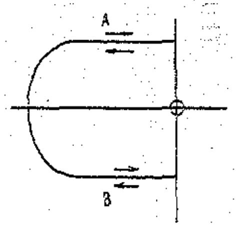
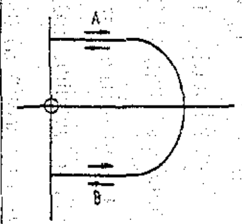
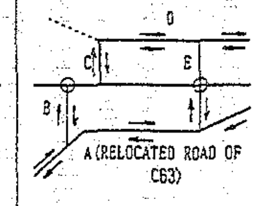
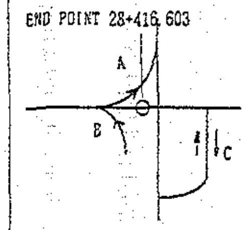
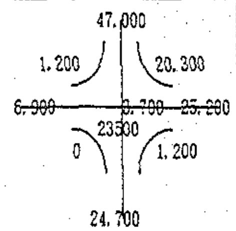
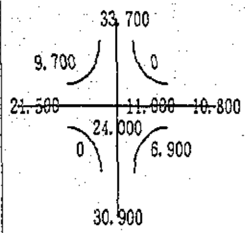
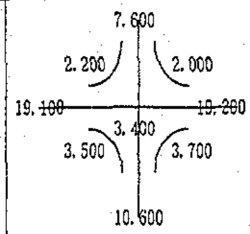
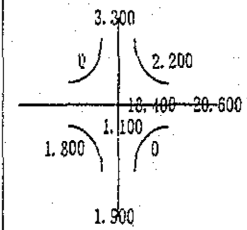
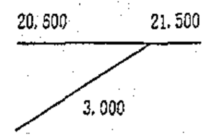
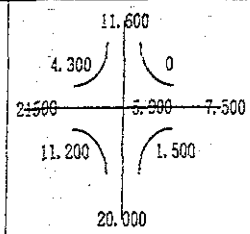
8.5 DESIGN OF JUNCTIONS

8.5.1 General

The Nairobi Bypass has a full control system throughout, with seven junctions. The design conditions of these junctions are described in the following page.

CONSIDERATIONS OF INTERSECTOINS

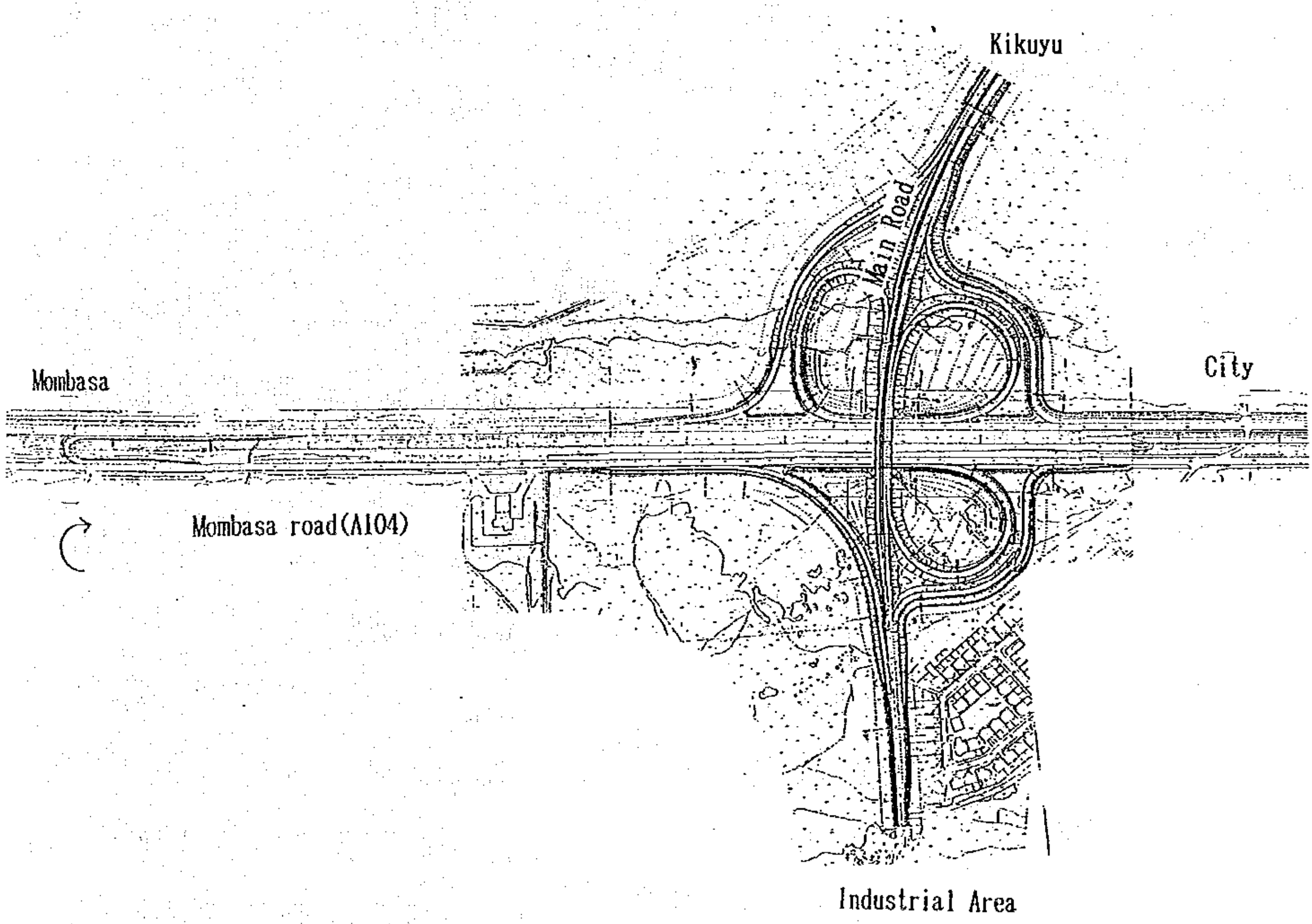
NAME OF JUNCTION		MOMBASA ROAD J.C	UHURU MONUMENT J.C	NGONG ROAD J.C	DAGORETTI FOREST J.C	THOGOTO J.C	KIKUYU TOWN J.C	KIKUYU J.C
INTERVAL (m)		397.588 / 6297.369	9006.295	5413.668	2239.368	3430.587	1320.000	496.603 / 28601.478
DESIGN SPEED	MAIN ROAD	80Km/hr / 100Km/hr	80Km/hr					
	SLIP ROAD	50Km/hr		40Km/hr				40 ~ 50Km/hr
NAME OF ACCESS ROAD		MOMBASA ROAD . LIKONI ROAD	LANGATA ROAD(C58)	NGONG ROAD(60)	DAGORETTI ROAD(C63)	THOGOTO ROAD(D411)	DAGORETTI ROAD(C63)	KABETE LIMURU ROAD(A104)
SKETCH OF JUNCTION NAME OF SLIP ROAD								
TRAFFIC VOLUME AADT IN 2000						NO DATA		
COMPOSITION OF WIDTH	APPROACH ROAD (m)	MOMBASA ROAD(A104) 4 LANE S C M C S 3.50+7.00+28.50+7.00+3.50 LIKONI ROAD S C S 1.50+7.00+1.50=10.00	LANGATA ROAD(C58) 4 LANE P G C M C 2.00+4.75+7.50+6.50+7.00 G P +4.75+2.00=34.50 TEMPORARY ROAD S C S 1.50+3.50+1.00=6.00	NGONG ROAD(C60) 2 LANE S C S 1.50+7.00+1.50=10.00 WITH RIGHT TURN LANE S C S 1.50+10.50+1.50=13.50	DAGORETTI ROAD(C63) 2 LANE S C S 1.50+7.00+1.50=10.00 WITH RIGHT TURN LANE S C S 1.50+10.50+1.50=13.50	THOGOTO ROAD(D411) 2 LANE S C S 1.25+6.00+1.25= 8.50 WITH RIGHT TURN LANE S C S 1.25+ 9.00+1.25=11.50	DAGORETTI ROAD(C63) A,B,C,D,E 5 SLIP ROAD A SLIP ROAD(RELOCATED ROAD) S C S CH 00~1+324 1.50+7.00+1.50=10.00 S C S CH 1+324~500 1.50+4.00+1.00=6.50 B SLIP ROAD S C S 1.50+5.50X2+1.50=14.00	KABETE LIMURU ROAD(A104) 4 LANE S C M C S 1.50+10.50+1.60+7.00+1.50 =22.10(INCLUDING CLIMBING LANE)
P:PEDESTRIAN G:GREEN BELT C:CARRIAGE WAY M:MEDIAN STRIP	SLIP ROAD	A,B,C,D,E,F,G 6 SLIP ROAD ONE LANE S C S 1.50+4.00+1.00=6.50	A,B,C,D 4 SLIP ROAD ONE LANE S C S 1.50+4.00+1.00=6.50	A,B 2 SLIP ROAD TWO LANE S C S 1.50+8.00+1.50=11.00	A,B 2 SLIP ROAD TWO LANE S C S 1.50+8.00+1.50=11.00	A,B 2 SLIP ROAD TWO LANE S C S 1.00+6.00+1.00= 8.00	C SLIP ROAD S C S 1.50+8.00+1.50=11.00 D SLIP ROAD CH 00~629 S C S 1.50+7.00+1.50=10.00 S C S CH 629 ~768 1.25+6.00+1.25= 8.50 E SLIP ROAD 1.50+7.00+1.50=10.00	A,B,C 3 SLIP ROAD A SLIP ROAD 1 LANE S C S 1.50+4.00+1.00=6.50 B SLIP ROAD 1 LANE S C S 1.50+3.50+1.00= 6.00 C SLIP ROAD 2 LANE S C S 1.50+8.00+1.50=11.00

8.5.2 Outline of Junction Configuration

The configuration of each junction is outlined below.

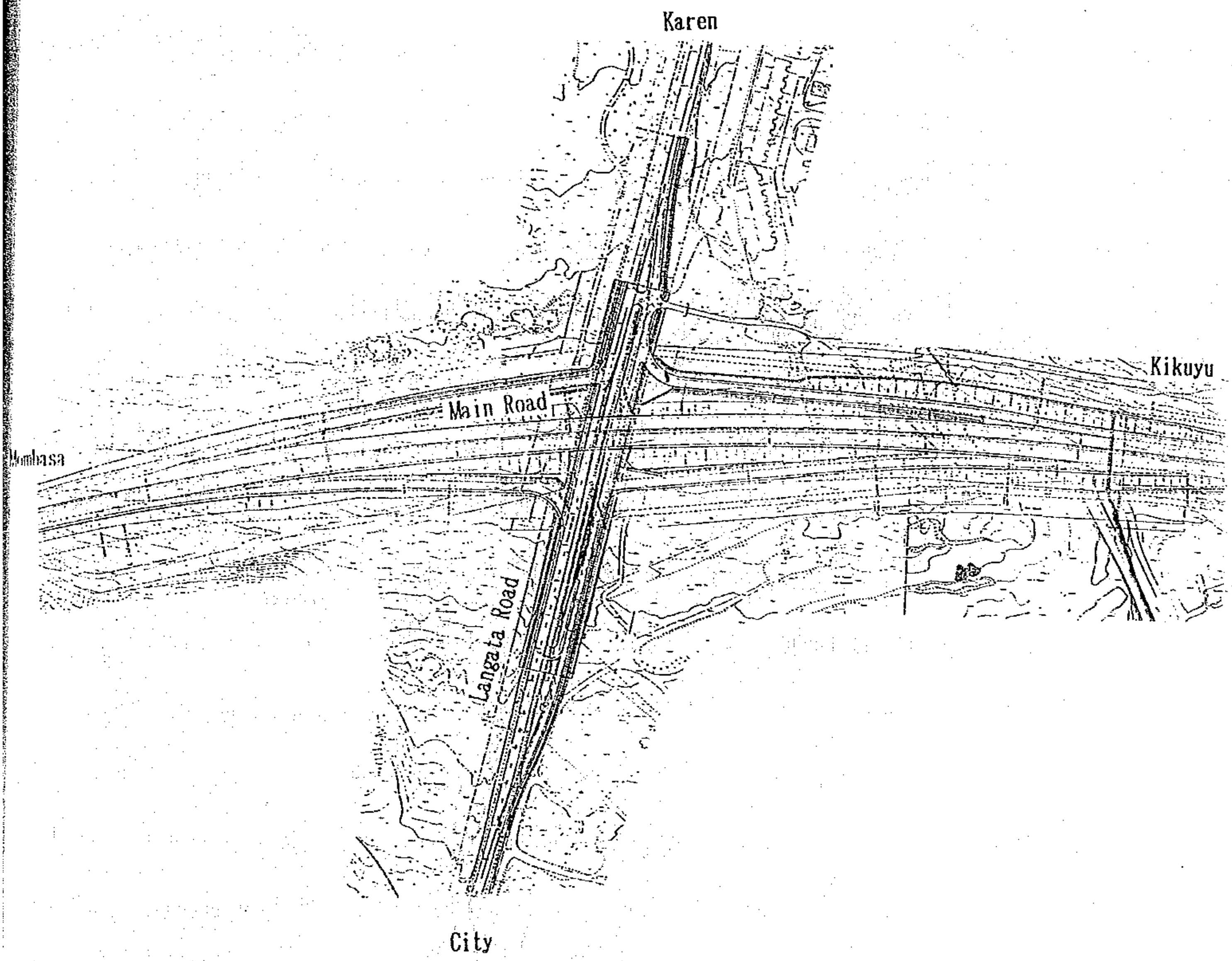
(1) Mombasa Road Junction

This is a clover-leaf grade separation with seven slip roads. At the time of the Feasibility Study, the junction was planned to have four slip roads in view of the likely traffic volume. The subsequent request by the MOPW, however, resulted in an additional three slip roads to allow traffic flow from the junction in all directions except a right turn on the A104 from the city center in the Kikuyu direction. Flow of traffic from the industrial area to the city center is designed by a U-turn road in the central reserve of A104. The center-line of the Bypass will join Likoni Road (a planned two lane road connecting the industrial area with the A104).



(2) Uhuru Monument Junction

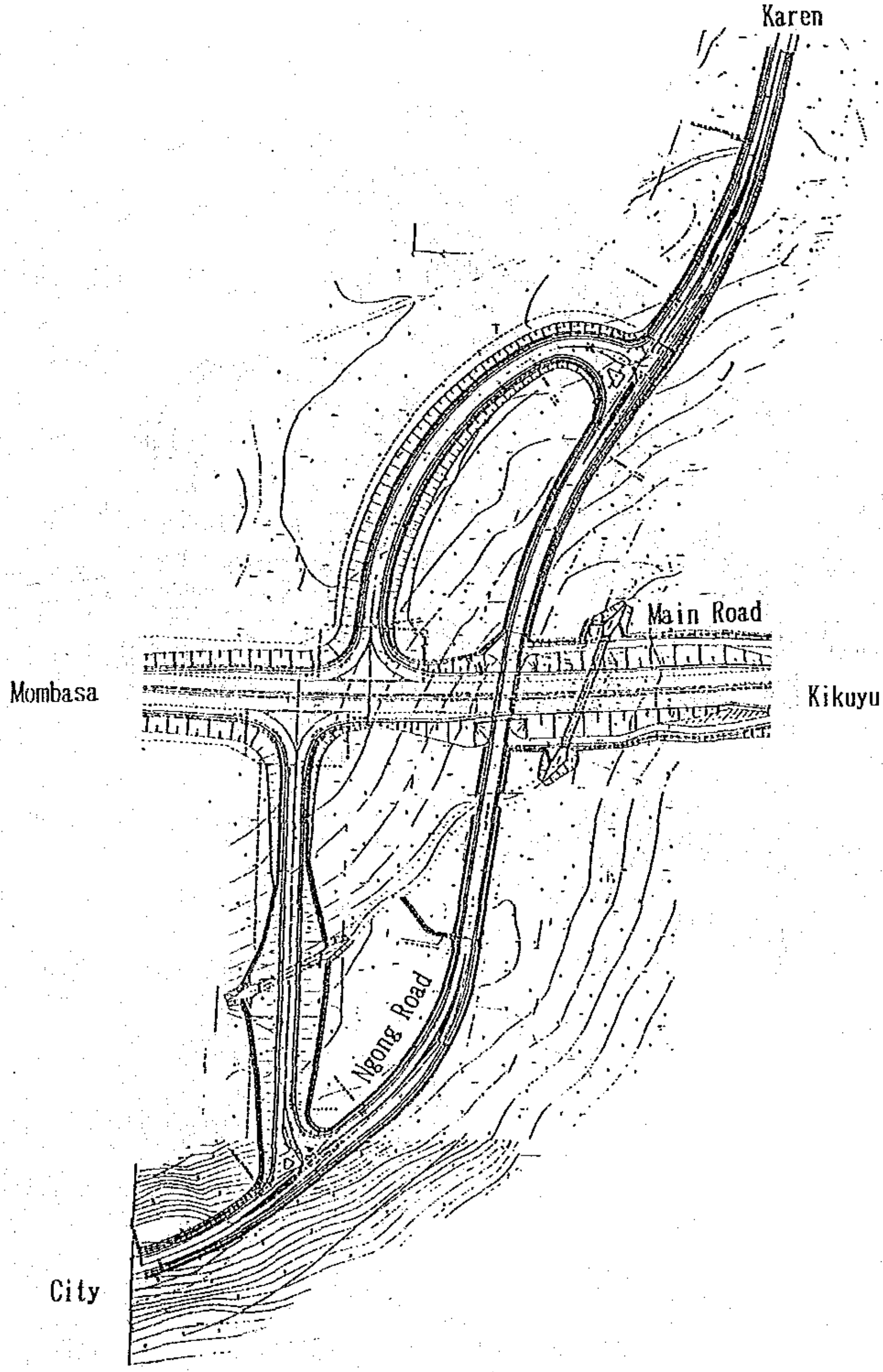
This is a diamond type grade separate junction connecting with Langata Road (C58) which will be widened from its present two lanes to four lanes in the future. The approach will have an improved cross-section in anticipation of the above widening of Langata Road.



(3) Ngong Road Junction

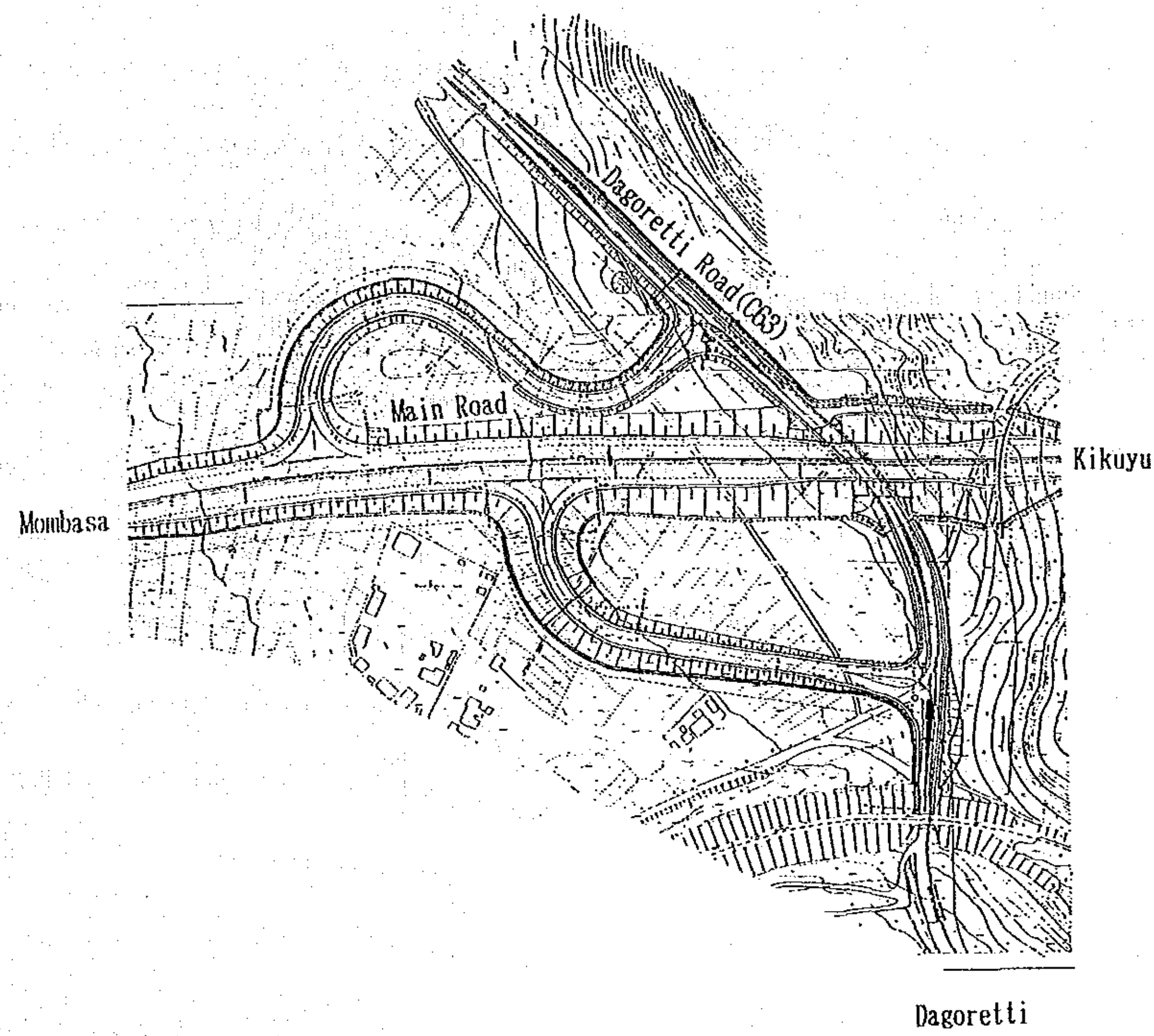
The function of this junction is to allow access to the Bypass from Ngong Road (C63). The approach site of the slip road has been decided based on the following conditions.

- To avoid the steep gradient section of Ngong Road.
- To secure a sight distance of 120 m from the box culvert under the main road.



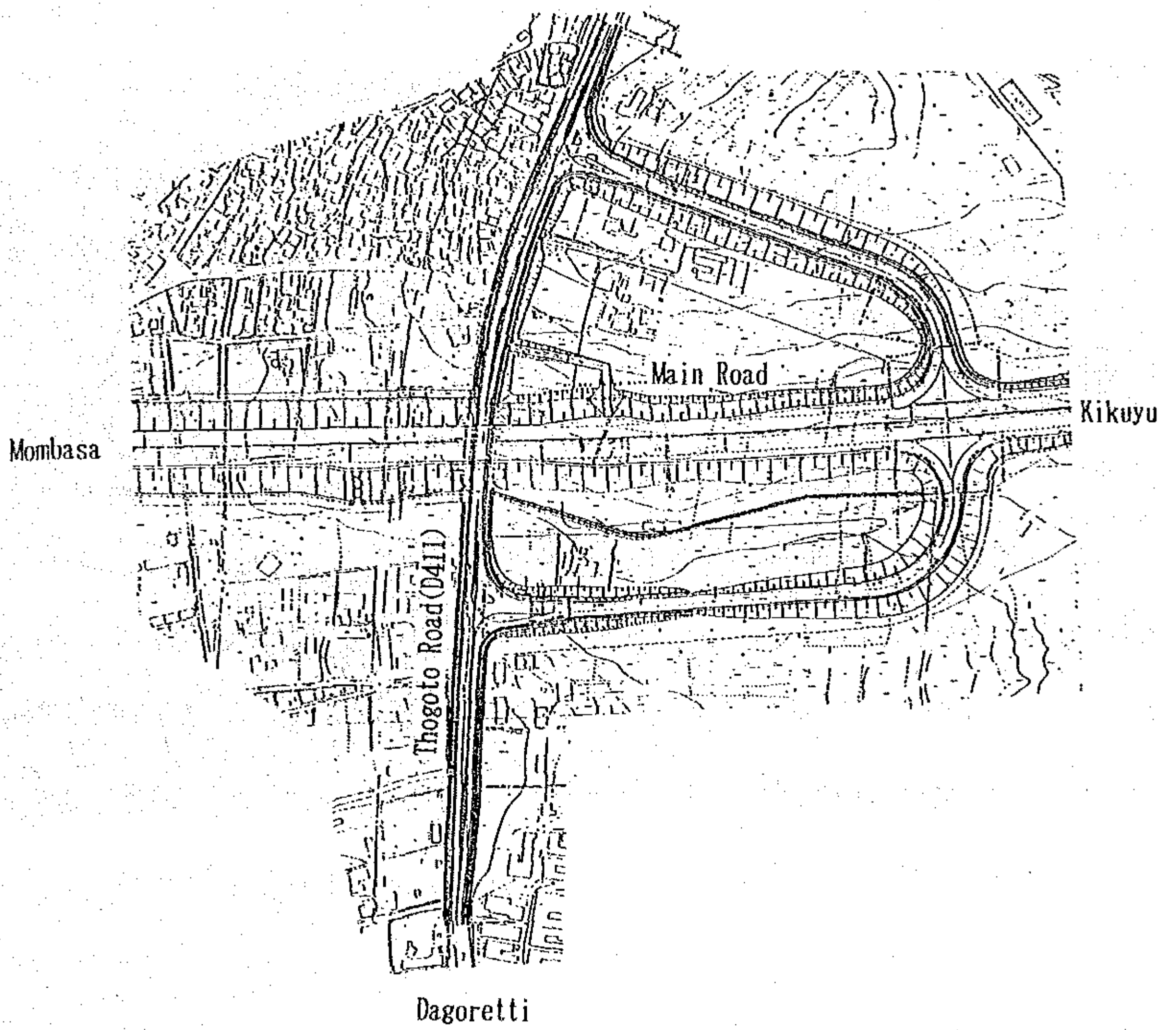
(4) Dagoretti Forest Junction

The design conditions are the same as those for the Ngong Road Junction. The location of the approach at the main road has been decided to avoid the steep gradient (5 %) section. Both the acceleration and deceleration lanes on the steeper side have been lengthened in view of safety.



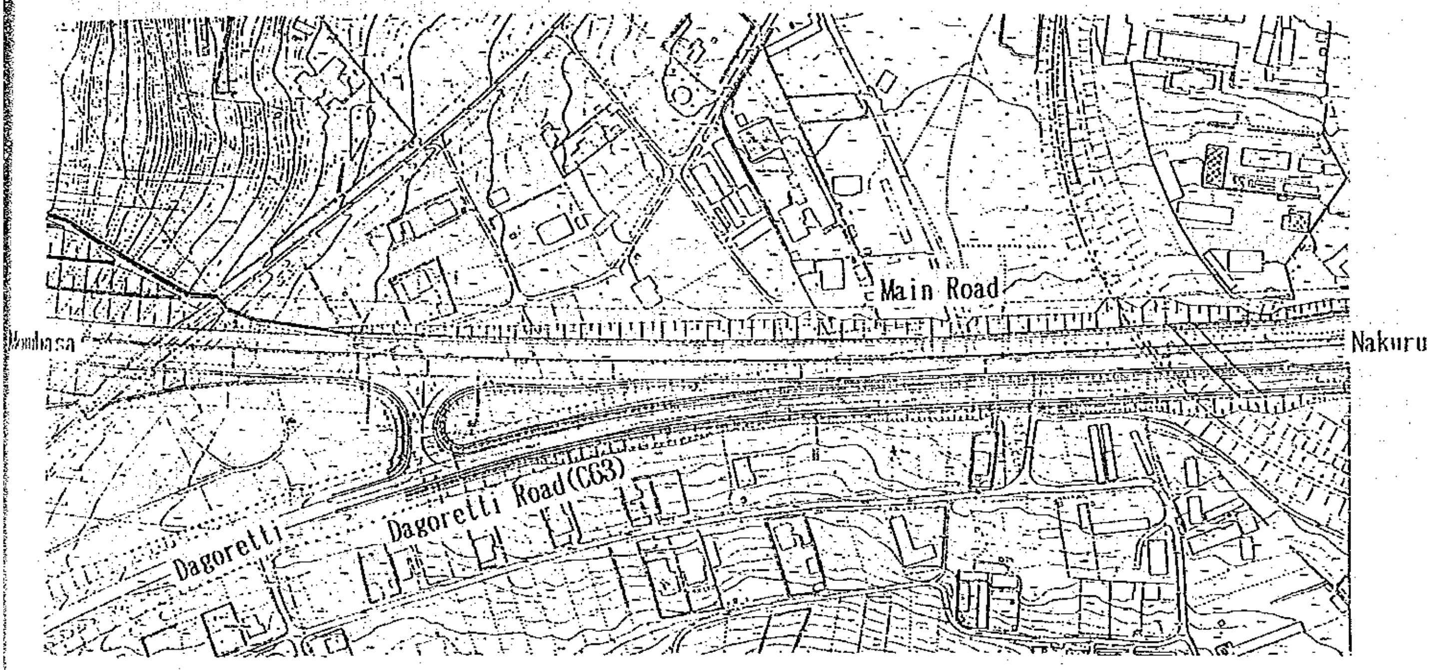
(5) Thogoto Junction

The design conditions are the same as those for the Ngong Road Junction. Since the slip road is a D class, the standard of the slip road will be lower than at other junctions as a result of economic restrictions.



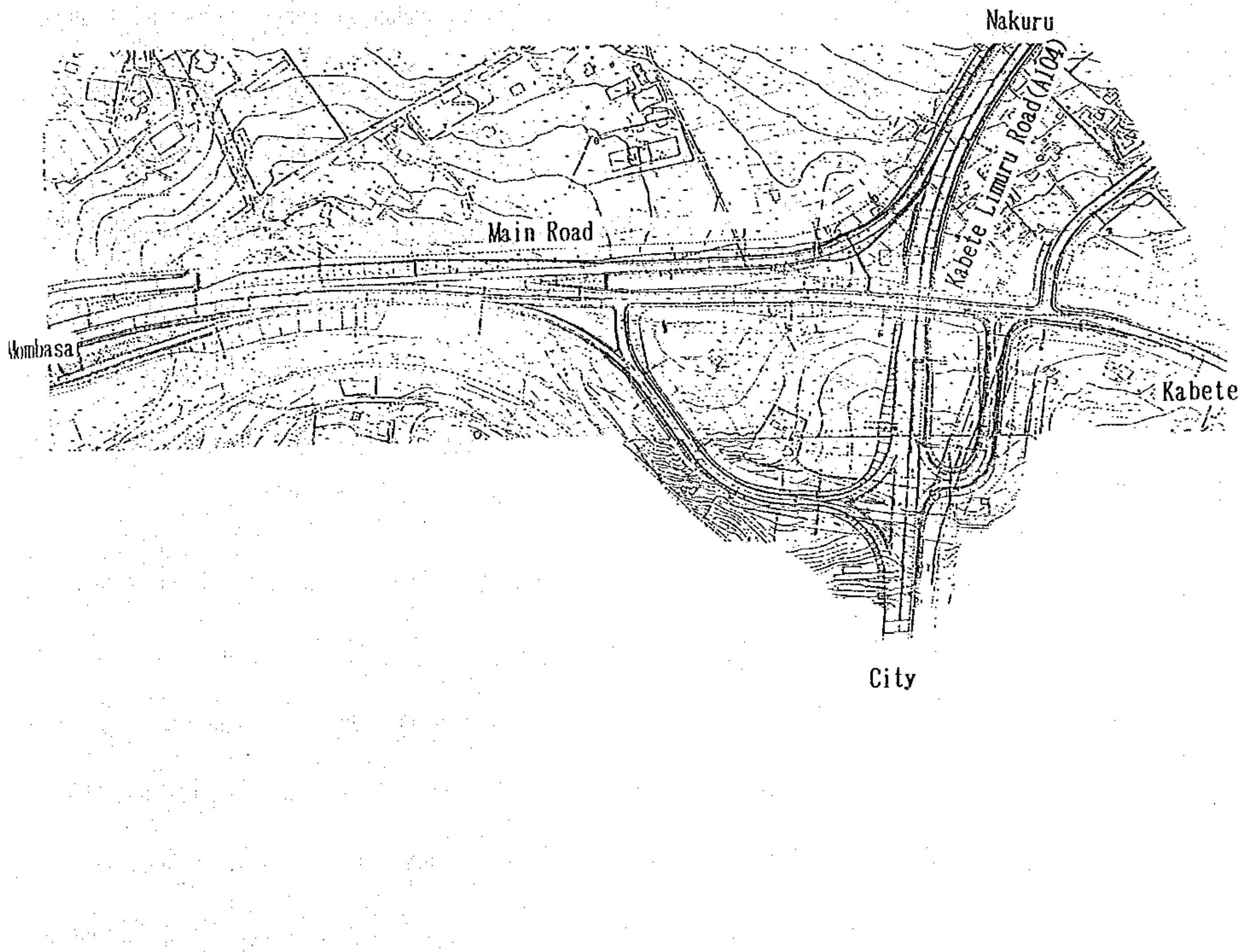
(6) Kikuyu Town Junctions

The introduction of this junction was requested by the MOPW. Kikuyu Town currently has a population of 10,000 and a junction is planned here in anticipation of further development of this area. As the town is divided into two zones by a main road, a connection between the two zones is necessary. The final design, originally proposed by the JICA Design Team and approved through consultations with the MOPW, involves the relocation of Dagoretti Road (C63).



(7) Kikuyu Junction

The Kikuyu Junction was originally designed during the Preliminary Design Study to facilitate the main traffic flow towards Nakuru which connects with Kabete Limuru Road (A104). The final design allows the future expansion of the northbound lanes to four lanes as requested by the MOPW in consideration of the road's role as part of the Nairobi Ring Road.

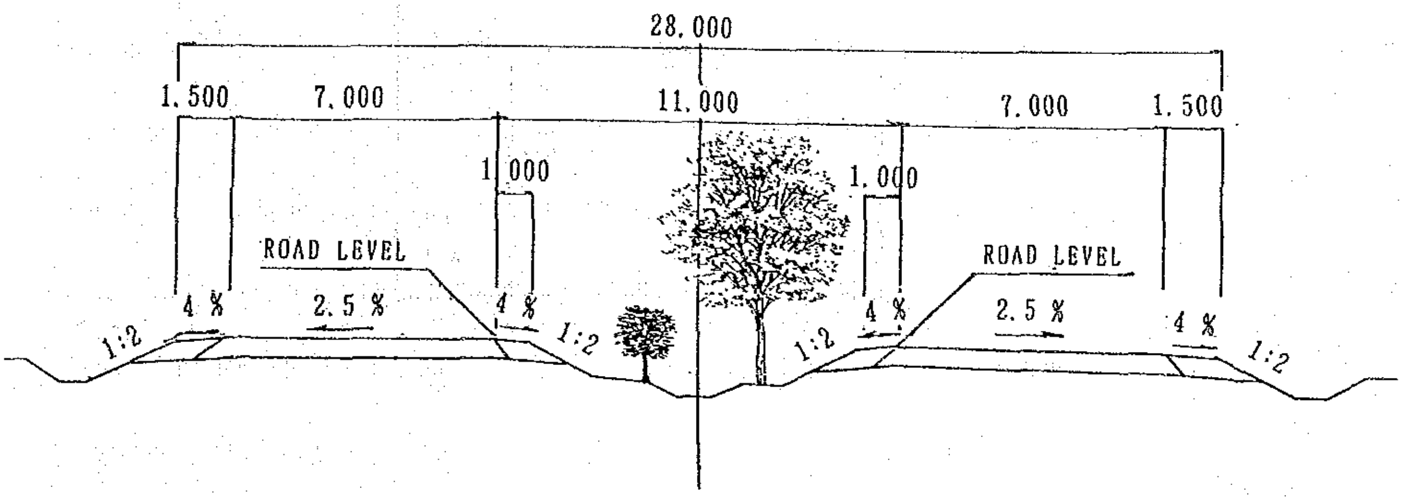


8.6 TYPICAL CROSS-SECTION

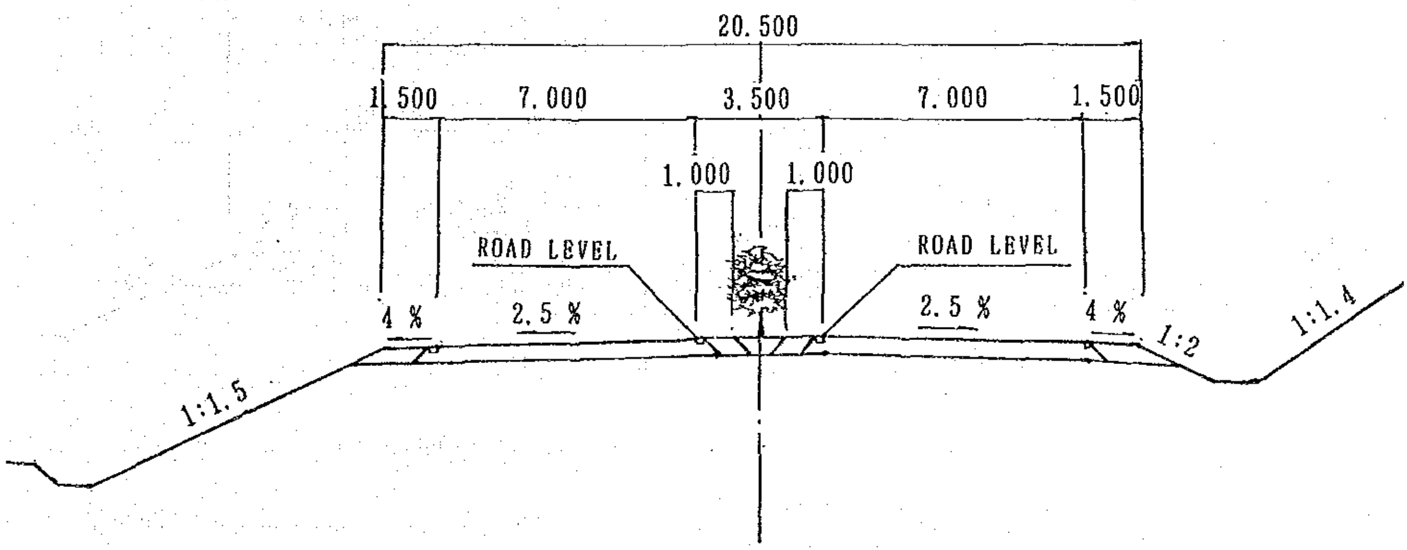
The Typical cross-section for the Nairobi Bypass was decided through consultations with the MOPW pursuant to the Geometric Design Manual Part I. The width of the central reserve is narrowed for the section between the Uhuru Monument Junction and the Kikuyu junction to reduce the cost of construction involving the excavation of rock and high embankment.

MAIN ROAD

Mombasa road junction ~ Uhuru monument junction

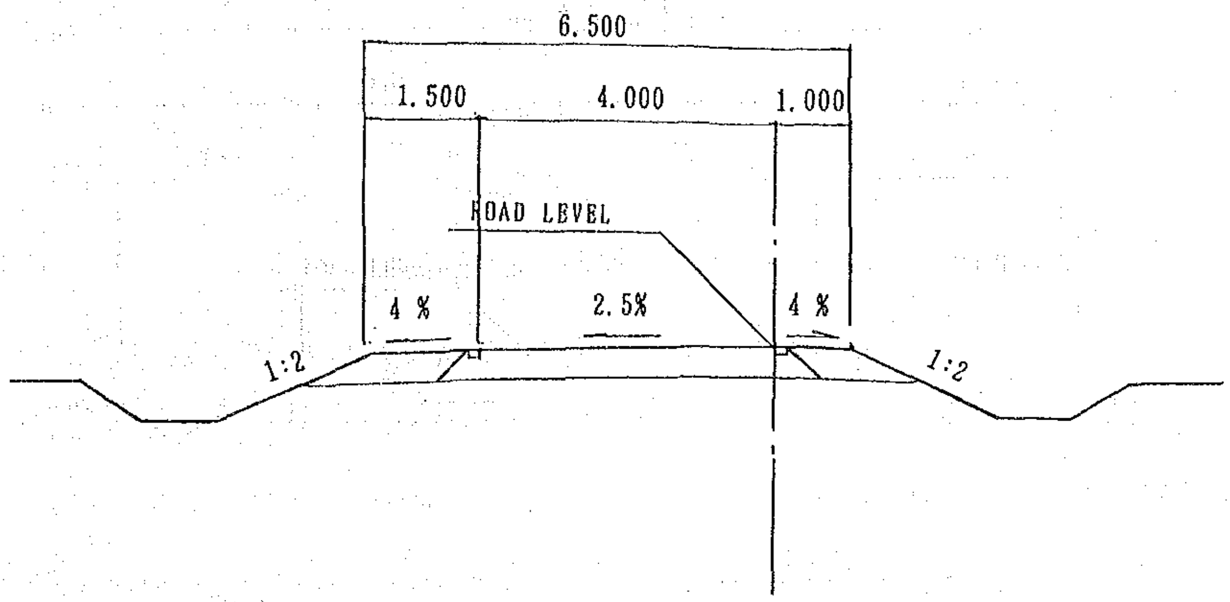


Uhuru monument junction ~ Kikuyu junction

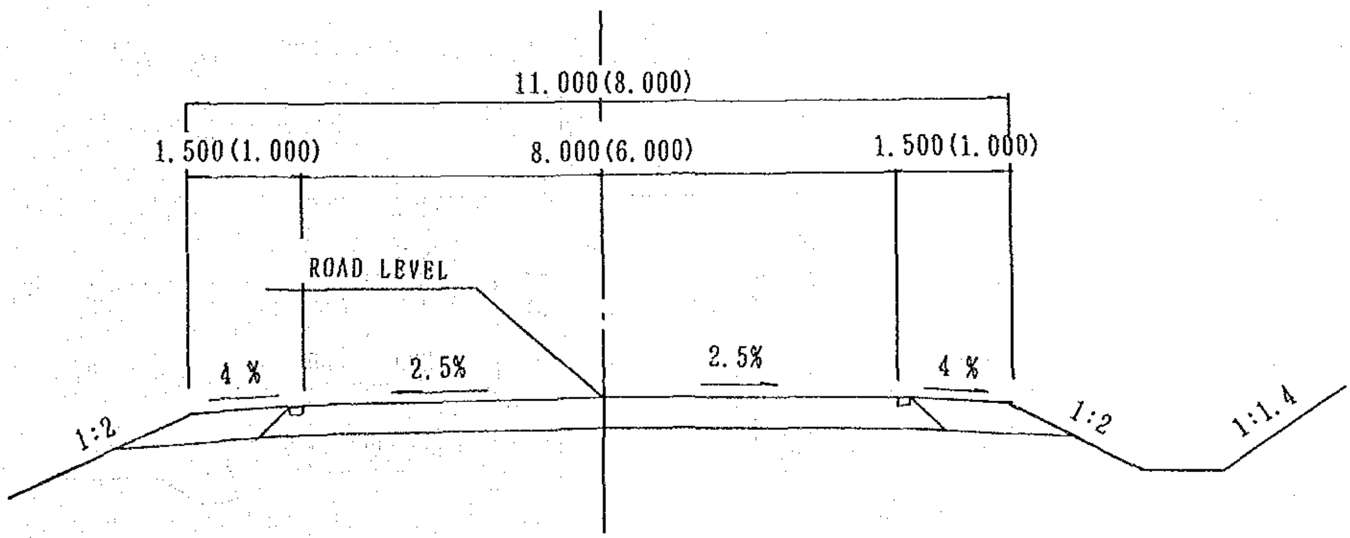


SLIP ROAD

One lane



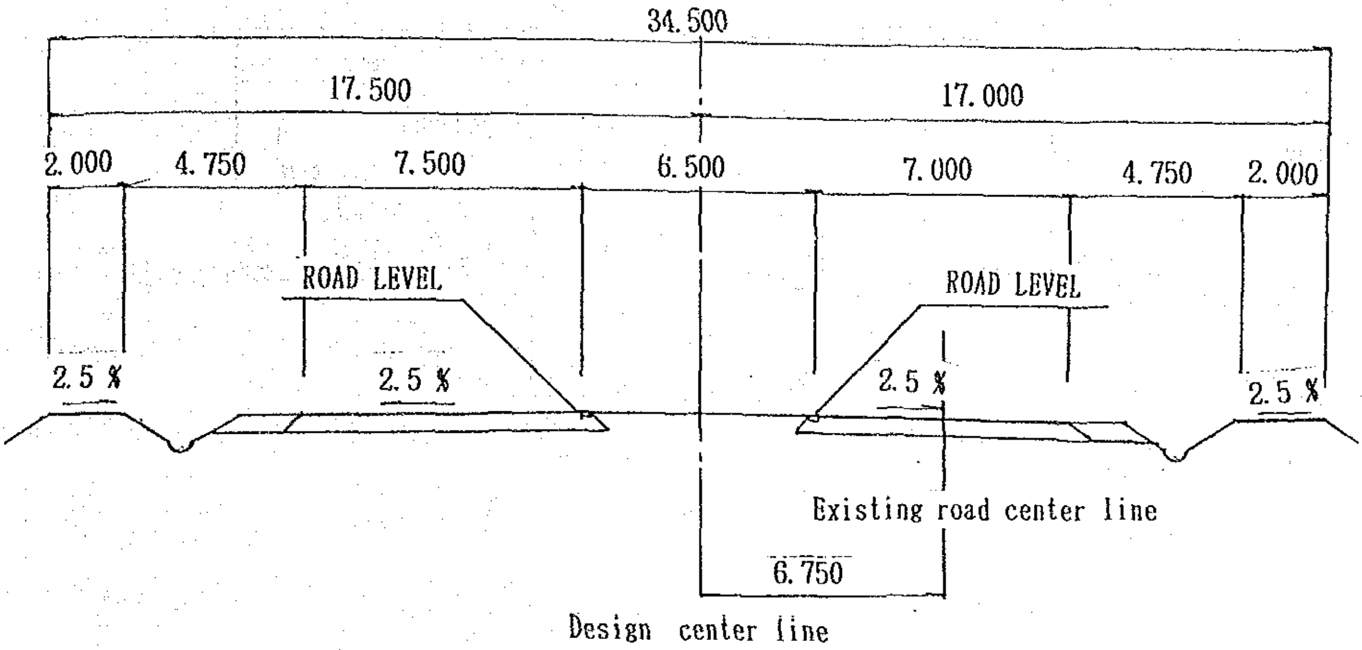
Two lane



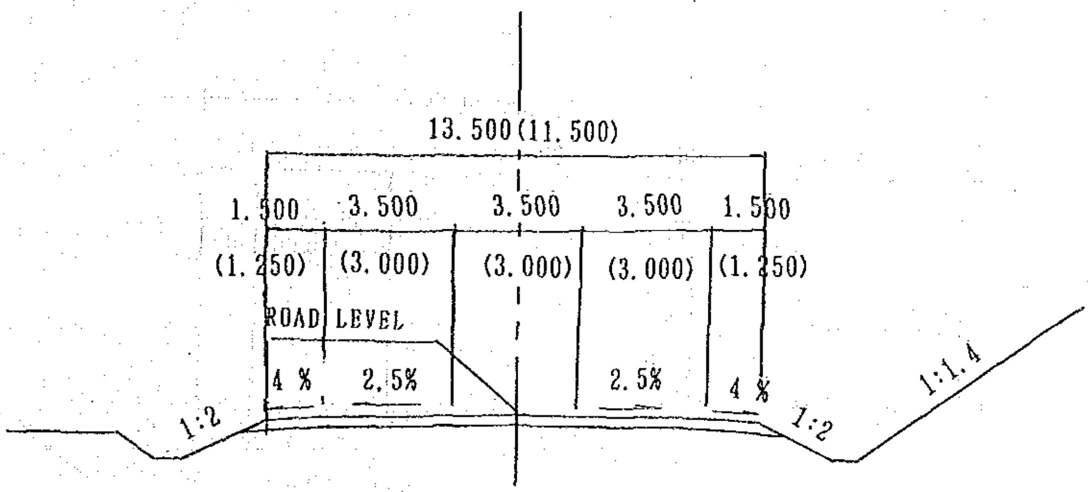
Note ( ) show at Thogoto junction

APPROACH ROAD

Uhuru monument J,C (Langata road)



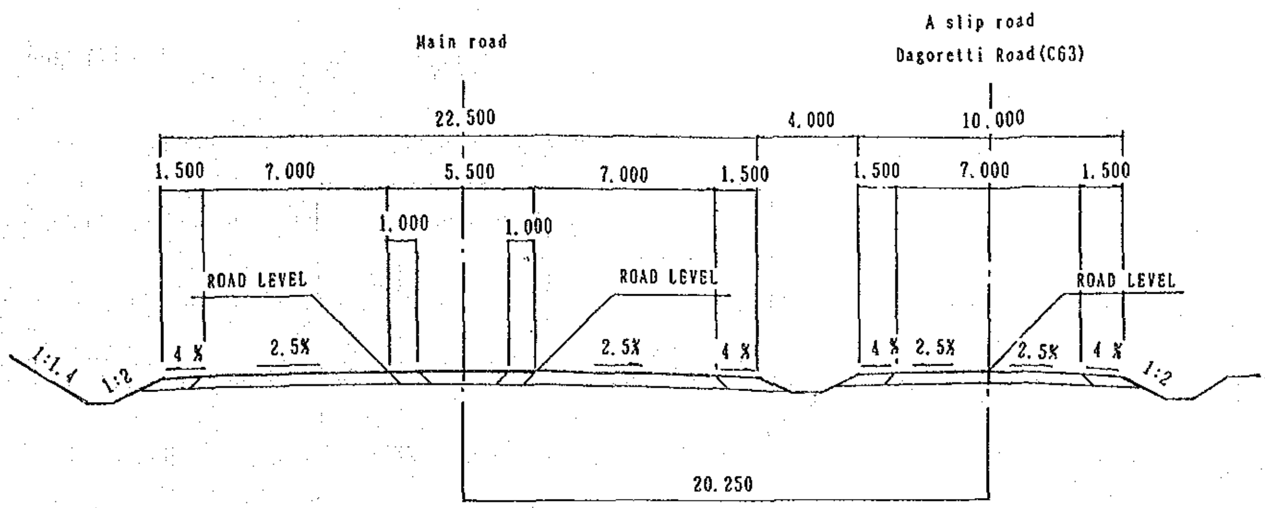
Ngong Road J,C Dagoretti Forest J,C Thogoto J,C



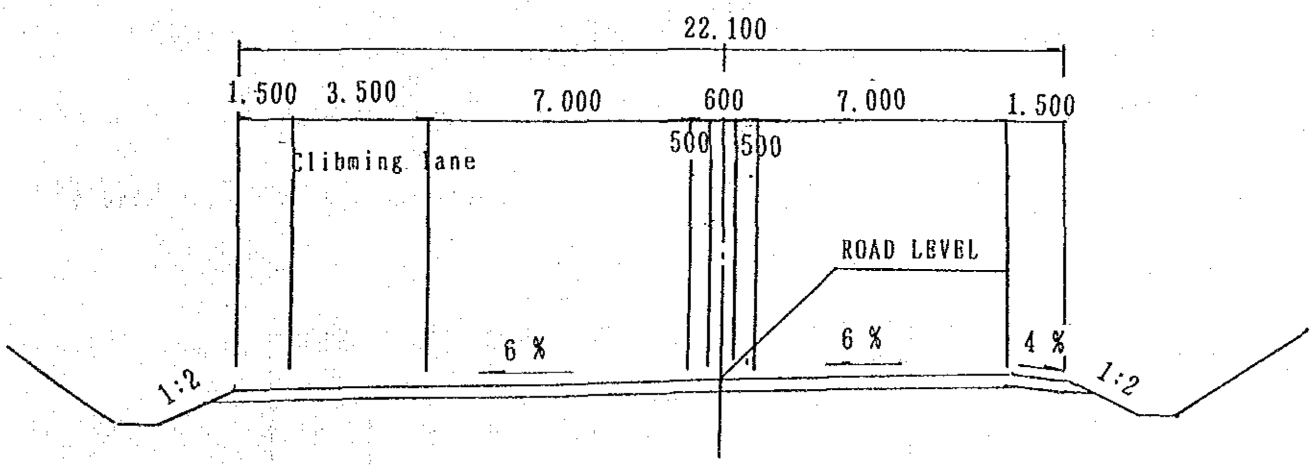
To be improved at section with right turn lane

Note ( ) show at Thogoto junction

Kikuyu Town J.C

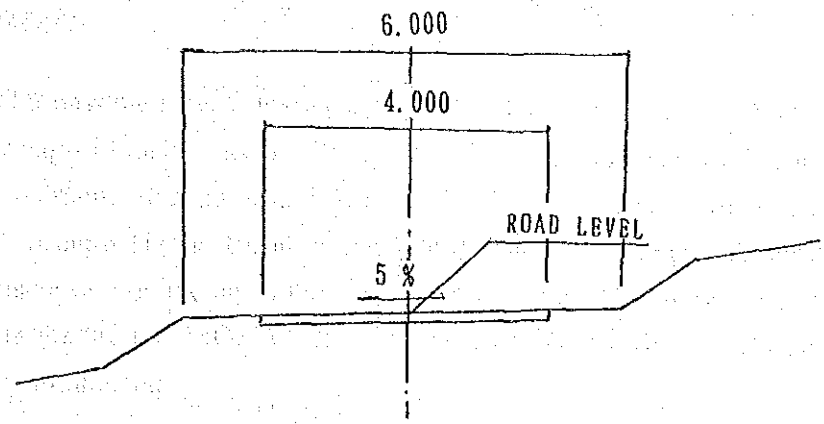


Kabete-Limuru road

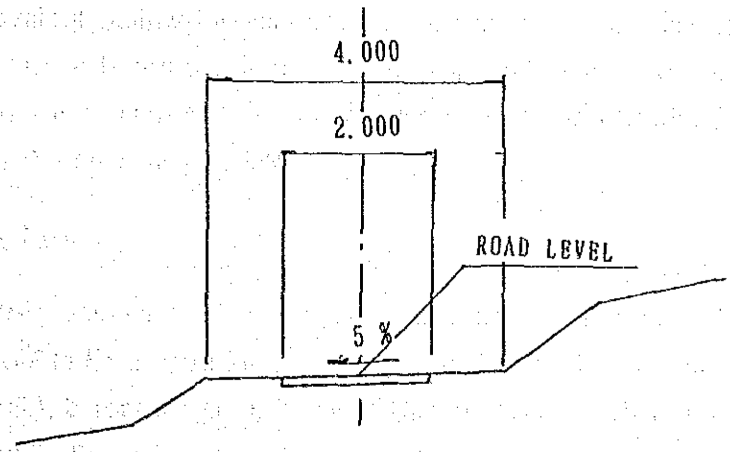


S E R V I C E   R O A D

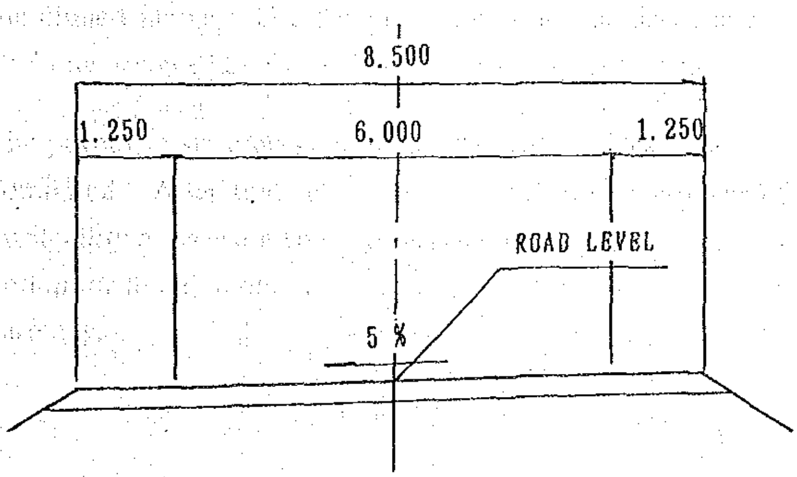
For vehicle



For pedestrian



Approach road at box culvert



8.7 PAVEMENT DESIGN

8.7.1. General

Pavement design was carried out in close consultation with the material branch of the MOPW referring to the "Road Design Manual Part III" issued by the MOPW.

The pavement was designed separately by four design methods, i.e. Road Design Manual Part III, Road Note No. 29, AASHTO Guide for Design of Pavement Structures and Manual for Design and Construction of Asphalt Pavement (Japan Road Association) which were later compared. After a discussion on the pavement design between the JICA study team and material branch of the MOPW, the pavement design by Road Note No. 29 was recommended.

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 MOPW in the end of 1989.

8.7.2 Main Road

In 1991, a concrete plan was set for the construction of the Oil Pipeline from Nairobi to Kisumu/Eldoret. use of the pipeline by KPC for oil will commence in 1993, before the completion of Nairobi Bypass. Therefore the pavement design of the main road of the bypass took this into consideration.

The pavement structure was designed separately by four design methods as mentioned above. The design results were compared and the pavement structure designed by Road Note No. 29 has been recommended.

The pavement structures, especially the types of base were also studied and compared. After that lean concrete base was recommended in view of availability of base materials, construction method, preventing cracks into the bottom of the base due to oxidization, construction cost and saving foreign currency.

Recommended pavement structure is as follows:

Surfacing (Asphalt concrete)	:	120 mm
Base (Lean concrete)	:	200 mm
Subbase (Graded crushed stone)	:	150 mm

8.7.3 Ramp (Slip road)

Pavement design of slip roads of each interchanges (at grade junction) was carried out with the same procedure as the main road.

The commutative number of ESA for each ramp was based on the future traffic forecast in the Feasibility Study Report.

Recommended pavement structure for each junction are as follows:

	Thickness of Layer (mm)		(Wearing course +)
Road	Subbase	Base	Surfacing (Base course)
Junction			
Mombasa	150	200	200 (40 + 80)
Uhuru Monument	150	180	100 (40 + 60)
Ngong Road	150	180	100 (40 + 60)
Dagoretti	150	180	100 (40 + 60)
Thogoto	150	180	100 (40 + 60)
Kikuyu Town	150	180	100 (40 + 60)
Kikuyu	150	200	200 (40 + 80)
Main Road	150	200	120 (40 + 80)

Pavement material

Subbase	:	Graded crushed stone
Base	:	Lean concrete (High qualitative cement-stabilized material)
Surfacing	:	Asphalt concrete

8.7.4 Approach Roads

The pavement structure of the approach roads to the junctions is the same as the existing pavement structure except underpass (C58) at UHURU MONUMENT JUNCTION.

Route C58 has been planned by the city council to improve it into dual carriage way, then the pavement structure was designed with the traffic forecast in the Feasibility Study Report for Nairobi Bypass Project. The pavement structure for approach roads and route C58 are as follows:

Pavement structure of existing "C" class road

Surface dressing	:	25 mm
Base (G.C.S)	:	130 mm
Subbase (G.C.S)	:	100 mm

Pavement structure of underpass (C58) of
UHURU MONUMENT JUNCTION

Surfacing (Asphalt concrete)	:	150 mm
Base (Lean concrete)	:	200 mm
Subbase (G.C.S)	:	150 mm

8.7.5 Service Road

The pavement of the service roads along the Bypass is basically same pavement as existing one. It, however, was designed in accordance with the Road Design Manual Part III as follows:

Pavement structure for the service road:

Wearing course : 150 mm

as: traffic T = 15-50 (both directions)

9 BRIDGES AND BOX CULVERTS DESIGN

9.1 GENERAL

Design work for two highway bridges, one railway bridge, two vehicle overbridge, two pedestrian bridges, seven box culverts for vehicles four box culverts for pedestrian and five box culverts for drainage was carried out in close consultation with the MOPW bridge section.

9.2 DESIGN STANDARD

The design standard for structure design is referred to BS5400 (BS153 for the Railway Bridge), technical data for the design of bridges in regard to earthquake, temperature, wind, rainfall, etc., and Road Design Manual Part IV in consultation with the Bridge section of the MOPW. The width and clearance of the road referred to Road Design Manual Part I (MOPW) and the results of discussion between the MOPW and JICA teams. Design criteria of the railway bridge is also based on BS5400 and BS153. For detailed design, BS5400 was adopted as a design standard after discussion between engineers from Kenya Railway and the Nairobi Bypass project design team with the relevant MOPW engineers.

9.3 TYPE, SIZE AND LOCATION OF STRUCTURE

(1) Bridges

Types of bridges, their location and their scale on Nairobi Bypass are as shown in Table 9.1.

Table 9.1

Type	No.	Location	Length (m)	Width (m)
For Road	1	Mombasa Road JC Bridge (Starting point of Bypass Road)	57.0	17.0
	2	Uhuru Monument JC Bridge (Crossing of C58 Road)	58.0	20.5
	3	Railway Bridge Over Bypass in CH27 + 20.0 m	56.85	11.4
Over Bridge	2	Over Bypass CH15 + 980.0 m	30.1	6.0
	4	Over Bypass CH15 + 920.0 m	28.1	10.0
Footpath	1	Over Bypass CH1 + 180.0 m	38.20	3.0
	2	Over Bypass CH1 + 220.0 m	48.40	3.0

(2) Box Culverts

Types, location and scale of Box Culverts are as follows:-

Table 9.2

Type	No.	Location	Length (m)	Width b x h (m)
For Road	1	Crossing of C60 Ngong Road CH15 + 540.0	32.3	10.0 x 5.5
	2	Crossing of CH19 + 500.0	37.5	8.0 x 5.5
	3	Crossing of Rump for Dagoretti JC CH20 + 930.0	32.0	10.0 x 5.5
	4	Crossing of D411 Thogoto Road CH23 + 193.0	26.7	8.5 x 5.5
	5	Crossing of Public Road (E) CH23 + 169.4	26.7	8.5 x 5.5
	6	Crossing of Public Road CH24 + 980.0	25.5	8.5 x 5.5
	7	Crossing of D422 Ondiri Road CH26 + 464.0	50.2	8.5 x 5.5
For Drainage	1	Ruora River in Ngong Forest CH13 + 978.0	59.0	3.0 x 3.0
	2	Motoine River in Ngong Forest CH14 + 934.0	34.2	3.0 x 2.0
	3	Motoine River in Ngong Forest CH15 + 560.0	67.0	3.5 x 3.0
	4	Motoine River in Ngong Forest CH0 + 157.0 (Ngong JC-Rump)	40.0	3.5 x 3.0
	5	Ondiri River CH26 + 355.0	132.0	3.5 x 3.5 (Double)
Footpath	1	CH18 + 400.0	28.0	3.3 x 3.0
	2	CH20 + 200.0	21.5	3.0 x 3.0
	3	CH22 + 880.0	21.5	3.0 x 3.0
	4	CH26 + 220.0	22.1	3.0 x 3.0

9.4 SELECTION OF STRUCTURE TYPE

1) Types of structures are studied and selected in consideration of low construction cost and especially the following items:

   a) Easy construction by Kenyan contractors

   b) Construction works by using local material and easily imported material in Kenya

   c) Easy maintenance works after construction

   d) No interference with natural environment

There exists in Kenya standards for design of bridges to span length up to 10.0 m long, but all bridges over 10.0 m in span and box culverts will be designed using BS5400 due to lack of Kenyan design standards. All structures are planned and designed after field investigations, study of existing structures and discussion with the MOPW engineers.

2) Selected types of structures and reasons of the selection are as follows:

   A) Bridges for road and railway

      i) Superstructure type

      Reinforced concrete T-Grider type is adopted for the superstructure of bridges in view of construction costs, which are shown in Appendix -F-1. The new Railway Bridge requires a long span to cross the Bypass, with four lanes, and relocated road C63. The existing railway bridge will be used as a temporary bridge during the construction period and it will be replaced by the new railway bridge.

      ii) Sub-structures

         a) Abutments

         The abutments for bridges are adopted Cantilever Type in view of construction cost which are shown in Appendix -F-2 .

10. ROAD FURNITURE

10.1 GENERAL

Road furniture of the Nairobi bypass was planned on the basis of Chapter 8, Manual for Traffic Signs in Kenya Part I and II, June 1975, of the Road Design Manual Part I, January 1979.

10.2 ROAD FURNITURE

(1) Traffic Islands and Kerbs

Flush kerbs are installed on the main road, ramps, and approach roads. Raised kerbs are installed on the traffic islands and bus stops on the main road and ramps to prevent vehicles from riding on them. Traffic islands on approach road are paved with hatched and chevron markings.

(2) Marker Posts

Marker posts shall be installed on the guardrails at dangerous points where the horizontal alignment of the ramp is sharply curved.

(3) Guardrails

Guardrails are planned on the bases of the guardrail installation chart shown on Fig. 8.5.1 of the Road Design Manual Part I.

A guardrail will be installed at those points were the value of the Guardrail Need Index (G.N.I.) on the chart is 60 or greater and at other points where the installation of a guardrail is considered necessary.

(4) Fences and Gates

Fences are installed along the portion of the bypass that passes through the pasture of the Alliance high school to prevent cattle from entering the road.

(5) Traffic Signs and Markings

Traffic signs and markings are planned on the basis on the Manual for Traffic Signs in Kenya Part I and II, June 1975 and upon consultation with the MOPW.

(6) Planting of trees and shrubs

Shrubs shall be planted on the central reserve of a width of 3.5 m, at intervals of 4 m where a guardrail is installed and at intervals of 5 m where no guardrail is installed, to reduce the light from cars in the opposite lane. Shrubs shall be planted at intervals of 4 m where a guardrail on the road side is installed to guide driver's eyes. Trees and shrubs shall be planted on the central reserve of a width of 11 m and at the Mombasa road junction to provide a good view. Refer to the drawings for the details of planting.

11. COST ESTIMATES

The cost estimates have been made by JICA study team.

Description of the project cost was excluded from this "Main Report", and is reported in one (1) volume as follows :

"Cost Estimate Report"

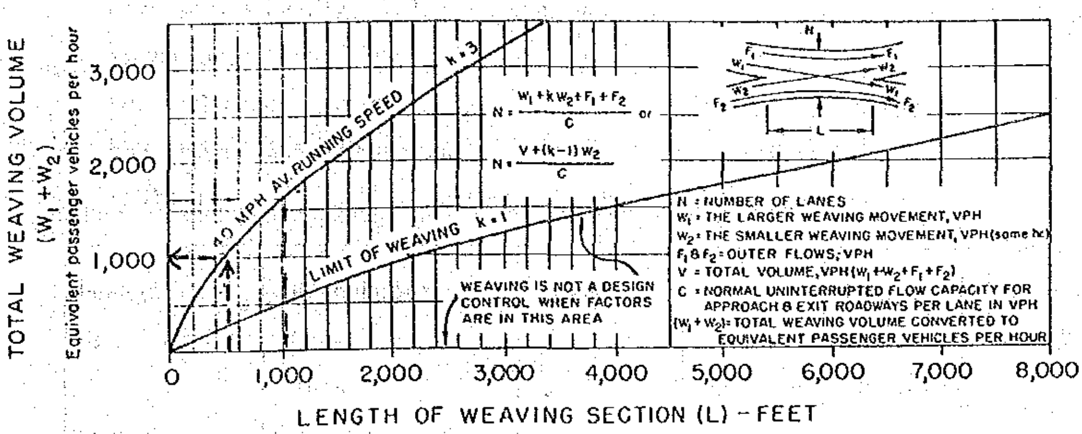
The report describes the total project cost, basic data for cost estimates, estimated cost by Group of Specifications, foreign currency component of the cost, annual disbursement, unit price breakdown, and prepared under "Confidential" cover.

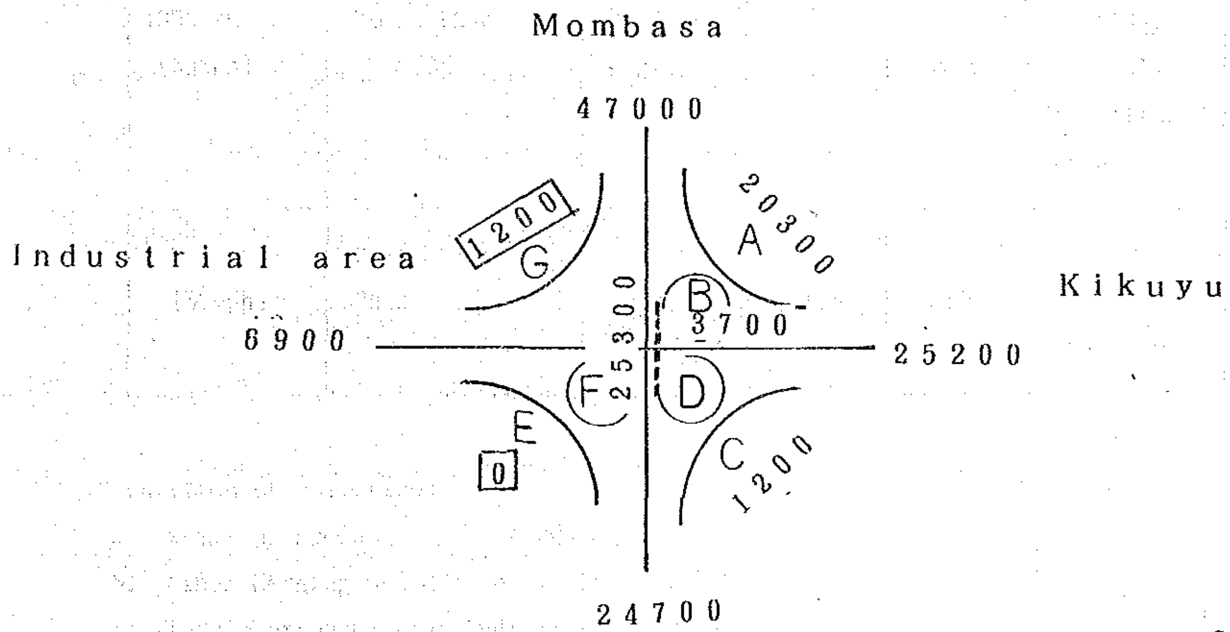
The period Bill of Quantities is also prepared in the same volume.

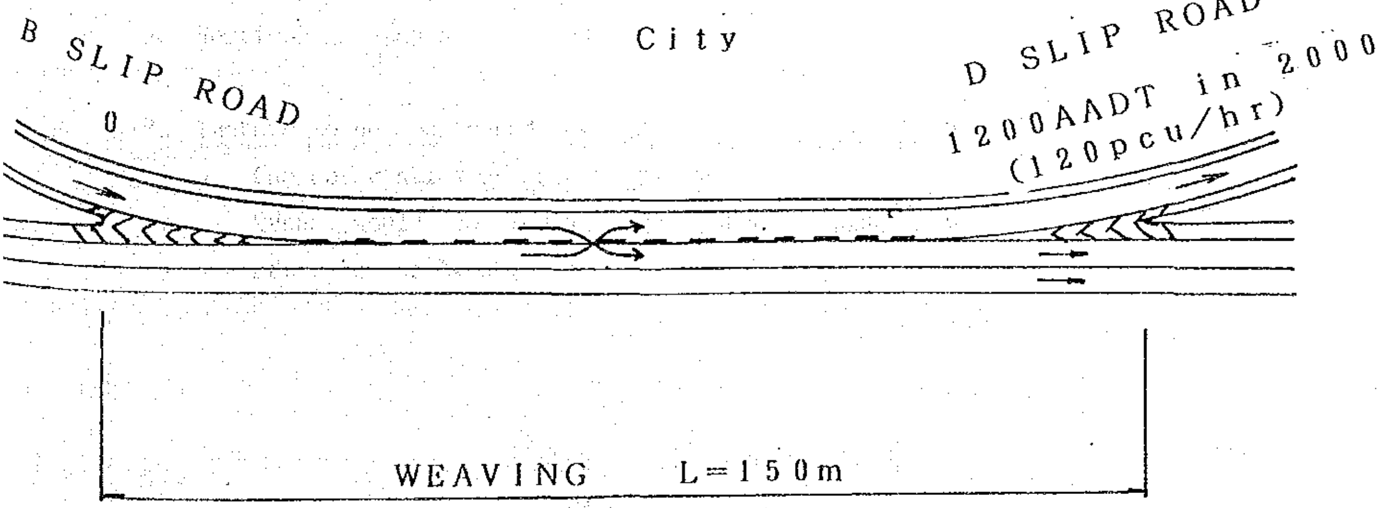
APPENDIX - A(Speed-change Lane, etc)

Weaving Length of B and D slip road at Mombasa Junction.

According to the following figure (AASHO), weaving lane with 150m long has a capacity of 1000pcu weaving volume per hour.







Acceleration Lane Length

1. Comparison of Acceleration length in other Manuals.
   Road Design Manual Part I indicate that Fig. 5.5.2 shall be used to determine the required acceleration distances but Acceleration length determined by Fig. 5.2.2. seems not to be reasonable because the length is so long.
   For reference, we compared it with other Manuals and a theoretical formula, and the reults are as shown in Table I herebelow.

   Table 1. Length of Acceleration Lane

Design Speed km/hr	Road Design Manual Part I	AASHO (Rural)	B. S. (Rural)	Japan Design Manual	Theoretical Formula
100km/hr (60mph)	more than 950m	1075ft 326m	270m	240m	191m ~ 261m See Attached Formula
80km/hr (50mph)	Heavy Vehicle 340m	625ft 192m	210m	210m	109m ~ 143m

Condition of comparison.

a. Original speed V = 30km/hr

b. Final Merging Speed = Design Speed x 80%

c. Acceleration Length: including Taper

d. Vertical gradients : i < 2%

2. Factors to be considered for designing acceleration lane
   a. Characteristics of Nairobi Bypass
      Bypass would be used very much as urban type road after ten or twenty years.

b. Type of Interchanges

Bypass hand has seven interchanges, and except Mombasa junction, the others are urban type interchanges which are designed with small entrance radius of 30m. It is considered that heavy vehicles will scarcely use these junctions, since most of them will be through traffic.

c. Manouver of Drivers and other conditions.

In Kenya, majority of cars are small cars .Generally Drivers in Kenya do not use acceleration lane effectively.

d. Recommendation

The length of acceleration lane should be composed of a length which come from theoretical formula and a length for merging.

Design Speed	100km/hr	80km/hr
Length by theoretical formula	226m	126
Length for merging:	0m	67m
Total (including taper)	226m≒230m	193≒200m
(Taper length)	50m	40m

Note: Time for merging = 3 ∼ 5 seconds

$$\frac{60}{3.6} \times (3 \sim 5) = 50m \sim 83m \text{ Average } 67m$$

Taper length should be designed according to section 6.5.3 (i) Table 6.5.1 of Manual Part I.

* Length by theoretical formula, see table (2)

Acceleration Lanes (by Theoretical Formula)

The length of an acceleration lane is based on following factors in combination

(1) Vehicular running speed at merging through traffic.

(2) Vehicular running speed at nose of the acceleration lanes.

(3) Driver's manner of accelerating.

Distance of Acceleration is expressed as follows:

$$L = \frac{1}{2 \times 3.6^2 \times \alpha} \times (V^2 - V_o^2)$$

L = Distance of Acceleration (m)

α = Accerelation ($1 \sim 1.5$ m/Sec^2)

V = Final merging Speed (km/hr)

Vo = Original Speed at nose (km/hr)

V = 0.8 x VD VD : Design Speed
as VD = 100km/hr . V = 80 km/hr
as VD = 80km/hr . V = 60km/hr

Case 1. as Vo = 20km/hr and V = 60km/hr

$$L = \frac{1}{2 \times 3.6^2 \times (1 \sim 1.5)} \times (60^2 - 20^2)$$

$$= (0.0385 \sim 0.0257) \times 3200 = 123m \sim 82m$$

Case 2. as Vo = 30km/hr and V = 60km/hr

=(0.0385 ~0.0257)x 2700 = 103 m ~ 69 m

Therefore the necessary Length of Acceleration Lane in the Case 1, and Case 2, ranges from 69m to 123m and in the case of VD = 100km/hr.

Lengths of acceleration lane are as follows.

Vo = 20km/hr L = 231m ~154m

Vo = 30km/hr L = 211m ~141m

Table 2. Summary of Acceleration lane length

Design Speed of Road	Final Speed at the end of Acceleration lane	Original Speed at Nose	Length by calculation	Taper	Length of Acceleration
80km/hr	60km/hr	20km/hr 30km/hr	82~ 123 69~ 103	40m	122m~163m 109m~143m Average 126m
100km/hr	80km/hr	20km/hr 30km/hr	154 ~ 231 141 ~ 211	50m	204m~281m 191m~261m Average 226m

NOTE: Factor (3) is neglected in these cases.

Study of Climbing Lane

The need for a climbing lane will be considered in areas with steep gradient of 5% or more.

1. Section: From Dagoretti Junction to Thogoto Junction

2. Climbing lane is designed in total considering the following factors:-

   (i) Length of speed reduced section is more than 200m
   (ii) Construction Cost
   (iii) Capacity of Traffic Volume

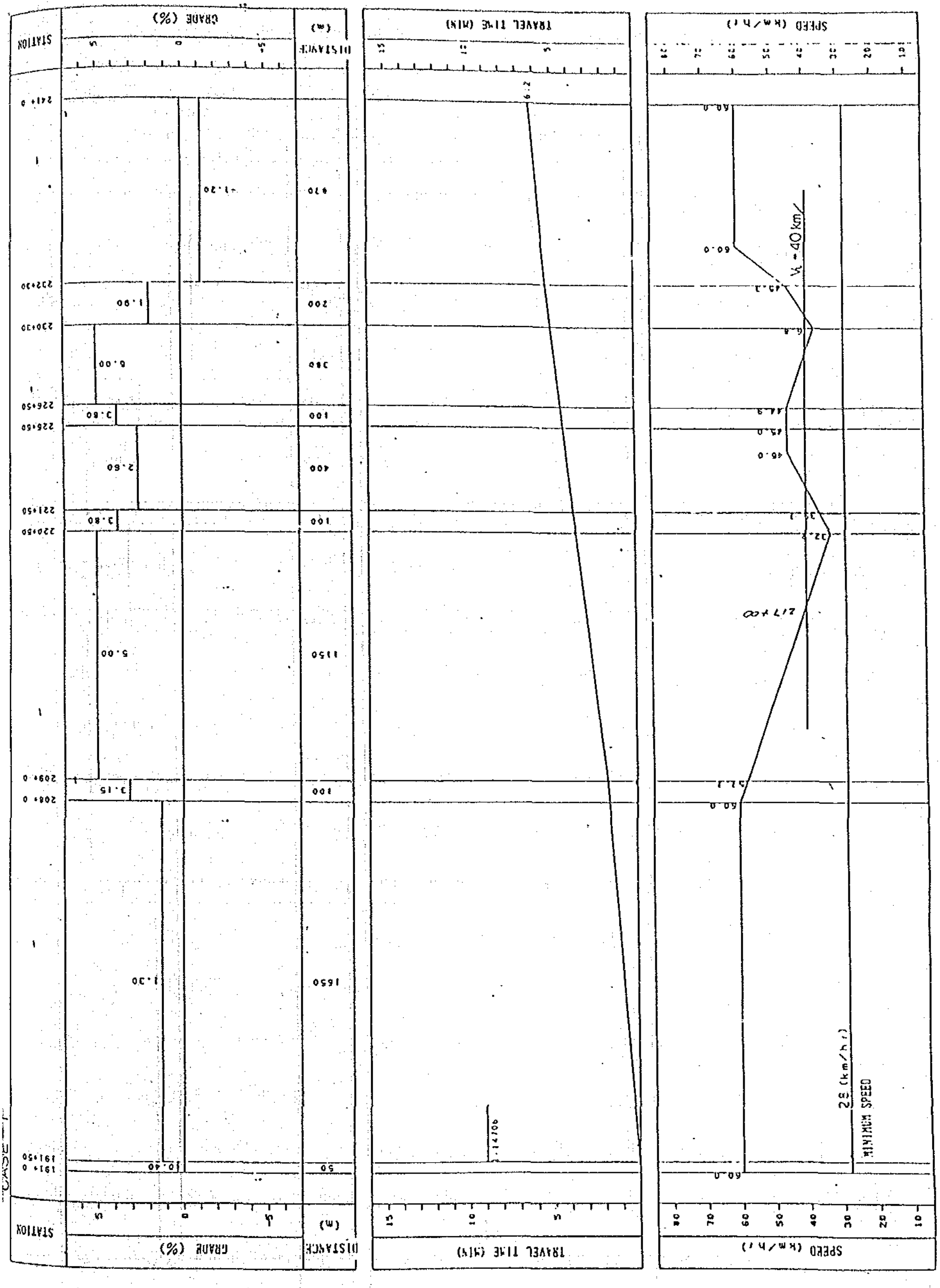
3. Speed Gradient - Diagram

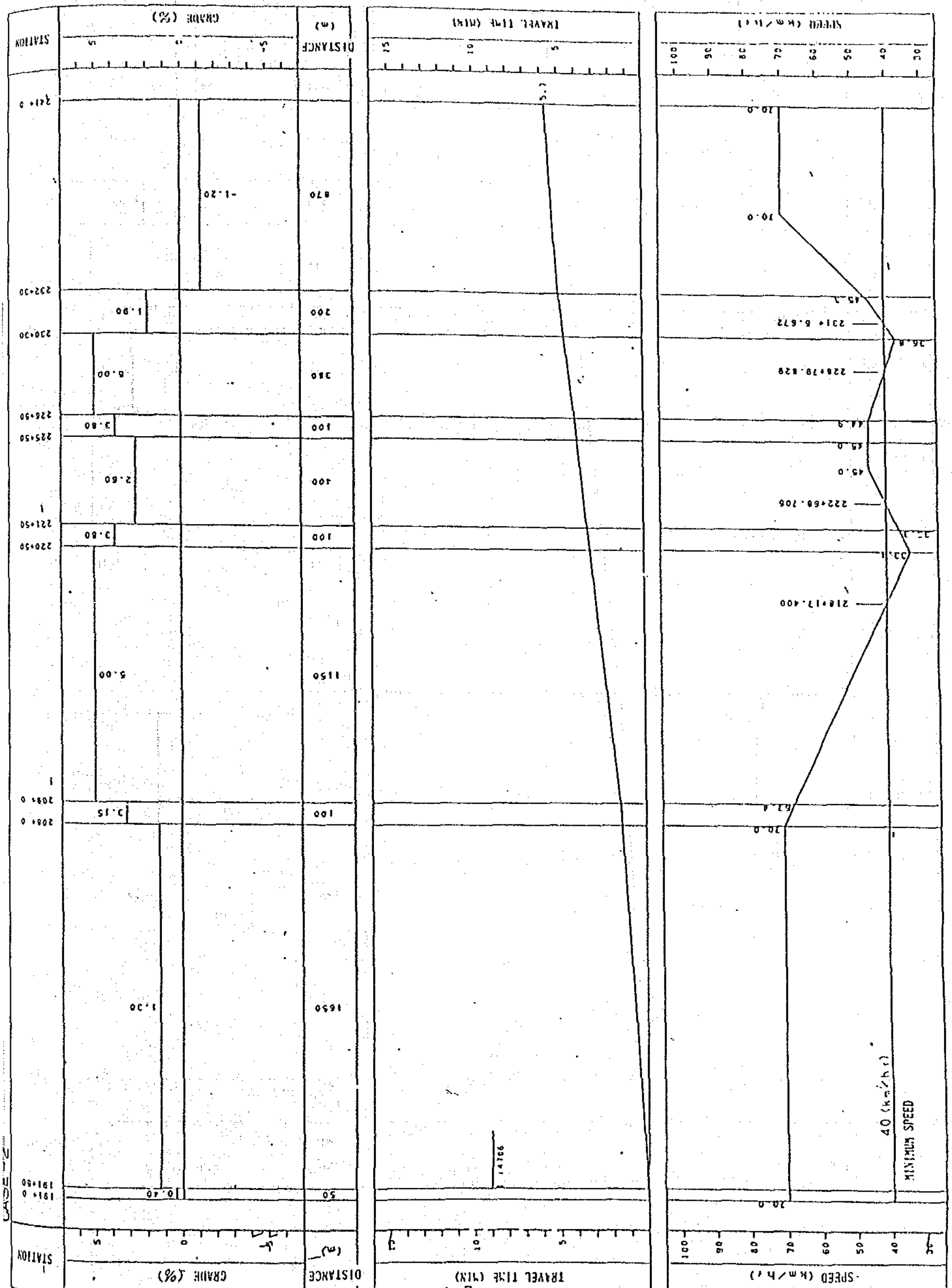
Speed Gradient-Diagram shows as follows

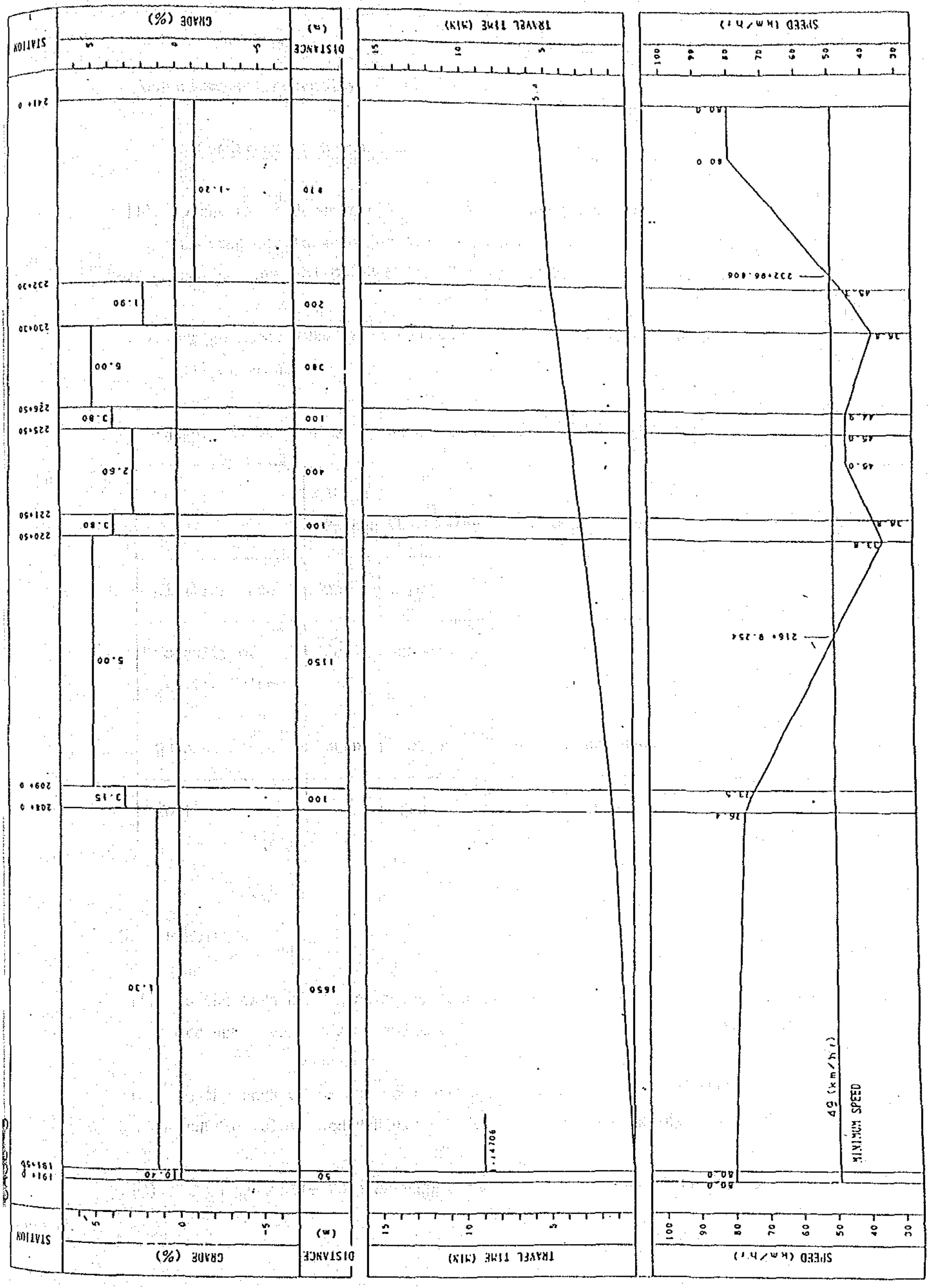
Case 1.	Stage I	VD = 60km/hr	VL = 28km/hr	L = 0
Case 2.	Stage II	VD = 70km/hr	VL = 41km/hr	L = 250m
				L 450m on two section
Case 3.	Stage III	VD = 80km/hr	49km/hr	L = 1700m

NOTE: Case 1 2 lane road
Case 2 Cases 3,4 lane road (Dual carriage way)
VL = VD x 8-15km/hr
VD = Design Speed
VL = Lowest Down Speed to be sustained.

Speed Gradient - Diagram was studied in design speed of 60km/hr for stage I and 70km/hr and 80km/hr for stage II. The diagrams show as follows:-


STATION
GRADE (%)
DISTANCE (m)
TRAVEL TIME (MIN)
SPEED (km/h)
241+0
232+30
230+30
226+50
225+60
221+50
220+50
209+0
208+0
191+50
191+0
410
200
380
100
400
100
1150
100
1650
50
-1.20
1.00
6.00
3.60
2.60
3.80
5.00
3.15
1.30
6.2
60.0
45.3
44.9
45.0
46.0
32.2
V = 40 km/
217+00
29 (km/h)
MINIMUM SPEED


STATION
GRADE (%)
DISTANCE (m)
TRAVEL TIME (MIN)
SPEED (km/h)
MINIMUM SPEED
40 (km/hr)


STATION
GRADE (%)
DISTANCE (m)
TRAVEL TIME (MIN)
SPEED (km/hr)
MINIMUM SPEED
40 (km/hr)

4.Comparison for necessity of climbing lane.

Condition of Comparison

(1). Earthwork is done in 4-lane width because Dagoretti junction and Thogoto junction are constructed in 4 lane width and the interval of each junction is short.

(2). Design speed 70km/hr is reasonable due to mountanious or rolling area.

Table: Summary of Study on necessity of climbing lane

	Stage I 2-lane VD=60km/hr		Stage II 4-lane VD=70km/hr	
Climbing lane	no	yes	no	yes
Capacity of Traffic Volume	down	enough	—	up
Running Speed	down	not down	down	not down
Cost	—	few	—	much

5. Results

(1) In the case of 2-lane road, traffic capacity and vehicle running speed are very much reduced and traffic accident of collision is forecasted.

(2) In the case of 4-lane road without climbing lane the capacity of traffic volume and vehicle running speed are not so much reduced.

(3) It is desirable to construct climbing lane in stage I (2-lane road).

6. Section of climbing lane

(i) Conditions for setting of climbing lane

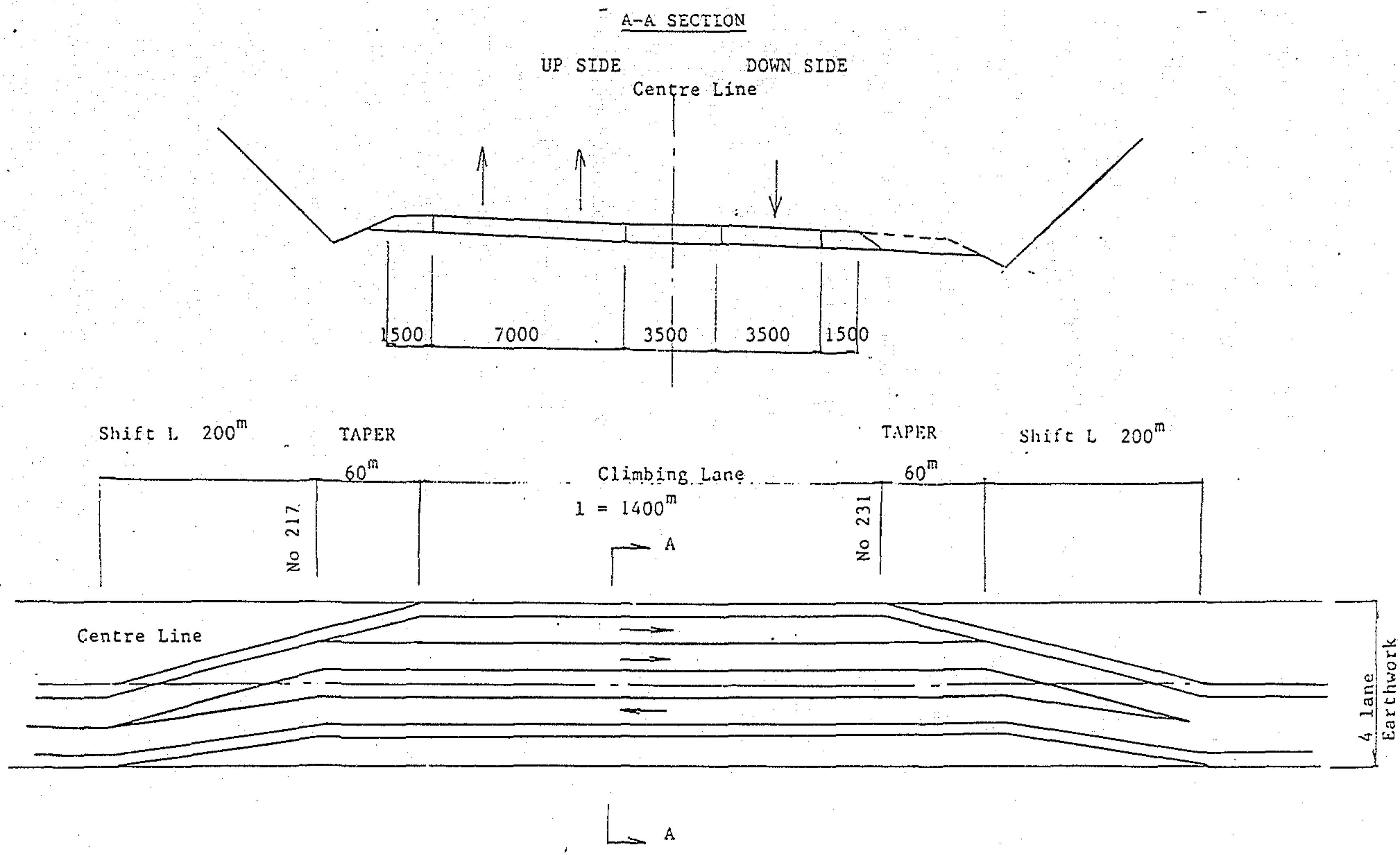
. Target of critical speed is 40km/hr

(ii) Section of climbing lane

According to the Speed-Gradient diagram of case I and case II climbing lane should be set between Km 21 + 700 and Km 23 + 100 (L = 1400m).

7. Plan of climbing lane

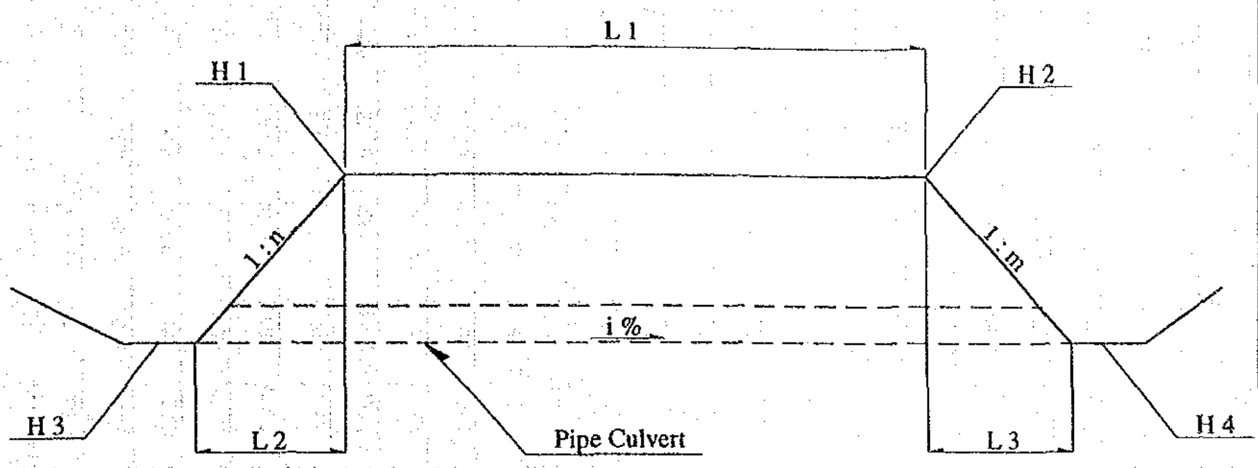
see page 7-13



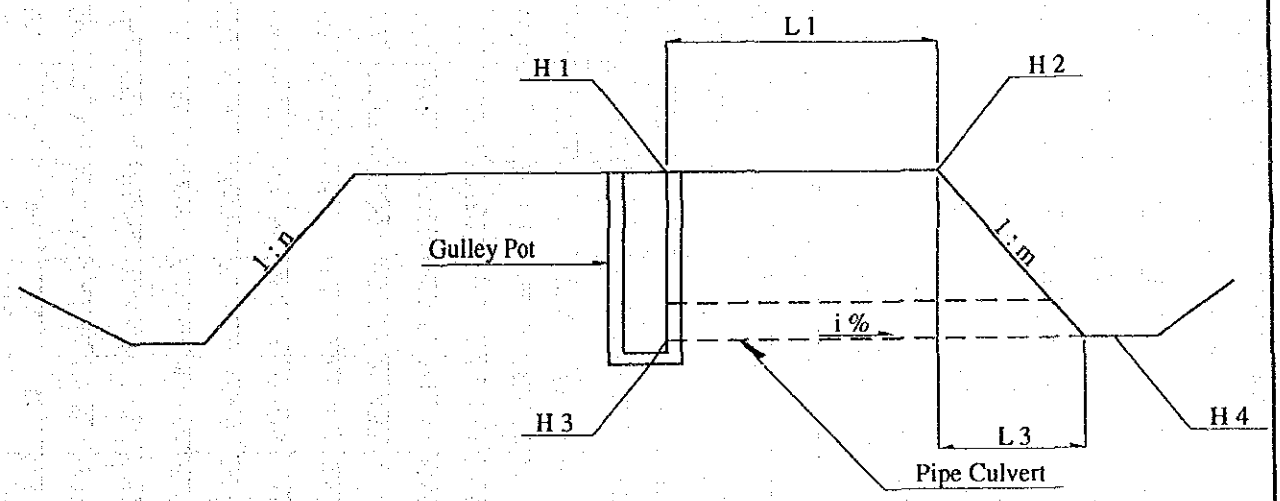
PLAN OF CLIMBING LANE AT STAGE I

APPENDIX - B (Pipe culvert)

Calculation of Pipe Culvert Elevation and Length



Type-I



Type-I

Figure B.1 Location of Pipe Culvert

Table B.1 Caluculation Sheet of Pipe Culvert Elevation and Length

Chainage	Diameter (mm)	H1 (m)	H2 (m)	H3 (m)	H4 (m)	H5 (m)	H6 (m)	H1-H5 (m)	H2-H6 (m)	L (m)	n	m	L1 (m)	L2 (m)	L3 (m)	i (%)	Remarks
Nairobi Bypass CH.0+300	600	1,654.053	1,654.103	1,652.650	1,652.700	1,652.657	1,652.700	1.396	1.403	15.605	1.500	0.000	13.500	2.105	0.000	-0.320%	M.D.- Left
CH.0+760	2x900	1,651.090	1,650.530	1,648.900	1,648.170	1,648.792	1,648.286	2.298	2.244	29.600	2.000	2.000	20.500	4.380	4.720	2.466%	
CH.0+820	600	1,650.474	1,650.184	1,649.074	1,648.400	1,649.074	1,648.578	1.400	1.606	13.518	0.000	2.000	9.950	0.000	3.568	4.986%	M.D.- Right
CH.1+000	900	1,651.177	1,650.963	1,649.777	1,649.463	1,649.736	1,649.522	1.441	1.441	16.040	1.500	2.000	10.940	2.100	3.000	1.958%	M.D.- Right
CH.5+280	2x900	1,683.914	1,683.588	1,681.036	1,681.400	1,681.140	1,681.321	2.774	2.267	20.082	2.000	2.000	9.950	5.756	4.376	-1.813%	M.D.- Left
CH.5+300	2x900	1,683.728	1,683.343	1,681.500	1,681.543	1,681.508	1,681.534	2.220	1.809	17.942	1.500	2.000	11.000	3.342	3.600	-0.240%	Right - M.D.
CH.6+200	600	1,705.865	1,706.028	1,702.776	1,704.100	1,703.267	1,704.100	2.598	1.928	16.667	2.000	0.000	10.489	6.178	0.000	-7.944%	M.D.- Left
CH.7+020	2x900	1,715.534	1,715.182	1,710.400	1,707.200	1,709.904	1,707.970	5.630	7.212	49.728	1.500	1.500	30.054	7.701	11.973	6.435%	
CH.7+028.438	600	1,715.282	1,715.312	1,710.900	1,713.400	1,711.701	1,713.400	3.581	1.912	20.523	1.500	0.000	13.950	6.573	0.000	-12.181%	M.D.- Left
CH.7+450	600	1,715.995	1,716.180	1,714.050	1,714.400	1,714.148	1,714.400	1.847	1.780	13.840	2.000	0.000	9.950	3.890	0.000	-2.529%	M.D.- Left
CH.7+700	900	1,724.343	1,724.980	1,722.100	1,722.300	1,722.130	1,722.265	2.213	2.715	30.346	2.000	2.000	20.500	4.486	5.360	-0.659%	
CH.8+000	600	1,729.168	1,729.494	1,727.700	1,728.000	1,727.768	1,728.000	1.400	1.494	12.886	2.000	0.000	9.950	2.936	0.000	-2.328%	M.D.- Left
CH.8+180	600	1,730.038	1,730.323	1,727.920	1,727.100	1,727.920	1,727.423	2.118	2.900	16.396	0.000	2.000	9.950	0.000	6.446	5.000%	M.D.- Right
CH.8+250	1200	1,730.078	1,730.508	1,728.000	1,724.400	1,727.600	1,725.577	2.478	4.931	37.372	2.000	2.000	21.000	4.156	12.216	9.633%	
CH.8+400	600	1,731.875	1,731.710	1,730.284	1,730.310	1,730.290	1,730.310	1.585	1.400	13.132	2.000	0.000	9.950	3.182	0.000	-0.200%	M.D.- Left
CH.8+880	600	1,740.376	1,740.177	1,738.751	1,738.777	1,738.758	1,738.777	1.619	1.400	13.200	2.000	0.000	9.950	3.250	0.000	-0.200%	M.D.- Left
CH.8+940	900	1,742.520	1,742.522	1,736.000	1,728.500	1,734.536	1,731.649	7.984	10.873	66.796	2.000	2.000	25.712	13.040	28.044	11.228%	
CH.9+340	600	1,754.722	1,755.048	1,753.314	1,753.340	1,753.320	1,753.340	1.402	1.708	12.766	2.000	0.000	9.950	2.816	0.000	-0.200%	M.D.- Left
CH.9+783.604	900	1,774.598	1,775.215	1,772.700	1,770.900	1,772.496	1,771.365	2.102	3.850	33.426	2.000	2.000	21.000	3.796	8.630	5.385%	
CH.9+800	600	1,775.853	1,776.014	1,773.709	1,772.900	1,773.709	1,773.211	2.144	2.803	16.178	0.000	2.000	9.950	0.000	6.228	5.000%	M.D.- Right
CH.11+100	600	1,789.347	1,789.394	1,787.950	1,787.898	1,787.950	1,787.910	1.397	1.484	12.942	0.000	2.000	9.950	0.000	2.992	0.400%	M.D.- Right
CH.11+240	1200	1,790.975	1,790.403	1,787.903	1,787.250	1,787.781	1,787.375	3.193	3.028	32.949	2.000	2.000	20.500	6.143	6.306	1.982%	
CH.12+400	2x900	1,807.186	1,807.186	1,805.380	1,805.296	1,805.369	1,805.308	1.817	1.878	27.891	2.000	2.000	20.500	3.612	3.779	0.300%	
CH.12+555.218	600	1,808.448	1,808.458	1,807.000	1,807.039	1,807.009	1,807.039	1.439	1.419	12.846	2.000	0.000	9.950	2.896	0.000	-0.300%	M.D.- Left
CH.12+900	600	1,811.171	1,810.866	1,808.567	1,808.600	1,808.578	1,808.600	2.593	2.266	15.158	2.000	0.000	9.950	5.208	0.000	-0.218%	M.D.- Left

Table B.1 Caluculation Sheet of Pipe Culvert Elevation and Length

Chainage	Diameter (mm)	H1 (m)	H2 (m)	H3 (m)	H4 (m)	H5 (m)	H6 (m)	H1-H5 (m)	H2-H6 (m)	L (m)	n	m	L1 (m)	L2 (m)	L3 (m)	i (%)	Remarks
CH.13+400	1200	1,814.816	1,814.816	1,811.524	1,810.296	1,811.300	1,810.603	3.516	4.213	36.124	2.000	2.000	20.500	6.584	9.040	3.400%	
CH.13+484.164	600	1,814.960	1,814.775	1,813.400	1,813.362	1,813.400	1,813.370	1.560	1.405	12.777	0.000	2.000	9.950	0.000	2.827	0.300%	M.D.- Right
CH.13+760	600	1,816.937	1,816.737	1,815.250	1,815.320	1,815.268	1,815.320	1.669	1.417	13.324	2.000	0.000	9.950	3.374	0.000	-0.525%	M.D.- Left
CH.14+595.083	600	1,820.588	1,820.403	1,819.030	1,818.998	1,819.030	1,819.005	1.558	1.398	12.760	0.000	2.000	9.950	0.000	2.810	0.250%	M.D.- Right
CH.14+865.086	600	1,822.862	1,821.498	1,820.424	1,819.800	1,820.424	1,819.959	2.438	1.539	13.346	0.000	2.000	9.950	0.000	3.396	4.676%	M.D.- Right
CH.15+160	600	1,822.862	1,823.182	1,821.370	1,821.780	1,821.465	1,821.780	1.397	1.402	12.934	2.000	0.000	9.950	2.984	0.000	-3.170%	M.D.- Left
CH.15+400	600	1,824.000	1,824.291	1,822.500	1,822.890	1,822.590	1,822.890	1.410	1.401	12.950	2.000	0.000	9.950	3.000	0.000	-3.012%	M.D.- Left
CH.15+440	600	1,825.325	1,825.558	1,823.925	1,823.890	1,823.925	1,823.897	1.400	1.660	17.284	0.000	2.000	13.950	0.000	3.334	0.200%	M.D.- Right
CH.15+700	600	1,826.824	1,826.992	1,825.424	1,825.397	1,825.424	1,825.404	1.400	1.588	13.256	0.000	2.000	10.067	0.000	3.189	0.200%	M.D.- Right
CH.16+100	600	1,833.030	1,833.215	1,831.600	1,831.750	1,831.633	1,831.750	1.397	1.465	12.810	2.000	0.000	9.950	2.860	0.000	-1.171%	M.D.- Left
CH.16+400	600	1,838.051	1,838.236	1,836.620	1,836.770	1,836.654	1,836.770	1.397	1.466	12.812	2.000	0.000	9.950	2.862	0.000	-1.171%	M.D.- Left
CH.17+360	900	1,856.343	1,856.343	1,850.400	1,854.250	1,851.284	1,853.835	5.059	2.508	38.813	1.500	2.000	25.712	8.914	4.186	-9.919%	
CH.17+717.493	600	1,865.563	1,865.573	1,864.147	1,864.173	1,864.153	1,864.173	1.410	1.400	12.781	2.000	0.000	9.950	2.831	0.000	-0.200%	M.D.- Left
CH.18+160	900	1,873.967	1,873.416	1,866.100	1,871.620	1,867.637	1,871.152	6.330	2.264	42.393	1.500	2.000	27.000	11.801	3.592	-13.021%	
CH.18+360	900	1,874.247	1,874.597	1,864.000	1,869.500	1,865.673	1,868.668	8.574	5.929	50.516	1.500	1.500	27.500	15.371	7.645	-10.888%	
CH.18+580	600	1,873.810	1,873.975	1,872.410	1,872.380	1,872.410	1,872.387	1.400	1.588	13.140	0.000	2.000	9.950	0.000	3.190	0.228%	M.D.- Right
CH.18+820	600	1,872.912	1,873.090	1,871.500	1,871.550	1,871.511	1,871.550	1.401	1.540	12.774	2.000	0.000	9.950	2.824	0.000	-0.391%	M.D.- Left
CH.19+020	600	1,872.512	1,872.677	1,871.112	1,870.550	1,871.112	1,870.718	1.400	1.959	14.204	0.000	2.000	9.950	0.000	4.254	3.957%	M.D.- Right
CH.19+100	900	1,872.615	1,872.965	1,864.600	1,867.500	1,865.456	1,866.916	7.159	6.049	40.720	1.500	1.500	20.500	12.023	8.197	-7.122%	
CH.19+520	900	1,879.469	1,879.565	1,867.600	1,871.900	1,869.107	1,870.927	10.362	8.638	50.801	1.500	1.500	21.500	17.804	11.497	-8.464%	
CH.19+665.167	600	1,880.345	1,880.160	1,878.500	1,876.750	1,878.500	1,877.344	1.845	2.816	15.065	0.000	1.500	9.950	0.000	5.115	11.616%	M.D.- Right
CH.19+900	600	1,881.050	1,880.865	1,879.490	1,879.460	1,879.490	1,879.467	1.560	1.398	12.760	0.000	2.000	9.950	0.000	2.810	0.235%	M.D.- Right
CH.20+120	600	1,881.875	1,881.710	1,880.260	1,880.310	1,880.272	1,880.310	1.603	1.400	13.180	2.000	0.000	9.950	3.230	0.000	-0.379%	M.D.- Left
CH.20+240	2x900	1,882.256	1,881.906	1,877.375	1,877.900	1,877.479	1,877.786	4.777	4.120	36.833	1.500	2.000	21.500	7.322	8.012	-1.425%	
CH.20+340	600	1,882.716	1,882.551	1,878.700	1,880.500	1,879.504	1,880.500	3.212	2.051	17.982	2.000	0.000	9.950	8.032	0.000	-10.010%	M.D.- Left

Table B.1 Caluculation Sheet of Pipe Culvert Elevation and Length

Chainage	Diameter (mm)	H1 (m)	H2 (m)	H3 (m)	H4 (m)	H5 (m)	H6 (m)	H1-H5 (m)	H2-H6 (m)	L (m)	n	m	L1 (m)	L2 (m)	L3 (m)	i (%)	Remarks
CH.20+600	600	1,886.265	1,886.100	1,881.650	1,883.900	1,882.566	1,883.900	3.699	2.200	22.680	2.000	0.000	13.450	9.230	0.000	-9.921%	M.D.- Left
CH.21+010	750	1,904.590	1,905.090	1,897.400	1,888.900	1,895.848	1,892.395	8.742	12.695	78.760	2.000	2.000	32.000	14.380	32.380	10.792%	
CH.21+060	600	1,906.850	1,907.015	1,905.450	1,904.350	1,905.450	1,904.662	1.400	2.353	18.780	0.000	2.000	13.450	0.000	5.330	5.857%	M.D.- Right
CH.21+600	600	1,933.850	1,934.015	1,932.450	1,932.424	1,932.450	1,932.430	1.400	1.585	13.133	0.000	2.000	9.950	0.000	3.183	0.200%	M.D.- Right
CH.22+380	2x1200	1,962.105	1,962.105	1,960.120	1,960.000	1,960.103	1,960.018	2.002	2.087	28.680	2.000	2.000	20.500	3.970	4.210	0.418%	
Outfall Channel CH.22+400	2x900	1,942.800	1,942.600	1,941.550	1,940.836	1,941.338	1,941.135	1.462	1.465	8.428	2.000	2.000	2.400	2.500	3.528	8.470%	
Outfall Channel CH.22+400	2x900	1,927.630	1,926.970	1,926.250	1,924.812	1,925.946	1,925.286	1.684	1.684	13.077	2.000	2.000	6.000	2.760	4.317	11.000%	
CH.23+560	900	1,989.170	1,989.257	1,987.220	1,987.156	1,987.212	1,987.164	1.958	2.093	32.102	2.000	2.000	24.000	3.900	4.202	0.200%	
CH.23+780	900	1,986.096	1,986.096	1,979.500	1,977.600	1,979.084	1,978.136	7.012	7.960	45.138	1.500	1.500	22.500	9.894	12.744	4.209%	
CH.24+280	600	1,979.886	1,979.638	1,978.486	1,978.164	1,978.486	1,978.237	1.400	1.401	12.899	0.000	2.000	9.950	0.000	2.949	2.500%	M.D.- Right
CH.24+380	2 x1200	1,981.379	1,980.889	1,977.300	1,976.955	1,977.239	1,977.034	4.140	3.855	34.486	1.500	2.000	20.500	6.118	7.868	1.000%	
CH.24+700	600	1,989.743	1,989.488	1,988.243	1,988.037	1,988.243	1,988.084	1.500	1.404	12.851	0.000	2.000	9.950	0.000	2.901	1.600%	M.D.- Right
CH.25+248.062	600	1,997.992	1,997.807	1,996.492	1,996.364	1,996.492	1,996.393	1.500	1.415	12.837	0.000	2.000	9.950	0.000	2.887	1.000%	M.D.- Right
CH.25+420	2x1200	1,997.256	1,997.256	1,993.400	1,993.250	1,993.375	1,993.285	3.881	3.971	34.296	1.500	2.000	20.500	5.784	8.012	0.437%	
CH.27+700	900	2,030.213	2,030.749	2,027.400	2,024.319	2,027.081	2,024.967	3.132	5.782	54.342	2.000	1.779	37.279	5.626	11.437	5.670%	
CH.27+800	600	2,030.293	2,030.081	2,028.700	2,028.674	2,028.700	2,028.680	1.593	1.401	12.763	0.000	2.000	9.950	0.000	2.813	0.200%	M.D.- Right
CH.28+040	600	2,029.530	2,029.310	2,027.930	2,027.904	2,027.930	2,027.910	1.600	1.400	12.761	0.000	2.000	9.950	0.000	2.811	0.200%	M.D.- Right
CH.28+240	750	2,029.130	2,028.800	2,022.196	2,022.150	2,022.164	2,022.150	6.966	6.650	14.901	1.500	0.000	4.500	10.401	0.000	0.309%	
CH.28+260	600	2,028.943	2,028.870	2,023.491	2,026.870	2,024.642	2,026.870	4.301	2.000	24.005	1.500	0.000	15.827	8.178	0.000	-14.076%	M.D.- Left
CH.28+380	600	2,028.393	2,028.510	2,026.943	2,027.110	2,026.992	2,027.110	1.401	1.400	9.850	2.000	0.000	6.950	2.900	0.000	-1.695%	M.D.- Left
CH.0+010R	600	1,645.470	1,645.560	1,644.365	1,644.557	1,644.399	1,644.526	1.071	1.034	12.616	2.000	2.000	8.400	2.210	2.006	-1.522%	
Monbasa Rd. J/C A-Slip Rd. CH.0+140	600	1,648.480	1,648.774	1,647.060	1,647.150	1,647.080	1,647.127	1.400	1.647	12.989	2.000	2.000	6.901	2.840	3.248	-0.693%	
B-Slip Rd. CH.0+275.614	600	1,648.424	1,648.750	1,646.800	1,646.850	1,646.811	1,646.837	1.613	1.913	14.148	2.000	2.000	7.100	3.248	3.800	-0.353%	
C-Slip Rd. CH.0+240	600	1,647.911	1,648.261	1,646.400	1,646.600	1,646.444	1,646.552	1.467	1.709	13.844	2.000	2.000	7.500	3.022	3.322	-1.445%	
D-Slip Rd. CH.0+065	600	1,648.205	1,648.471	1,646.820	1,646.750	1,646.805	1,646.769	1.400	1.702	13.008	2.000	2.000	6.796	2.770	3.442	0.538%	

Table B.1 Caluculation Sheet of Pipe Culvert Elevation and Length

Chainage	Diameter (mm)	H1 (m)	H2 (m)	H3 (m)	H4 (m)	H5 (m)	H6 (m)	H1-H5 (m)	H2-H6 (m)	L (m)	n	m	L1 (m)	L2 (m)	L3 (m)	i (%)	Remarks
E-Slip Rd. CH.0+025	600	1,647.304	1,647.694	1,645.900	1,645.930	1,645.906	1,645.922	1.398	1.772	13.836	2.000	2.000	7.500	2.808	3.528	-0.217%	
F-Slip Rd. CH.0+300	600	1,647.609	1,647.869	1,646.210	1,646.180	1,646.204	1,646.188	1.405	1.681	12.947	2.000	2.000	6.771	2.798	3.378	0.232%	
G-Slip Rd. CH.0+300	600	1,647.903	1,648.138	1,646.490	1,646.550	1,646.504	1,646.535	1.399	1.603	12.502	2.000	2.000	6.500	2.826	3.176	-0.480%	
Monbasa Rd.(A104) CH.0-800 L	2 x 900	1,645.680	1,645.680	1,642.650	1,643.080	1,642.795	1,642.956	2.885	2.724	17.960	2.000	2.000	6.700	6.060	5.200	-2.394%	
Monbasa Rd.(A104) CH.0-800 R	2 x 900	1,645.420	1,645.420	1,643.320	1,644.100	1,643.504	1,643.985	1.916	1.435	17.840	2.000	2.000	11.000	4.200	2.640	-4.372%	
Monbasa Rd.(A104) CH.0-650	2 x 900	1,646.900	1,646.900	1,645.516	1,645.434	1,645.499	1,645.452	1.401	1.448	13.500	2.000	2.000	7.800	2.768	2.932	0.607%	
Monbasa Rd.(A104) CH.0-260R	2 x 900	1,648.400	1,648.400	1,647.130	1,647.050	1,647.111	1,647.070	1.289	1.330	10.840	2.000	2.000	5.600	2.540	2.700	0.738%	
Monbasa Rd.(A104) CH.0+950	600	1,647.300	1,647.300	1,645.000	1,645.700	1,645.165	1,645.547	2.135	1.753	14.650	1.500	2.000	8.000	3.450	3.200	-4.778%	
Monbasa Rd.(A104) CH.0+950	600	1,647.300	1,647.300	1,645.000	1,645.700	1,645.165	1,645.547	2.135	1.753	14.650	1.500	2.000	8.000	3.450	3.200	-4.778%	
Service Rd. CH.1+220R	900	1,651.740	1,651.690	1,650.552	1,650.478	1,650.540	1,650.490	1.200	1.200	14.800	2.000	2.000	10.000	2.376	2.424	0.500%	
Uhuru Monument J/C A-Slip Rd.(CH.0+221.233) CH.6+520	600	1,716.602	1,716.722	1,715.000	1,715.300	1,715.085	1,715.300	1.517	1.422	11.254	2.000	0.000	8.050	3.204	0.000	-2.666%	
Langata Rd. (C58) CH.0+110L	600	1,721.517	1,721.044	1,719.995	1,719.025	1,719.760	1,719.336	1.757	1.708	12.582	2.000	2.000	5.500	3.044	4.038	7.710%	
Langata Rd. (C58) CH.0+140L	600	1,719.728	1,719.286	1,718.126	1,717.482	1,718.022	1,717.599	1.706	1.687	19.812	2.000	2.000	13.000	3.204	3.608	3.250%	
Langata Rd. (C58) CH.0+165R	600	1,718.495	1,718.931	1,716.871	1,717.556	1,717.006	1,717.442	1.489	1.489	16.498	2.000	2.000	10.500	3.248	2.750	-4.152%	
Langata Rd. (C58) CH.0+177L	300	1,718.270	1,718.270	1,717.148	1,717.128	1,717.141	1,717.135	1.129	1.135	6.527	2.000	2.000	2.000	2.244	2.283	0.300%	
Langata Rd. (C58) CH.0+220L	300	1,716.000	1,716.000	1,714.940	1,714.959	1,714.946	1,714.952	1.054	1.048	6.203	2.000	2.000	2.000	2.120	2.083	-0.300%	
Langata Rd. (C58) CH.0+235L	600	1,715.413	1,714.830	1,714.072	1,713.171	1,713.930	1,713.347	1.483	1.483	17.000	2.000	2.000	11.000	2.682	3.318	5.300%	
Langata Rd. (C58) CH.0+240R	300	1,714.840	1,714.840	1,713.840	1,713.858	1,713.846	1,713.852	0.994	0.988	5.964	2.000	2.000	2.000	2.000	1.964	-0.300%	
Langata Rd. (C58) CH.0+260R	600	1,713.648	1,714.310	1,711.989	1,712.969	1,712.165	1,712.827	1.483	1.483	18.500	2.000	2.000	12.500	3.318	2.682	-5.296%	
Service Rd. (C-Slip Rd.) CH.0+220	900	1,712.180	1,711.980	1,710.880	1,710.730	1,710.832	1,710.730	1.348	1.250	6.150	1.500	0.000	4.200	1.950	0.000	2.439%	
Service Rd. CH.7+020R	2x900	1,708.860	1,708.660	1,707.200	1,706.816	1,707.200	1,707.000	1.660	1.660	7.689	0.000	2.000	4.000	0.000	3.689	5.000%	
Service Rd. CH.7+340L	900	1,715.496	1,715.505	1,713.487	1,713.514	1,713.496	1,713.505	2.000	2.000	12.000	2.000	2.000	4.000	4.018	3.982	-0.225%	
Ngong Rd. J/C A-Slip Rd. CH.0+040	600	1,825.038	1,824.926	1,823.560	1,823.522	1,823.554	1,823.527	1.484	1.399	19.064	2.000	2.000	13.300	2.956	2.808	0.200%	
Ngong Rd. CH.0+260	600	1,815.197	1,815.510	1,813.970	1,814.100	1,813.991	1,814.076	1.206	1.434	15.274	2.000	2.000	10.000	2.454	2.820	-0.851%	
Ngong Rd. CH.0+440	600	1,819.800	1,819.400	1,818.200	1,817.000	1,817.987	1,817.320	1.813	2.080	18.000	2.000	2.000	10.000	3.200	4.800	6.667%	

Table B.1 Caluculation Sheet of Pipe Culvert Elevation and Length

Chainage	Diameter (mm)	H1 (m)	H2 (m)	H3 (m)	H4 (m)	H5 (m)	H6 (m)	H1-H5 (m)	H2-H6 (m)	L (m)	n	m	L1 (m)	L2 (m)	L3 (m)	i (%)	Remarks
Ngong Rd. CH.0+620	600	1,830.233	1,830.447	1,829.038	1,829.000	1,829.033	1,829.006	1.200	1.441	18.784	2.000	2.000	13.500	2.390	2.894	0.202%	
Ngong Rd. CH.0+740L	300	1,833.600	1,833.600	1,832.399	1,832.312	1,832.380	1,832.332	1.220	1.268	10.978	2.000	2.000	6.000	2.402	2.576	0.792%	
Service Rd. CH.18+400R	600	1,871.370	1,871.240	1,870.120	1,869.970	1,870.079	1,870.012	1.291	1.228	9.040	2.000	2.000	4.000	2.500	2.540	1.659%	
Service Rd. CH.18+480R	600	1,874.250	1,874.310	1,872.720	1,872.869	1,872.766	1,872.826	1.484	1.484	9.942	2.000	2.000	4.000	3.060	2.882	-1.500%	
Service Rd. CH.19+060 L	900	1,865.800	1,866.100	1,864.100	1,864.500	1,864.193	1,864.412	1.607	1.688	10.950	1.500	1.500	6.000	2.550	2.400	-3.653%	
Service Rd. CH.19+520 L	900	1,868.975	1,869.275	1,867.200	1,867.600	1,867.295	1,867.510	1.680	1.765	11.175	1.500	1.500	6.000	2.662	2.513	-3.579%	
Service Rd. CH.20+200L	300	1,878.210	1,878.150	1,877.253	1,877.072	1,877.210	1,877.121	1.000	1.029	8.070	2.000	2.000	4.000	1.914	2.156	2.240%	
Service Rd. CH.20+200R	300	1,879.548	1,879.660	1,878.490	1,878.710	1,878.548	1,878.658	1.000	1.002	8.016	2.000	2.000	4.000	2.116	1.900	-2.745%	
Service Rd. CH.20+220 L	2x900	1,882.200	1,881.850	1,877.000	1,878.650	1,877.361	1,878.354	4.839	3.496	35.700	1.500	2.000	21.500	7.800	6.400	-4.622%	
Dagoretti Forest J/C A-Slip Rd. CH.0+040	600	1,887.456	1,887.129	1,882.090	1,882.975	1,882.348	1,882.775	5.108	4.354	27.573	1.500	1.500	13.293	8.049	6.231	-3.210%	
Dagoretti Forest J/C A-Slip Rd. CH.0+260	600	1,887.095	1,887.605	1,885.040	1,885.600	1,885.160	1,885.483	1.935	2.122	19.120	2.000	2.000	11.000	4.110	4.010	-2.929%	
Dagoretti Forest J/C B-Slip Rd. CH.0+080	600	1,890.781	1,891.301	1,884.020	1,883.100	1,883.749	1,883.429	7.032	7.872	34.443	1.500	1.500	12.000	10.141	12.302	2.671%	
Approach Rd. (C63) CH.0+040	600	1,886.422	1,886.422	1,884.950	1,885.005	1,884.959	1,884.996	1.463	1.426	18.229	2.000	2.000	12.450	2.944	2.835	-0.300%	
Approach Rd. (C63) CH.0+160	900	1,888.905	1,889.425	1,887.150	1,887.950	1,887.309	1,887.816	1.596	1.609	17.626	2.000	2.000	11.166	3.510	2.950	-4.539%	
Approach Rd. (C63) CH.0+340	1200	1,888.310	1,888.310	1,886.200	1,886.625	1,886.285	1,886.557	2.025	1.753	21.090	2.000	2.000	13.500	4.220	3.370	-2.015%	
Service Rd. CH.21+000L	2x900	1,898.300	1,898.600	1,896.540	1,897.170	1,896.719	1,897.024	1.581	1.576	12.380	2.000	2.000	6.000	3.520	2.860	-5.089%	
Service Rd. CH.21+000R	900	1,893.600	1,892.500	1,892.400	1,890.240	1,891.999	1,890.996	1.601	1.504	12.920	2.000	2.000	6.000	2.400	4.520	16.718%	
Service Rd. CH.22+380 L	600	1,962.960	1,963.160	1,961.600	1,960.120	1,961.340	1,960.702	1.620	2.458	11.600	1.500	1.500	5.000	2.040	4.560	12.759%	
Service Rd. CH.22+380 R	2 x1200	1,962.200	1,962.000	1,960.000	1,959.850	1,959.957	1,959.892	2.243	2.108	11.525	1.500	1.500	5.000	3.300	3.225	1.302%	
Service Rd. CH.22+880L	900	1,976.840	1,976.900	1,975.300	1,975.425	1,975.338	1,975.388	1.502	1.512	10.030	2.000	2.000	4.000	3.080	2.950	-1.246%	
Service Rd. CH.22+880R	900	1,977.350	1,977.322	1,975.877	1,975.785	1,975.850	1,975.813	1.500	1.509	10.020	2.000	2.000	4.000	2.946	3.074	0.918%	
Service Rd. CH.23+100R	600	1,981.370	1,981.350	1,980.156	1,980.134	1,980.150	1,980.140	1.220	1.210	8.860	2.000	2.000	4.000	2.428	2.432	0.248%	
Service Rd. CH.23+240L	900	1,989.900	1,989.900	1,986.560	1,987.080	1,986.757	1,986.914	3.143	2.986	13.240	1.500	1.500	4.000	5.010	4.230	-3.927%	
Approach Rd. (D411) CH.0+010L	300	1,977.100	1,977.100	1,975.691	1,975.966	1,975.776	1,975.897	1.324	1.203	9.086	2.000	2.000	4.000	2.818	2.268	-3.027%	
Approach Rd. (D411) CH.0+080L	300	1,977.340	1,977.340	1,976.183	1,976.212	1,976.190	1,976.205	1.150	1.135	9.570	2.000	2.000	5.000	2.314	2.256	-0.303%	

Table B.1 Caluculation Sheet of Pipe Culvert Elevation and Length

Chainage	Diameter (mm)	H1 (m)	H2 (m)	H3 (m)	H4 (m)	H5 (m)	H6 (m)	H1-H5 (m)	H2-H6 (m)	L (m)	n	m	L1 (m)	L2 (m)	L3 (m)	i (%)	Remarks
Approach Rd. (D411) CH.0+140L	300	1,977.740	1,977.740	1,976.673	1,976.212	1,976.576	1,976.350	1.164	1.390	10.190	2.000	2.000	5.000	2.134	3.056	4.524%	
Approach Rd. (D411) CH.0+230	900	1,982.325	1,982.325	1,980.750	1,980.845	1,980.770	1,980.826	1.555	1.499	14.610	2.000	2.000	8.500	3.150	2.960	-0.650%	
Approach Rd. (D411) CH.0+280	900	1,985.917	1,985.810	1,984.200	1,984.349	1,984.234	1,984.319	1.683	1.491	14.857	2.000	2.000	8.500	3.434	2.923	-1.000%	
Approach Rd. (D411) CH.0+285L	300	1,986.650	1,986.650	1,984.420	1,985.520	1,984.878	1,985.288	1.772	1.362	10.720	2.000	2.000	4.000	4.460	2.260	-10.261%	
Approach Rd. (D411) CH.0+320L	600	1,987.925	1,988.155	1,986.510	1,987.032	1,986.673	1,986.903	1.252	1.252	9.076	2.000	2.000	4.000	2.830	2.246	-5.750%	
Approach Rd. (D411) CH.0+325L	300	1,988.800	1,988.800	1,987.670	1,987.900	1,987.734	1,987.849	1.066	0.951	8.060	2.000	2.000	4.000	2.260	1.800	-2.854%	
Approach Rd. (D411) CH.0+340L	300	1,990.017	1,990.017	1,988.880	1,989.150	1,988.931	1,989.111	1.086	0.906	12.008	2.000	2.000	8.000	2.274	1.734	-2.249%	
Thogoto J/C A-Slip Rd. CH.0+040	900	1,990.669	1,990.975	1,988.790	1,989.180	1,988.867	1,989.107	1.802	1.868	19.082	2.000	2.000	11.734	3.758	3.590	-2.044%	
Thogoto J/C B-Slip Rd. CH.0+040	900	1,990.978	1,990.942	1,984.000	1,983.900	1,983.969	1,983.931	7.009	7.011	33.733	1.500	1.500	12.703	10.467	10.563	0.296%	
Thogoto J/C B-Slip Rd. CH.0+280	600	1,978.415	1,978.372	1,976.550	1,976.600	1,976.561	1,976.590	1.854	1.782	17.174	2.000	2.000	9.900	3.730	3.544	-0.291%	
Service Rd. CH.25+420 L	2x900	1,995.250	1,994.950	1,993.600	1,993.400	1,993.554	1,993.443	1.696	1.507	10.800	1.500	1.500	6.000	2.475	2.325	1.852%	
Ondiri Swamp CH.26+420R	600	2,013.200	2,013.800	2,011.600	2,012.620	2,011.832	2,012.449	1.368	1.351	14.060	2.000	2.000	8.500	3.200	2.360	-7.255%	
Ondori Swamp CH.26+490L	900	2,018.000	2,018.700	2,016.250	2,017.200	2,016.479	2,017.003	1.521	1.697	14.500	2.000	2.000	8.000	3.500	3.000	-6.552%	
Kikuyu Town J/C A-Slip Rd. CH.0+020	600	2,022.778	2,022.603	2,021.300	2,020.820	2,021.214	2,020.924	1.564	1.679	16.522	2.000	2.000	10.000	2.956	3.566	2.905%	
Kikuyu Town J/C A-Slip Rd. CH.0+310R	300	2,025.160	2,025.165	2,024.052	2,024.073	2,024.059	2,024.066	1.101	1.099	6.699	2.000	2.000	2.300	2.215	2.184	-0.313%	
Kikuyu Town J/C A-Slip Rd. CH.0+335R	300	2,025.206	2,025.358	2,024.144	2,024.258	2,024.175	2,024.226	1.031	1.132	7.824	2.000	2.000	3.500	2.124	2.200	-1.457%	
Kikuyu Town J/C A-Slip Rd. CH.0+540	300	2,028.791	2,028.791	2,027.800	2,027.400	2,027.746	2,027.475	1.045	1.316	14.764	2.000	2.000	10.000	1.982	2.782	2.709%	
Kikuyu Town J/C A-Slip Rd. CH.0+640R	600	2,032.500	2,031.725	2,031.560	2,030.640	2,031.488	2,030.723	1.012	1.002	24.050	2.000	2.000	20.000	1.880	2.170	3.825%	
Kikuyu Town J/C A-Slip Rd. CH.1+060	900	2,024.552	2,024.552	2,023.000	2,022.350	2,022.885	2,022.514	1.667	2.038	17.508	2.000	2.000	10.000	3.104	4.404	3.713%	
Kikuyu Town J/C A-Slip Rd. CH.1+105R	300	2,026.400	2,026.100	2,024.900	2,024.099	2,024.682	2,024.390	1.718	1.710	11.002	2.000	2.000	4.000	3.000	4.002	7.280%	
Kikuyu Town J/C A-Slip Rd. CH.1+165R	300	2,029.129	2,028.914	2,028.029	2,027.434	2,027.912	2,027.592	1.217	1.322	11.161	2.000	2.000	6.000	2.200	2.961	5.335%	
Kikuyu Town J/C A-Slip Rd. CH.1+265R	300	2,034.758	2,034.600	2,033.529	2,033.007	2,033.409	2,033.164	1.349	1.436	10.643	2.000	2.000	5.000	2.458	3.185	4.900%	
Kikuyu Town J/C A-Slip Rd. CH.1+440	600	2,031.325	2,031.185	2,027.800	2,025.900	2,027.303	2,026.645	4.022	4.540	20.215	1.500	1.500	7.000	5.288	7.927	9.399%	
Kikuyu Town J/C C-Slip Rd. CH.0+040	600	2,032.950	2,032.608	2,031.150	2,031.220	2,031.163	2,031.210	1.787	1.398	19.741	2.000	2.000	13.365	3.600	2.776	-0.355%	
Kikuyu Town J/C C-Slip Rd. CH.0+060 L	600	2,034.278	2,034.278	2,031.810	2,032.793	2,032.067	2,032.639	2.211	1.639	18.906	2.000	2.000	11.000	4.936	2.970	-5.200%	

Table B.1 Caluculation Sheet of Pipe Culvert Elevation and Length

Chainage	Diameter (mm)	H1 (m)	H2 (m)	H3 (m)	H4 (m)	H5 (m)	H6 (m)	H1-H5 (m)	H2-H6 (m)	L (m)	n	m	L1 (m)	L2 (m)	L3 (m)	i (%)	Remarks
Kikuyu Town J/C D-Slip Rd. CH.0+030 L	300	2,039.631	2,039.639	2,037.593	2,037.716	2,037.628	2,037.683	2.003	1.956	14.423	2.000	2.000	6.500	4.076	3.847	-0.850%	
Kikuyu Town J/C D-Slip Rd. CH.0+040	600	2,038.653	2,038.653	2,037.350	2,037.300	2,037.341	2,037.309	1.312	1.344	15.312	2.000	2.000	10.000	2.606	2.706	0.327%	
Kikuyu Town J/C D-Slip Rd. CH.0+050 R	300	2,039.328	2,039.328	2,038.180	2,038.047	2,038.146	2,038.086	1.182	1.242	8.858	2.000	2.000	4.000	2.296	2.562	1.500%	
Kikuyu Town J/C D-Slip Rd. CH.0+090 L	300	2,039.945	2,039.945	2,038.480	2,038.577	2,038.509	2,038.549	1.436	1.396	9.667	2.000	2.000	4.000	2.930	2.737	-1.000%	
Kikuyu Town J/C D-Slip Rd. CH.0+120R	300	2,039.935	2,039.935	2,038.630	2,038.650	2,038.637	2,038.644	1.298	1.291	8.179	2.000	2.000	3.000	2.610	2.569	-0.250%	
Kikuyu Town J/C D-Slip Rd. CH.0+135L	300	2,039.665	2,039.666	2,038.628	2,038.581	2,038.614	2,038.596	1.051	1.069	6.742	2.000	2.000	2.500	2.074	2.168	0.690%	
Kikuyu Town J/C D-Slip Rd. CH.0+150R	300	2,039.371	2,039.371	2,038.345	2,038.469	2,038.382	2,038.436	0.989	0.935	6.856	2.000	2.000	3.000	2.052	1.804	-1.810%	
Kikuyu Town J/C D-Slip Rd. CH.0+160L	300	2,039.086	2,039.086	2,038.185	2,037.917	2,038.126	2,037.994	0.960	1.092	8.140	2.000	2.000	4.000	1.802	2.338	3.290%	
Kikuyu Town J/C D-Slip Rd. CH.0+260L	600	2,035.050	2,034.866	2,033.692	2,032.939	2,033.541	2,033.153	1.509	1.713	13.569	2.000	2.000	7.000	2.716	3.853	5.550%	
Kikuyu Town J/C D-Slip Rd. CH.0+420L	900	2,029.350	2,029.450	2,027.468	2,027.525	2,027.484	2,027.508	1.866	1.942	13.315	2.000	2.000	5.700	3.764	3.851	-0.425%	
Kikuyu Town J/C D-Slip Rd. CH.0+444.278	900	2,029.978	2,029.978	2,027.800	2,028.000	2,027.848	2,027.957	2.130	2.021	18.312	2.000	2.000	10.000	4.356	3.956	-1.092%	
CH.27+095L	900	2,027.886	2,027.886	2,026.032	2,026.321	2,026.131	2,026.238	1.755	1.648	10.837	2.000	2.000	4.000	3.708	3.129	-2.670%	
CH.28+050L	600	2,029.600	2,028.900	2,028.445	2,027.470	2,028.274	2,027.682	1.326	1.218	13.170	2.000	2.000	8.000	2.310	2.860	7.403%	
Kikuyu J/C A-Slip Rd. CH.0+460	900	2,036.314	2,036.529	2,034.200	2,032.950	2,033.913	2,033.437	2.401	3.092	18.386	2.000	2.000	7.000	4.228	7.158	6.799%	
Kikuyu J/C A-Slip Rd. CH.0+120	600	2,027.291	2,027.131	2,025.930	2,025.680	2,025.883	2,025.730	1.408	1.401	14.624	2.000	2.000	9.000	2.722	2.902	1.710%	
Kikuyu J/C A-Slip Rd. CH.0+020	600	2,024.890	2,024.952	2,022.300	2,023.500	2,022.543	2,023.364	2.347	1.588	25.584	2.000	2.000	17.500	5.180	2.904	-4.690%	
Road 3.1(Kabete-Limuru) CH.0+380	600	2,025.008	2,024.883	2,023.588	2,023.683	2,023.607	2,023.667	1.401	1.216	14.240	2.000	2.000	9.000	2.840	2.400	-0.667%	
CH.27+700	900	2,030.213	2,030.749	2,027.400	2,024.319	2,027.081	2,024.967	3.132	5.782	54.342	2.000	1.779	37.279	5.626	11.437	5.670%	

M.D.: Median Drain

APPENDIX - C (Drainage pond)

Substitute Plan of Soak Pit near Thogoto J/C

In Preliminary Design Stage, it was proposed to construct a soak pit near Thogoto Junction, because of no stream or river to drain the surface run-off in this valley. 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. (refer to Material Report 3.7 GROUND CONDITION OF SOAK PIT)

In this stage, a drainage pond was designed as substitute plan of soak pit.

Design Discharge

In this case, calculations of the increased discharge by the road construction are as follows.

The area of new construction road and slope are about 52,000 m^2 in this valley.

This area of cultivated land changes to road and slope, so the run-off coefficient (C) changes to 0.9 from 0.4.

$$Q = 0.278 \times C \times I \times A$$

Q : The expected flow (m^3/sec)

C : The run-off coefficient (0.5)

I : The intensity of rainfall (mm/h)

A : The area drained (0.052km^2)

Return Period : 25 years

Duration time (hr.)	I (mm/hr.)	Total discharge (m3)
0.1	120.0	5,179
0.2	110.0	9,494
0.3	100.0	12,946
0.4	93.0	16,053
0.5	89.0	19,204
1.0	70.0	30,208
2.0	48.0	41,428
3.0	37.0	47,901
4.0	29.0	50,059
5.0	24.0	51,785
10.0	13.3	57,395
20.0	6.7	57,827
24.0	5.6	58,000

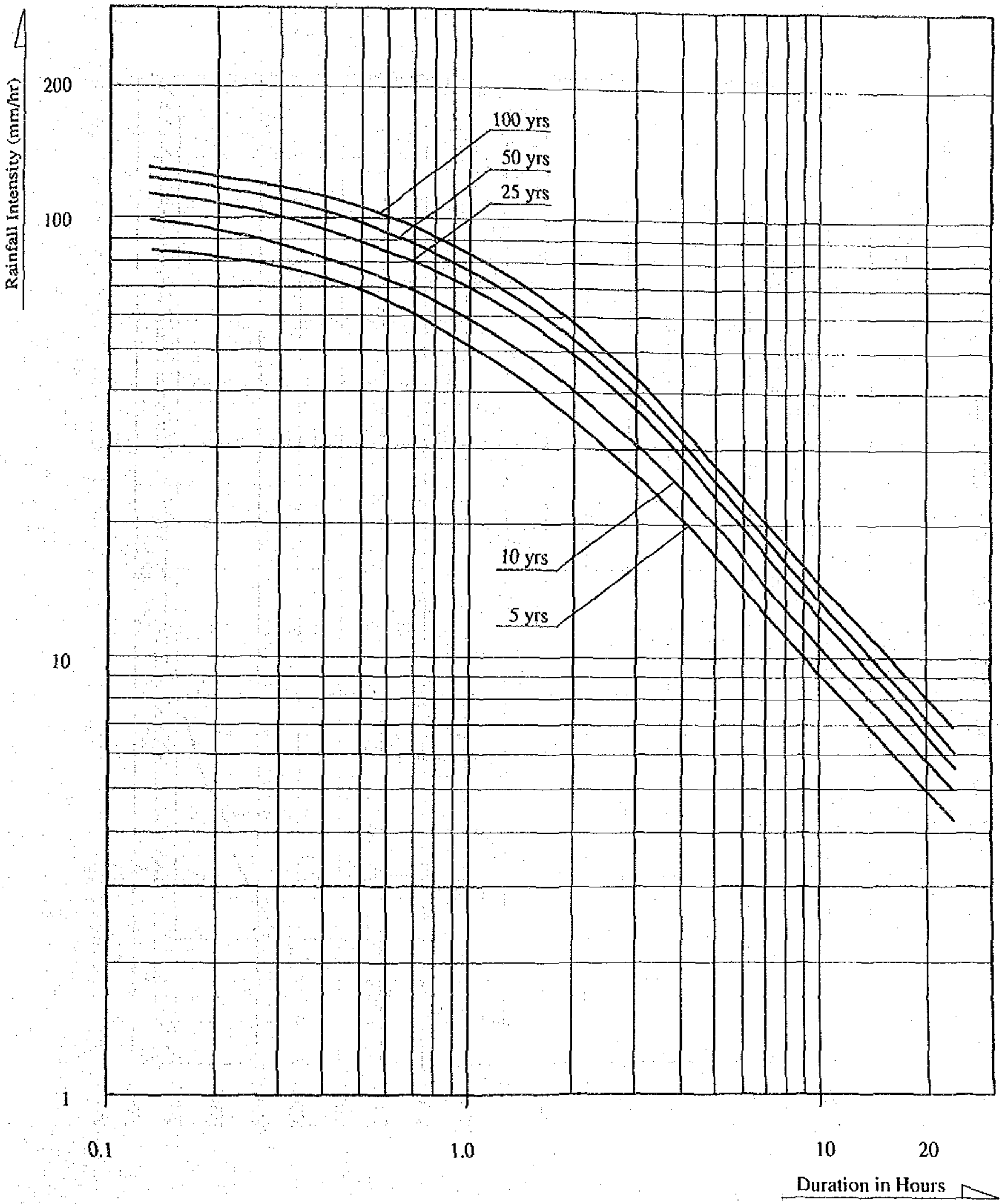


Figure C.1 Rainfall Intensity - Duration - Frequency Relationships for Dagoretti Headquarter

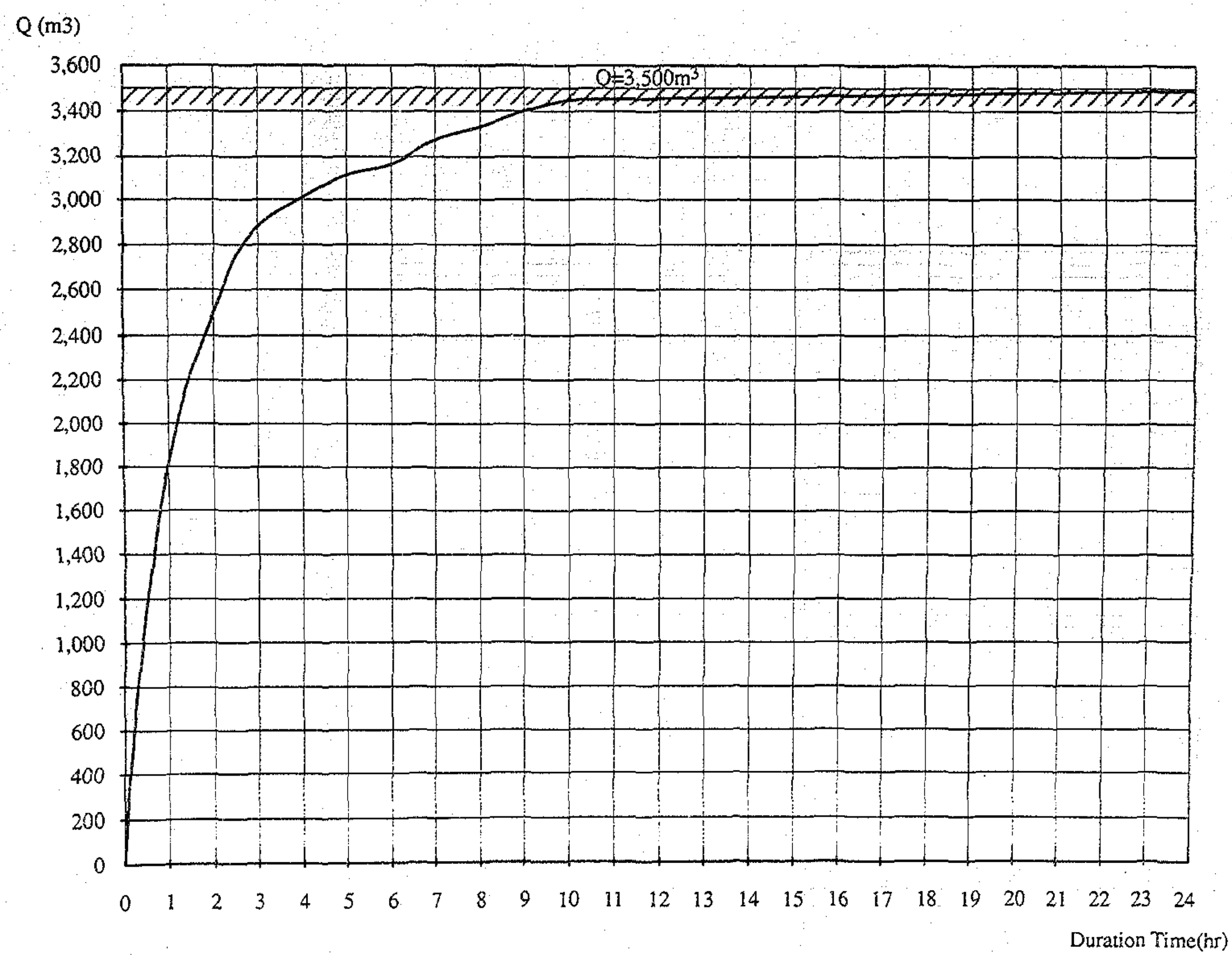


Figure C.2 Total Discharge (Return Period 25years)

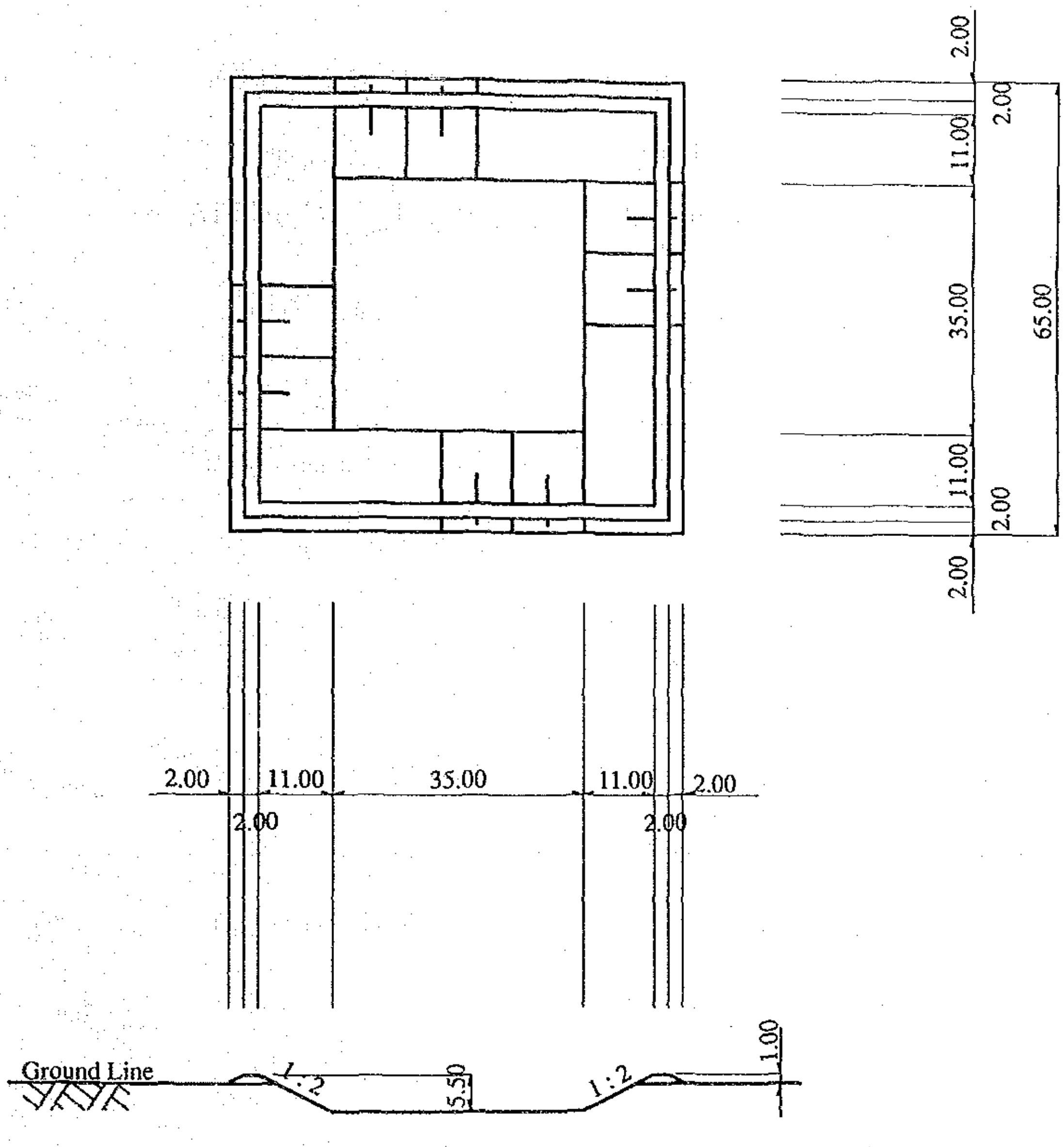


Figure. C.3 Plan and Profile of Drainage Pond

Scale 1:1,000

APPENDIX - D (Discharge calculation)

Discharge Calculation

(1) Box culvert (13 + 978) (36°44.5'E, 1°19.2'S)

- Area 2.93 km^2
- Design return period 25 years
- Longest channel 2,500 m
- Average slope of the catchment

$$S_1 = \frac{1,875 - 1,805}{4,200} = 1.67\%$$

- Average slope of main channel

$$S_1 = \frac{1,840 - 1,805}{2,500} = 1.40\%$$

- Run-off coefficient C = 0.40

- Catchment areas elevation difference

$$H = 1,840 - 1,805 = 35 \text{ m}$$
$$tc = 41.64 \text{ minutes}$$

From Rainfall Frequency Atlas of Kenya 25 years 1 hour rainfall

Rainfall intensity for 60 minutes

$$1 = 70 \text{ mm/hr}$$

Rainfall intensity for 41.64 minutes

$$1 = 80 \text{ mm/hr}$$

$Q' = 26.1\ m^3/sec$ (THE RAINFALL FREQUENCY ATLAS METHOD)

From site inspection, catchment type close to poor pasture.

lag time K = 0.5 hrs

Standard contribution area coefficient (Cs)

Cs = 0.38 [catchment slope : 1.67%; soil type : slightly impeded drainage]

Catchment wetness factor (Cw)

(Nairobi is a wet zone)

$$Cw = 1.00$$

Land use factors (C1)

$$C1 = 1.00$$

Contributing area coefficient (C_A) given as

$$(C_A = 0.38 \times 1.0 \times 10 = 0.38)$$

Initial retention (Y) = 0

Estimated rainfall time for East African 10-years storms. (Kenya Aberdare Uluguru zone)

$$n = 0.85, \ Tp = 2.0$$

Design storm rainfall to be allowed for during time interval TB hours

$$TB = Tp + 2.3k + TA$$

TA : Flood wave in stream system taken as zero

$$\text{Base time } TB = 2.0 + 2.3 \times 0.5 = 3.15$$

Rainfall during base time

$$RTB = \frac{TB}{24}\left(\frac{24.33}{TB + 0.33}\right)^{n} \times R^{2/24}$$

$$RTB = 90.48 \text{ mm}$$

Areal reduction factor

$$ARF1 = 1 - 0.04 \times T^{1/3} A^{1/2} = 0.95$$

Average Rainfall (P)

$$P1 = ARF \times RTB = 86.25 \text{ mm}$$

Total Volume of Run-off

$$RO_1 = (P-Y) \times Ca \times A \times 10^3 = 96{,}035\ m^3$$

Average flow

$$Q_1 = \frac{0.93 \times RO}{3{,}600 \times TB} = 7.88\ m^3/sec$$

$$Q_2 = 7.69\ m^3/sec$$

$$\Delta = \frac{Q_2 - Q_1}{Q_1} \times 100 = 2.4\% < 5\%$$

$$\underline{\underline{Q'' = 2.8 \times 7.69 = 21.5\ m^3/sec}}$$ (The TRRL (EA) flood model)

$$Q' > Q''$$

$$Q' < Q'' \times 1.5$$

$$\underline{\underline{Q = 26.1\ m^3/sec}}$$

(2) Box culvert (14 + 943) (36°44'E, 1°187'S)

- Area 2.73 km^2
- Design return period 25 years
- Longest channel 650 m
- Average slope of the catchment

$$S_1 = \frac{1,890 - 1,813}{5,100} = 1.51\%$$

- Average slope of main channel

$$S_1 = \frac{1,821 - 1,813}{650} = 1.23\%$$

- Run-off coefficient C = 0.4

- Catchment areas elevation difference

$$H = 1,821 - 1,813 = 8 \text{ m}$$
$$tc = 15.51 \text{ minutes}$$

From Rainfall Frequency Atlas of Kenya 25 years 1 hour rainfall

Rainfall intensity for 60 minutes

1 = 70 mm/hr

Rainfall intensity for 5.51 minutes

1 = 103 mm/hr

Q' = 31.3 m^3/sec (THE RAINFALL FREQUENCY ATLAS METHOD)

From site inspection, catchment type close to poor pasture.

lag time K = 0.5 hrs

Standard contribution area coefficient (Cs)

Cs = 0.38 [catchment slope : 1.51% ; soil type : slightly impeded drainage]

Catchment wetness factor (Cw)

(Nairobi is a wet zone)

$$Cw = 1.00$$

Land use factors (C1)

$$C1 = 1.00$$

Contributing area coefficient (C_A) given as

$$C_A = 0.38 \times 1.0 \times 1.0 = 0.38$$

Initial retention (Y) = 0

Estimated rainfall time for East African 10-years storms. (Kenya Aberdare Uluguru zone)

$$n = 0.85, \ Tp = 2.0$$

Design storm rainfall to be allowed for during time interval TB hours

$$TB = Tp + 2.3\,k + TA$$

TA : Flood wave in stream system taken as zero

$$\text{Base time } TB = 2.0 + 2.3 \times 0.5 = 3.15$$

Rainfall during base time

$$RTB = \frac{TB}{24}\left(\frac{24.33}{TB + 0.33}\right)^{n} \times R^{2/24}$$

$$RTB = 90.48 \text{ mm}$$

Areal reduction factor

$$ARF1 = 1 - 0.04 \times T^{1/3} A^{1/2} = 0.95$$

Average Rainfall (P)

$$P1 = ARF \times RTB = 86.40 \text{ mm}$$

Total Volume of Run-off

$$RO_1 = (P-Y) \times Ca \times A \times 10^3 = 89,632 \text{ m}^3$$

Average flow

$$Q_1 = \frac{0.93 \times RO}{3,600 \times TB} = 7.35 \text{ m}^3/\text{sec}$$

$$Q_2 = 7.30 \text{ m}^3/\text{sec}$$

$$\Delta = \frac{Q_2 - Q_1}{Q1} \times 100 = 0.7\% < 5\%$$

$\underline{Q'' = 2.8 \times 730 = 20.4 \text{ m}^3/\text{sec}}$ (The TRRL (EA) flood model)

$$Q' = 31.3 > 30.6 = Q'' \times 1.5$$

$\underline{Q = 30.6 \text{ m}^3/\text{sec}}$

(3) Box culvert (15 + 560) (36°43.5'E, 1°18.5'S)

(4) Box culvert (Ngong Rd J/C B-Ramp 0 + 157)

- Area 7.36 km^2
- Design return period 25 years
- Longest channel 5,200 m
- Average slope of the catchment

$$S_1 = \frac{1,990 - 1,810}{7,700} = 2.34\%$$

- Average slope of main channel

$$S_1 = \frac{1,880 - 1,810}{5,200} = 1.35\%$$

- Run-off coefficient C = 0.3

- Catchment areas elevation difference

$$H = 1,880 - 1,810 = 70 \text{ m}$$
$$tc = 74.29 \text{ minutes}$$

From Rainfall Frequency Atlas of Kenya 25 years 1 hour rainfall

Rainfall intensity for 60 minutes

I = 70 mm/hr

Rainfall intensity for 74.29 minutes

I = 63 mm/hr

Q' = 43.0 m^3/sec (THE RAINFALL FREQUENCY ATLAS METHOD)

From site inspection, catchment type close to poor pasture.

lag time K = 0.5 hrs

Standard contribution area coefficient (Cs)

Cs = 0.38 [catchment slope : 2.34%; soil type : slightly impeded drainage]

Catchment wetness factor (Cw)

(Nairobi is a wet zone)

$$Cw = 1.00$$

Land use factors (C1)

$$C1 = 0.50$$

Contributing area coefficient (C_A) given as

$$C_A = 0.38 \times 1.0 \times 1.0 = 0.38$$

Initial retention (Y) = 0

Estimated rainfall time for East African 10-years storms. (Kenya Aberdare Uluguru zone)

$$n = 0.85, \quad Tp = 2.0$$

Design storm rainfall to be allowed for during time interval TB hours

$$TB = Tp + 2.3k + TA$$

TA : Flood wave in stream system taken as zero

$$\text{Base time } TB = 2.0 + 2.3 \times 0.5 = 3.15$$

Rainfall during base time

$$RTB = \frac{TB}{24}\left(\frac{24.33}{TB + 0.33}\right)^n \times R^{2/24}$$

$$RTB = 90.48 \text{ mm}$$

Areal reduction factor

$$ARF1 = 1 - 0.04 \times T^{1/3} A^{1/2} = 0.93$$

Average Rainfall (P)

$$P1 = ARF \times RTB = 83.78 \text{ mm}$$

Total Volume of Run-off

$$RO_1 = (P\text{-}Y) \times Ca \times A \times 10^3 = 117{,}160 \text{ m}^3$$

Average flow

$$Q_1 = \frac{0.93 \times RO}{3{,}600 \times TB} = 9.61 \text{ m}^3/\text{sec}$$

$$Q_2 = 9.14 \text{ m}^3/\text{sec}$$

$$\Delta = \frac{Q_2 - Q_1}{Q1} \times 100 = 4.89\% < 5\%$$

$$\underline{\underline{Q'' = 2.8 \times 9.14 = 25.6 \text{ m}^3/\text{sec}}} \quad \text{(The TRRL (EA) flood model)}$$

$$Q' = 43.0 > 38.4 = Q'' \times 1.5$$

$$\underline{\underline{Q = 38.4 \text{ m}^3/\text{sec}}}$$

(5) Box culvert (26 + 335) (36°39.5'E, 1°15'S)

- Area 38.74 km^2
- Design return period 25 years
- Longest channel 3,500 m
- Average slope of the catchment

$$S_1 = \frac{2,310 - 1,992}{18,000} = 177\%$$

- Average slope of main channel

$$S_1 = \frac{2,020 - 1,992}{3,500} = 0.8\%$$

- Run-off coefficient C = 0.2

- Catchment areas elevation difference

$$H = 2,020 - 1,992 = 28 \text{ m}$$
$$tc = 66.92 \text{ minutes}$$

From Rainfall Frequency Atlas of Kenya 25 years 1 hour rainfall

Rainfall intensity for 60 minutes

$$1 = 70 \text{ mm/hr}$$

Rainfall intensity for 66.92 minutes

$$1 = 67 \text{ mm/hr}$$

$Q' = 150.8\ m^3/sec$ (THE RAINFALL FREQUENCY ATLAS METHOD)

From site inspection, catchment type close to good pasture.

lag time K = 1.5 hrs

Standard contribution area coefficient (Cs)

$$Cs = 0.38 \begin{bmatrix} \text{catchment slope: } 1.77\% \\ \text{soil type: slightly impeded drainage} \end{bmatrix}$$

Catchment wetness factor (Cw)

(Nairobi is a wet zone)

$$Cw = 1.00$$

Land use factors (C1)

$$C1 = 0.50$$

Contributing area coefficient (C_A) given as

$$C_A = 0.38 \times 1.0 \times 0.50 = 0.19$$

Initial retention (Y) = 0

Estimated rainfall time for East African 10-years storms. (Kenya Aberdare Uluguru zone)

$$n = 0.85. \quad Tp = 2.0$$

Design storm rainfall to be allowed for during time interval TB hours

$$TB = Tp + 2.3k + TA$$

TA : Flood wave in stream system taken as zero

$$\text{Base time } TB = 2.0 + 2.3 \times 1.5 = 5.45$$

Rainfall during base time

$$RTB = \frac{TB}{24}\left(\frac{24.33}{TB + 0.33}\right)^n \times R^{2/24}$$

$$RTB = 101.70 \text{ mm}$$

Areal reduction factor

$$ARF1 = 1 - 0.04 \times T^{1/3} A^{1/2} = 0.86$$

Average Rainfall (P)

$$P1 = ARF \times RTB = 87.32 \text{ mm}$$

Total Volume of Run-off

$$RO_1 = (P-Y) \times Ca \times A \times 10^3 = 642{,}700 \ m^3$$

Average flow

$$Q_1 = \frac{0.93 \times RO}{3{,}600 \times TB} = 30.46 \ m^3/sec$$

$$Q_2 = 29.4 \ m^3/sec$$

$$\Delta = \frac{Q_2 - Q_1}{Q1} \times 100 = 3.5\% < 5\%$$

$\underline{\underline{Q'' = 2.3 \times 29.4 = 67.6 \ m^3/se}}$ (The TRRL (EA) flood model)

$$Q'' = 150.8 > 101.4 \ m^3/sec = Q'' \times 1.5$$

$\underline{\underline{Q = 101.4 \ m^3/sec}}$