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COMPUTER AIDED GEOMETRIC DESIGN OF ACCESS ROADS FOR HOUSING ESTATES USING GENERATED TRAFFIC DATA: THE AFRICAN UNIVERSITY OF SCIENCE AND TECHNOLOGY/ BRIDGE ESTATE, ABUJA, NIGERIA, AS A CASE STUDY

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ABSTRACT

The proposed Access Roads which will connect the Airport Road to the main gate of the African University of Science and Technology, Abuja, Nigeria and the proposed Bridge Housing Estate when constructed will foster broader community goals by promoting business activities within and around the University environment. Topographic data were taken, traffic count/ speed study and traffic volume forecast where carried out; minimum curve radii, curve lengths were calculated. The speed study for the Main Access Road gave the 85th percentile speed of 62.07km/hr. the corresponding traffic volume forecast gave an average daily traffic (ADT) of 1,137 for the Internal Access Road, 4,466 for the Main Access Road and a speed of 40km/hr and 60km/hr respectively. Therefore design speeds of 40km/hr and 60km/hr were adopted for the design. Minimum vertical curve length (Crest) calculated was 85m for the Main Access Road and 55m for the Internal Access Road. Minimum vertical curve length (sag) gave 140m for the Main Access Road and 115m for the Internal Access Road. The total earthwork volume for the two roads gave 7,832.8m^3 cut and 21,249.81m^3 fill. It therefore follows that the driving population affects road types and design speed, and design speed affects road curve lengths.

Keywords: AutoCAD, CivilCAD, Cross Section Elements, Design Speed, Internal Access Road, Main Access Road, Super-Elevation, Horizontal Alignments,Vertical Alignments,

1.0 INTRODUCTION

Geometric design of roads is the branch of highway engineering concerned with the positioning of the physical elements of the roadway according to standards and constraints. Geometric roadway design can be broken into three main parts: horizontal alignment, vertical profile, and cross-section which combine to provide a three-dimensional layout for a roadway (Hameed, 2013). The basic objectives in geometric design are to optimize efficiency and safety while minimizing cost and environmental damage [Federal Highway Administration, 2012) and Wook K. et al. 2013]. Geometric design also affects an emerging objective called "livability," which is defined as designing roads to foster broader community goals, including providing access to employment, schools, businesses and residences, accommodate a range of travel modes such as walking, bicycling, transit, and automobiles, and minimizing fuel use, emissions and environmental damage [Federal Highway Administration (2012) and Hameed (2013)].

Road design may be dated back to the existence of highways but many engineers still find it difficult to design safe roads. Many Nigerian road projects are still being contracted to foreign consultants for design and construction. We still have roads that are highly discomforting to road users, roads that are prone to accidents as a result of bad geometric design; roads that are inconsistent with design standards, hence this project work.

The aim of the work is to produce a geometric design of Access Roads for housing Estate using traffic generated data and with the objectives to carry out a Traffic study (speed/ volume count) and using generated data to produce working drawings and compute the earthwork volumes for cost planning using the CivilCAD software.

2.0 MATERIALS AND METHODS

Data collected include alignment photograph, topographic data, traffic data, population information and soil samples.

Methods of information collection include taking of alignment photograph using a digital camera, use of surveying equipment and manual soil sampling.

Photographs taken include both land and Google map photographs along the route of the proposed roads for knowledge of the route vegetation, terrain, water courses, existing facilities and housing settlements. Topographic survey data (coordinates and spot heights) were taken along the proposed road alignment, 5m beyond the corridor of the proposed road on both sides of the road center line using the Laica total station instrument. Soil samples were taken along the proposed roads alignment at 200m intervals and were transported to a laboratory for analysis to determine the material subgrade properties. Traffic speed /Volume study were carried out to determine the design speed.

Analysis and design were done using some of the most recent instruments and computer software in the engineering and construction industry; hence the reliability of this work.

3.0 RESULTS AND DISCUSSION

3.1 Topographic Data and Contour Map:

Topography data taken from the site along the proposed road alignment were used to produce the contour map that forms the basis for the geometric design using the CivilCAD software.

3.2 Design Speed and Volume Studies:

This is the speed determined for design and correlation of the physical features of a road that influence vehicle operations. According to the Federal Highway Administration, FHWA (2013). It is the safe maximum speed that can be maintained over a specified section of a road when conditions are so favourable that the design features of the road govern. It sets the limits for curvatures, sight distance and other geometric features. In sections where changes in terrain and other physical features are significant, a change in design speed may be necessary, according to Vehicle Speed Measurement on All Purpose Roads (1981). For the purpose of this design the traffic study and the traffic forecast methods were used to determine the design speed as shown in table 3.1 and table 3.2.

3.3 Traffic Volume Count:

A traffic study entails a count of vehicular or pedestrian traffic, which is conducted along a particular road, path, or intersection. A traffic count is commonly undertaken either automatically (with the installation of temporary or permanent electronic traffic recording device), or manually by observers who visually count and record traffic on a hand-held electronic device or tally sheets [Garber, N.J.; Hoel, L. A (2001) and FHWA (2013)]. Traffic counts can provide the source data used to calculate the Annual Average Daily Traffic (AADT). In (FHWA, 2013), traffic counts that include speeds are used for design speed in geometric design of similar functional roads.

In carrying out this traffic count, manual observers, count and record on a hand-held electronic device and tally sheets were used. The exercise which is primarily for the purpose of speed determination was conducted at the Access Road linking Stella Maris Schools, Godab Estate and ACO Estate, Life Camp in Kafe District Road.

3.3.1 Traffic Count Report: the traffic study was conducted using manual observers with digital watches who counted and recorded on a hand-held electronic devices and tally sheets. The result of the study is recorded as shown in table 3.1.

Total number of vehicles counted = 153nos

Total Cars counted = 125nos, Total Trucks counted = 28nos

Total number of vehicles sampled for speed determination (n) = 47 nos

Average Speed (D /t) = 54.10Km/hr (from table 3.1). Where D= distance between the entry point and the exit point (0.5km), t = time taking to move from entry point to exit point (hours)

3.3.3 The 85th Percentile Speed:

The 85th percentile is often used to determine the speed limits for roads. It is the speed below which 85 percent cars travel on a test road, and is figured to be the highest safe speed for that road. Federal Highway Administration (2013).

To determine this, arrange the car speeds in order from slowest to fastest and find the 85^{th} speed.

The vehicle sitting at the 85^{th} position of the 47^{th} ordered speed = $\frac{85}{100} \times 47 = 40^{th}$ position.

So, the 85^{th} percentile speed is the speed corresponding to number 40 in table 1 which is = 62.07km/hr.

Table 1. Traffic count report and 8th percentile determination

Count Location: Access Road linking Stella Maris Schools, Godab Estate and ACO Estate,
Date of count: 22^{nd} April 2019. Time of counting: 8:00am to 10:15am

CARS	Count dist.(km)	Entry Time	Exit Time	Time (sec)	Time (hr) = t sec/3600	SPEED (km/hr)	Speed (km/hr) in Ascending order
1	0.5	08:10:00	08:10:25	25	0.00694	72.00	34.62
2	0.5	08:15:00	08:15:26	26	0.00722	69.23	35.29
3	0.5	08:18:00	08:18:26	26	0.00722	69.23	36.00
4	0.5	08:22:00	08:22:32	32	0.00889	56.25	36.00
5	0.5	08:26:00	08:26:33	33	0.00917	54.55	38.30
6	0.5	08:30:00	08:30:31	31	0.00861	58.06	40.00
7	0.5	08:34:00	08:34:37	37	0.01028	48.65	40.72
8	0.5	08:38:00	08:38:41	41	0.01133	44.12	44.12
9	0.5	08:42:00	08:42:45	45	0.0125	40.00	44.12
10	0.5	08:46:00	08:46:47	47	0.01306	38.30	48.65
11	0.5	08:50:00	08:50:50	50	0.01389	36.00	50.00
12	0.5	08:54:00	08:54:52	52	0.01444	34.62	50.00
13	0.5	08:58:00	08:58:50	50	0.01389	36.00	50.00
14	0.5	09:02:00	09:02:51	51	0.01417	35.29	52.94
15	0.5	09:06:00	09:06:41	41	0.01133	44.12	52.94
16	0.5	09:10:00	09:10:34	34	0.00944	52.94	52.94
17	0.5	09:14:00	09:14:34	34	0.00944	52.94	52.94
18	0.5	09:18:00	09:18:44	44	0.01228	40.72	52.94
19	0.5	09:22:00	09:22:29	29	0.00806	62.07	52.94
20	0.5	09:10:00	09:10:34	34	0.00944	52.94	52.94
21	0.5	09:12:00	09:12:32	32	0.00889	56.25	52.94
22	0.5	09:14:00	09:14:34	34	0.00944	52.94	52.94
23	0.5	09:16:00	09:16:34	34	0.00944	52.94	52.94
24	0.5	09:18:00	09:18:30	30	0.00833	60.00	52.94
25	0.5	09:20:00	09:20:33	33	0.00917	54.55	54.55
26	0.5	09:22:00	09:22:34	34	0.00944	52.94	54.55
27	0.5	09:24:00	09:24:36	36	0.01100	50.00	54.55
28	0.5	09:26:00	09:26:34	34	0.00944	52.94	54.55
29	0.5	09:28:00	09:28:34	34	0.00944	52.94	54.55
30	0.5	09:30:00	09:30:34	33	0.00917	54.55	56.25
31	0.5	09:32:00	09:32:34	31	0.00861	58.06	56.25
32	0.5	09:34:00	09:34:34	32	0.00889	56.25	56.25
33	0.5	09:36:00	09:36:34	33	0.00917	54.55	56.25
34	0.5	09:38:00	09:38:34	34	0.00944	52.94	56.25
35	0.5	09:40:00	09:40:34	36	0.0120	50.00	58.06
36	0.5	09:48:00	09:48:27	32	0.00889	56.25	58.06
37	0.5	09:50:00	09:50:24	31	0.00861	58.06	60.00

38	0.5	09:52:00	09:52:27	33	0.00917	54.55	60.00
39	0.5	09:50:00	09:50:24	31	0.00861	56.25	60.00
40	0.5	09:52:00	09:52:27	33	0.00917	**60.00**	**62.07** (85th
41	0.5	09:55:00	09:55:34	32	0.00889	58.06	64.29
42	0.5	09:57:00	09:57:27	30	0.00833	60.00	66.18
43	0.5	09:58:00	09:58:27	31	0.00861	58.06	69.23
44	0.5	10:00:00	10:00:31	30	0.00833	72.00	69.23
45	0.5	10:02:00	10:02:27	31	0.00861	64.29	72.00
46	0.5	10:06:00	10:06:31	25	0.00694	66.18	72.00
47	0.5	10:07:00	10:07:31	28	0.00778	75.63	75.63
		Average speed				**54.1**	

Source: field work: 2019

3.4 Traffic Volume Forecasts:

This method makes use of the estimated projected population (Road users) and motorisation to calculate road width and design speed. The area under study is comprised of two zones; zone 'A' is a residential area (the estate) and zone 'B' is the academic area. This method applies table2 below, which forecast the Average Daily Traffic (ADT) from human population in the housing estate, assuming 70% of the population to own cars while number of trips per person per day is 1.8. (FCDA, 1981) and Sofretu, 2000). The building units and population are taken from the estate planner (TPL. Olusegun, S.O).

Table 2. Population/Traffic computation Table

Zones/ Land Use	Building Type	Building Units	Persons/ building	Population	Motorization (70% Max)	Trips/ Person/ Day (1.8)	Average Daily Traffic (ADT)
Zone A	5-Bedroom Terrace	28	7	196	137.2	246.96	247
Residential	4-Bedroom Terrace	22	6	132	92.4	166.32	166
	3-Bedroom Terrace	32	5	160	112	201.6	202
	2-Bedroom Terrace	34	5	170	119	214.2	214
	4-Bedroom Duplex	8	6	48	33.6	60.48	61
	3-Bedroom Duplex	12	6	72	50.4	90.72	91
	Visitors (5% total pop.)			44.5	31.15	56.07	56
				822.5			**1,137.00**
Zone B	Offices- Single	21	24	504	353	636	635
Academic	Offices-General	15	60	900	630	1,134.00	1,134.00
	Social Arenas	5	45	225	157.5	283.5	284
	Classrooms	23	36	828	579.6	1,043.30	1,044.00
	Library	2	26	52	36.4	65.52	66
	Services/ Business Trips (5% of Total Population)			122.5	85.75.5	154.35	166
TOTAL- Zone B				**2,326.50**			**3,329.00**
GRAND TOTAL				**3,201.00**			**4,466.00**

Source: university/Estate developer

Table 3. Traffic Forecast summary table and lane capacity calculation

SN	Roads	Average Daily Traffic (ADT)	Lane capacity (PCU'S/HR) = (ADT/8hrs)
1	Main Access Road	4,466	559
2	Internal Access	1,137	143

Source: Calculated

The average daily traffic (ADT) is computed as in table 2 above while the lane capacity (passenger car unit per hour) is calculated by dividing the average daily traffic (ADT) by the active daily traffic hours (8hours) in Pcu/hr in table 3. The calculated ADT and PCU in table3 are used to select the design data from table 4.

4.0 GEOMETRIC DESIGN

4.1 Lane width and Cross Section Design:

Current AASHTO Width Criteria Width-related elements of rural highway include roadway features (lanes and shoulders) as well as roadside features (fore slopes, ditches, back slopes). Federal Capital Development Authority, FCDA (1981) and Transport and Road research Laboratory (1988). Table 4. below presents the road width, maximum gradient and maximum design speed for the various ranges of average daily traffic flow, terrain and road functions. Main Access Road will be two lanes of 3.65m width each and a 3.0m parking lane, while the Internal Access Road will be two lanes of 3.0m width each.

Table 4. Guidelines for Design of Infrastructural Services, FCDA, January 1981.

DESCRIPTION	ROAD CLASSIFICATION				
	ARTERIAL ROADS	**COLLECTOR ROADS**	IMPORTANT STREET ROADS	LOCAL STREET ROADS	MINOR STREET ROADS
Design Speed (Km/hr)	80	**60**	50	50	**40**
Lane Capacity (Pcu's/hr)	700	**600**	500	400	**<400**
Through Lanes (both direction) (Nos)	6	**2**	2	2	**2**
Lane Width (M)	3.5	**3.65**	3.65	3.65	**3**
Parking lane width (m)	3	**3**	2.5		
Shoulder width (m)				2.5	**2.5**
Median width (m)	6	**3**			
Verge/Plant Bed (m)	2.5	**2**	2	2	**2**
Bicycle track width (m)	2.5	**3**			
Road cross-fall (Camber) %	2.5	**2.5**	2.5	2.5	**2.5**
Sidewalk width (m)	2.5	**3**	3		
Vertical clearance (AASHTO) (m)	5	**5**	5	5	**5**
Horizontal curve radius-minimum (m)	229	**113**	73	73	**73**

Vertical curve K Value (=L/A) Min crest	26	**11**	7	7	**7**
Vertical curve K Value (=L/A) Min SAG	30	**18**	13	13	**13**
Maximum grade (%)	7	**8**	9	9	**8**
Upgrade (minimum) %	0.35	**0.35**	0.35	0.35	**0.35**
Grade difference (A) (%)	6.65	**7.65**	8.65	8.65	**9**
Super-elevation rate-Maximum (%)	8	**8**	8	8	**8**

Source: Federal capital development Authority, Nigeria

4.2 Horizontal Alignment Design:

The tables below are vital in calculating the horizontal alignment curve data

Table 5. AASHTO Coefficient of lateral friction. AASHTO (1984).

Design speed (Km/hr)	50	65		80	100	110	120
Max. lateral friction (f)	0.16	0.15		0.14	0.12	0.10	0.09

4.2.1 Minimum Horizontal Curve Radius:

The horizontal curves calculated below will be the minimum value of radius at which a vehicle moving on the main access road will travel to avoid discomfort to the motorist,

Using the formula, $$R = \frac{v^2}{127(e+f)}$$

Where R= horizontal curve radius, V= Design speed (Km/hr)

e = Super-elevation rate, f = coefficient of lateral friction

4.2.2 Main Access Road:

So, for the Main Access road $$R = \frac{60^2}{127(0.08+0.15)} = \frac{3,600}{127(0.23)} = 3,600/29.21 = 123.25\text{m}$$

A radius of 125m minimum should be used for the Main Access Road

4.2.3 Internal Access Road:

Also, for the Internal Access Road $$R = \frac{40^2}{127(0.08+0.16)} = \frac{1,600}{127(0.24)} = 1,600/30.48 = 52.9\text{m}$$

A radius of 73m should be adopted being the minimum specified in table 4.

4.3 Super-elevation:

Garber, N.J. and Hoel, L. A. (2001) defines superelevation as the banking provided on roads to resist the centripetal force on the vehicles while travelling along the curves. This can be calculated by;

$$S = \frac{v^2}{2.824R}$$

Where V= Design speed (Km/hr) and R = Curve radius (m)

4.3.1 Main Access Road:

Maximum Super-elevation for the Main access road

$$S = \frac{60^2}{2.824*150} = 3600/423.6 = 8.5\%$$

From Table 4. the maximum allowed is 8%, so super-elevation of 7% will be adopted for this design.

4.3.2 Internal Access Road:

Maximum Super-elevation for the Internal Access Road

$$S = \frac{40^2}{2.824*73} = 1600/207.32 = 7.7\%$$

From Table 4. the maximum allowed is 8%, so super-elevation of 6% will be adopted for this design.

4.4 Vertical alignment design data:

Two types of vertical curves exist: (1) Sag Curves and (2) Crest Curves. Sag curves are used where the change in grade is positive, such as valleys, while crest curves are used when the change in grade is negative, such as hills. Garber, N.J. and Hoel, L. A. (2001). Both types of curves have three defined points: PVC (Point of Vertical Curvature), PVI (Point of Vertical Intersection), and PVT (Point of Vertical Tangency). PVC is the start point of the curve while the PVT is the end point of the curve.

4.4.1 Crest Vertical Curve Data:

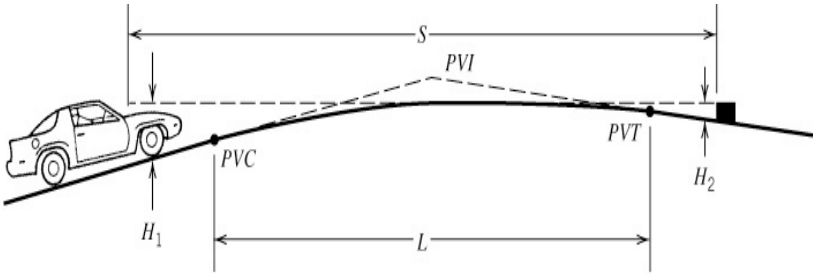

Fig 1. A Typical Crest Vertical Curve (Profile View)

Where L = curve length (m), A= algebraic grade difference (%)
S= sight distance for passing or stopping, H_1 = height of drivers eye above the road
H_2 = height of object above the roadway

4.4.2 Crest curve length -Main Access Road:

To calculate the minimum crest curve length, the formula L= KA is used
Where L= curve length
K= 11 (from table 4.1), A= 7.65 (from table 4)
So, L= 11*7.65 = 84.15m,
Minimum crest curve length of 85m will be used for the design of the main access road.

4.4.3 Crest curve length -Internal Access Road:

To calculate the minimum crest curve length, the formula L= KA is used
Where L= curve length
K= 7 (from table 4), A= 7.65 (from table 4)
So, L= 7*7.65 = 53.6m,
Minimum crest curve length of 55m will be used for the design of the internal access road.

4.4.4 Sag Vertical Curve Data:

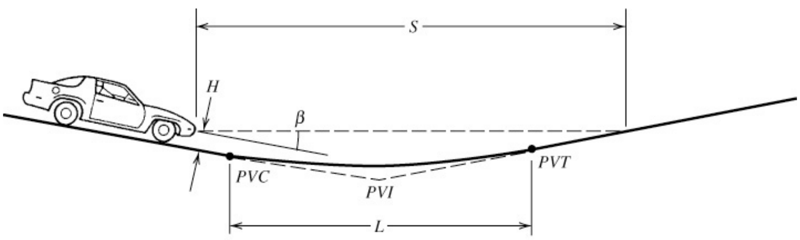

Fig 2. A Typical sag Vertical Curve (Profile View)

When sight distances that is greater than the curve length; S> L

Where L = curve length (m), A= algebraic grade difference (%)

S= sight distance for passing of stopping, H = head light height above roadway

β = upward divergence of headlight beam/ degree

4.4.5 Sag curve length -Main Access Road:

To calculate the minimum crest curve length, the formula L= KA is used

Where L= curve length, K= 18 (from table 4),

A= 7.65 (from table 4.), So, L= 18*7.65 = 137.7m,

Minimum sag curve length of 140m will be used for the design of the main access road.

4.4.6 Sag curve length -Internal Access Road:

To calculate the minimum crest curve length, the formula L= KA is used

Where L= curve length, K= 13 (from table 4)

A= 8.65 (from table 4), So, L= 13*8.65 = 112.45m,

Minimum sag curve length of 115m will be used for the design of the internal access road.

4.4.7 Summary of designed data:

Table 5 below summarises the generated data, results of all design and standard specifications with which the software produced the working drawings.

Table 5. summary of design parameters (Calculated, generated and standard specifications)

Description	Road Information/ Design Figures	
Road name	Major Access Road	Internal Access Road
Road classification	Collector roads	Important street roads
Traffic flow (ADT)	4,466	1,137
Design Speed (Km/hr)	60	40
Lane Capacity (Pcu's/hr)	600	400
Through Lanes (both direction) (Nos)	2	2
Lane Width (m)	3.65	3
Parking lane (m)	3.0	-
Sidewalk width (m)	1.5	2
Verge (m)	2	1.5
Road cross-fall (Camber) %	2.5	2.5
Vertical clearance (AASHTO) (m)	5	5
Horizontal curve radius- min. (m)	150	75
Vertical curve K Value (=L/A) Min crest	11	7
Vertical curve K Value (=L/A) Min SAG	18	13

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Maximum grade (%)	8	9
Upgrade (min.) %	0.35	0.35
Grade difference (A) (%)	7.65	8.65
Vertical curve length- crest min. (m)	85	55
Vertical curve length- sag min. (m)	140	115
Super-elevation rate- Max (%)	7	6

Source: Generated Data, 2019

The drawings so produced include the General Layout with all the horizontal alignment information shown in fig. 3, the Vertical Alignment Profiles in fig. 4 and 5, And the typical cross sections elements in fig. 6.

4.5 DESIGNED DRAWINGS

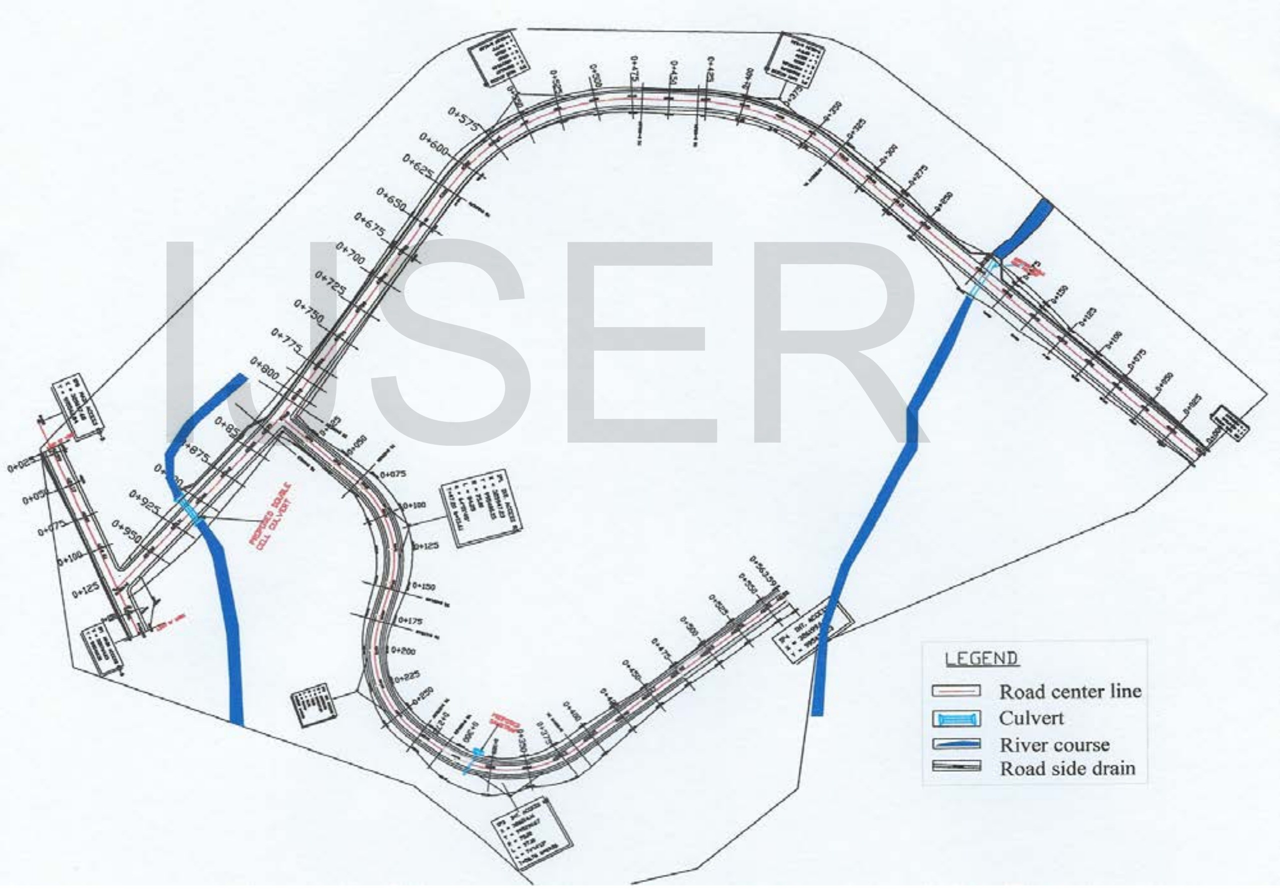

Fig. 3. General Site Layout

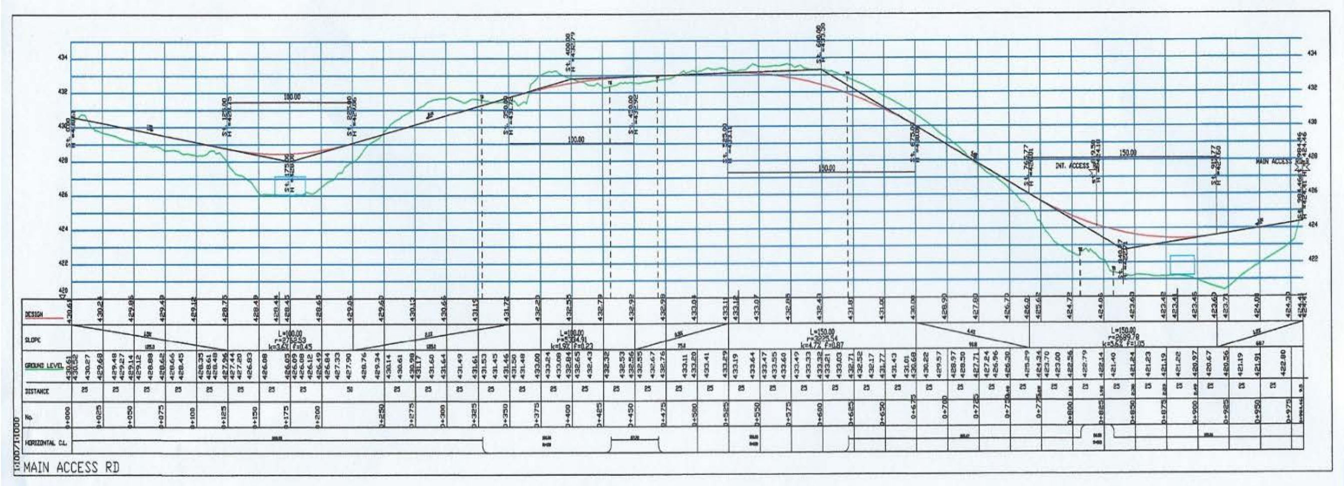

Fig. 4. LONGITUDINAL PROFILES- Main Access road

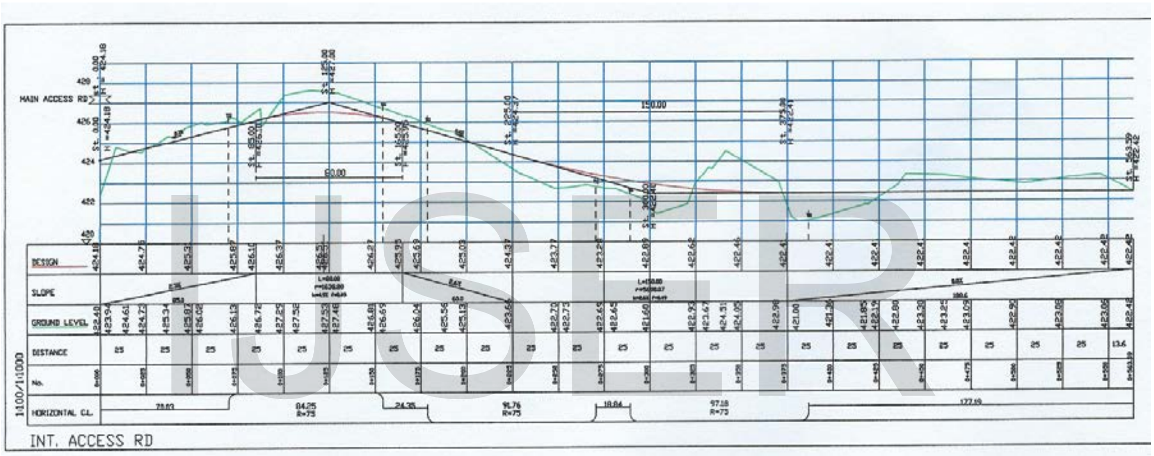

Fig. 5. longitudinal profile -Internal Access Road

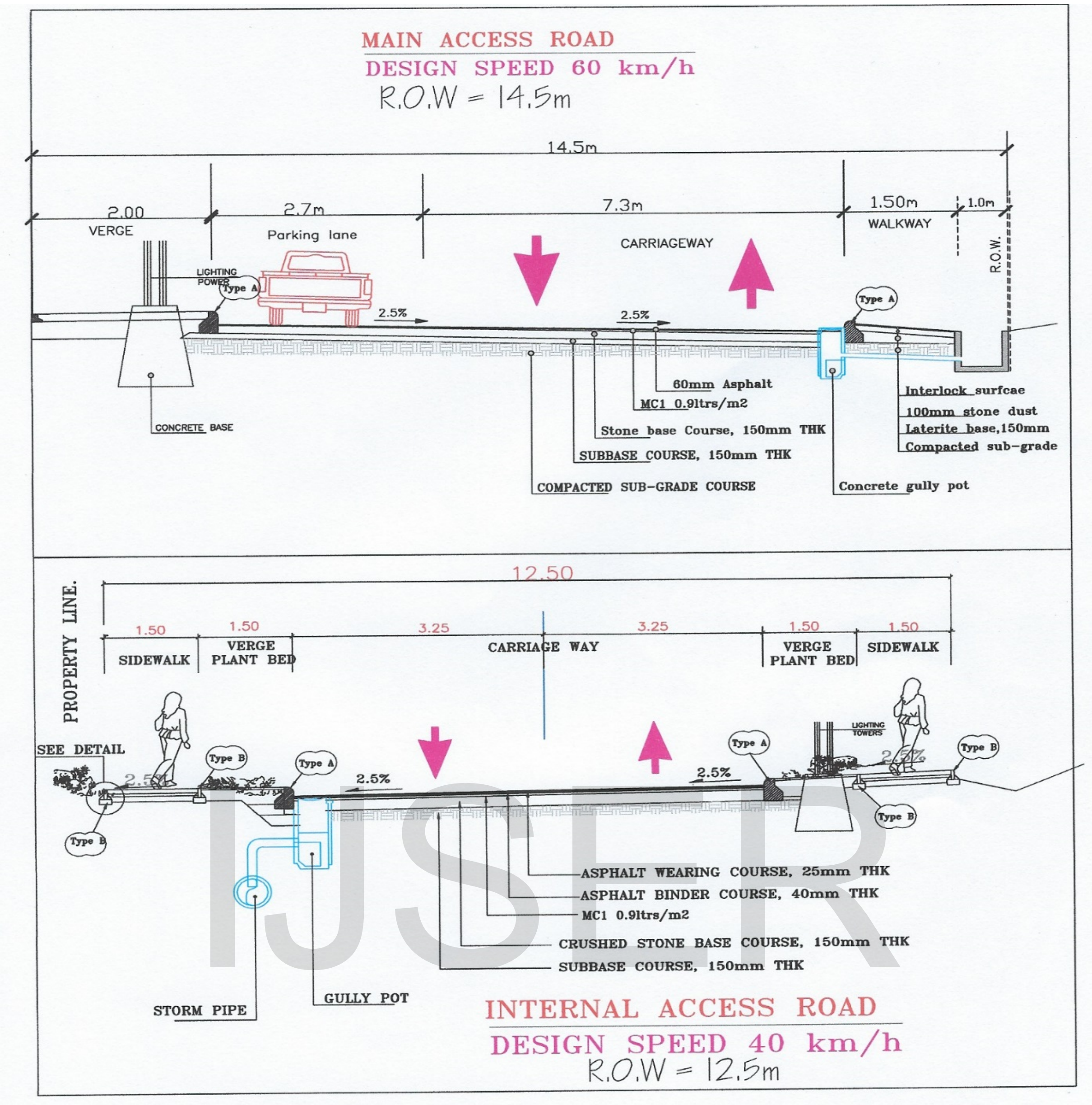

Fig. 6. Typical road cross section- Main Access Road and Minor Access Road

4.6 Earthwork Volume

Below shows the summary of the earthworks volumes as computed with the software.

Table 6. Earthwork Volume Summary

Road	Quantities	
INT. ACCESS RD	Cut volume (m3)	Fill volume (m3)
	3,487.31	3,686.75
MAIN ACCESS RD	Cut vol. (m3)	Fill vol. (m3)
	4,345.49	17,563.06
	7,832.80	**21,249.81**

Source: Generated volume, 2019

4.7 Interpolation/Curves data Informations (for setting out)

The figures in table 7 and 7b below presents the software generated design information for beginning chainage, end chainage and at all curves

Table 7. Internal Access Road - Center Line data

Station	Geometric data	X Y
2IP0 St. 0.000 2IP0..2IP1	 D = 381.687 az = 311_58'38"	326479.677 995532.976
2IP1 TG St. 328.346 TG St. 430.844	 L = 102.498 R = 150.00 <- - - T = 53.341 a = 39_9'6"	326195.926 995788.261 326235.580 995752.585 326142.650 995790.891
2IP1..2IP2	D = 174.472 az = 272_49'33"	
2IP2 TG St. 468.629	 L = 152.150 R = 150.00 <- - - T = 83.347 a = 58_7'1"	326021.666 995796.862 326104.911 995792.753
TG St. 620.779 2IP2..2IP3	 D = 282.115 az = 214_42'32"	325974.208 995728.346
2IP3 TG St. 806.254	 L = 26.549 R = 200.00 - - - > T = 13.294 a = 7_36'21"	325861.028 995564.947 325868.598 995575.875
TG St. 832.803 2IP3..2IP4	 D = 164.954 az = 222_18'53"	325852.078 995555.117
2IP4 St. 984.463		325749.981 995442.970

Table 7b. Internal Access Road - Center Line data

Station	Geometric data	X Y
6IP0 St. 0.000 6IP0..6IP1	 D = 117.229 az = 132_25'57"	325860.701 995565.245
TG St. 154.284 6IP1..6IP2	 D = 124.155 az = 196_47'42"	325933.588 995440.965
6IP2 TG St. 178.629	 L = 91.761 R = 75.00 <- - - T = 52.614 a = 70_6'2"	325911.351 995367.289 325926.553 995417.658
TG St. 270.391 6IP2..6IP3	 D = 128.216 az = 126_41'40"	325953.538 995335.850
6IP3 TG St. 289.233	 L = 97.176 R = 75.00 <- - - T = 56.760 a = 74_14'13"	326014.159 995290.674 325968.647 995324.591
TG St. 386.409 6IP3..6IP4	 D = 233.946 az = 52_27'27"	326059.164 995325.261
6IP4 St. 563.595		326199.655 995433.229

Note: D= distance, L= Tangent length, R= radius, az= bearing and a= angle

5.0 CONCLUSION

In conclusion, for traffic safety, comfort and economy the expected driving population on a road must be correlated with the road type (road width and number of lanes) and the design speed. The design also shows that the higher the driving population, the higher the average daily traffic (ADT), hence the lane properties. Higher design speed also require larger curve radii (for both horizontal and vertical curves) for driving safety. And for every increase of average daily traffic (ADT) by 1,500 the roads type (road width and road lanes properties) changes.

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