



# Customized Design of a Proposed Alignment at MAU Yola Campus in Civil 3D Using Nigerian Federal Ministry of Works Highway (FMWH) Manual

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**Abstract:** This study tested the capability of Civil3D to design a carriageway using FMWH Manual. For this purpose, the guidelines outlined in the manual were accommodated. The route under consideration is a proposed dual carriageway alignment at Modibbo Adama University (MAU) Yola, Adamawa State, Nigeria. Methodology focused on field work, data acquisition, and roadway alignment design. Data for this project was obtained directly from the field using conventional ground survey method, Google Earth, GARMIN GPSMAP64 Hand Held GPS, and Kern-Swiss K1-M 292272 Theodolite. Reduce level was computed using Microsoft excel and the output was imported into the design software (Autodesk Civil 3D V.2023) as a dot csv (.csv) data file known as PENZD.csv. A simple horizontal circular curve with a radius of 200m was designed at chainage 0+268.55 to 0+290.41 between two tangents. Two Sag curves at chainages 0+160.95 and 0+655.33 were designed for the vertical alignment. A trapezoidal channel was provided to discharge storm water and also, a single cell box culvert to be sited at chainage 0+524 to 0+532.5. Equally, a pipe culvert was proposed at 0+722 to 0+723. QR Code for data used is also presented. The results indicate that the designed alignment was adequate and economical based on FMWH Manual.

**Keywords:** Road alignment design, FMWH Manual, Civil3D, MAU Yola, horizontal & vertical alignment

## 1. Introduction

Road is essential part of infrastructure services such as such as railways, bridges, tunnels, water supply, electric grids, telecommunications, etc. Roadways are the commonest means of transportation. Apart from their low - cost, the socio-economic importance cannot be over emphasized. They are responsible for increasing the rate of urbanization in rural areas. Benefits of roadways to society cannot be overemphasized because of the improvement in the provision of services such as education, healthcare, agricultural extension, etc. They connect people together, and convert village to cities, and megacities [1]. However, this requires adequate design of the road furniture and its appurtenances.

Design of roadway geometry involves creating and plotting the road alignment profile using easting and northing coordinates obtained from route survey. Parameters required includes stations and elevations of points along the proposed route; calculation of sight distances, radii of horizontal curves, and lengths of vertical curves; computation of earthwork quantities, and numerous other analyses and calculations aimed at finding the optimum alignment while

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satisfying design standards and constraints. Road horizontal alignment is one of general features having a significant impact on driving and safety. It consists of straight segments (tangents) connected by horizontal curves (and other transition elements). Specifically, curves are places of special interest because of the higher risk of a traffic accident due to additional centripetal forces exerted on a vehicle, driver expectations, and other factors [2].

Automation in design and construction has simplified road alignment design process, a deviation from time-consuming and cumbersome manual design. The road geometry orientation provided in 2 - D plane to the center line of road on the ground presenting the horizontal and vertical planes is called the alignment of road. Horizontal alignment suggests the direction of the track and includes straight path and curves (XY Cartesian plane). Vertical alignment defines the elevation, rise and fall within the vertical plane including level track, gradients and vertical curves (The Z component). The cross section shows the position and number of vehicle and bicycle lanes and sidewalks, along with their cross slope or banking. Cross sections also show drainage features, pavement structure and other items outside the category of geometric design. The selection of alignment broadly depends upon the choice of gauge, dominant points, topography of the location, geological formation, climatic conditions and flood impact on the particular chosen area. The alignment of road should be so chosen that the development cost is least. This is only workable by providing balanced cuts and fill of earthwork, limiting rock cutting and drainage crossing. The alignment should be designed such that it provides safety to the users or merchandise. This can be attained by providing curves with appropriate transition lengths, designing vertical curves for gradients and incorporating other technical features [3 - 4].

The plan view gives the horizontal alignment of a highway where the length expressed in terms of distance from a reference station, as 'stations.' Each station is 100 m. Distance from a reference station, and direction of the reference station describes the horizontal alignment. The vertical alignment is given in the profile view, and the latter is the view along the length of the highway. Elevations are also specified in the profile view.

Geometric design governs the safety, efficiency and economic considerations in design and operation of a highway [5]. The work of Neeraj and Kazal [6] further reinforced this notion, that the importance of planning and design of geometric features of the highway during the initial alignment consideration cannot be overemphasized. This involves taking into consideration the future growth of traffic flow and possibility of the road being upgraded to a higher category or to a higher design speed standard at a later stage. In this regard, route location has been identified as major factor that can lead to early alignment deterioration [7].

In Ahmadu et al. [8], remedies for early deterioration of constructed roads in Nigeria were investigated. Route location, data acquisition, and geometric design were considered as parameters to be studied. They also recommended route survey and design for all proposed roadways. Studies (9 - 10) have also been conducted on the geometric design parameters using superhighway theory, and on rural horizontal curve speed.

A variety of survey methods are available to be used for generating maps and terrain models, and they are dependent on the type of equipment for the survey. A technique that is gaining wide acceptance is Digital Elevation Modelling (DEMs) which present terrain's surface in 3 - D with man-made features and vegetations. It can also be used to represent surfaces of other planets such as the moon or asteroids [11 - 12]. DEMs are differentiated from other models in that, they show accurately how the morphology is presented. They are used in Geographic Information Systems (GIS) and are the most common basis for digitally-produced relief maps. DEMs have the advantage that elevation is available continuously at each location in a study area. The use of Light Detection and Ranging (LiDAR), Interferometry Synthetic Aperture Radar (IfSAR) and satellite mapping such as GTOPO, SRTM, ASTER GDEM1, ASTER GDEM2 are very common nowadays [13].

To obtain alignment data GPS technology has been used recently to collect alignment data for these purposes and various authors have used different approaches for obtaining alignment parameters from GPS data [14]. Nevertheless, each method has its disadvantages such as limited accuracy or dependency on manual processing. Often a combination of manual and automatic identification is used; a universal automated method of road alignment inference does not exist [15 - 16].

The need to provide connectivity, better-performance as well as a befitting grand entrance for the university necessitated this study. Also, the need to overcome the limitations of overtaking and parking on road sides along the present MAU main entrance is worth considering. Since dualization of the existing road was impermissible, a new virgin site was proposed for the alignment design of MAU main entrance. However, existing design process/procedures takes into account parameters and design standards outside the shores of Nigeria. This study presents an alignment design for the proposed road using Computer Aided Design Software (Autodesk Civil 3D V.2023) with the aid of Nigerian Road Design manual, both geometry and material properties.

## 2. Objectives & Significance of the Study

The objectives of the study are to provide a detail design and plan for the alignment, estimate the volume of earthworks, and to provide or recommend an appropriate drainage for the alignment. The significance of the study is in the area of proper planning and future development of the route, and update to the existing campus master plan. Outcome of the study will be of immense benefit to the Directorate of Physical Planning, MAU. Similarly, it will also serve as a resource material for instructors in teaching Computer Aided Courses in Civil Engineering.

### 3. Methodology and Study Area

The study was carried out at Modibbo Adama University (MAU) Yola, Girei Local Government in the North Eastern part of Nigeria in zone 33 of the Universal Traverse Mercator system (UTM-WGS 1984 datum, Zone 33 North, Meter; Cent. Meridian 15d E) which is located between Latitude  $9^{\circ} 20' 16''$  N North of the Equator and Longitude  $12^{\circ} 29' 20''$  E East of Greenwich meridian to the Northern part of River Benue. Adamawa state lies between latitude  $09^{\circ} 20' N$  and longitude  $12^{\circ} 30' E$  with Yola as its capital, and has a total area of about 36,917sqKm.

#### 3.2 Design Elements Activities

The following are specific order of activities to be executed, and they are presented as follows:

##### 3.2.1 Route Location

The proposed route is located in the Future Development Area of MAU, Yola, and is the proposed main entrance of the university off Mubi - Yola Road, and spans about 1 Km.

##### 3.2.2 Office Study

All available data on the proposed area in which the road is to be constructed was examined. These data were obtained from the University Master Plan from the Directorate of Physical Planning, MAU Yola, as well as the use of Google Earth. This was to consider alternative sites that might be suitable.

##### 3.2.3 Reconnaissance Survey

Reconnaissance (usually referred to as recce) being the first thing to be done in any survey operation. This was carried out with the help of survey assistants, with the sole aim of deciding and selecting points to be established as control stations and taking into consideration the inter-visibility between the survey stations. In this phase of study, several feasible routes, each within limited width of a few meters were explored. This was done by physically visiting the site and evaluating all alternative routes base on the following;

- Terrain.
- Serviceability of the route.
- Crossing of other facilities such as rivers, electric utilities.
- Directness of route.
- Vegetation of the area and physical condition of the soils.

The report on site investigation and coordinates & Height of Final Control stations are presented in the appendix.

##### 3.2.4 Preliminary Location Survey

In here, the exact positions of the feasible routes were set by establishing control points (see Appendix). Three (3) stations were established to serve as controls for this project work. The control points were numbered A, B & C and were established with inter-visibility between the adjacent stations. Their distances were within an acceptable range i.e., no distance between two adjacent stations should be 400m apart. Also, the positions of structures and drainage channels were noted.

##### 3.2.5 Final Location Survey

The phase of the survey was to establish detailed layout of the chosen route. Kern-Swiss (K1-M 292272) analogue theodolite was use to traverse survey point and to range and establish intermediate points. These points were measured with a linen tape and were peg 25m longitudinally and at 6m & 12m perpendicular to the center line both Left and right sides. The horizontal and vertical alignments were then determined by incorporating spot elevations taking with their respective northing and easting in Autodesk Civil 3D Version 2023.

##### 3.2.6 Design Standard

The design standard used were the Federal Ministry of Works Highway Manual Part I Volume I Geometric Design and Volume V Drainage Design.

##### 3.2.7 Method of Data Collection

Data acquisition implies survey coordinates for control extension purpose in a compatible form, and geometric data were collected in digital form. Data used for this study were obtained directly from the field using conventional ground survey method, and plate vial test was carried out on the instruments to ensure accuracy of data recorded to ensure that the bubble is not off its Centre of run during the course of the survey because of its sensitivity to temperature. Reduce

level was computed using Microsoft excel and the output was imported into design software (Autodesk Civil 3D V.2023) as a dot csv (.csv) data file known as PENZD.csv.

Google Earth was used to acquire satellite imagery for preliminary reconnaissance survey and control points, and to also explore how economic feasibility of the alignment taking into consideration intervisibility between survey stations, directness & serviceability of the route, crossing of other facilities such as rivers & electric utilities etc. Google Earth is also simple to operate and is easily accessible.

A Handheld GPS was used to record the northing and easting of the control points which serves as baseline. Theodolite was used to tie Natural Ground Level (NGL), establish from the first principle by taking Field Short Data (FSD) of elevation of established point along the baseline using a dumpy level (SUN DSC232) to obtain the true level of the alignment. Other points northing and easting were located by taking successive offset from the baseline in Autodesk Civil 3D, and their appropriate reduced levels from FSD were attached to them. Also, deflection angles of the centreline of the proposed alignment were obtained from the software.

### 3.2.8 Instrument and Materials Used for Data Collection

The following were the Instruments used in the data acquisition;

- Google Earth
- Dumpy Level (SUN DSC232)
- Tripod 2Nos.
- Levelling Staff
- Theodolite (Kern swiss K1-M 292272)
- Ranging Rods 3Nos
- Handheld GPS
- Linen Tapes (50m) 1Nos. & Steel band tape (7.5m) 1Nos.
- Cutlass 1 Nos.
- Wooded Pegs
- Hammer
- Umbrella
- Caution Tape

### 3.2.9 Application Used

- Autodesk Civil 3D V.2023
- Microsoft Office Excel
- Microsoft Office Word

### 3.2.10 Design Criteria

Design criteria based on the Nigerian Federal Ministry of Works Highway Manual [17]; was proposed and parameters assigned based on the following:

- i.Design speed = 50 km/h
- ii.Type of Road = Class D Minor Road; Dual Carriage road
- iii.Super elevation rate = 6%
- iv.Friction factor  $f = 0.19$
- v.Minimum Stopping Sight Distance = 70 m
- vi.Maximum grade = 6%
- vii.Minimum K (rate of vertical curvature) for crest curves = 7
- viii.Minimum K (rate of vertical curvature) for sag curves = 13
- ix.Right of way = 24m
- x.Width of formation Roadway width = 18.8 m
- xi.Lane width = 3.65 m
- xii.Shoulder width = 1.2 m
- xiii.Median width = 1.8 m

### 3.2.11 Method of Data Analysis

In the design software (Autodesk Civil 3D V.2023), units and zone were set appropriately to match field observation data from the Drawing Setting menu i.e (Zone = UTM-WGS 1984 datum, Zone 31 North, Meter; Cent. Meridian 3d E). The Northing and Easting of final control points were entered into the design software and using the alignment creation tool from the home tab in the create design panel, straight line alignment was drawn by linking the control point. Using the command "CREATEPOINTDIVIDEALIGN" points that are equally spaced at an interval of

25m were generated along the centre line of the alignment. These points were then exported to a PEN.txt file containing Point No., Easting and Northing of the generated points.

These file (PEN.txt) was extracted to Microsoft Excel and were place into columns. Additional column of elevation & description was created where reduced level of FSD was entered against there respective Northing and Easting and a description of CL was append to the points. These same procedures were repeated for perpendicular offset point that are 6m & 12m on both Left and Right of the Centre Line; and an appropriate description of L1, L2, R1 & R2 were appended to the points (see Appendix).

The Microsoft Excel file was then saved as a dot csv ( .csv) data file known as PENZD data file containing columns of Point No., Easting, Northing, Height, and Description.

### 3.2.12 Geometric Design with FMWH Manual

Conventional geometric design is based on AASHTO using criteria-based design, however, to customized the software using FMWH Manual, it has to be modified. Below outlines the method and procedures that were follow to realize the objectives of these study.

- A new workspace was created in the design software and units and zone were set to Meters and Minna Datum respectively from the drawing-settings-menu to enable coordinate transformation from UTM-WGS84 Datum.
- The PENZD.csv file was imported into the model work space. From the inset tab- and import panel by clicking the Point-from-file button. Appropriate point group was then created and point styles were then applied to the points.
- Existing ground surface was Modelled/created from the home tab in create ground data panel.
- Alignment was created by linking straight line tangents to Point of Intersection (PI) and assigning a suitable horizontal curve to the tangents using alignment creation tool from the home tab in the Create Design panel.
- Design criteria base on the Federal Republic of Nigeria Federal Ministry of Works Highway Manual (2013) (FMWHM) was loaded into the software by modifying the existing AASHTO 2011 criteria with corresponding extracts from the FMWHM.
- Existing ground profile generated using the profile creation tools of the Home tap from the create design panel.
- Formation level (finished grade) was created using the profile creation tools.
- Assembly defines the cross-sectional component, was created by connecting subassembly objects.
- Finally, the corridor which shows the resulting dynamic 3D model from combination of the design elements. These was done by clicking corridor from the home tab in the create design panel.
- Calculate the volume of earthworks and extract information of cut and fill from the Analyze tab-Volumes and Material Panel- Volume report.

### 3.2.13 Importing Federal Ministry of Works Highway Manual into Civil 3D

Design criteria sub-menu in Civil 3D contains standards tables for parameters mentioned in Section 2.2.10, i.e., the minimum design standards for alignment and profile objects. This file includes criteria to support automatically adding widening to dynamic offset alignments. A flowchart of activities is provided in fig. 1 describing the series of activities. In situations where local agency standards is different from standards in supplied design criteria file (i.e., AASHTO to FMWH Manual), the file can be customized to reflect the local agency requirements/design standards through Design Criteria Editor; Which is a dialogue box that provides an interface for making modification to the design criteria XML file.

- 1 To access the Design Criteria Editor Dialog Box;
  - a. From the command prompt text box, type “DesignCriteriaEditor” without the quotation marks nor space, and press enter key on the keyboard.
  - b. Or click an alignment or profile in a drawing which opens up a contextual ribbon. From the contextual ribbon > Modify Profile panel > Click Design Criteria Editor.
- 2 To import a pre-configured design criteria file, click “Open” in the design criteria Editor dialog box and browse through the location of the file and select it by double click.
- 3 Click “New Button” to create an untitled design criteria file containing Units, Alignments and Profiles nodes in the design criteria hierarchy panel.
- 4 To edit the default AASHTO design criteria, from the Design Criteria Editor dialogue box; click “Expand all” button to expand all folders/nodes into tree view in design criteria hierarchy panel on the left side of the dialog box.
- 5 Edit contents of the design criteria file as desired.
 

To create new tables and folders in the tree view, right-click the desired node and use the commands on the context menu.

To rename a table in the tree view, double click on the table-name an input a new name, then press enter key on the keyboard.

The table contents are displayed withing attribute Columns in grid view on the attribute panel (right side of the dialog box).

Attribute Columns specify the attributes for the currently selected criteria table. Values in the individual cells are editable.

To edit a value in the grid view, double-click the value.

To add a row to a table, click “+” icon.

To remove a row from a table, click “X” icon.

- 6 Click “Save As”, input a name (e.g., FMWH Design Standards 2013 Metric) and finally click “Save” to save the design criteria file with the new changes in form of .XML file format. Close the Design Criteria Editor dialog box.

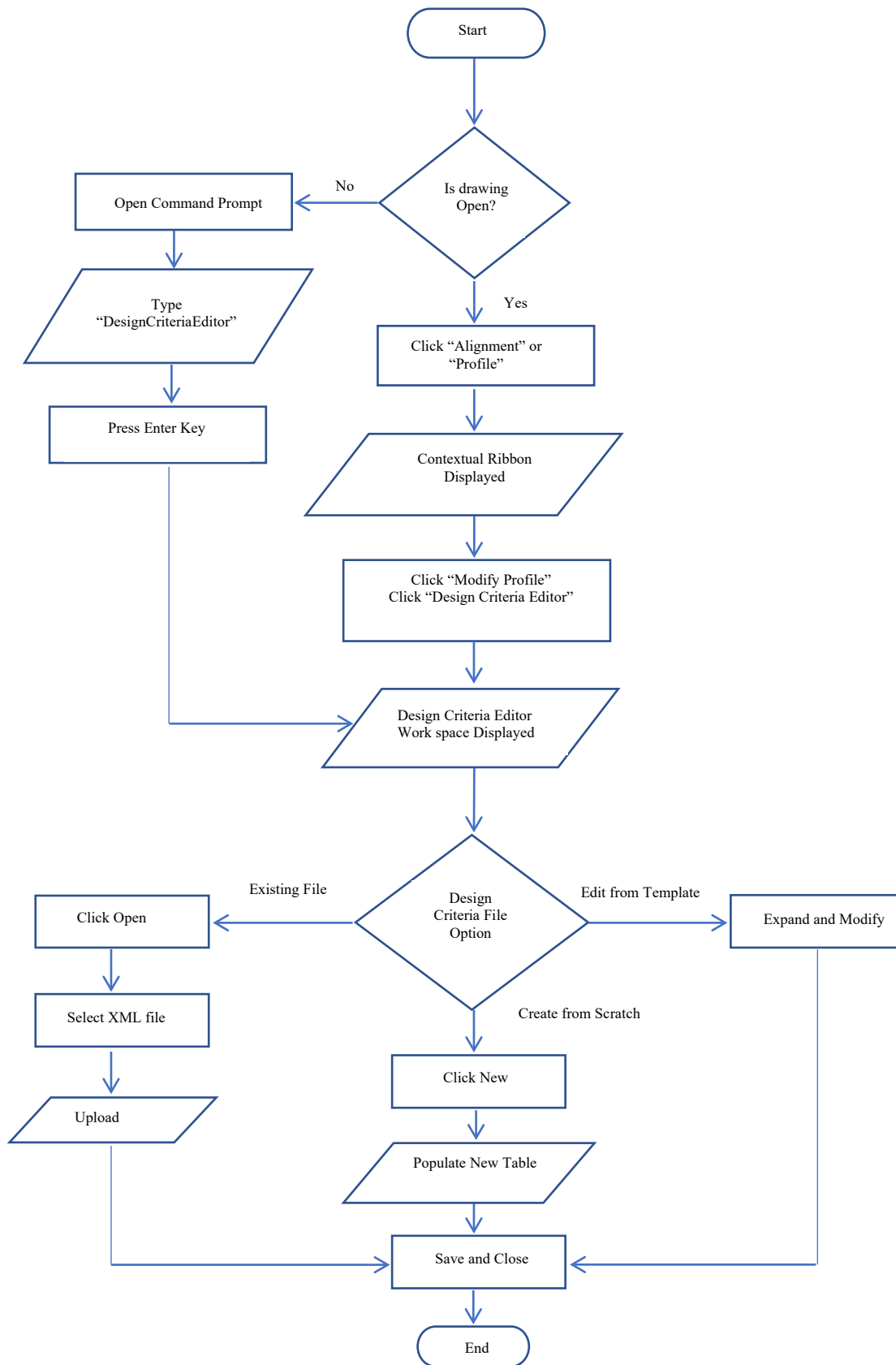
Attribute Columns specify the attributes for the currently selected criteria table. Values in the individual cells are editable.

To edit a value in the grid view, double-click the value.

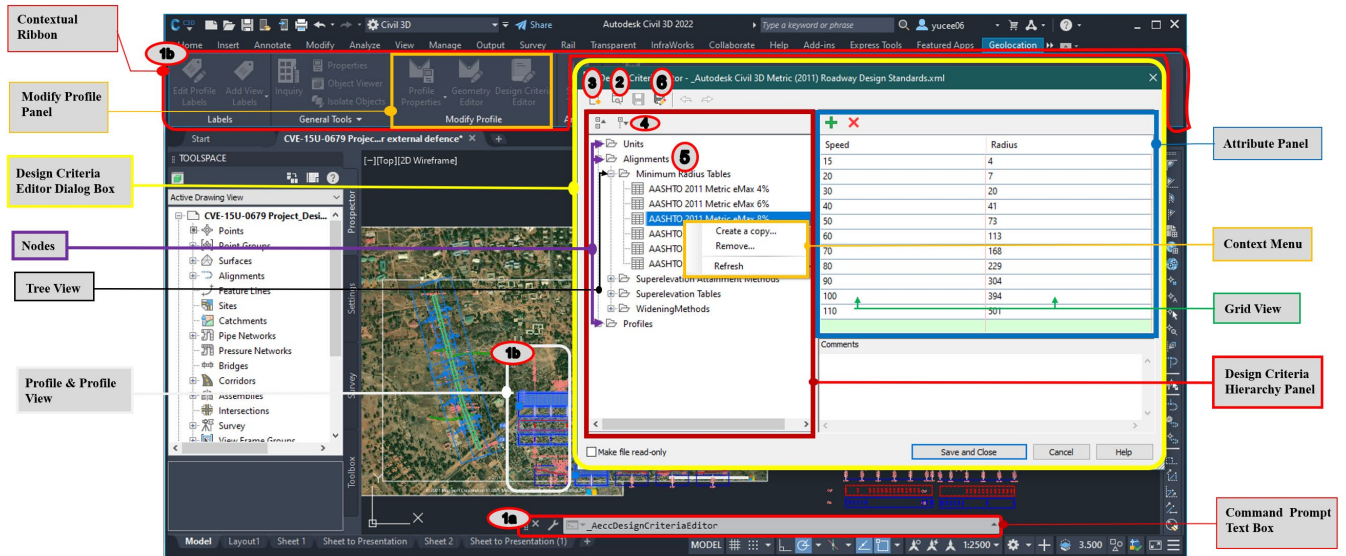
To add a row to a table, click “+” icon.

To remove a row from a table, click “X” icon.

- 7 Click “Save As”, input a name (e.g., FMWH Design Standards 2013 Metric) and finally click “Save” to save the design criteria file with the new changes in form of .XML file format. Close the Design Criteria Editor dialog box.



**Fig. 1 - Flowchart of activities for the design criteria**



**Fig. 2 - Importing and configuring FMWH Manual design criteria**

**Example 1:** - To configure minimum radius table based on recommendation of table 10 of FMWH Manual 2013 Pg. 3-13 by modifying the default criteria.

*Step 1:* To access the Design Criteria Editor Dialog Box;

- 1a. From the command prompt text box, type “DesignCriteriaEditor” without the quotation marks nor space, and press enter key on the keyboard. Or
- 1b. Click an alignment or profile in a drawing which opens up a contextual ribbon. From the contextual ribbon > Modify Profile panel > Click Design Criteria Editor.

*Step 2:* Click “Expand all” button to expand all folders/nodes into tree view in design criteria hierarchy panel on the left side of the dialog box.

*Step 3:* From the design criteria hierarchy panel, head on to Alignment Node > Minimum Design Radius > AASHTO 2011 Metric  $e_{Max}$  6%.

- Double Click on the table name (AASHTO 2011 Metric  $e_{Max}$  6%) an input a new name (e.g., FMWH Manual 2013 Metric  $e_{Max}$  6%), then press enter key on the keyboard.
- Withing attribute Columns in grid view on the attribute panel (right side of the dialog box), double-click the value to modify and input new values and press enter key. i.e., **for Design speed of 50km/h &  $e_{max}$  6%, Minimum radius = 79.** (Table 10).
- To add a new row to the table/grid view, click “+” icon.
- To remove a row from a table/grid view, click “X” icon.

*Step 4:* Complete the table and click “Save and Close” button to save unsaved changes to the currently open design criteria file.

**Example 2:** - To configure minimum K table for Stopping Sight Distance (Crest Vertical Curves) and Headlight (Sag Vertical Curve) Sight Distance; based on recommendation of table 18 and figure 11 to 15 of FMWH Manual 2013 Pg. 3-36 & pg. 3-40 to 3-44 respectively by modifying the default criteria.

*Step 1:* To access the Design Criteria Editor Dialog Box;

- 1a. From the command prompt text box, type “DesignCriteriaEditor” without the quotation marks nor space, and press enter key on the keyboard. Or
- 1b. Click an alignment or profile in a drawing which opens up a contextual ribbon. From the contextual ribbon > Modify Profile panel > Click Design Criteria Editor.

*Step 2:* Click “Expand all” button to expand all folders/nodes into tree view in design criteria hierarchy panel on the left side of the dialog box.

*Step 3:* From the design criteria hierarchy panel, head on to Profile Node > Minimum K Tables > AASHTO 2011 Standard.

- Double click on the table name (AASHTO 2011 Standard) an input a new name (e.g., FMWH Manual 2013 Standard), then press enter key on the keyboard.
- Withing attribute columns in grid view on the attribute panel (right side of the dialog box), double-click the value to modify and input new values and press enter key. i.e., **for Design speed of 50km/h, K Value for Stopping Sight Distance (Crest Vertical Curves) = 7 and for Headlight Sight Distance (Sag Vertical Curve) = 13** (from Table 18 & figure 11 to 15).



- To add a new row to the table/grid view, click “+” icon.
- To remove a row from a table/grid view, click “X” icon.

Step 4: Complete the table and click “Save and Close” button to save unsaved changes to the currently open design criteria file.

### 3.2.14 Volume of Earth Works

A feature within Autodesk Civil 3D allows for the calculation of earthwork required on a project by click of a button. Volume of earth work involve was estimated by using the earthworks panel in the contextual ribbon of civil 3D base on the corridor of the alignment. Analyze tab-Volumes and Material Panel- Volume report.

If we have two or more surfaces in a drawing, we can create a volume surface which is able to gather information and analyse the volume between one base surface (NGL) and another comparison surface (Formation Level). After creating the ground surface and the proposed finished grade surface, Autodesk Civil 3D makes it easy to create a comparison surface which highlights the elevation difference and computes the volume between the two surfaces.

This was done by going to the home ribbon, under create ground data panel click on surface then on create surface. In the popup window chose TIN-Volume-Surface as the type of surface to be created. Chose to surfaces to be compared in the given spaces provided and click okay (OK) button. The end result is a new surface providing coloration showing the different elevations of our volume. Upon Right-Clicking on our volume surface in prospector of the toolspace, chose surface properties, and under statistics we have the reported volume. Whether we entered a shrinkage and swell factor; it will provide the adjusted values, total net and then the unadjusted volume as well. The process of calculating earthwork begins by clicking ‘Surfaces’ on the Modify tab. A volume report sheet can then be printed.

## 4. Results and Discussion

The findings of the study and discussions are presented. fig. 2 - 5 presents the alignment design using this criterion.

### 4.1 Safety Design Criteria

**Table 1 - Parameter definition and safety design criteria**

Parameter Definition	Safety Design Criteria (FMWHM [17])
<b>Road Characteristics:</b> Access road Flat terrain 50km/h design speed	
<ul style="list-style-type: none"> <li>• <b>Lane Width</b> This affects the driver in trying to undergo evasive maneuvers.</li> </ul>	An Optimum Lane width value of <b>3.65m</b> was adopted for safe and comfortable riding. <i>(Figure 19 of the code)</i>
<ul style="list-style-type: none"> <li>• <b>Curve Radius</b> In general, when the road radius is small, crashes are higher [36].</li> </ul>	<p>Derived from equation 3-1 of the code &amp; Table 10 &amp; 11 page 3-12; V= 50km/h, e<sub>max</sub> = 6%, f<sub>max</sub> = 0.19 used for the design.</p> $R_{min} = \frac{v^2}{127(e_{max} + f_{max})}$ $R_{min} = 78.7m \approx 79m$
<ul style="list-style-type: none"> <li>• <b>Sight Distance</b> Drivers’ ability to see ahead so that they can control operations on the roadway.</li> </ul>	<p>SSD dependent on reaction time (t=2.5s) and braking distance (a=3.4m/s<sup>2</sup>).</p> $SSD_{min} = 0.278Vt + 0.039 \frac{v^2}{a}$ $SSD_{min} = 63 m$
<ul style="list-style-type: none"> <li>• <b>Super-elevation</b> Transverse slope due to raising outer edge of pavement to counteract centrifugal force, preventing vehicle from overturning and skidding.</li> </ul>	<p>If vehicle is not skidding, forces are at equilibrium given by:</p> $e + f = \frac{v^2}{127R}$ <p>(Equation 3-2 of the code). <i>Also, Case 1 of 3 (Divided Multilane page 3-</i></p>

Parameter Definition	Safety Design Criteria (FMWHM [17])
	17): The whole of the travelled way, including the median is super elevated as a plane section.
<ul style="list-style-type: none"> <li><b>Grades</b></li> </ul> <p>A longitudinal slope measured as vertical rise or fall per 100 meters, is an important safety parameter for vertical alignment [36].</p>	<p>maximum grade for safety reasons for an access road at a design speed of 50km/h on a flat terrain is = 6%</p>

Table adopted from Nkurunziza et al. [18]

### 4.2 Horizontal Alignment

The designed horizontal alignment consists of two straight-line segments connected with one circular curve as in table 2.

Table 2 - Horizontal alignment design

S/N	Parameters	Length (m)	Radius	Direction	Deflection	Start Chainage (m)	End Chainage (m)
1	Tangent 1	268.554		N21°06'10"		0+000	0+268.55
2	Radius	21.859	200m		6.2620(d)	0+268.55	0+290.41
3	Tangent 2	702.748		N14°50'27"		0+290.41	0+993.16

The radius provided has a chord length of 21.846m and a degree of curvature by arc of 8.7319°. Alignment Name: MAU Main Drive.

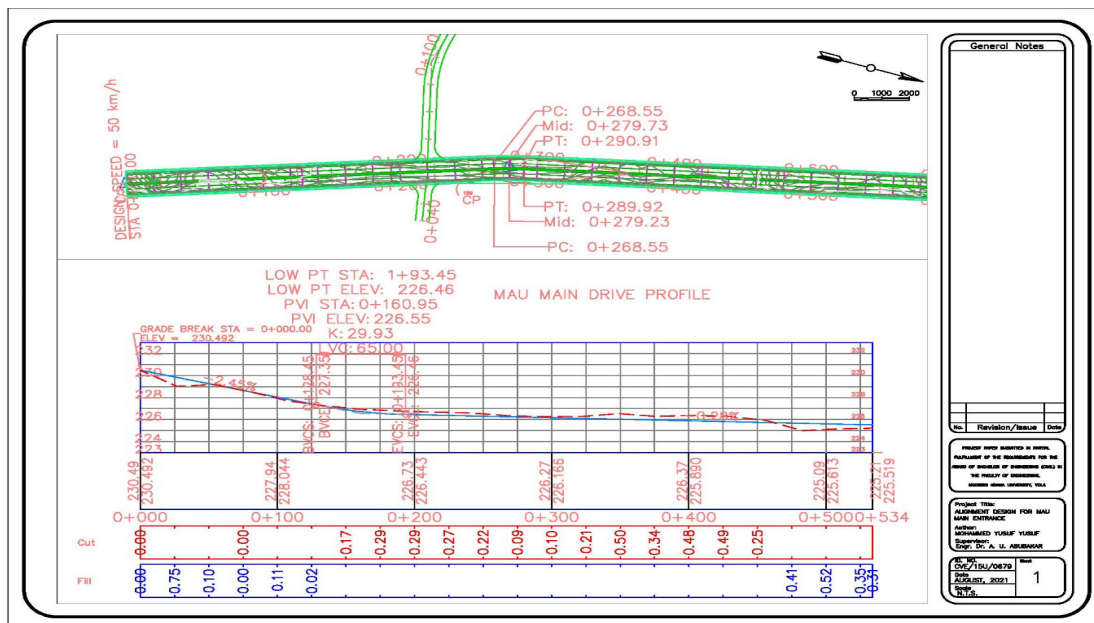


Fig. 3 - Horizontal alignment

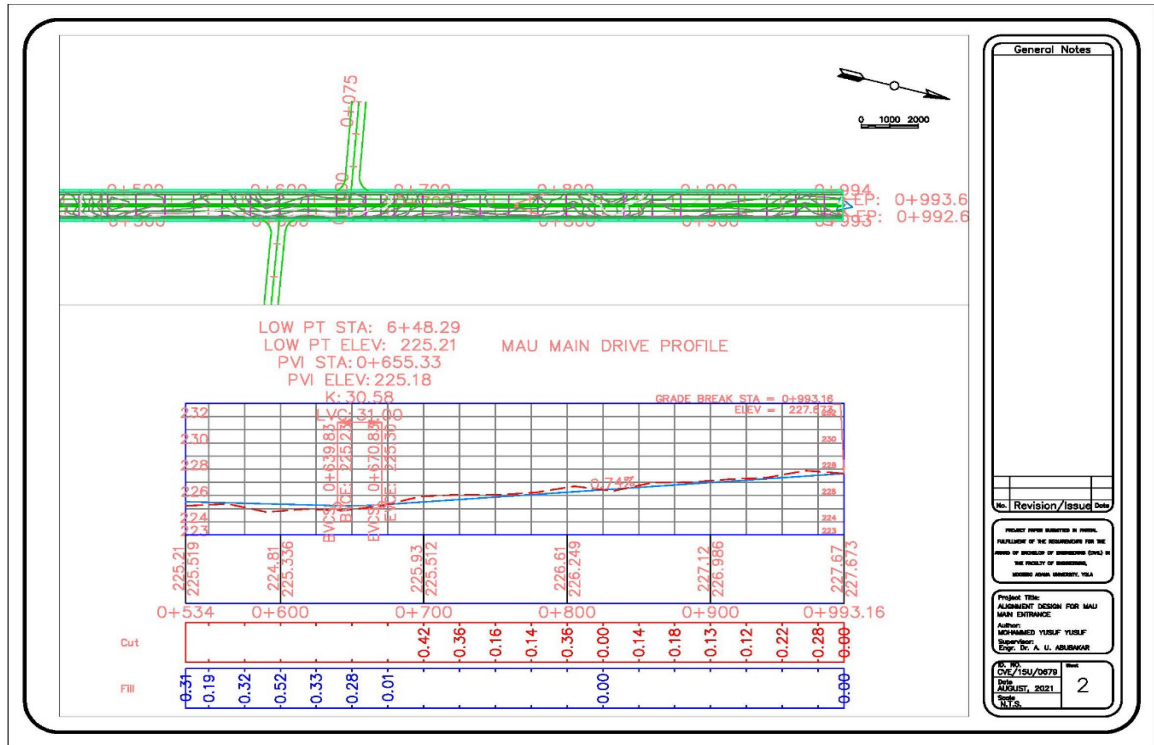


Fig. 4 - Vertical alignment

### 4.3 Vertical Alignment

Ground profile was generated using the profile tool from the home tab of the contextual ribbon, while the finished grade was created graphically using the profile creation tool. Minimum and maximum values of K for sag and crest curves were used to satisfy comfort, SSD and appearance criteria. Two sag curves were provided as presented in table 3.

Table - 3 Vertical alignment design

Profile Curve Type	Profile Curve Length (m)	K Value	Curve Radius (m)	VIP Chainage (m)	VIP Level (m)	Gradient In	Gradient Out	Gradient Change
-	-	-	-	0+000.00	230.492	-	-2.45%	-
Sag	65m	29.930	2993.03	0+160.95	226.551	-2.45%	-0.28%	2.17%
Sag	31m	30.579	3057.93	0+655.33	225.183	-0.28%	0.74%	1.01%
-	-	-	-	0+993.16	227.673	0.74%	-	-

### 4.4 Drainage Design

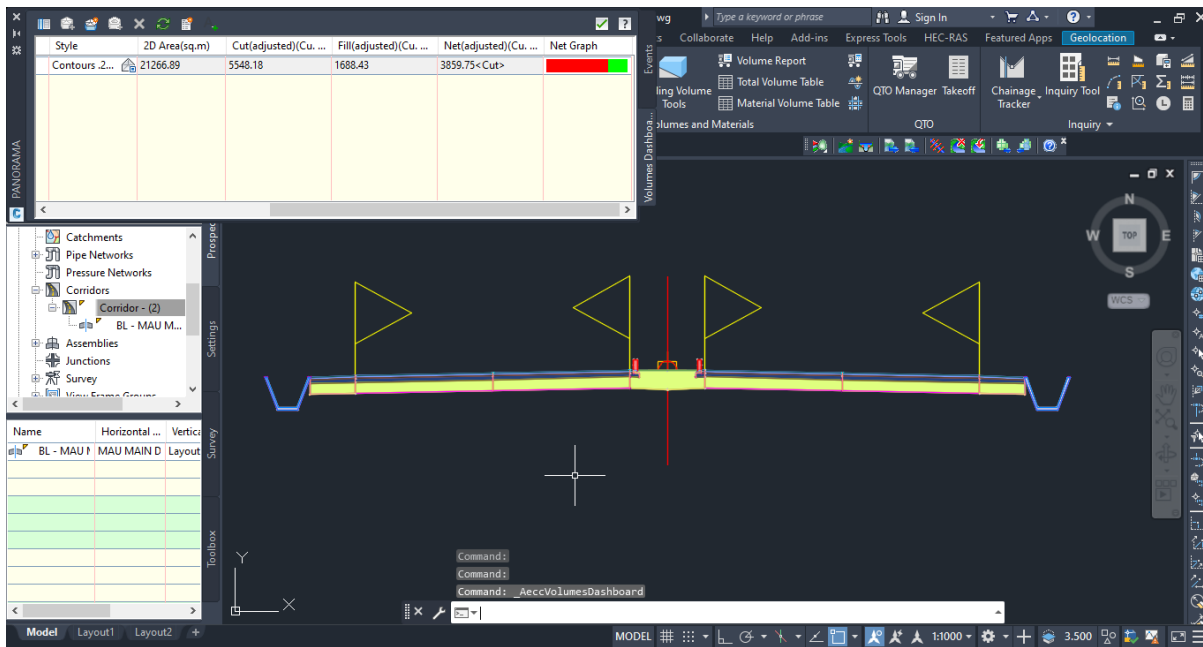
Drainage design was carried out by attaching a trapezoidal channel to the assembly of the road geometry fig. 4. The drainage channel has 0.8m depth with a bottom width of 0.5m and a top width of 1.1m. Base on the reconnaissance survey carried out, Box culvert was proposed to be sited at chainage 0+524 to 0+532.5 with the following dimension; Length = 18.8m, Width = 6m with 45° flared ends, Height = 2m. This is required to allow safe cross drainage of canal runoff that spans from the nearby mountains and passes through the alignment. This conforms to the specifications of the FMWH Manual Part 1 Volume V. Equally, a pipe culvert was proposed to be sited at 0+722 to 0+723 with the following dimension; Length = 18.8m, Width = 1m with 45° flared ends, Height = 2m. Table 4 gives the summary.

**Table 4 - Proposed culverts of the proposed alignment**

S/N	Chainage	Type of Drainage	No of Drainage	Dimension $m^3$
1	0+524 to 0+532.5	Box Culvert	1	<b>18.8m X 8m X 2m</b>
2	0+722 to 0+723	Pipe Culvert	1	<b>18.8m X 1m X 1m</b>
3	0+000 to 0+993	Trapezoidal Channel	1 both sides	0.5m bottom width, 1.1m top width, 0.8m depth.

### 4.5 Earthworks

In Civil 3D cut and fill quantities in earthworks can be extracted by creating ground surface and proposed corridor for the finished grade, subsequently, a “Cut and Fill” report is automatically generated. The software highlights the elevation difference and computes the volume between the two surfaces. Base on the comparison, Volume of cut was found to be 5,548.18  $m^3$  and that of fill was found to be 1688.43  $m^3$  with a net cut-volume of 3859.75 $m^3$ .



**Fig. 5 - Assembly and volume of earthworks calculation**

### 4.6 Discussion

Horizontal and Vertical alignment were designed and appropriate curves were provided, with a simple circular curve having a radius of 200m at chainage 0+268.55 to 0+290.41. This radius conforms to standard which required a minimum curve radius of 79m sited between two tangents with a deflection angle of 6.2620°. The Alignment was design to be as direct as possible and consistent with the topography with less environmental impact and a smaller number of drainages crossing which conforms to the study of Ahmadu et. al. [18]. Enough radius has been provided to allow drivers move safely from one line to the next without the need for transition curves. This is in line with FMWHM specification that no transition curve is required if a long radius is use. The lanes were wide enough so as to allow movement from one side of the lane to the other.

Two Sag curves were provided; one towards the beginning of the alignment at chainage 0+160.95 and a sag curve towards the ends of the alignment at change 0+655.33. This result shows that there would be both cut and fill in the project with more fill required at the beginning of the alignment. This is due to higher formation level than the NGL conforming to [19].

Shoulder width attached to the alignment provides an all-weather surface. The code specifies shoulder widths requirements of 3 meters are desirable on all highways but narrower widths are acceptable on low volume highways, as such 1.2m was proposed based on Table 22 of the code which shows widths of shoulders on divided multilane highways.

Flat and level grades on uncurbed pavements will function satisfactorily when the pavement is adequately crowned to drain the surface laterally. When flat or level grades are used, independent profile gradients are required for the roadway median and roadside ditches to ensure efficient drainage. The code specifies that with curbed pavements, longitudinal grades should be provided to facilitate surface drainage. A minimum grade for the usual case is 0.5% but a

grade of 0.3% may be used where there is an adequate pavement, accurately crowned and supported on a firm sub grade.

Equally, a pipe culvert was proposed to be sited at 0+722 to 0+723 with the following dimension; Length = 18.8m, Width = 1m with 45° flared ends, Height = 1m. This is required to drain excess runoff, and in line with the work of [6,8]. Reconnaissance survey carried out in the area also shows that a box culvert is proposed to be sited at chainage 0+524 to 0+532.5 with the following dimension; Length = 18.8m, Width = 6m with 45° flared ends, Height = 2m. This is required to allow safe cross draining of canal runoff that spans from the nearby mountains and passes through the alignment.

Earthwork quantification provides useful information in road construction works. Total volume of cut was found to be 5548.18m<sup>3</sup>, and fill 1688.43m<sup>3</sup> with a net volume of 3859.75m<sup>3</sup>. This shows high volume of cut is available, and can be attributed to extra earth materials cut from the trapezoidal ditch. This extra material could be used as a fill material leading to economical design. This is in line with the study of [20]. Table 5 gives a summary of interpretation of the code used in the design of the proposed alignment.

**Table 5 - Summary of Interpretation of the Code: FMWH Manual - geometric design**

Design Criteria	Minimum	Proposed	Remark	Reference in the Manual
Design speed V: <i>Class D Minor Road</i>	40 km/h	50 km/h	Ok	Clause 2.1.3 Pg.2-9. Table 2.
Lane width	3.65m But narrower lane width can be considered.	3.65m	Ok	Clause 3.3.2 Pg. 3-47.
Super Elevation (e)	5% to 6%	6%	Ok	Clause 3.1.6 Pg. 3-16. Table 11
Shoulder Width	1.2m Minimum. 1.8m Desirable for ADT 50-250.	1.2m	Ok	Clause 3.3.3 Pg. 3-49. Table 22.
Cross Slope	2% to 3% for Bituminous mix Pavements	2%	Ok	Clause 3.3.2 Pg. 3-49. Table 20.
Shoulder Cross Slope	3%	3%	Ok	Clause 3.3.3 Pg. 3-51.
Side Slope	6:1 For height in cut of 0-1.5m & For height of fill 0-3m.	6:1	Ok	Clause 3.3.6 Pg. 3-53. Table 23.
Median Width	1.2m	1.8m	Ok	Clause 3.3.5 Pg. 3-52. Figure 25.
SSD	65m for design speed of 50 km/hr.	70m	Ok	Clause 3.1.2 Pg. 3-2. Table 7.
SSD on Grades	Downgrade (e = 6%) = 70m Upgrade (e= 6%) = 59m	Downgrade =70m Upgrade = 65m	Ok	Clause 3.1.2 Pg. 3-4. Table 8.

Design Criteria	Minimum	Proposed	Remark	Reference in the Manual
PSD	N/A	N/A	Ok	Clause 3.1.2 Pg. 3-2 & 3-3.
Decision SD	At intersection, side distance to turn lane = 150m.	150m	Ok	Clause 3.14 Pg. 3-4. Table 9.
Driver reaction time	2.5 Sec		Ok	Clause
Transition curve	N/A	N/A	Ok	Clause 3.1.7 Pg. 3-23.
K Value	Cress Vertical Curves = 7 Sag Vertical Curves = 13	Cress Vertical Curves = 7 Sag Vertical Curves = 13	Ok	Clause 3.2.1 Pg. 3-36. Table 18.
Grade	Flat and level grades on uncurbed pavements will function satisfactory. Minimum = 0.5% on curbed but can be reduced to 0.3% where there is adequate pavement.	0.1%	Ok	Clause 3.2.1 Pg. 3-34
	Maximum grade on flat terrain = 6%	6%	Ok	Clause 3.2.1 Pg. 3-35. Table 17.

## 5. Conclusions

The capabilities of Autodesk Civil 3D to accommodate Nigerian FMWH Manual [17] in alignment design has been tested, and the following conclusions have drawn:

- The platform has been able to be modified to incorporate design criteria based on local available sourced construction materials;
- Geometric design of the pavement and appurtenances was conducted successfully making provisions for horizontal and vertical alignment, drainages, and volume of earthwork computations;
- A step-by-step description for the design process is provided for reproducibility and repeatability. This can also be validated by using code of practice elsewhere using similar criteria.
- A QR Code for data repository is presented.

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## Appendix A: Importing FMWH Manual 2013 to Civil3D

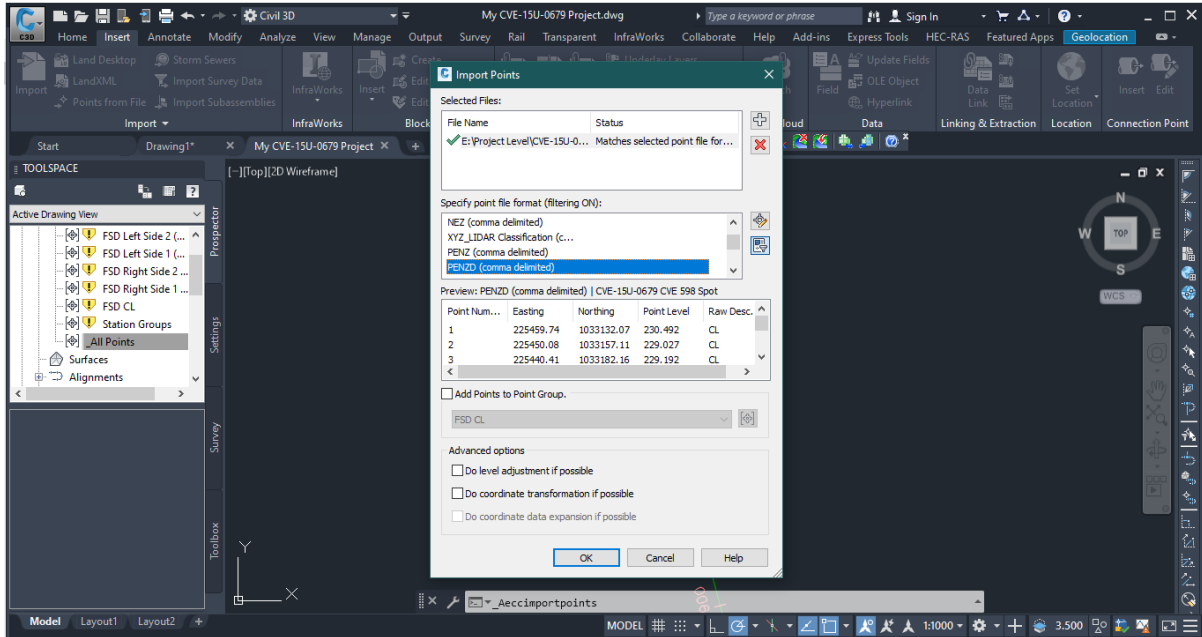


Fig. A1 - Importing PENZD.csv file into the workspace of Autodesk civil 3D

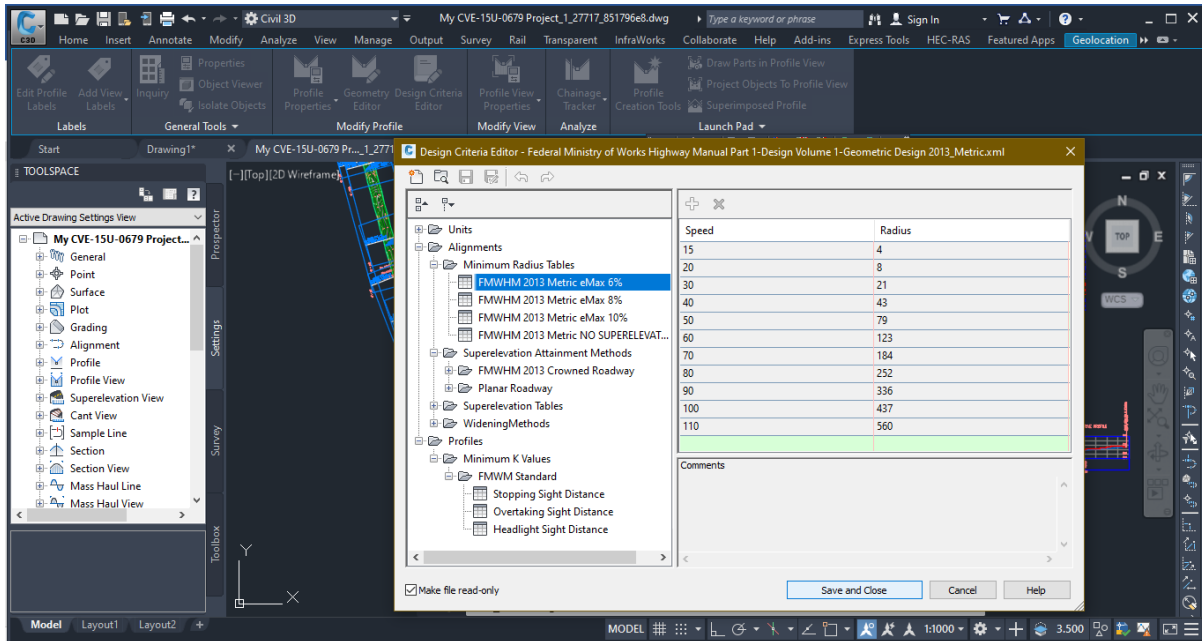


Fig. A2 - Applying FMWHM 2013 design criteria



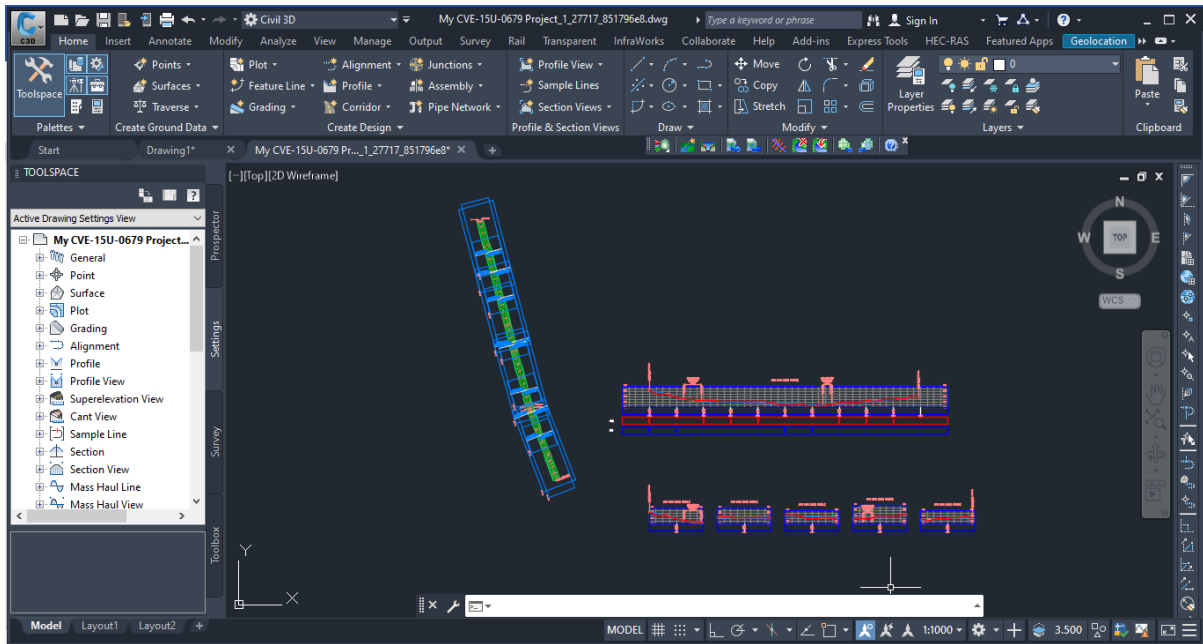


Fig. A3 - Design carried out in Autodesk Civil 3D V.2023

## Appendix B: Ground Control Points Used in the Study

Table B1 - Coordinate and height of final control station

From Points	Easting	Northing	Elevation	Bearing	Description
A	225354.91	1033078.37	230.132m	N21 <sup>0</sup> 06'10"	TBM
B	225359.11	1033392.80	-	N14 <sup>0</sup> 50'27"	Control Point
C	225151.38	1033987.46	227.940m	N14 <sup>0</sup> 50'27"	End of Survey





\ = Final Proposed alignment. ▽ = Control Station.



QR code repository for data used