Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 4 Issue 6, June - 2017

# Geometric Design of a Highway Using Autocad Civil 3d

**S.A. Raji**
Snr Lect.: Dept. of Civil Engineering, University of Ilorin
Saraji12000@gmail.com

**A. Zava**
PG Std. Dept. of Civil Engineering, University of Ilorin
aperzava@gmail.com

**K. Jirgba**
PG Std. Dept. of Civil Engineering, University of Ilorin
jirgbakavnen@yahoo.com

**A.B. Osunkunle**
PG Std. Dept. of Civil Engineering, University of Ilorin
raji.azizat@yahoo.com

***Abstract - Roadway geometry design involves such tasks as creating the road alignment and plotting the alignment profile using bearings or coordinates (easting and northing), 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 satisfying design standards and constraints. When performed manually, geometric design is very cumbersome, time-consuming and highly susceptible to very costly errors. Current trends are geared towards the use of computer programs for roadway geometry design. The programs offer amazing precision and save lots of time and effort. This paper presents a complete geometric design of a typical highway using AutoCAD Civil 3D software. The aim of the project was to demonstrate how roadway geometric design can be performed in a very short time with much ease and precision. The road design procedure using AutoCAD Civil 3D has been presented. Manual geometric design of the same road was also performed, the results of which was compared favourably with that of AutoCAD Civil 3D.***

***Keywords—Geometric Design; AutoCAD Civil 3D.***

## I. INTRODUCTION

Highways are expected to guarantee users' comfort and safety, to permit efficient traffic operation, and at the same time attract the least possible cost in construction and maintenance. Highways are also expected to cause minimum damage to the environment and be aesthetically pleasing in their finished form. Geometric design is the means through which these demands are met. As the Nigerian Federal Ministry of Works (FMW) Highway Manual [1] puts it, "geometric design focuses on the specific measures that provide for efficient and appropriate operation of the road, as well as provide for all the specific details that make roads safe and compatible with social and environmental circumstances surrounding the road".

Geometric design of roads can be subdivided into three main parts: horizontal alignment, vertical alignment and cross section, which when combined provide a three-dimensional layout for a highway [2, 3].

Horizontal alignment of a highway defines its location and orientation in plan-view. It comprises three geometric elements, including tangents (straight sections), circular curves and transition spirals between tangents and curves [2]

The vertical alignment (or roadway profile) is the longitudinal section of the road, comprising such geometric elements as crest and sag curves, and the gradients (straight grade lines) connecting them [1, 2]

The highway cross section shows the position and number of vehicle and bicycle lanes and sidewalks along with their cross slopes; shoulders, drainage ditches, etc.

Highway geometry elements are expected to be selected, sized and positioned in a way that satisfies such design criteria as sight distance, vehicle stability, driver comfort, drainage, economy, and aesthetics. The design process involves some drafting and a number of analyses and calculations. The tasks which are usually performed by the design engineer include: creating the road alignment and plotting the road profile using coordinates (or bearings), stations and elevations; 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 satisfying design standards and constraints.

Traditionally, these tasks are performed manually using drawing tools and mathematical techniques. When performed manually, geometric design is very cumbersome, time-consuming and highly susceptible to very costly errors [4, 5] The traditional approach is also based mainly on a two-dimensional (2-D) analysis which does not guarantee a satisfactory design, reports Yesser et al. [6]

Current trends are geared towards the use of very sophisticated computer programs for roadway geometry design that offer amazing precision and save lots of time and effort. Autodesk [7] summarizes the importance of specialized road design software saying the tools help civil engineering professionals working on transportation projects to: explore preliminary design options and optimize project performance; determine optimal horizontal and vertical roadway geometry that are constrained by design criteria; engineer roadway geometry in the context of the existing environment more efficiently and effectively. The tools also enable engineers to work with a more realistic model of what truly exists at the project site thereby affording engineers the opportunity to consider safety requirements earlier in project development. As Ananya and Sahimol [4] put it, these computer applications can produce amazing visual graphics that enable the design engineer to view the road on screen from the perspective of the driver. They [4] further state that "without the use of three-dimensional modeling, highway planning experiences a significant difficulty. Cut and fill calculation tends to consume a significant amount of time… By using the object-oriented approach, the process of cut and fill calculation can be performed automatically and in an accurate manner".

There are ongoing efforts to complete the development of campus road network of the University of Ilorin, located in southwestern Nigerian town of Ilorin. One of the links in the road network that has been selected for development is the one leading to students' hostels from the University bus stop. This paper presents a complete geometric design of this road using AutoCAD Civil 3D software. The aim is to demonstrate how roadway geometric design can be performed in a very short time with much ease and precision so as to encourage civil engineering practitioners in the developing world to embrace the use of road design software. To provide a basis for comparison, manual design of the geometry of the same road was also performed.

## II. AUTODESK AUTOCAD CIVIL 3D

AutoCAD Civil 3D is a civil engineering design and documentation tool developed by Autodesk. AutoCAD Civil 3D software supports Building Information Modeling (that is, digital representation of the physical and functional characteristics of a facility). It is used for modeling, analysis and design of a variety of civil infrastructure project types, including roads and highways, land development, rail, airports, and water. AutoCAD Civil 3D helps civil infrastructure professionals improve project delivery, maintain more consistent data and processes, and respond faster to project changes, all within the familiar AutoCAD environment [8]

Autodesk [7] lists the features of AutoCAD Civil 3D as follows:

i. BIM tools for civil engineering design: AutoCAD Civil 3D supports Building Information Modeling (BIM) and helps reduce the time it takes to design, analyze, and implement changes.
ii. Efficient civil design: AutoCAD Civil 3D performs faster design iterations with an intelligent, 3D model-based application that dynamically updates related civil design elements when changes are made. It streamlines time-consuming tasks for corridor design, parcel design, and pressure and gravity network design.
iii. It improves civil drafting and documentation. Connecting design and documentation helps boost productivity and deliver higher-quality designs and construction documentation. Changes to design elements are captured in documentation, minimizing manual updates.
iv. GPS surveying tools for faster processing. GPS surveying and data collection tools in AutoCAD Civil 3D can help you update your processes for improved project delivery.
**v.** Integrated storm water management and geospatial analysis. AutoCAD Civil 3D helps the designer to improve project delivery and make more informed decisions using visualization, simulation, and water analysis integrated with the design process for storm water management, geospatial analysis, and model analysis.

## III. DESIGN METHODOLOGY

### A. Survey Data Collection

The existing ground surface data are required for designing the geometry of highways. The survey information of the proposed route was obtained from the firm handling the development of the road. The survey information included Easting, Northing and elevations of points along the proposed route.

### B. Design Criteria

The following design criteria based on the Nigerian Federal Ministry of Works Manual [1] were assigned to the horizontal geometry of the center line and also to the profile and cross section of the roadway:

i. Design speed = 60 km/h
ii. Superelevation rate = 4%
iii. Friction factor = 0.14
iv. Minimum Stopping Sight Distance = 130 m
v. Minimum Passing Sight Distance = 540 m
vi. Maximum grade = 7%
vii. Minimum K (rate of vertical curvature) for sag curves = 30
viii. Minimum K (rate of vertical curvature) for crest curves = 26.
ix. Roadway width = 12.8 m
x. Carriageway width = 7.3 m
xi. Shoulder width = 2.75 m

### C. Overview of AutoCAD Civil 3D Design Procedure

- Import survey data (comprising easting, northing and levels and saved in Note Pad format) into the AutoCAD Civil 3D environment.
- Create existing ground surface
- Create alignment by linking points on the existing ground using polyline
- Apply the design criteria. In this project, the AASHTO design criteria was selected.
- Generate the existing ground profile.
- Create the formation level (finished) using the profile creation tools.
- Create the Assembly, which defines the cross-sectional component of the design. The assembly is constructed by connecting individual subassembly objects.
- Create the corridor, which is the resulting dynamic 3D model representation built from the combination of horizontal, vertical and cross-sectional design elements. Corridors may be used to calculate earthworks and quantity takeoffs, to perform sight and visual analysis, to generate surfaces, and to extract information for construction purposes.
- Generate volume table report.

### D. Design of the Horizontal Alignment

Horizontal alignment design entails determining the minimum curve radius and curve length, and the computation of horizontal offsets from tangents to the curve to facilitate locating the curve in the field. This section presents an overview of the horizontal alignment design procedure by means of AutoCAD Civil 3D and by manual method.

The survey data comprising easting, northing and elevations was imported into the Civil 3D environment in notepad format. This automatically generated the existing ground surface. After specifying the design criteria that were to be placed on the alignment, the polyline construction tool from the toolbar was used to draw the layout of the road. The ‘Geometry Editor’ tool was used to draw the circular and spiral curves and to extract the alignment curve report.

On the other hand, the easting and northing of the roadway center line was extracted from the survey data and plotted using Microsoft Excel with the easting as the abscissa and the northing as the ordinate. This plot produced the horizontal alignment of the proposed route. Using the design speed, superelevation rate and the friction factor specified in the design criteria, the minimum curve radius was calculated from the formula in equation 1

$$R = \frac{V^2}{127(e+\mu)}$$

(1)

Where R = minimum horizontal curve radius in meters

V = design speed in km/h
e = superelevation rate.
μ = friction factor.

### E. Design of the Vertical Alignment

The existing ground profile was generated using the ‘Profile’ tool from the toolbar, while the finished grades were created graphically using the profile creation tools. Profile geometry was determined by applying the design criteria of minimum K values for sag and crest vertical curves that satisfy the minimum requirements of stopping sight distance, comfort and appearance criteria.

Lengths of vertical curves were also calculated manually using the formula

$$L = KA$$

(2)

Where L = minimum length of vertical curve in meters.
K = the rate of vertical curvature, defined as the length of curve per percent algebraic difference in intersecting grades.
A = algebraic difference of grades in percent.

### F. Cut and Fill Calculation.

A feature within AutoCAD Civil 3D allows for the calculation of earthwork required on a project within a few seconds. After creating the ground surface and the proposed finished grade surface, AutoCAD Civil 3D makes it easy to create a comparison surface which highlights the elevation difference and computes the volume between the two surfaces. The process of calculating earthwork begins by clicking ‘Surfaces’ on the Modify tab. A volume report sheet can then be printed.

## IV. DESIGN OUTPUT

This section presents the geometric design output from AutoCAD Civil 3D and from manual design.

### A. Horizontal Alignment

The existing ground profile and the horizontal alignment produced by AutoCAD Civil 3D are presented in Figures 1 and 2 respectively. Also the horizontal alignment determined manually is presented in Figure 3. Comparison of Fig. 2 and 3 shows that the horizontal alignments produced by means of AutoCAD Civil 3D and manual design are similar.

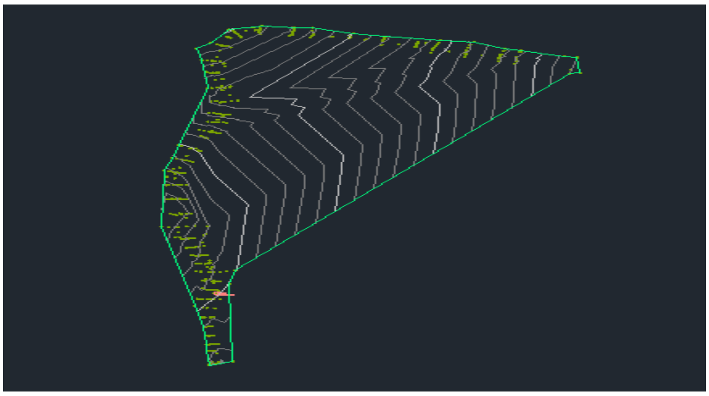

Fig. 1: Existing Ground Surface produced by AutoCAD Civil 3D.

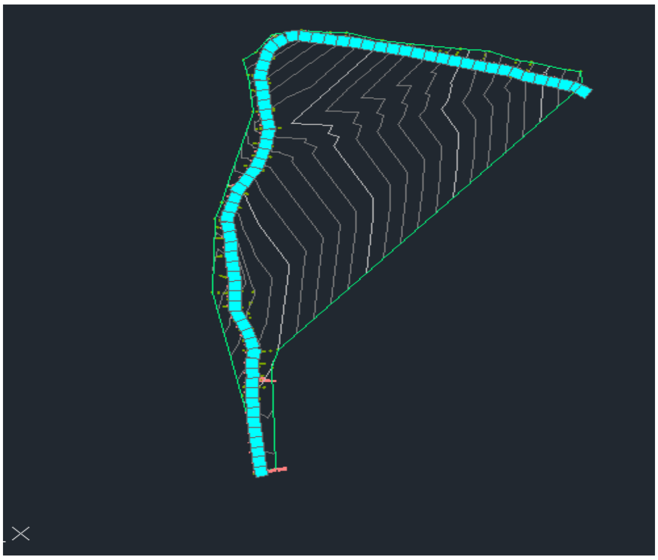

Fig. 2: Horizontal Alignment produced by AutoCAD Civil 3D

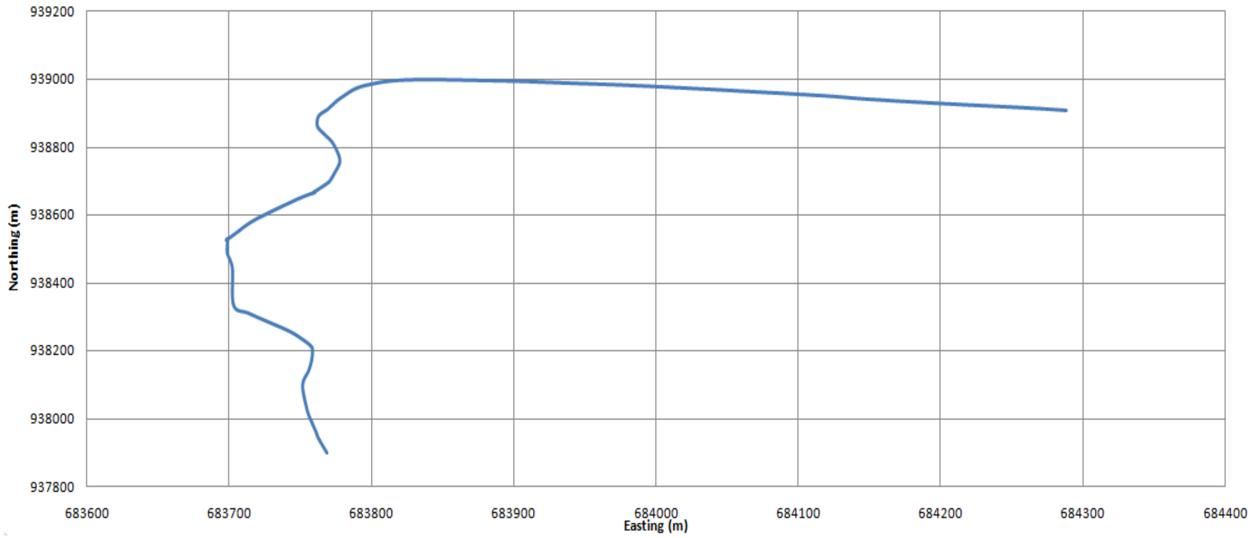


Fig. 3: Horizontal Alignment produced from the plot of Easting and Northing using Excel

**B. Vertical Alignment Design Output.**

The vertical alignment design outputs by both AutoCAD Civil 3D and manual designs are presented in Fig. 4 and 5 respectively. It is evident from these two figures that the profiles obtained by means of AuoCAD Civil 3D and manual methods are similar.

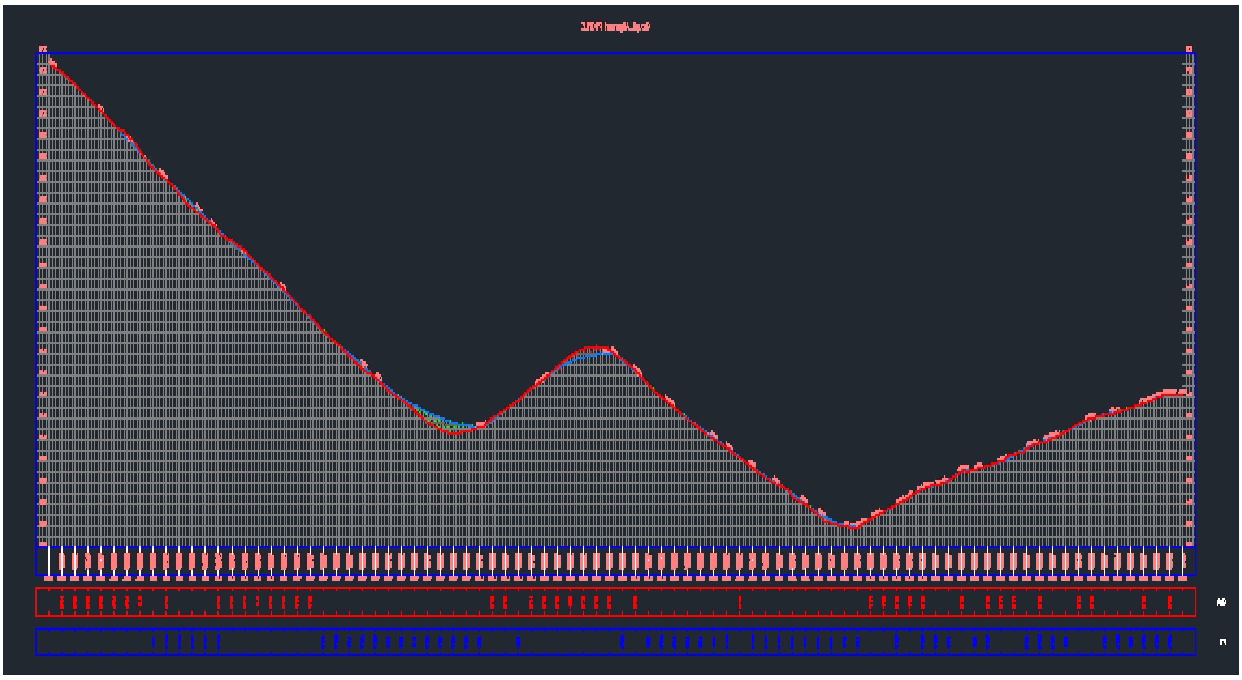

Fig. 4: Vertical alignment produced by AutoCAD Civil 3D

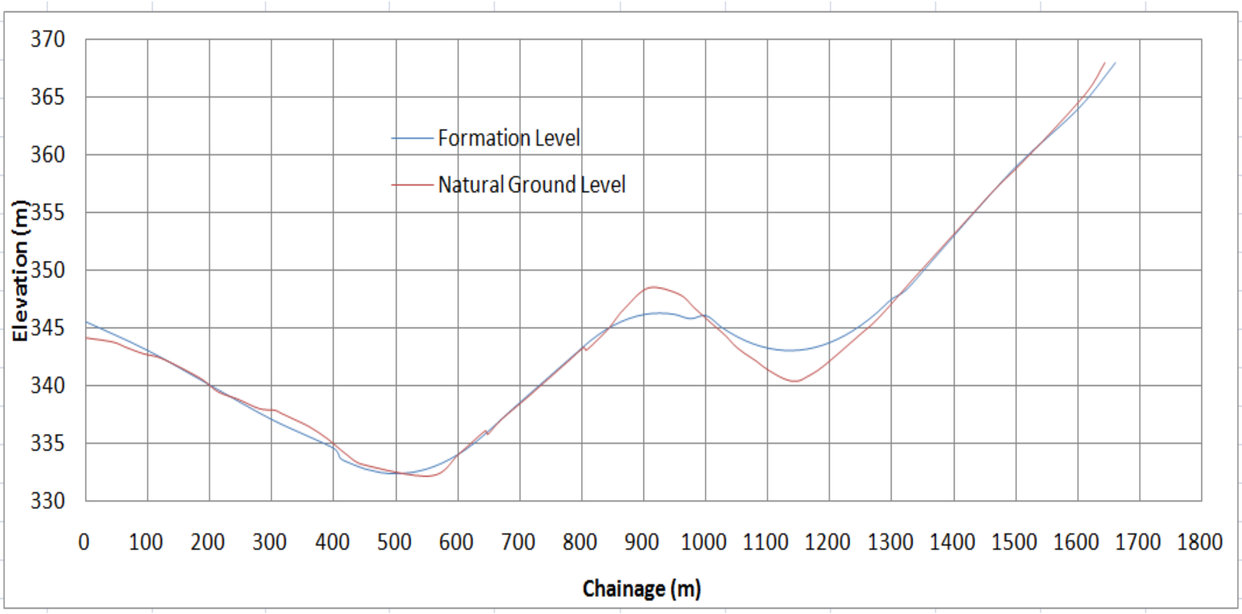


Fig. 5: Vertical alignment produced by manual design

**C. Cut and Fill Report**

Table 1 represents part of the volume report for this design.

Figure 1: Earth Volume Report

| Station | Cut Area (Sq.m.) | Cut Volume (Cu.m.) | Reusable Volume (Cu.m.) | Fill Area (Sq.m.) | Fill Volume (Cu.m.) | Cum. Cut Vol. (Cu.m.) | Cum. Reusable Vol. (Cu.m.) | Cum. Fill Vol. (Cu.m.) | Cum. Net Vol. (Cu.m.) |
|---|---|---|---|---|---|---|---|---|---|
| 0+020.000 | 4.23 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0+040.000 | 4.14 | 100.39 | 100.39 | 0.00 | 0.24 | 100.39 | 100.39 | 0.24 | 100.15 |
| 0+060.000 | 4.32 | 101.37 | 101.37 | 0.00 | 0.17 | 201.76 | 201.76 | 0.41 | 201.36 |
| 0+080.000 | 4.13 | 101.34 | 101.34 | 0.01 | 0.24 | 303.11 | 303.11 | 0.65 | 302.46 |
| 0+100.000 | 3.49 | 91.39 | 91.39 | 0.03 | 0.50 | 394.50 | 394.50 | 1.15 | 393.35 |
| 0+120.000 | 3.85 | 87.73 | 87.73 | 0.03 | 0.70 | 482.23 | 482.23 | 1.84 | 480.39 |
| 0+140.000 | 4.02 | 93.34 | 93.34 | 0.24 | 3.36 | 575.58 | 575.58 | 5.21 | 570.37 |
| 0+160.000 | 4.75 | 108.02 | 108.02 | 0.16 | 4.34 | 683.60 | 683.60 | 9.55 | 674.05 |
| 0+180.000 | 3.50 | 98.13 | 98.13 | 0.07 | 2.79 | 781.73 | 781.73 | 12.34 | 769.39 |
| 0+200.000 | 3.73 | 84.40 | 84.40 | 0.18 | 3.26 | 866.13 | 866.13 | 15.60 | 850.53 |
| 0+220.000 | 4.29 | 98.20 | 98.20 | 0.14 | 3.58 | 964.33 | 964.33 | 19.19 | 945.15 |
| 0+240.000 | 4.36 | 104.14 | 104.14 | 0.22 | 4.36 | 1068.47 | 1068.47 | 23.55 | 1044.92 |
| 0+260.000 | 5.30 | 115.94 | 115.94 | 0.16 | 4.54 | 1184.41 | 1184.41 | 28.08 | 1156.33 |
| 0+280.000 | 5.79 | 133.57 | 133.57 | 0.01 | 2.02 | 1317.98 | 1317.98 | 30.10 | 1287.88 |
| 0+300.000 | 5.31 | 133.78 | 133.78 | 0.06 | 0.91 | 1451.76 | 1451.76 | 31.01 | 1420.75 |
| 0+320.000 | 4.67 | 120.29 | 120.29 | 0.06 | 1.46 | 1572.06 | 1572.06 | 32.47 | 1539.59 |

### D. Assemblies

Assemblies define the cross-sectional component of the design. They are built by connecting individual subassembly objects, thereby helping to simulate the geometry and material make up of the road. Fig. 6 shows the roadway assembly.

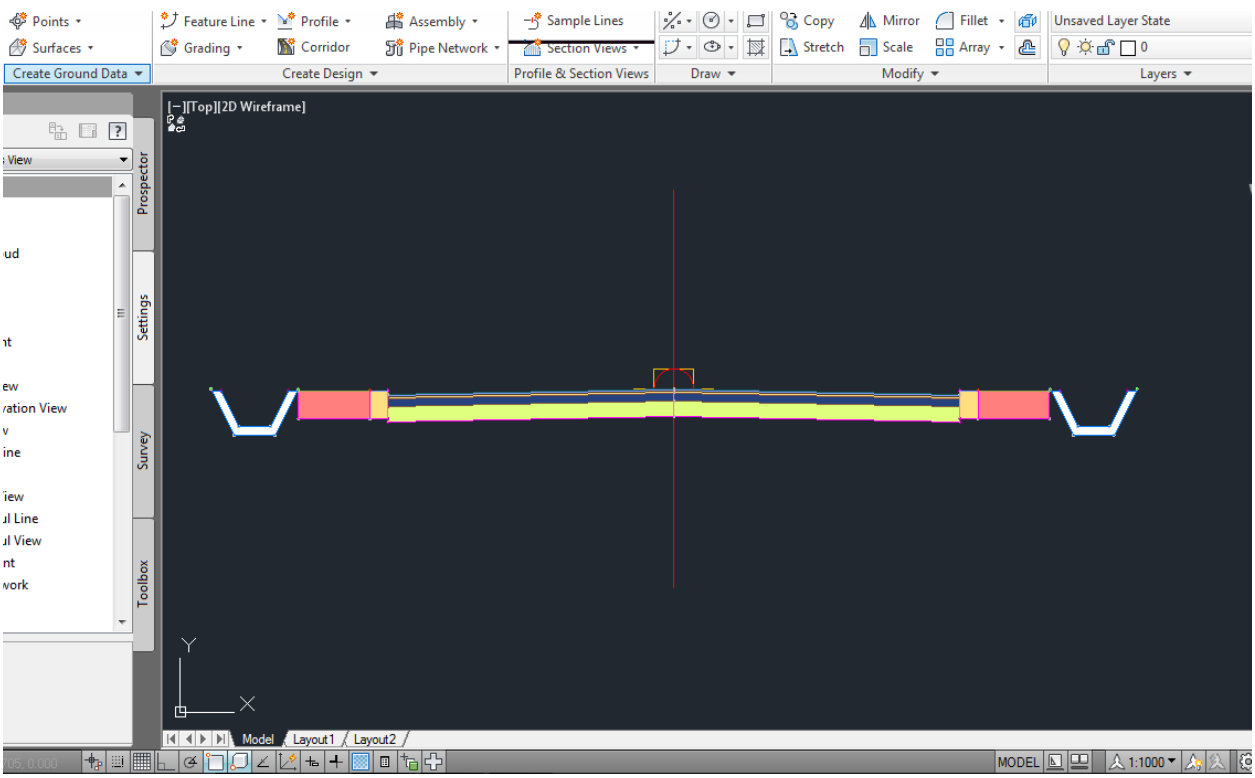


Fig. 6: Roadway Assembly.

## V. CONCLUSION

The use of AutoCAD Civil 3D for highway geometric design makes the design process to be completed within a very short time and with much ease and amazing precision. These capabilities of AutoCAD Civil 3D eliminate the major disadvantages of the manual design approach that is cumbersome, time consuming and highly prone to costly errors.

## REFERENCES

[1] Federal Ministry of Works Highway Manual, “Geometric Design”, Nigeria. Part 1, Vol. 1, 2013.

[2] E.T. Demetrios, “Highway Engineering”, The McGraw-Hill Companies, Inc. New York, USA, 1999.

[3] Wikipedia “Geometric Design of Roads”. Available from: https://en.wikipedia.org/wiki/Geometric_design_of_roads. Accessed February 2107.

[4] A. Ananya, and E. Sahimol, “3D Model for Highway Alignment”, International Journal of Scientific Engineering and Research (IJSER), Volume 4, Issue 3, March 2016.

[5] L. Chen-Fu and D.M. Levinson, “ROAD: Interactive Geometric Design Tool for Transportation Education and Training”, Journal of Professional Issues in Engineering Education & Practice, Vol. 139, No. 2, pp 116 – 122, April 2013.

[6] H. Yasser, M.E. Said, and A.O. Abd El Halim, “State-of-the-Art of Three-Dimensional Highway Geometric Design”, Canadian Journal of Civil Engineering, Vol. 25, No. 3, pp. 500-511, 1998. Available from: http://www.nrcresearchpress.com/doi/pdf/10.1139/l97-111.

[7] Autodesk, “Highway Engineering and Road Design Software – InfraWorks”, Available from: http://www.autodesk.com.au/products/infraworks-family/vertical-apps/roadway-design/all/list-view. Accessed February 2107

[8] Autodesk, “Civil Engineering Design/AutoCAD Civil 3D”, Available from: http://www.autodesk.com/products/autocad-civil-3d/features/all. Accessed February 2107.

[9] Excitech Ltd., ” AutoCAD Civil 3D 2017”, Available from: http://www.excitech.co.uk/Products/AutoCAD-Civil-3D-2017. Accessed February 2107.