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Village Road Geometric Design Using AutoCAD® CIVIL 3D: The Case of Majalengka, Indonesia †

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Abstract: The latest technology to support geometric road planning must be implemented properly. Village road design using digital applications is believed to be able to produce the best planning. This paper aims to analyze the geometric planning of village roads using the AutoCAD® Civil 3D application. The data and planning location is on Village Road in Majalengka Regency, Indonesia. The research method used is to digitize manual planning using the AutoCAD application. The planning standard uses a combination of AASHTO and Indonesia Standard. The study results show that using AutoCAD® Civil 3D for village road planning provides convenience, speed, and the best planning precision.

Keywords: digital application; geometric design; village road

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1. Introduction

Facilities and infrastructure are crucial for smooth and comfortable operations. Sometimes, the facilities and infrastructure of an institution are managed with minimal information, so there are often errors in their management [1]. The availability of transportation-related infrastructure and facilities influences the success of transportation. One of them, which is directly related to transportation, is the road. Roads are critical infrastructures in various countries because they can support all transportation activities. The provision of infrastructure is one of the solutions to becoming a developed country. Roads are essential in everyday life because they provide humans with access to travel and connect areas in a location [2].

At a regional level, such as in Asia, road infrastructure is critical in supporting mobility and economic activity. A country requires economic growth to improve the standard of living and welfare of its citizens. The government needs supporting factors, including infrastructure [3]. The quality of roads' geometric design dramatically affects the smooth flow of traffic, road user safety, and travel comfort. Good road geometric planning and design is crucial in urban areas and around activity centers such as campuses, schools, and other public places. Poor geometric design (e.g., unbalanced lane arrangement and inadequate lane spacing) can lead to driving errors and cause accidents. Therefore, it is necessary to understand how geometric design affects road safety on freeway segments with closely spaced entry and exit lanes to provide design guidance to improve traffic safety [4].

This is often a challenge at the national level, especially for Indonesia, a developing country. Transportation infrastructure and improved transportation facilities are critical to people's lives in Indonesia [5]. Thus, in this case, the Indonesian government needs to improve the quality of roads and develop national road infrastructure. In Indonesia, infrastructure development stimulates employment in the relevant sector, increases government and public consumption, and encourages other constructive efforts [6]. Civil infrastructure systems, such as transportation, energy, housing, and water, are essential for the survival of society [7]. The availability of good road infrastructure will facilitate mobility and comfort for its users, making driving smoother, faster, and more efficient. Software has been developed to solve problems that occur in various fields. One such type of software is AutoCAD® Civil 3D, a specialized software program for the planning and design of models related to civil engineering [8].

In Majalengka itself, road infrastructure is essential so that the economic mobility in Majalengka Regency can be improved. One relevant area is Sidamukti Village Road, a road geometry design that needs to be improved. Transportation problems are severe at present. Industrialized countries and developing countries alike face them. Even in large countries with advanced transportation infrastructure, transportation problems such as congestion and traffic density persist [9]. However, with the rapidly growing population and competition to provide more luxurious travel services, road infrastructure has become more significant and challenging to manage [10].

A practical road geometric design is needed given the increasing activity in the Majalengka area, especially in tourist areas, where Sidamukti provides access to tourist attractions. Tourists visiting any region of the world for tourist, medical, or recreational purposes should receive quality transportation services and be able to reach all recreational and tourist facilities, regardless of location [11]. Therefore, our paper focuses on the geometric design of roads with AutoCAD® Civil 3D on Sidamukti Village Road, Majalengka Regency. The results of this study are expected to provide ideas to the local government regarding how influential road geometry designers are using AutoCAD® Civil 3D. With the planning of the road geometry on the Sidamukti Majalengka road section, we seek to determine the effectiveness of AutoCAD® Civil 3D by examining several variables, such as road traces, horizontal alignment, vertical alignment, assembly, corridors, and sample lines.

2. Literature Review

2.1. Civil 3D for Road Design

Civil 3D is an advanced software program developed by Autodesk. It is now a commonly used instrument in civil engineering, particularly road design and construction. AutoCAD® Civil 3D is a building information modeling (BIM) system application that can help to reduce the time needed to design, analyze, and implement changes. AutoCAD® Civil 3D is a fast and intelligent design program. The program is built on a 3D model that dynamically updates the associated civil design [12]. The use of AutoCAD® Civil 3D for the planning and design of road geometries has attracted increasing attention recently, as it offers a range of advanced features and functions that can simplify the design process and improve the accuracy of the results. One of the main advantages of using Civil 3D is its ability to create accurate, data-driven road alignment, profile, and cross-section models, which can be easily modified and updated as the design progresses. The road design procedure using AutoCAD® Civil 3D has been presented. A manual geometric design for the same road was also created, the results of which were compared with those of AutoCAD® Civil 3D [13]. By incorporating detailed terrain data, survey information, and other relevant factors, Civil 3D allows engineers to design roads that meet regulatory requirements and optimize safety, efficiency, and environmental considerations [14]. This is particularly important in planning and constructing new roads and rehabilitating and reconstructing existing infrastructure.

AutoCAD® Civil 3D is more than just a tool that helps students with their projects and coursework [15]. This powerful software for analysis and visualization further enhances the design process, making it possible to identify potential problems, evaluate alternative scenarios, and communicate design concepts more effectively with designers. Computer-aided design (CAD) is an essential part of information technology (IT) [16]. Regarding the use of AutoCAD® in planning applications, the flexibility and analytical capabilities of microcomputer-based CAD software such as Civil 3D can be highly beneficial for tasks such as spatial data input, environmental analysis, and construction drawing creation [17]. By automating various aspects of the design process, Civil 3D can help to reduce the time and resources required while improving the overall quality and consistency of the final design.

2.2. Road Geometry

The design and construction of road networks is a critical component of modern transportation infrastructure, with the road geometry playing an essential role in ensuring safety, efficiency, and sustainability. As the main structure in the highway industry, especially for freeways, the progress of asphalt pavement design must be balanced with the calculation of pavement structures [18]. The current trend in road geometric design uses software for CAD, such as AutoCAD® Civil 3D, which enables more precise planning and saves time and effort [19]. Road geometric design includes a variety of factors, including horizontal and vertical alignment, sight distances, gradients, and intersections, all of which are critical in ensuring the safety and comfort of road users. The road is expected to provide comfort and safety for users, enable efficient traffic operations, and simultaneously attract the minimum possible construction and maintenance costs [20].

This highlights the importance of performance-based analysis in civil engineering, particularly in geometric design and traffic operations. The impact of road accidents disproportionately affects those with lower socioeconomic status, with pedestrians, motorcyclists, and passengers using public transportation being the primary victims [21]. This approach evaluates designs based on specific performance measures, such as the sight distance, rather than simply following predefined design standards. Road geometric design must balance various considerations, including safety, efficiency, and environmental impacts, and adapt to the unique characteristics of the terrain and the needs of the local community. The characteristics of the traffic flow, the vehicle size and movement, the role of the driver in directing the vehicle, and the nature of the car itself are all derived from geometric planning. Using the components of highway geometry, several analyses and calculations are performed so as to meet the requirements [22].

Roads have three essential parts. These three parts are horizontal and vertical alignments and cross-sections, which, when combined, will result in three-dimensional road formats [23]. The horizontal alignment of a road is an essential aspect of its geometric design, as it determines the location and orientation of the road in plain view. The proper selection of the horizontal curve radius is critical, affecting vehicle stability, the required superelevation, and overall road safety. Researchers analyze the horizontal alignment design through the parameters involved (deficiency, excess, and uncompensated lateral acceleration) and then justify the constraints needed to determine the limit values of these parameters (passenger comfort, lateral stability, and maintenance cost) [24].

2.3. Horizontal Alignment and Vertical Alignment

The work performed by highway planning engineers includes alignment and road profile planning, consisting of coordinates and elevations, horizontal curve radii, vertical curve lengths, sight distance calculations, and earthwork quantity calculations, as well as various calculations and analyses related to optimal alignment, while meeting design standards and constraints [25]. Road geometric alignments are used as input modules, including horizontal alignment, vertical alignment, cross slope, and their combinations [26]. Vertical alignment is an essential aspect of road design that is related to elevation changes along the road. It includes features such as inclines, declines, and dips. Proper vertical alignment is critical in maintaining visibility, vehicle stability, and drainage. Steep grades and sudden vertical curves can increase accident rates due to reduced visibility and vehicle control problems [27]. Inadequate vertical alignment can lead to excessive fuel consumption and vehicle wear, underscoring the importance of an optimized vertical profile. Vertical alignment is divided into straight and curved segments that can be seen from the starting point of planning [28].

Horizontal alignment is one of the most challenging parts of highway design, yet geometric design is a fundamental component of planning [29]. Horizontal alignment consists of circular arcs combined with transitional or circular arcs and curved straight lines [30]. Horizontal alignment involves the layout of the road in the plan view, including straight sections (tangents) and horizontal curves. Critical elements of horizontal alignment include the radius of curvature, superelevation, and transition curves. Proper horizontal alignment ensures that vehicles can safely navigate curves at appropriate speeds without losing control [31]. The average number of crashes reported in the United States shows that the frequency of crashes on horizontal curves is higher than on straight segments [32]. The importance of horizontal alignment lies in maintaining lateral stability and reducing the risk of rollover. The relationship between the curve radius, superelevation, and vehicle speed is also crucial. An insufficient curve radius or superelevation can increase the lateral friction demand, resulting in higher crash rates. The strong correlation between the horizontal curve radius and crash rate indicates that sharper curves are associated with a higher crash frequency. In addition, using spiral transition curves can improve vehicle handling and reduce the risk of accidents on sharp curves.

The American Association of State Highway and Transportation Officials (AASHTO) provides these guidelines and standards that are widely used worldwide, including in Indonesia, to ensure that a road design is safe, efficient, and comfortable for road users. The parameters required include the stations and elevations of points along the proposed route; the calculation of the sight distances, radii of horizontal curves, and lengths of vertical curves; the computation of earthwork quantities; and numerous other analyses and calculations to find the optimum alignment while satisfying design standards and constraints [33]. Research suggests that several geometric design elements, such as the horizontal curvature, vertical curvature, slope, curve radius, and superelevation, are critical for traffic safety [34].

3. Method

This study utilizes a qualitative research methodology. The primary sources for this research are horizontal and vertical alignment calculations, assembly, corridor, and cut and fill. The secondary data include plan speed data, road classifications, and a topographic map of Sidamukti Village. The geometric design of this road uses the AutoCAD® Civil 3D application, involving several other supporting applications, such as Google Earth and Global Mapper, and it is then processed using AutoCAD® Civil 3D.

The design of road geometrics is carried out using the AutoCAD® Civil 3D application concerning design road modeling based on the AASHTO's 2011 Policy on the Geometric Design of Highways and Streets. The first step is to obtain a map of the Sidamukti Village area, Majalengka Regency, as can be seen in Figure 1. By selecting the starting and end points in the road design using the Google Earth Pro software, a polygon is obtained, which covers the area at the starting and end points to determine the ground contour.

Furthermore, the data from Google Earth are entered into Global Mapper to obtain a DEM and generate the results of soil contours, and we then determine road tracing plans, horizontal alignments, vertical alignments, assemblies, corridors, and sample lines and finally the cut and fill volumes in the AutoCAD® Civil 3D software.

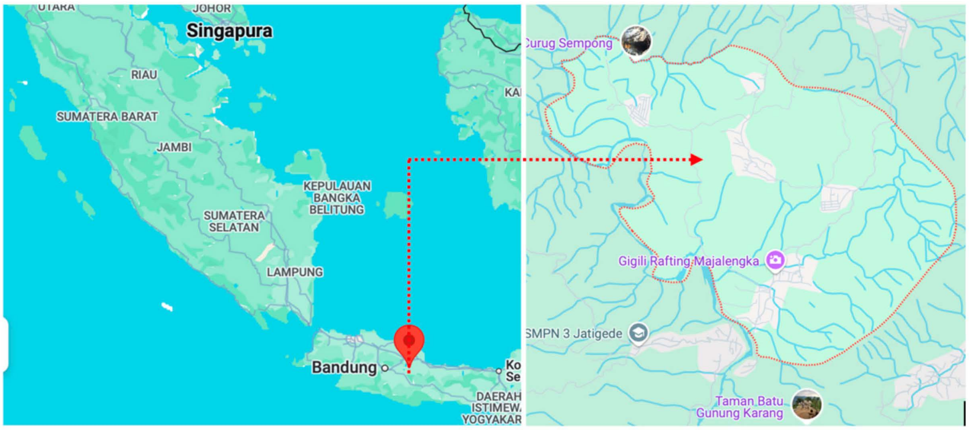


Figure 1. Research locations.

4. Results and Discussion

We perform road modeling using the AASHTO's 2011 Policy on Highway and Street Geometric Design, focusing on Sidamukti, Majalengka Regency, including local roads with village road status. The planned road type is a two-way, two-lane, undivided road, with a road width of 5 m. The plan speed = 50 km/h, eMax = 10%, and the maximum slope = 7–12%. Indonesia uses the UTM zone to design road geometries. Majalengka Regency is located at UTM 49 S in the AutoCAD® Civil 3D software drawing settings, and the following steps are undertaken.

4.1. Road Trace

Road design is performed using the AutoCAD® Civil 3D software to determine the road geometry in Sidamukti Village, Majalengka Regency, avoiding essential buildings such as places of worship, schools, and others. In the road trace, we select points P1–P5 of the road to be designed, spanning from STA 0 + 000.00 to 0 + 951.60, as shown in Figure 2.

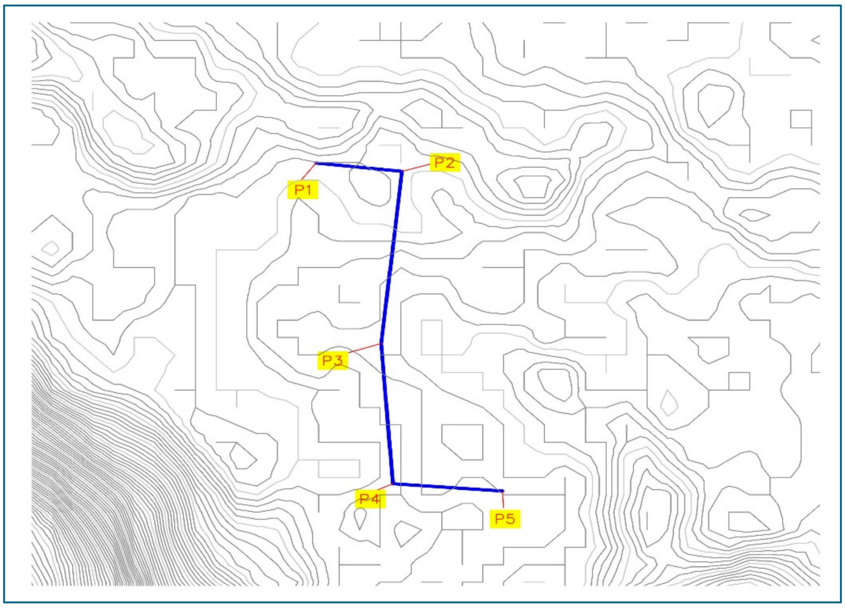
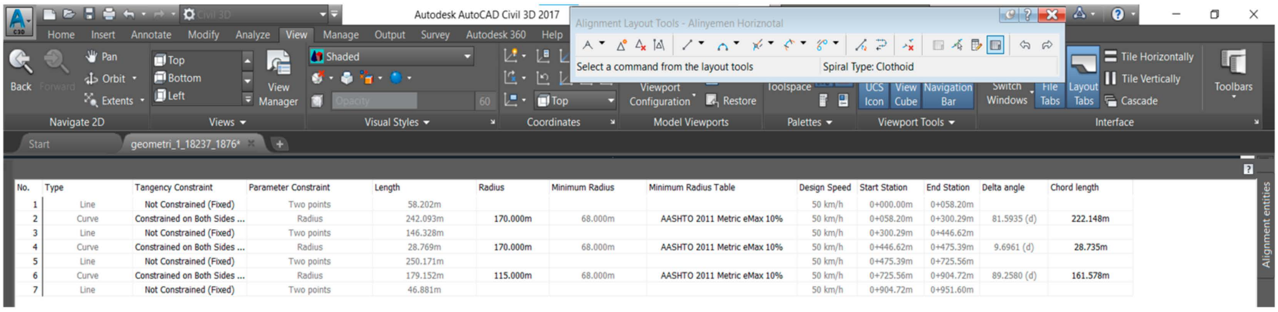


Figure 2. Road trace.

4.2. Horizontal Alignment

This road design plan in Sidamukti Village, Majalengka Regency considers a speed of 50 km/h and a width of 5 m. Before horizontal alignment, we refer to the AASHTO 2011 Policy on the Geometric Design of Highways and Streets, using the eMax 10% method. All data and design criteria are inputted on the application dashboard, as shown in Figure 3.



No.	Type	Tangency Constraint	Parameter Constraint	Length	Radius	Minimum Radius	Minimum Radius Table	Design Speed	Start Station	End Station	Delta angle	Chord length
1	Line	Not Constrained (Fixed)	Two points	58.202m				50 km/h	0+000.00m	0+058.20m		
2	Curve	Constrained on Both Sides ...	Radius	242.093m	170.000m	68.000m	AASHTO 2011 Metric eMax 10%	50 km/h	0+058.20m	0+300.29m	81.5935 (d)	222.148m
3	Line	Not Constrained (Fixed)	Two points	146.328m				50 km/h	0+300.29m	0+446.62m		
4	Curve	Constrained on Both Sides ...	Radius	28.769m	170.000m	68.000m	AASHTO 2011 Metric eMax 10%	50 km/h	0+446.62m	0+475.39m	9.6961 (d)	28.735m
5	Line	Not Constrained (Fixed)	Two points	250.171m				50 km/h	0+475.39m	0+725.56m		
6	Curve	Constrained on Both Sides ...	Radius	179.152m	115.000m	68.000m	AASHTO 2011 Metric eMax 10%	50 km/h	0+725.56m	0+904.72m	89.2580 (d)	161.578m
7	Line	Not Constrained (Fixed)	Two points	46.881m				50 km/h	0+904.72m	0+951.60m		

Figure 3. Screen capture of results of horizontal alignment calculation.

Viewed as a whole, the horizontal alignment must ensure safety and comfort for road users. Thus, according to the AASHTO 2011 Policy on the Geometric Design of Highways and Streets, every design speed determined has a minimum radius that is allowed during planning. The curve types in horizontal alignment are divided into three categories as follows. (1) Full Circle—This curve shape is used if, in the planning, a large R-value is obtained. This type of bend only consists of part of a circle. (2) Spiral Circle Spiral—This bend shape is a curved transition from a straight section (tangent) to a circle shape. The primary function of the curve transition is that the centrifugal changes that occur when the vehicle enters or leaves the curve can happen gradually and not suddenly. In this way, it is hoped that vehicles can traverse the lanes provided comfortably. (3) Spiral Spiral—This is a curve without a circular arc. Spiral bends are used for sharp bends. The equations used to find the bend parameters are the same as those used for spiral circle spiral bends. Especially for spirals, it is used when Lc < 25 m. Furthermore, this is the result of the horizontal alignment design in Figure 4.

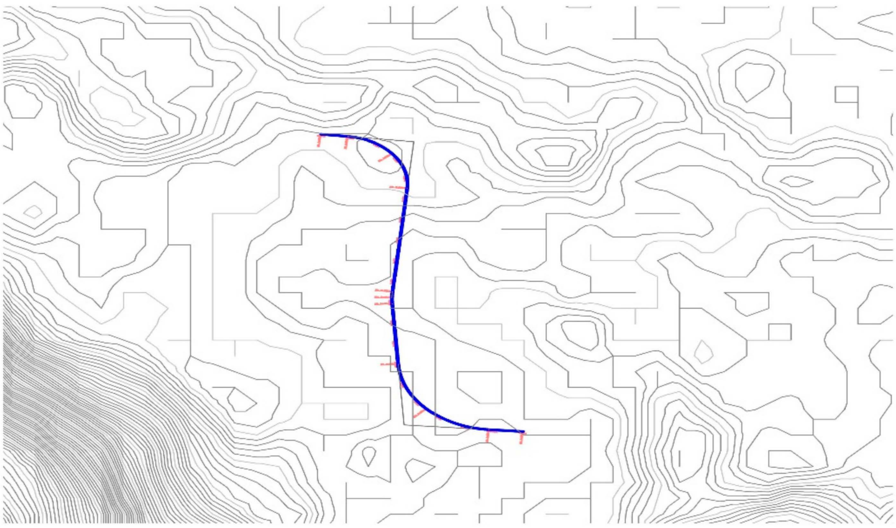


Figure 4. Horizontal alignment design.

Road geometric planning requires planning data, one type of which is the topography. The topography in question is the difference in the land surface height (contour) and land use, which is a reference in road planning. Topographic analysis methods use GIS applications, including ArcGIS, Google Earth, and Global Mapper, which prepare the topography based on road planning data and the location. The data required for topography creation are geospatial and spatial, and topographic preparation is performed using Google Earth Pro. In Figure 5, we show the horizontal alignment conversion performed on Google Earth Pro.

Figure 5. Horizontal alignment conversion on Google Earth Pro.

4.3. Vertical Alignment

Vertical alignment can be divided into two forms. First, there is a curved vertical curve, where the point of intersection between the two tangents is above the surface of the road in question. Changing from one slope to another requires a vertical curve, which is planned to ensure safety and comfort. After performing the horizontal alignment, the next step is to align vertically with the plan prepared in Figure 6 below.

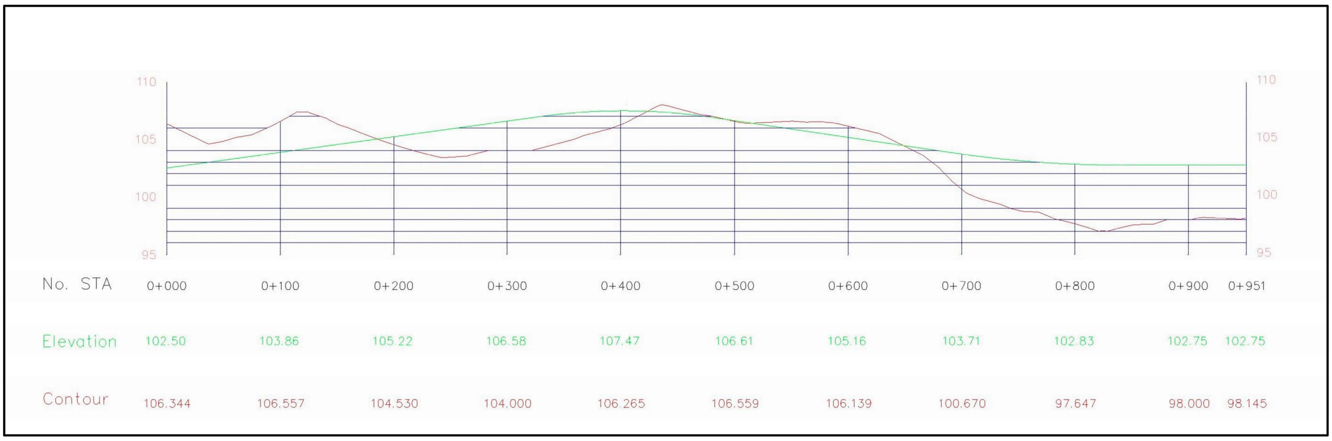


Figure 6. Vertical alignment design.

A road cross-section is a cross-section perpendicular to the road axis. In a cross-section of the road, one can see parts of the road. The calculation of the volume using the average cross-sectional method is generally influenced by the cross-sectional distance or transverse profile, which is determined at specific intervals. Each cross-section or profile is marked with the notation STA (station). The STA notation indicates the place or location of the section of the road being designed or implemented and the length of the road. A problem that often occurs in the field is that there are differences in the use of distance intervals between STAs in each work implementing agency, and there needs to be standardization. If we refer to the training module document provided by the Ministry of Public Works and Public Housing, the STA distance intervals for highway work are approximately every 100 m. In the AASHTO method, the maximum slope at 50 km/h is 7–12%. The condition of the road influences the maximum slope.

4.4. Assembly

After creating the horizontal and vertical alignment design, we use the "Create Assembly" menu to create it. Then, it will appear in the assembly, and we create an assembly with planning. The stages of road geometry design start with the width of the road, 5 m, an AOR superelevation lane of −3, and a 1 m shoulder. After completion, we obtain the road assembly, as shown in Figure 7.

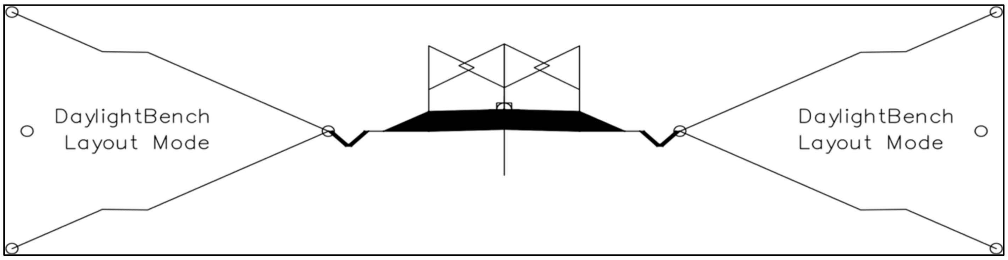


Figure 7. Assembly.

4.5. Corridor and Sample Lines

After creating the road assembly, we create the corridor using the "Create Corridor" menu. It is necessary to focus on this section and ensure that a horizontal alignment is created. Then, when the selected vertical profile is created, the road corridor will be drawn automatically in AutoCAD® Civil 3D. The results of data input, running, and simulation of corridors and sample lines can be seen in Figure 8.

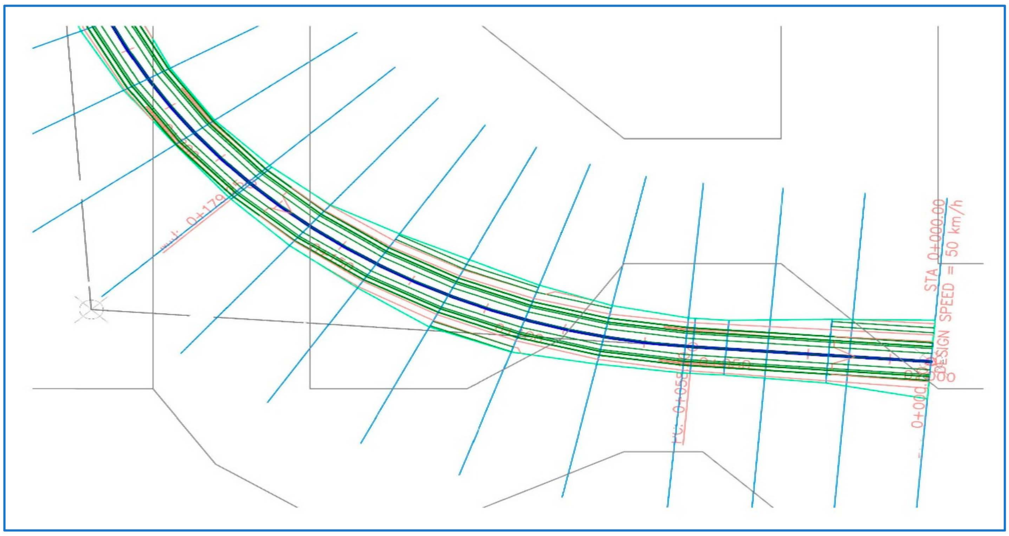


Figure 8. Corridors and sample lines.

The road corridor defines the cut-and-fill slope area created for the placement of the road plan. Next, we can simulate the road created using the "Drive" menu and select the horizontal alignment. The road simulation is depicted in Figure 9 below.

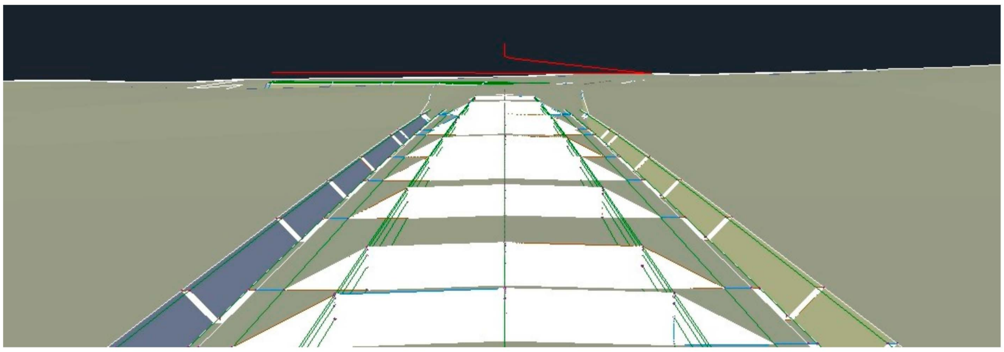


Figure 9. Screen capture of road simulation.

This study uses topographic profile data at three different intervals. Based on the data processing results, surface models from the topographic data at intervals of 25 m, 50 m, and 100 m are obtained. The surface model is arranged using different sample points at each interval. In addition, the surface model results are presented in three dimensions.

The horizontal alignment must ensure safety and comfort for road users. Thus, according to the AASHTO's 2011 Policy on Highway and Street Geometric Design, the curve types of horizontal alignment are divided into three categories, namely full circle (FC), spiral circle (S-C), and spiral circle spiral (S-C-S). At the P2 bend, there is a line–curve–line segment with a planned radius of 170 m; at the P3 bend, there are curved lines with a planned radius of 170 m; and, at the P4 bend, there is a line–curve–line segment with a planned radius of 115 m.

The data processing stage consists of creating a surface model, creating a road pavement plan, and calculating the volume of excavation and embankment using the topographic data (longitudinal profile and transverse profile) at STA intervals of 25 m, 50 m, and 100 m. Thus, three volumes of excavation and embankment are included on straight and curved roads. Next, this will be analyzed using the standard deviation of the volume results at each interval and the ASTM tolerance test for the results of the excavation and embankment volume calculations, which are considered correct. In this study, the calculation results for the volumes of excavation and embankment that are considered correct are those obtained with topographic profile data with an STA interval of 25 m and a section interval of 25 m.

The AutoCAD® Civil 3D software used here has unique features that are highly sophisticated and very supportive in road geometric planning compared to AutoCAD Manual, which is only a simple tool that does not have the same features as in AutoCAD® Civil 3D. In terms of detail and design, AutoCAD® Civil 3D enables automation with standard data that are available. Thus, AutoCAD® Civil 3D can save time and improve the ease of the design process compared to AutoCAD Manual.

5. Conclusions

In the design of road geometrics, the use of AutoCAD® Civil 3D greatly facilitates the work of designers because there are items that are interconnected between the tools in AutoCAD® Civil 3D. Thus, at the time of modeling, the design of the road geometry in Sidamukti Village, Majalengka Regency, using AutoCAD® Civil 3D is more effective. We perform the design process for the Sidamukti Village Road using STA 0 + 000.00 to 0 + 951.60 based on the AASHTO's 2011 Policy on the Geometric Design of Highways and Streets, and we include several design aspects, such as road tracing, horizontal alignment, vertical alignment, assembly, corridors and sample lines, and cut-and-fill volumes. This design has a plan speed of 50 km/h, a road width of 5 m, a two-way road type, two undivided lanes, and a road length of 951.6 m. The study results show that the use of AutoCAD® Civil 3D for village road planning provides convenience, speed, and the best planning precision.

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