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The implementation of AutoCAD® Civil 3D for highway geometric redesign: a case of Indonesian toll road

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Abstract. Transportation infrastructure is one of the primary needs in increasing a country's economic growth. In the last decade, Indonesia has continued to build toll roads to accelerate the provision of these needs. In some toll road development projects, a redesign is required as a form of field adaptation. The redesign process requires accuracy, speed, and convenience, so the development process goes according to plan. This paper discusses the implementation of using AutoCAD® Civil 3D for toll road redesign in Indonesia. The data is taken from the construction of toll roads in the Greater Jakarta-Indonesia area in 2023. The research method was carried out by comparing manual calculations and AutoCAD® Civil 3D. The study results show that some adjustments to the toll road design must be implemented faster and more precisely according to field needs. The selection of these applications makes it easier for designers to determine various options for planning the toll road. The conclusion of this paper shows that the use of AutoCAD® Civil 3D increases the efficiency and effectiveness of toll road redesign.

1. Introduction

Highways are one of the most critical infrastructures in all countries. With the Highway, all access becomes more accessible and comfortable, and the travel distance becomes shorter and more efficient. All countries are competing to continuously innovate in the development of Highways so that the level of safety in driving will also increase. Expansion in terms of road infrastructure is one of the critical components in the world's conservation planning and development. It is recorded in history that the drivers of vehicles on the road have always interpreted speed, safety, and comfort in driving as a responsibility that is said to be simple and only sufficient regarding road construction assurance [1].

In Indonesia, the Highway is a barrier-free access road, an integrated road system. Highways in Indonesia are also roads where Highway users are given a fee for using the Highway. Road capacity in Indonesia is no longer sufficient because the traffic volume increases yearly, causing traffic jams. Highways are public roads that are part of the road network system and are national roads whose users must pay a toll [2].

Construction of the Jakarta Outer Ring Road 2 (JORR-2) connected Jakarta and South Tangerang. The structure of this Highway is intended to support the smooth flow of traffic links in Greater Jakarta areas. Moreover, it can help logistics access points for goods and services to increase the area's economic level. In planning on road geometry, the part of road planning that is always a concern and focus is on planning in the form of the road itself, which aims to ensure the actual function of the road

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itself, namely by providing services on road and vehicle lanes that are optimal for each traffic flow: traffic that occurs and links to settlements [3].

Road geometric planning cannot be separated from horizontal alignment or horizontal curvature, including the length of sections, straight and curved roads, bend radius to superelevation, and vertical alignment, including at roads and slopes up and down. These parts are interconnected to meet the requirements to be designed according to function and purpose. Currently, planning in road geometry has been designed and implemented more quickly due to current technological developments in the construction field, which have a significant impact and innovations that continue to grow and develop [4].

Along with the times and the use of developing technological developments, currently, many applications can be used in road planning. One is AutoCAD® Civil 3D, which can be used in this planning, especially in geometric road planning. Civil engineering professionals utilize the AutoCAD® Civil 3D software to plan and design projects. Using different features of the AutoCAD® Civil 3D software, we can generate the total cut and fill, Volume Report Sheets, and end of that study area [5].

This paper aims to show how to use AutoCAD® Civil 3D to redesign road geometry on the horizontal curve of the JORR-2. With the use of AutoCAD® Civil 3D in geometric road planning, this software will immediately show or notify if a radius in the planning is not following the standard. In other words, the purpose and benefits are to make it easier to understand how to utilize application development technology in geometric road planning properly.

2. Literature review

2.1. AutoCAD® Civil3D

AutoCAD® Civil 3D is an application in design in the world of civil engineering specially designed by Autodesk. This software supports and supports the modeling of a construction building. With this software, the user/users are given convenience in terms of design. The software's information is detailed; notifications will be issued if something violates planning standards. The design in AutoCAD® Civil 3D is very functional and supports facilitating planning. The use of AutoCAD® Civil 3D provides convenience in designing the desired structure and provides output for more accurate design results. AutoCAD® Civil 3D is a tool for developing models in the Civil Engineering [6].

This three-dimensional (3D) design is a highly developed technology today. In fact, along with the development of the times, this three-dimensional technology continues to develop and improve functions to continue to grow and facilitate the design. They also revealed that simulation at a high level of perfection would put pressure on novice students and be a barrier to learning. Civil3D creates 3D models of the project and helps to adapt for both small- and large-scale projects. It helps to imagine things in 3D visualization, reducing time and budget. It also inherits many benefits of using civil 3D [7].

The AutoCAD® Civil 3D is more realistic than the current 2D software because it tends to the visual perception of each element and accentuates the projection of existing lines. AutoCAD® Civil 3D provides easy modeling in complex designs, which wastes time and anticipates errors. AutoCAD® Civil 3D assists in design and drafting and efficiently reduces time spent evaluating methods and various situations [8].

2.2. Road geometric planning

In the Regulation of the Minister of Public Works No. 19/PRT/M/2011 concerning Road Technical Requirements and Road Technical Planning Criteria, Article 55 explains Road Geometric Requirements. Geometric road planning requirements must comply with geometric road rules based on traffic safety. It is also stated that the elements in the planning include horizontal and vertical alignment and road sections that have been arranged following the provisions of the Road Technical Requirements. The geometric design suggests that these demands are met. Horizontal alignment has three geometric components: curves, tangents, and transitions. Highway geometry additives depend on chosen, estimated, and in a manner that fulfills such design standards as sight distance, driver isolation, drainage, economy, vehicle stability, and aesthetics [9].

The concepts used in the process of planning or geometric design of roads must be as effective and efficient as possible, have economic values, put safety first, and must also be environmentally conscious according to what has been regulated in government regulations. It is essential to apply these concepts to make this Highway as it should be so that it is safe and there is no prolonged repair. Safety and security are a priority in planning. Can optimize Driver safety and security by focusing on determining speed without compromising vehicle design, including the engine power ratio to vehicle weight; the driver is no exception [10].

In the initial design planning process, the cross sections of the road topography have interrelationships and influences related to the horizontal and vertical alignment of a road. In general, this horizontal alignment is in the form of a series of straight and curved road sections in the form of circular arcs and then connected by transition curves and without transition curves. In carrying out the planning or design, determining the design speed according to the classification and consideration of horizontal curves, which can be in the form of steep slopes or gradients, also needs to be considered to pay attention to the safety of road users. Horizontal alignment is a series of arc arcs connected without transitional arches or by intermediate arcs. Horizontal alignment connects straight roads. There are three factors, namely the number of intersection points, their location, and the radius of the curve [11].

In planning rainwater runoff, roads must be a concern. The pavement layer is easily damaged due to inundation because the fundamental nature of the asphalt mixture forming material is not too strong against water immersion [12].

2.3. Highway

The Highway is a Highway where the purpose of the development itself is to make it easier for people, especially in Indonesia, to increase their mobility from an economic and social perspective correctly and quickly and, of course, safely. This development is needed, especially in Indonesia, because the other main goal is to overcome and reduce inefficiencies resulting from congestion on main roads other than Highways and to improve system services in delivering or distributing all kinds of goods, materials, and services. Based on the classification, roads are divided into general and roads. Public roads are designed for public traffic; the Freeway and Highway are no exception and are maintained and run by the government. Roads are not intended for general traffic because they are only for the benefit of specific individuals, groups, communities, business entities, or organizations [13].

Road classification shows the operating standards that are needed, and this classification is a beneficial aid in planning. In Indonesia itself, based on the regulations regarding geometric road planning that are regulated and published by Bina Marga, existing roads are divided into their respective classes, and this placement is based on their function. There are exceptions in road construction. This development can be carried out sustainably due to several conditions. An example of this is limited funds. This sustainable development is initiated so that the wheel of life in a region develops [14].

Following Law No. 38 of 2004, the road is divided into two based on the type and function. Then, based on its function, this classification is further divided into four parts: arterial, collector, local, and environmental roads. In this case study, specifically on the JOOR-2, this Highway is classified based on government administration. The JOOR-2 is a National Road, with the details that this is an arterial road and a collector road adapted to the primary network connection system connecting cities and provinces. Roads are a crucial means for most of the movement of people, goods, and services. Humans depend on this infrastructure in daily activities because it is an advice and transportation that is always used and the primary means. Not only that, but this infrastructure also has a massive role in developing the country's economy [15].

3. Methodology

The horizontal alignment plan that will be discussed is the JOOR-2, which is part of the Jakarta Network Road, which is planned to be connected to the Kunciran-Serpong Tool Road in the western region and the Cinere-Jagorawi in the eastern region as shown in figure 1. The location of this Highway connects South Tangerang with Depok and is managed by PT Cinere Serpong Jaya. The JOOR-2 is divided into Section 1 of the 6.5 km Serpong-Pamulang Section, Section 2 of the 3.64 km

Pamulang-Cinere Section, and Section 3 of the Cinere-Jagorawi Section, which is planned to be operational in 2024.

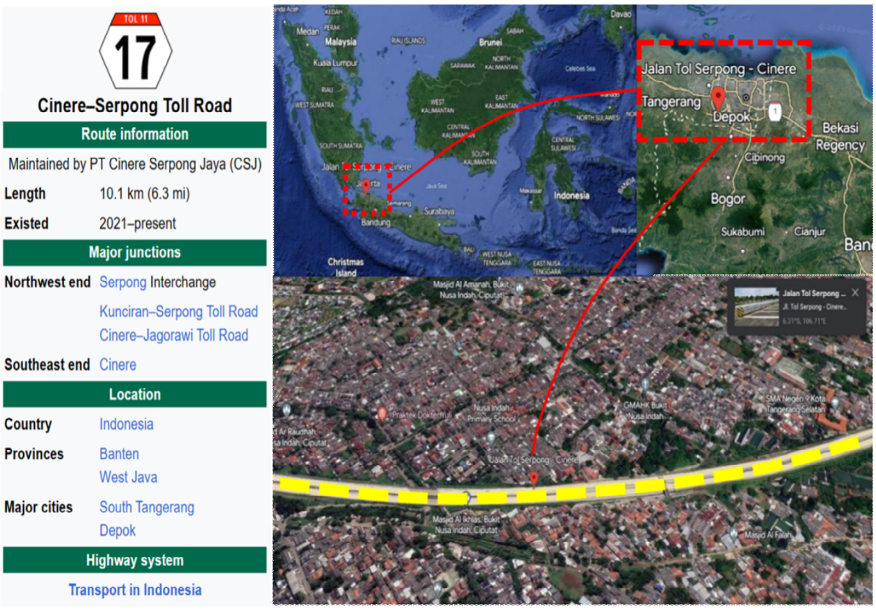

Figure 1. Mapping of Serpong-Cinere Toll Road

The process of redesign or research is systematic and must be started by identifying existing and appropriate problems. Compilation of a structured arrangement must begin by identifying an exact problem [17] [18]. Essential planning is also needed to determine the data collection and research methods. Data, analysis, and calculations are critical in preparing scientific research and interpretation [16]. Data is a critical component in compiling the required analysis and modeling. Then, the data collected and planned to be used in this report are classified as secondary data because these data can also be obtained from satellite imagery via Google Earth. Secondary data or information obtained from various sources or indirectly can meet the information needs of the survey [19]; [20]; [21]; [22].

This planning uses AutoCAD® Civil 3D Software, which uses the AASHTO 2011 reference standard. Meanwhile, the Indonesia Highway Design Standard 2022 still plans the planning criteria. This planning is limited to standard inter-city highways. The planned road geometric planning is in horizontal and vertical alignment. This plan needs to calculate the cost of carrying out the work, consider side clearance and widening of bends, and consider the bridgework and the visibility of the existing light beams.

Data was obtained from PT Cinere Serpong Jaya and the Directorate of General Highway Indonesia. After obtaining secondary data, geometric planning is carried out manually to determine planning criteria based on the 2022 Indonesia Highway Design Standard. Then, the process uses AutoCAD® Civil 3D to plan horizontal and vertical alignments. After the results come out, these results will be validated with manual calculations, and on alignment planning horizontally, the selection of the type of bend is based on the 2022 Indonesia Highway Design Standard.

4. Result and analysis

Toll roads, part of national roads, were developed to support and accelerate economic growth and significantly improve the quality of public services. Of course, in realizing this, toll roads must comply with technical requirements. As a primary arterial road, toll roads have higher safety and convenience than public roads. In its development, transportation capacity will increase by adding highways, motorways, and the like. These types of roads in Indonesia are better known as toll roads. The feature of toll roads is that they connect regions and centers of national and regional activities in urban and rural areas. This condition can reduce travel times, transport costs, and environmental and social impacts and minimize costs to the local economy. Following the basic principles, reducing economic costs will encourage efficiency and effectiveness in increasing government services to the community.

The geometric redesign is using AutoCAD® Civil 3D. This redesign and planning are equipped with standard steps already available in the AutoCAD® Civil 3D and are easy to manage, as shown in figure 2.

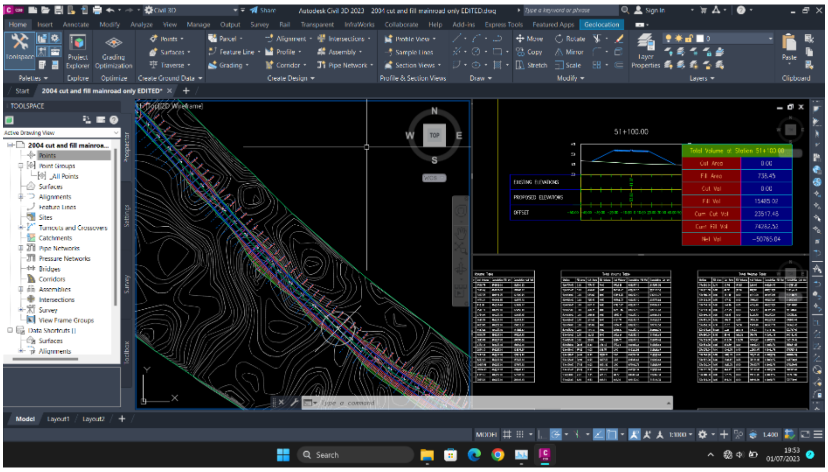

Figure 2. AutoCAD® Civil 3D window display

4.1. Trace of the road geometric design

Redesign of the Road geometric planning in this study used a design speed of 100 km/hour, with a road width of 12 m consisting of 2 lanes from the outer edge of the median to the inner edge of the road shoulder and a value of bend design which includes determining the bend radius Rc = 346,8729404 m. This Redesign Road traffic planning uses AutoCAD® Civil 3D based on the contour data obtained, which connects South Tangerang with Depok as shown in figure 3 and divided into several points of interest of road design starting from STA 50+750 and ending at STA 61+535,98.

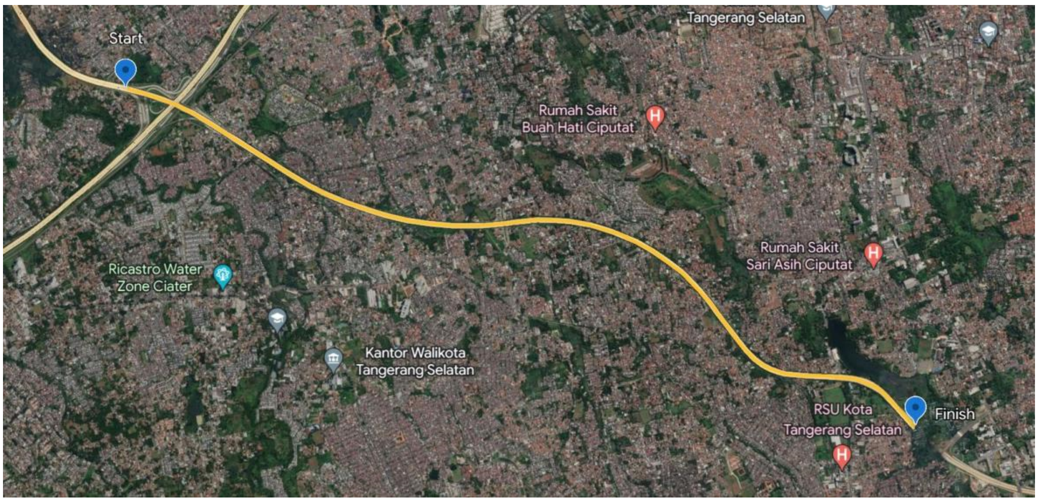

Figure 3. Trace of geometric planning

4.2. Alignment horizontal

Suppose the planning of the trace lines has been made and determined. In that case, an analysis of the calculations as data can be carried out to make the desired horizontal description and plan using AutoCAD® Civil 3D, and one of them is also by calculating the minimum curvature (Rmin) as will be described and explained in formula (1). Start by doing calculations for the minimum arc size (Rmin), which is adjusted to the required design speed (Vr)of 100 km/hour, then with the maximum superelevation slope plan (e_{max}) of 10% and using the transverse friction coefficient (f) which is determined at 0.127 explained in formula (2).

$$R_{min} = \frac{V_R{}^2}{127\ (0{,}01\ x\ e_{max} + f_{max}} \quad (1)$$

$$f_{max} = -0{,}00065\ x\ V_R + 0{,}192 \quad (2)$$

Furthermore, if the calculation of the minimum arch (Rmin) has been carried out, the next thing to do is to calculate the switching arch (L_{smax}) maximum length of a spiral as described in formula (3).

$$L_{smax} = \sqrt{24\ (P_{max})R} \quad (3)$$

Then, an estimated $L_{s\ design}$ value of 130 m is obtained by estimating the planned value and can be said to meet the requirements of the $L_{s\ design,}$ which is smaller than L_{smax} ($L_{s\ design} < L_{smax}$). When the analysis process is completed, the results of calculating the five points of interest (PI) for road traffic planning are obtained, as shown in table 1.

Table 1. Horizontal alignment calculation result.

	Parameter	Manual	Civil 3D	Comparation
ΔP$_1$		27,00	27,00	=
ΔP$_2$		30,29	30,29	=
ΔP$_3$		32,28	32,28	=
ΔP$_4$		21,53	21,53	=
ΔP$_5$		26,72	26,72	=
Vr		100	100	=
θs	(90 x Ls)/(π x Rc)	5,209	5,213	±
θc	ΔPI1 - 2θs	17.039	17,039	=
Lc	(θc/360) x 2π x Rc	163,563	163,565	±
Lt	Lc + 2Ls	363,563	363,565	±
Xs	Ls - (Ls^3/(40 x Rc^2))	99,917	99,917	=
Ys	Ls^2 / 6 x Rc	3,030	3,032	±
K	Xs- Rc(sin θs)	49,986	49,986	=
P	Ys- Rc(1 -cos θs)	0,759	0,764	±
Ts	(Rc + P) x tan (ΔPI1/2) + K	184,534	184,534	=
Es	Rc + P) x sec (ΔPI1/2) - Rc	16,956	16,958	±

The planned bends have five bends based on the size of the bend angle, the distance between the two bends, and the topographical conditions according to the bend selection criteria still following the standards, and the SCS bend is obtained. The results of SCS bend calculations using AutoCAD Civil 3D assistance and manual calculations using the Indonesia Highway Design Standard 2022 reference with the same radius and spiral length to see the difference between the two from $P_1 – P_5$ can be seen in table 1. As shown in table 1 between the calculation results of the AutoCAD Civil 3D application with the Indonesian Highway Design Standard 2022use the same planning criteria, there is still a slight difference, namely in the calculation of the horizontal alignment at the SCS corner on the parameters Xs, Ys, P, K, Ts, and ES, the difference is less than 0.3 m caused by differences in the processing process where in manual calculations the value of Rc and the value of Ls is the value that is entered into the calculation to proceed to the following calculation, whereas in Civil 3D the significant value of Rc is entered after the length of Ls is entered. This difference is also due to the possibility of a difference in the formula equation between planning using Civil 3D calculations and manual planning, referring to the Indonesian Highway Design Standard 2022.

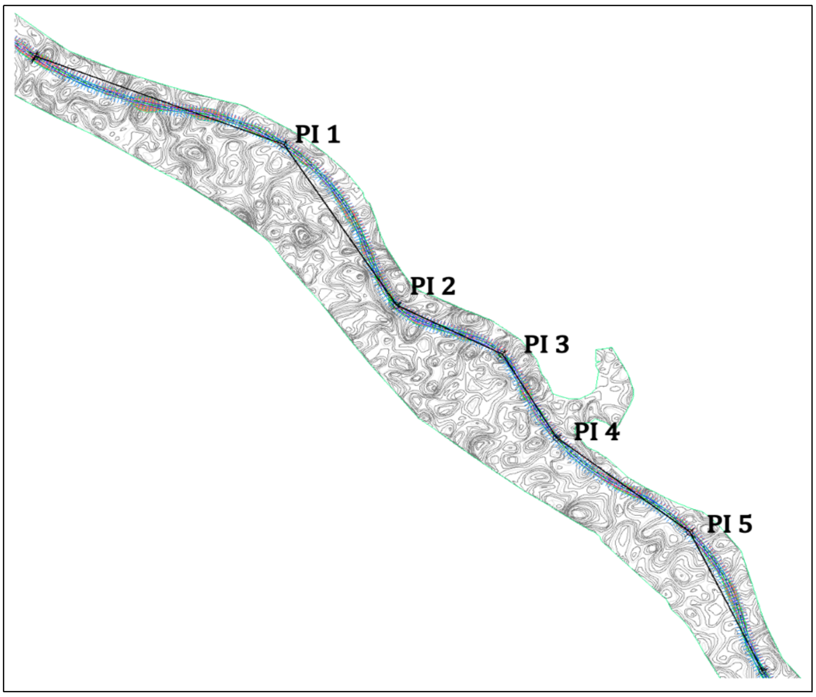

Figure 4. Alignment horizontal redesign.

The horizontal alignment design plan above, shown in Figure 4, is the result of planning using AutoCAD® Civil 3D. From planning horizontal alignment using AutoCAD® Civil 3D, we will get a design or longitudinal section, as shown in figure 5.

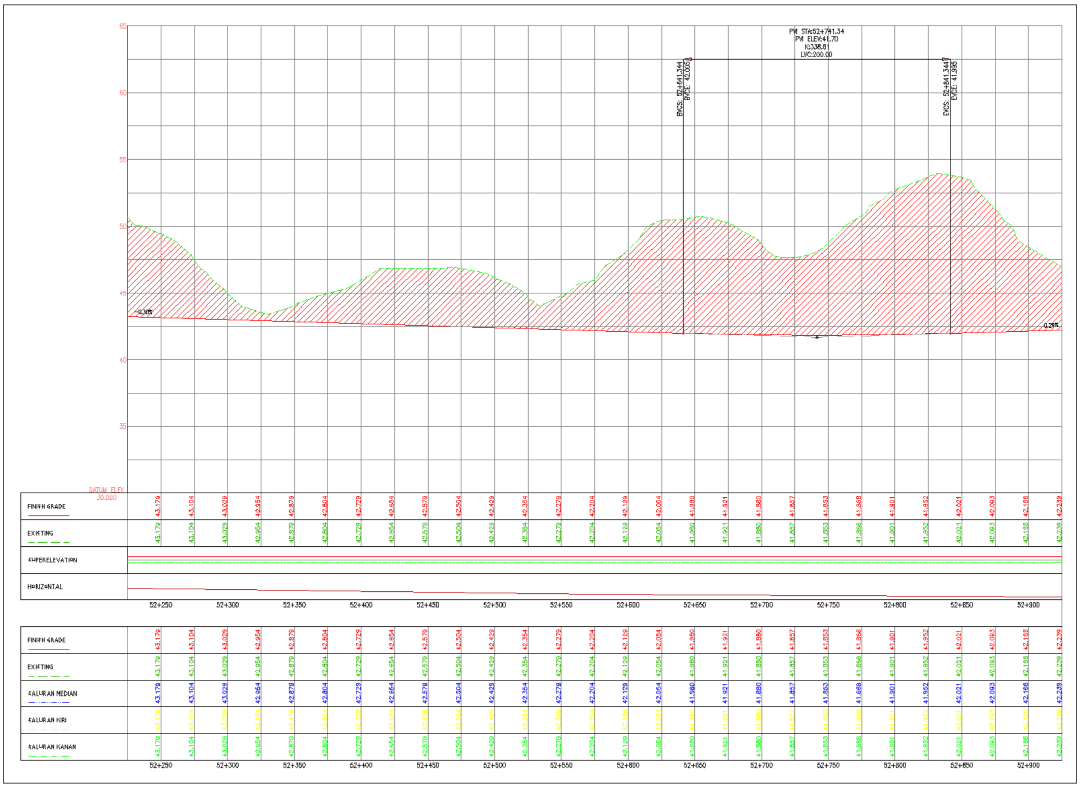

Figure 5. Longitudinal section of horizontal alignment design planning.

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4.3. Assembly

At this stage, the assembly needs to be planned before starting to carry out the process of making the planning corridor. Then begin planning an assembly by creating an assembly in the toolbar area, then adjust the style based on the planning; if the desired adjustments have been made, after clicking OK, an assembly sign display will appear, then the assembly sign rectangle that appears will make it easier to find it. The following is the result of the assembly planning that has been carried out, which is shown in figure 6.

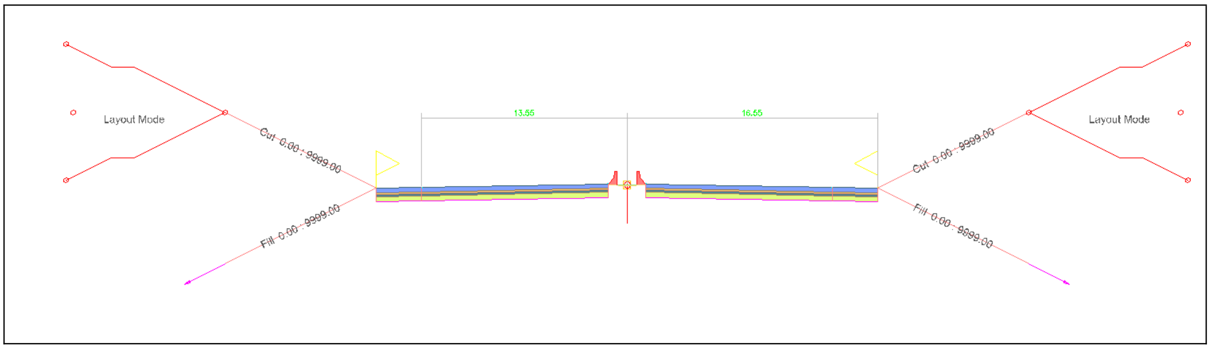

Figure 6. Assembly road design planning

4.4. Corridor

The next step is to plan the corridor by creating a corridor after the assembly process. This corridor planning aims to determine the stockpile area and excavations that will be used for laying the road body that has been designed and planned. An example of corridor planning is shown in figure 7.

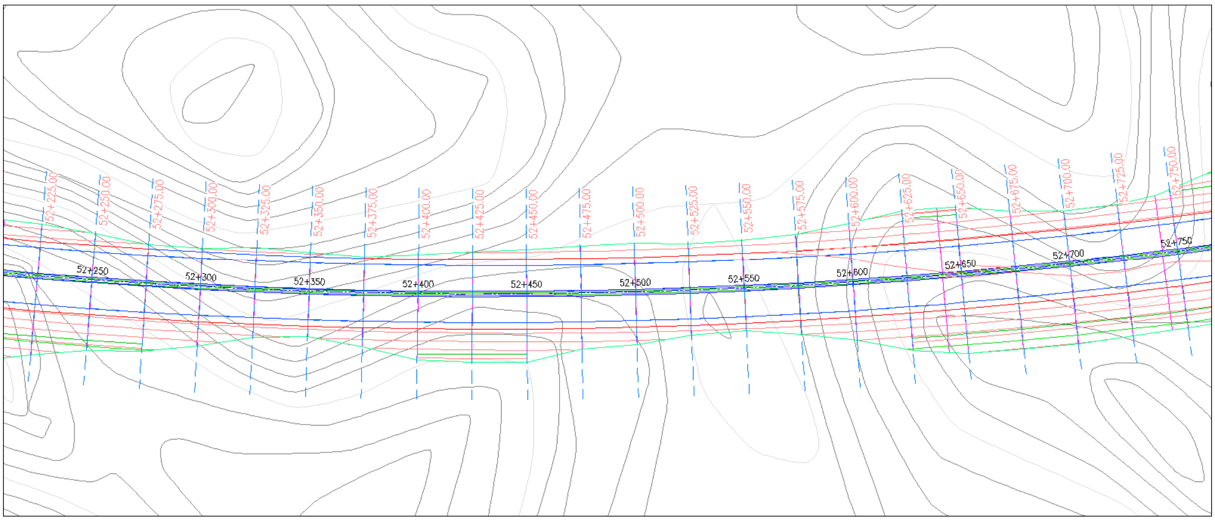

Figure 7. Corridor design planning

4.5. Cut and fill

The next stage of this planning, using AutoCAD® Civil 3D, is to increase the cut and fill volumes. The Estimator can use this output volume to calculate the costs for land leveling and land clearing or cut and fill work for structure or construction because the land leveling work to be carried out will cost a lot and can be very expensive. Then, from the planning carried out in this study, the cut and fill volumes were obtained, shown in figure 8 and figure 9, the cut and filled embankment volume from AutoCAD® Civil 3D.

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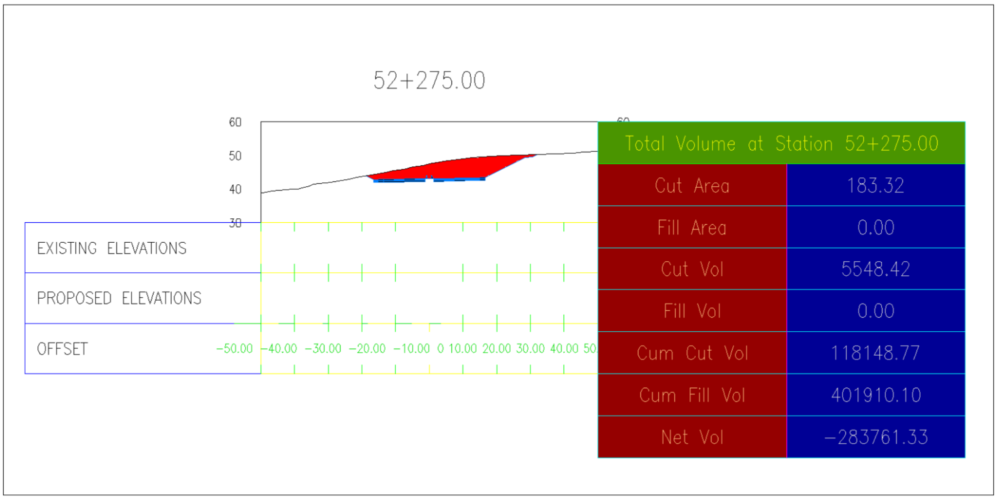

Figure 8. Screen capture of cut and fill in each point *(example)*

There are five points of concern in road traffic planning with different curves. The design speed (Vr) used is 100 km/hour, the maximum superelevation slope obtained (e_{max}) is 10%, and the transverse friction coefficient (f_{max})obtained is 0.127. With an average value of cut volume obtained from this plan with a range of STA 52+250 to STA 52+750 is around 200,000 m^3, and the fill volume obtained from this plan with a range of STA 52+250 to STA 52+750 is around 400,000 m^3. In AutoCAD® Civil 3D, after determining the point of interest (PI) on the road trace, then draw the tangent line on AutoCAD® Civil 3D to bring up the line that will be planned for the alignment, then after the planning of the alignment is complete to show and bring up automatic data from AutoCAD® Civil 3D you can click on the Alinyement > Geometry Editor > Geometry Grid View.

Total Volume Table						
Station	Fill Area	Cut Area	Fill Volume	Cut Volume	Cumulative Fill Vol	Cumulative Cut Vol
52+250.00	0.00	260.56	0.00	7616.78	401910.10	112600.35
52+275.00	0.00	183.32	0.00	5548.42	401910.10	118148.77
52+300.00	1.81	86.87	22.66	3377.33	401932.75	121526.09
52+325.00	9.14	30.81	136.85	1471.01	402069.60	122997.10
52+350.00	2.13	42.15	140.84	912.06	402210.44	123909.17
52+375.00	0.00	81.15	26.66	1541.31	402237.10	125450.48
52+400.00	0.00	137.65	0.00	2734.98	402237.10	128185.45
52+425.00	0.00	182.22	0.00	3998.36	402237.10	132183.81
52+450.00	0.00	188.49	0.00	4633.96	402237.10	136817.77
52+475.00	0.00	170.53	0.00	4487.86	402237.10	141305.62
52+500.00	0.00	150.97	0.00	4018.77	402237.10	145324.40
52+525.00	0.00	94.29	0.00	3065.68	402237.10	148390.08
52+550.00	0.00	95.48	0.00	2372.11	402237.10	150762.19
52+575.00	0.00	150.45	0.00	3074.10	402237.10	153836.29
52+600.00	0.00	264.24	0.00	5183.59	402237.10	159019.88
52+625.00	0.00	393.94	0.00	8227.26	402237.10	167247.14
52+650.00	0.00	439.34	0.00	10415.96	402237.10	177663.10
52+675.00	0.00	407.46	0.00	10584.93	402237.10	188248.03
52+700.00	0.00	337.79	0.00	9315.56	402237.10	197563.59
52+725.00	0.00	290.66	0.00	7855.56	402237.10	205419.15

Figure 9. Screen capture of cut and fill-in total in each sta *(Example)*

5. Conclusion

Based on the discussions, the redesign using AutoCAD® Civil 3D makes it easier to plan horizontal alignments by closing the possibility of human error. During the design process with AutoCAD® Civil 3D, if in planning bends, there is a unique situation. For example, by increasing the design speed (Vr) and changing Rmin, if Rmin is reduced, AutoCAD® Civil 3D will show if it is still allowed or not if it is lowered, and AutoCAD® Civil 3D will give a notification if the radius is not up to standard. Calculating cut and fill volumes is also more accessible and more accurate when done with the help of AutoCAD® Civil 3D compared to manual calculations. Ultimately, AutoCAD® Civil 3D is more efficient and accessible in geometric planning than manual planning. Then, this planning can also produce the data needed more quickly, precisely, and accurately.

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