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AutoCAD® 2D for Geometric Design of Terbanggi Besar–Pematang Panggang Highway (Sta.28+650 – Sta.53+650)

[1]Ratih Yuliani Gunawan, [2]Andri Irfan Rifai, [3]Muhammad Alamsyah Irianto
[1]Faculty of Engineering, Universitas Mercu Buana, Indonesia
[2]Faculty of Civil Engineering & Planning, Universitas Internasional Batam, Indonesia
[3]Directorate General of Highway, Ministry of Public Works & Housing, Indonesia
E-correspondence: liani.ratih@gmail.com

Abstract
With a length of approximately 2,818 kilometers, the Trans Sumatra Highway connects cities from Lampung to Aceh. Meticulous planning and adherence to the geometric and technical requirements of the route are required to provide good road service. The purpose of this paper is to specifically redesign the current route on the Terbanggi Besar-Pematang Panggang section of the highway. The information used in this report as a guide for re-planning came from the results of field surveys. The geometric design of this highway was carried out using the manual calculation method based on the Road Design Standards of Indonesia 2021 and visualized using AutoCAD® 2D. Based on available data, a design speed (V_D) of 120 kph is determined according to the maximum value on flat terrain on the highway. As a result of data processing on a particular road section, a horizontal alignment with a full circle curve type with a radius of 1500 m was created. Meanwhile, a sag vertical curve type is obtained in the vertical alignment with a length value at one point of the curve (L) of 75.6 m.

Keywords: Highway Design, Horizontal Alignment, Road Geometric, Vertical Alignment.

1. Introduction

Transportation infrastructure has always been a political instrument for decision-makers which is reflected in government programs and subsequently implemented through public policies to reduce inequality and encourage economic growth (Cigu, Agheorghiesei, Gavriluță, & Toader, 2018). Highways are infrastructure that can move people/goods from one place to another by reducing travel time. Furthermore, the highway also plays a significant role in achieving distribution effectiveness, especially logistical distribution, so that economic development can be equitable. Along with economic development, people's welfare also increases, so the intensity of road use also increases (Prasetyo, Widyastuti, & Kartika, 2020, p. E253). The growth of connectivity infrastructure aims to integrate the inter-regional economy by increasing efficiency and smoothing the flow of goods and services (Ardiyono, Parenrengi, & Faturachman, 2018). As one of the drivers of economic development, investment in infrastructure by building highways plays a crucial role and consequently allows the awareness of equitable development in all regions of the country. Here can also be used as a benchmark both micro and macroeconomically as well as evidence to show the readiness of civilization through fast and simple activities (Siswoyo, 2020).

In Indonesia, highway construction was carried out on a large scale from 2014 to 2019. About 1235 km of highways were built throughout Indonesia (Siswoyo, 2020). Currently, Indonesia's development is focused on big cities and has started to reach remote rural areas. Its implementation required integrated planning based on the needs of a region. The needs of an area can be persevering from the conditions and potential that exist in the region.

The construction of the Trans-Sumatra Highway aims to facilitate the development of the transportation and industrial sectors throughout Sumatra (Isradi, et al., 2021). This highway is a road that connects cities from Lampung to Aceh, with a length of ± 2,818 km. The Trans Sumatra Highway is expected to facilitate business activities and accelerate the flow of goods in and out (Fakhurozi, 2020). The Terbanggi Besar - Pematang Panggang – Kayu Agung section is the starting point of the Trans Sumatra highway network. The highway has a length of ± 189 km. In addition to economic objectives, the convenience of highway users must also be a top priority on these highways. Therefore, careful planning was needed by the technical geometric requirements of the road, both vertical alignment and horizontal alignment to provide good road service.

Supporting device in the form of software is needed to make the geometric design of the road, especially to visualize the design. The AutoCAD® 2D application is one of the supporting tools. AutoCAD® 2D is a computer-based application that can create digital drawings with precise lines. This application is very helpful in designing a road geometric more easily and quickly, especially in describing vertical and horizontal alignments. Furthermore, the output of the geometric design using AutoCAD® 2D is expected to provide accurate visualization.

Based on the above problems, a redesign will be carried out on the existing road, to be precise, on parts of the Terbanggi Besar – Pematang Panggang Sta. 28+650 – St. 53+650 highway by making horizontal alignment and vertical alignment at Sta. 28+650 - St. 31+150 along 2.5 km with manual calculations based on the Road Design Standards of Indonesia 2021 and visualized using AutoCAD® 2D. This paper is expected to be a solution for effective and efficient road geometric design.

2. Literature Review

2.1 AutoCAD® 2D

These days, *software* is applied to art, architectural design, and structural design in addition to science and technology. Some of this software can perform multiple functions at once, including simultaneous integration of architectural, structural, and construction management elements. Since its introduction in 1982, computer-aided design (CAD) technology has revolutionized how the world of architecture operates. It has eliminated the need for manual drawing and enabled businesses to plan, simulate, and produce new ideas all within the same program. With the aid of CAD®, it is possible to view many facets and viewpoints of building forms in a single software, facilitating the quicker and more effective identification of issues (Onur & Nouban, 2019).

AutoCAD® is the most common engineering program that helps to draw construction sections and detailed floor plan drawings. In this modern world where computerization is commonplace, AutoCAD® is equally crucial for every engineer. This program helps in designing ideas and visualizing concepts through realistic renderings (Palm, 2020). One of the software that can be used to design or visualize buildings in 2D is AutoCAD® 2D. By Using AutoCAD® 2D, the dimensions of an object to be drawn become more accurate and precise. Using AutoCAD® 2D to design a building or the geometric design of a road really helps to speed up the design process.

The current trend is toward using computer programs for road geometry design. The programs offer incredible precision and save a lot of time and effort. This paper presents a complete geometric design typical of highways using AutoCAD® Civil 3D software (Mandal, Pawade, & Sandel, 2019). Apart from visualizing buildings, AutoCAD® also aims to demonstrate how geometric designs can be carried out very quickly and accurately in a short time to enable civil engineering professionals from developing countries to plan road designs (Gaikawad & Ghodmare, 2020).

2.2 Geometric Design

Road geometric is part of road planning that emphasizes physical form planning to provide optimal service to traffic and access between locations. In general, designing road geometric involves several aspects such as road width, curve, road flatness, and visibility, as well as the combination of these parts for roads and crossings between two or more road segments. In addition, the geometric elements in road

planning consist of horizontal alignment and vertical alignment (Mandal, et al., 2017).

Road geometric design is concerned with the physical layout as it appears from the road and includes factors like cross sections, visibility, alignment, curves, and superelevation. (Veer, Gupte, & Juremalani, 2018). Changes in driver speed impact road alignment that incorporates horizontal and vertical curves on the highway, which can lead to safety issues (Wang & Wang, 2018). Based on this, of course, the main objective of road planning itself is the safety of road users. Of course, it must fulfill its function to provide optimum service to road users and produce safe, comfortable, and efficient infrastructure. Speed is a crucial parameter in the geometric design of roads and is related to road safety (Islam, Hua, Hamid, & Azarkerdar, 2019). Several parameters determine the degree of comfort and safety produced by a shaped road geometry. These parameters include the design vehicle; plan speed; traffic volumes; road service level; sight distance (Sukirman, 1999).

2.3 Horizontal Alignment & Vertical Alignment

Horizontal alignment is a projection of the road plan axis on the horizontal plane. Horizontal alignment is also known as "road situation" or "road alignment," which consists of straight lines connected by curved lines (Sasongko, 2018). The operation of the highway is directly affected by horizontal and vertical alignment. Many factors, including road classification, terrain, design speed, traffic volume, environmental conditions, and level of service required influence horizontal alignment design. Horizontal alignment must comply with special design criteria such as minimum radius, superelevation level, and visibility. These criteria maximize overall road safety and enhance the aesthetic appearance of the road (Abdulhafedh, 2019).

The horizontal alignment tends to be associated with a disproportionate number of severe accidents. Many measures have been proposed to reduce traffic accidents and deaths in horizontal alignment (Geedipally, Pratt, & Lord, 2019). Based on this, the main goal in designing the road geometry is safety. Creating a safe and comfortable driving environment is the aim of road safety design. Therefore, it is crucial to research how to optimize the horizontal alignment of the road because this can effectively improve the safety and economy of the designed horizontal alignment (You, Yu, Huang, & Hu, 2022).

The vertical alignment is a cross-section of the road. Completing the vertical alignment of the highway geometric design is a critical phase in a highway project and directly affects its construction costs (Ozkan, Tuydes-Yaman, & Acar, 2021). A vertical alignment (or road profile) is a longitudinal section of a roadway consisting of geometric elements such as convex and concave curves and the gradient (straight line) connecting them (Raji, Zava, Jirgba, & Osunkunle, 2017). The planned vertical alignment will be valid for quite a long time, so it is better if the selected vertical alignment can easily follow environmental developments (Sukirman, 1999).

The result of integration between the horizontal alignment and the vertical alignment of roads that are not aligned is not only a source of a potential traffic hazard but also causes a considerable increase in transportation costs and strain on drivers and passengers. Therefore, proper investigation and planning are most important in road projects, keeping in mind the current needs as well as the future development of the region (Chakole & Wadhai, 2022)

3. Methodology

Location of Geometric Design of Highway with AutoCAD® 2D: Case Terbanggi Besar – Pematang Panggang Section (Sta.28+650 – Sta.53+650) is in Lampung, Indonesia. The detailed location can be seen in figure 1. The analytical method used is quantitative (Andika, Rifai, Isradi, & Prasetijo, 2022). This method consists of several stages, namely the data collection stage, the road planning stage, and making a horizontal curve. The systematic scientific research process must begin with identifying the right problem (Rifai, Hadiwardoyo, Correia, & Pereira, 2016). Surveying was done on the Terbanggi Besar-Pematang Panggang (Sta. 28+650-Sta. 53+650) highways for this paper. The observation method is a data collection technique that involves observing and recording the state of the target object. The library method is an acting technique for collecting library data, identifying it, and processing the written data obtained. This

data collection is the next step after the preparation stage before this paper is carried out. The data collected is precise and appropriate because it follows the research plan (Rifai, Surgiarti, Isradi, & Mufhidin, 2022).
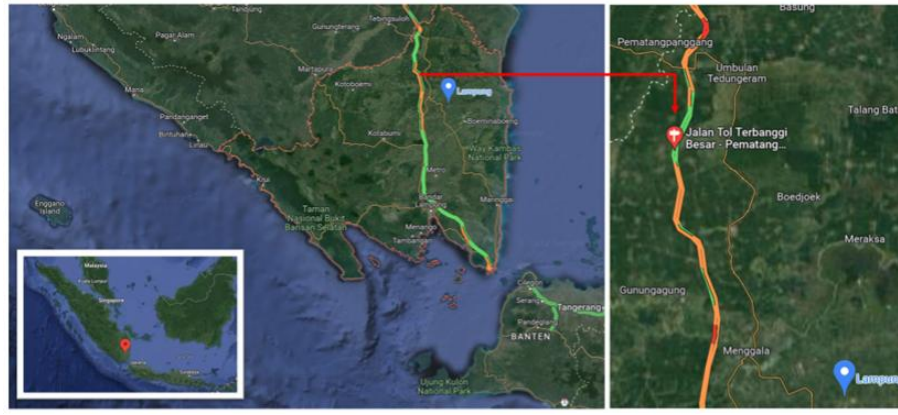

Figure 1. Map of research location

Data is one of the main strengths in compiling research and scientific modeling (Rifai, Hadiwardoyo, Correia, Pereira, & Cortez, 2015). The results of a topographical survey completed by PT. Waskita Karya Tbk. in June 2016 provided the secondary data used in this study. Data acquisition topographic survey reports were obtained directly from survey results in the field, which will then be used as a reference for re-planning in this study. Highway geometric design with AutoCAD® 2D: Case Terbanggi Besar Section – Pematang Panggang (Sta.28+650 – Sta.53+650) was carried out using manual calculations based on road geometric planning criteria following the Road Design Standards of Indonesia 2021. The results of the geometric road design will then be visualized into drawings using AutoCAD® 2D.

4. Result & Discussion

4.1 Alinyemen Horizontal

From the topographic map data that has been visualized with AutoCAD® 2D, the horizontal alignment or alignment of the highway section of Terbanggi Besar – Pematang Panggang (Sta.28+650 – Sta.53+650) is shown in figure 2.
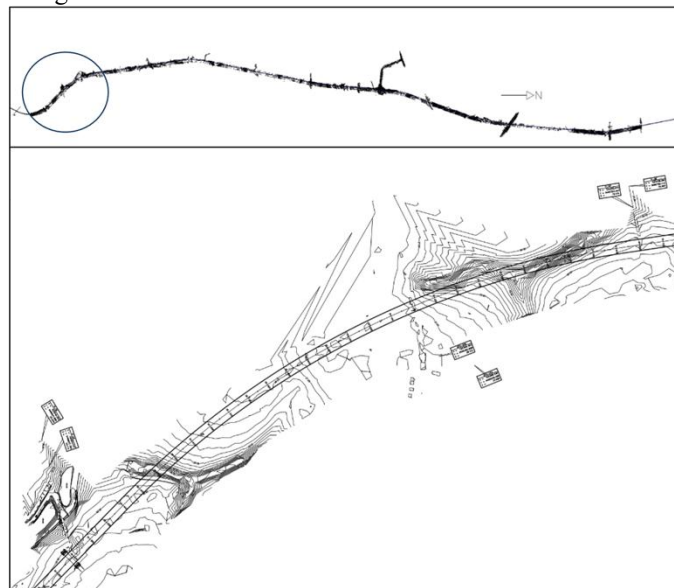
Figure 2. Horizontal Alignment

From Figure (2), it is determined at Sta.30+550 – Sta.31+500 to make horizontal curves on flat terrain based on data and calculations that the Road Design Standards of Indonesia 2021 guide.

4.2 Horizontal Curve

Terbanggi Besar – Pematang Panggang (Sta.28+650 – Sta.53+650) highway belongs to the Primary Intercity Road and is a highway on flat terrain, so the design speed range (V_D) is 80 – 120 kph according to Table 5.1 (p. 41) in the Road Design Standards of Indonesia 2021 (DGH, 2021) . For the case of the Terbanggi Besar – Pematang Panggang section (Sta.28+650 – Sta.53+650), the design speed (V_D) is set at 120 kph. Furthermore, based on Table 5.2 (p. 45) (DGH, 2021) to obtain a longitudinal slope (G) value on the flat terrain of 4%, and the highest maximum superelevation (e_{-max}) value was 8%. Superelevation and cross-sectional error values are needed to calculate the minimum radius (R_{min}) for a horizontal curve using the formula (1).

$$R_{min} = \frac{V_D^2}{127\,(f_{max}+e_{max})} \dots\dots\dots\dots\dots (1)$$
$$R_{min} = \frac{120^2}{127\,(0,09+0,08)} = 667\,m$$

For checking, it can be seen in Table 5-18 (p. 96) (DGH, 2021) for a design speed (V_D) of 120 kph, a side friction value of 0.09 is obtained, and R_{min} for an e_{-max} of 8% obtains a value of 665 m. Therefore, for the Terbanggi Besar – Pematang Panggang section (Sta.28+650 – Sta.53+650), the R is planned to be 1500 m. Furthermore, the length of the transition arc (Ls) is based on the travel time (T) of 3 seconds and can be calculated using formula (2).

$$Ls = \frac{V_D}{3,6}\,x\,T \dots\dots\dots\dots\dots (2)$$
$$Ls = \frac{V_D}{3,6}\,x\,T = \frac{120}{3,6}\,x\,3 = 100\,m$$

The minimum length of the transition arc (Ls) can be seen in Table 5-23 (p. 105) (DGH, 2021) for a road with a lane width of 3.50 m and fourth lanes. The minimum Ls value is 64 m. As Ls > Ls min, Ls of 64 m is used for the design. Next, the value of the tangent shift (p) at the curve is calculated to determine the type of horizontal curve using the formula (3).

$$p = \frac{Ls^2}{24\,Rc} \dots\dots\dots\dots\dots (3)$$
$$p = \frac{64^2}{24\,x\,1500} = 0,113 \leq 0,25$$

Based on the calculation results, it obtained a p-value ≤ 0.25 (DGH, 2021), so the type of horizontal curve used is a full circle. From the road alignment image in Figure 2 on the topographic map, the angle of intersection (β) is 37°. The tangent distance from the Tangent Circle (TC) – Point of Intersection (PI) and PI – Circle Tangent (CT) is determined, the outer distance from the arc PI to circular arc and arc length (LC) as explained and calculated in formulas (4), (5), and (6).

$$Tc = R\,x\tan\tfrac{1}{2}\beta \dots\dots\dots\dots\dots (4)$$
$$Tc = 1500\,m\,x-\tan\left(\frac{1}{2}\,x\,37°\right) = 501,89\,m$$

$$Ec = Tc\,x\tan\tfrac{1}{4}\beta \dots\dots\dots\dots\dots (5)$$
$$Ec = 501,89\,m\,x-\tan\left(\frac{1}{4}\,x\,37°\right) = 81,74\,m$$

$$Lc = 0,01745\,x\,\beta\,.R \dots\dots\dots\dots\dots (6)$$
$$Lc = 0,01745\,x\,37\,x\,1500 = 968,47\,m$$

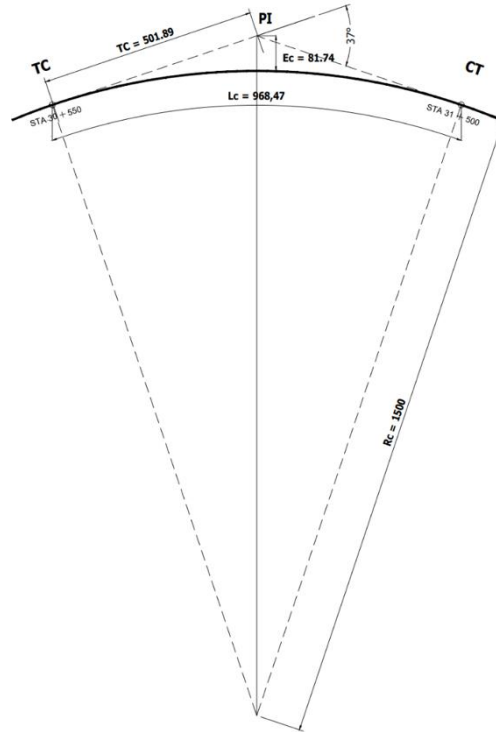The results of the curved calculations are visualized, as shown in figure 3.

Figure 3. Horizontal Curve

4.3 Superelevation Diagram

Based on the horizontal curve visualized in figure 3, a superelevation diagram was created, which can be seen in figure 4.
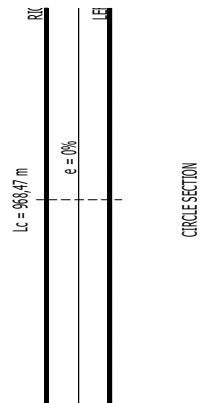

Figure 4. Superelevation Diagram

2.3 Vertical Alignment

Manual calculations and AutoCAD® 2D were used to visualize the vertical alignment on the Sta. 28+650 - Sta. 30+900 along 2.5 km. The maximum grade for expressways on flat terrain is 4%, according to Table 5-48 (page 143) (DGH, 2021).
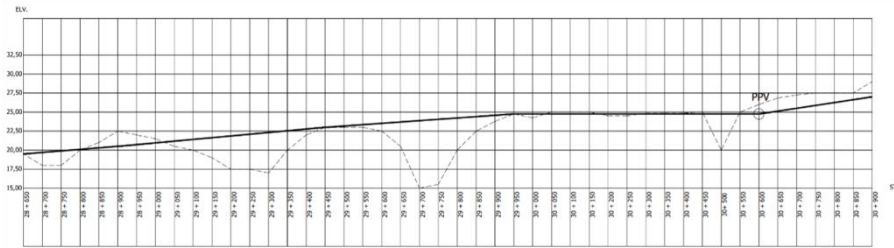
Figure 5. Vertical Alignment

From figure 5, the PPV point (vertical center of intersection) is taken at Sta.30+600 and has an elevation of +24.75 m. Next, the starting point is determined at Sta. 30+400 with elevation + 24.75 m, and the endpoint is Sta. 30+800 with elevation + 26.00 m. With these data, the value of the road's slope (g1 and g2), the algebraic difference of the road's slope (A), and the sag or crest vertical curve length (L) with the calculations in formulas (7) and (8).

$$g_1 = \frac{PPV\ elv. - Start\ Point\ elv.}{Sta.\ PPV - Sta. Start\ Point} x 100\% \dotfill (7)$$

$$g_1 = \frac{24,75 - 24,75}{30.600 - 30.400} x 100\% = 0\%$$

$$g_2 = \frac{End\ Point\ elv. - PPV\ elv.}{Sta.\ End\ Point - Sta.PPV} x 100\% \dotfill (8)$$

$$g_2 = \frac{26 - 24,75}{30.800 - 30.600} x 100\% = 0,625\%$$

$$A = g_{1-}\ g_2 = 0\% - 0,625\% = -0,625\% \ (sag\ vertical\ curve)$$

According to Figure 5-44 (p. 164) (DGH, 2021), the K value from a design speed (VD) of 120 kph is 112 to determine the vertical arch length (L) using formula (9).

$$L = KA \dotfill (9)$$

$$L = 112\ x\ (-0,625\%) = 75,6\ m$$

From the value of the vertical arc length (L), the value of the vertical shift from the PPV point to the curved section (Ev) can be determined by calculating the formula (10).

$$Ev = \frac{AL}{800} \dotfill (10)$$

$$Ev = \frac{0,625\ x\ 75,6}{800} = 0,059\ m$$

$$X = \frac{1}{4}\ x\ L = \frac{1}{4}\ x\ 75,6 = 18,9\ m$$

$$Y = \frac{A\ .\ X^2}{200.\ L} = \frac{0,625.\ 18,9^2}{200.75,6} = 0,024\ m$$

5. Conclusion

Based on the design results for the Terbanggi Besar – Pematang Panggang (Sta.28+650 – Sta.53+650) using AutoCAD® 2D and manual calculations . The design speed value (VD) is 120 kph, and the horizontal curvature radius is 1500 m, with a maximum slope of 4% and a maximum superelevation (e-max) of 8%. From these design criteria, the horizontal curve used is a full circle with a circular arc length (Lc) of 968.47 m. Furthermore, the results of calculations on the vertical alignment calculated on one of the PPV obtained a sag vertical curve type with the acquisition of a length value at one point of the vertical sag curve (L) of 75.6 m.

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