ROAD GEOMETRIC SAFETY AND SPEED CONSISTENCY AUDIT ON EXIT RAMP 43 ON THE CINERE - JAGORAWI HIGHWAY TOLL ROAD

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Abstract

This study primarily focuses on the design safety and speed consistency of the Cinere – Jagorawi Toll road, specifically on off-ramp 43, going eastward and exiting to Margonda Road. The main objective of this study is to determine whether the exit ramp is safe or not for the public to use. By doing so, this research may help improve the design safety of future road projects. This research outputs quantitative and qualitative data and measurements to determine the safety level of exit ramp 43. The study revealed significant flaws in the geometric design of the ramp, particularly the presence of sharp bends with minimal turning radius, which forced drivers to reduce speed drastically. This problem is exacerbated by deceleration zones that are too short and do not provide sufficient space for safe speed reduction, creating a potential crash risk, especially for drivers unfamiliar with the road conditions. In addition, the lack of clear warning signs and consistent speed guidance exacerbates this safety issue.

Introduction

Roads have always been essential to transportation, especially in regions or communities that rely heavily on motor vehicles to function well. With that, roads play a crucial role in accommodating the fast growth of the population. Generally, roads can be analyzed in 2 different manners simultaneously, which are qualitative and quantitative. The quantitative analysis of roads measures the capacity of infrastructures and facilities that can accommodate and serve the population's needs for transportation. On the other hand, the qualitative aspects of roads can be described as the degree of safety, security, seamlessness, neatness, and comfort.

When designing a road network, the most vital aspect to consider is the geometric design of the road network. Road geometrics must be planned and engineered carefully, as roads must accommodate adequate user service. The geometric design also has to consider design and speed consistency. Taking design and speed consistency into the geometric design process is crucial as it is the most significant determining factor in road safety and efficiency. This is because a road with good design and speed consistency improves driver expectations by providing a consistent and predictable environment. When drivers encounter unexpected changes in geometry, they may have to suddenly adjust their speed, which can increase the likelihood of traffic accidents.

This research conducts a geometric and speed consistency audit on a small section of the newly built JORR 2 (Jakarta Outer Ring Road) highway, specifically located on the Cinere-Jagorawi (also known as CiJago) segment. The section mentioned above will be audited: the toll road exit ramp heading eastward at Margonda, Depok region, specifically exit 43.

Figure

Figure 1 Close-up aerial view of the off-ramp

This segment, in particular, can be observed as having quite a tight turning radius for a free-flowing segment. This off-ramp requires the driver to decelerate from a highway speed (in this case, the speed limit is 120km/h) to 40km/h. The exit ramp requires drivers to decelerate a significant amount of speed along a considerably short entry lane. After decelerating, drivers must turn left constantly, making a complete u-turn, and then the road continues to connect with Margonda Rd. Assessing these conditions will bring previously irrelevant safety concerns to light and may provide a reference for future construction.

Based on the problem statements, several questions arise, which are:

1. Is the geometric design on exit ramp 43, Cinere-Jagorawi Toll, safe according to the most recent Binamarga standards and regulations?
2. Is the speed consistency on exit ramp 43, Cinere-Jagorawi Toll, safe for drivers?

The objectives of this research are:k

1. Assess and audit the geometric design safety on exit ramp 43, Cinere-Jagorawi Toll network, according to the most recent Binamarga standards and Regulations.
2. Assess whether the vehicle speed is consistent with the geometric design of exit ramp 43, Cinere-Jagorawi Toll network, according to the most recent design and speed consistency studies.
3. Provide feasible suggestions or solutions to improve the safety of the exit ramp further.

Literature Review

Road geometry refers to the way or path in which the road occurs. Geometric design, which includes pavement widths, horizontal and vertical alignment, and other features, are all considered when designing the dimensions and arrangement of the visible features of the road (Institute of Transportation Engineers). Geometric safety design features are road engineer's efforts to reduce common driver errors that can cause traffic accidents that may be lethal. According to the National Cooperative Highway Research Program (NCHRP), there are 13 controlling criteria for geometric design, which are design speed, land width, shoulder width, bridge width, structural capacity, horizontal alignment, vertical alignment, grade, stopping sight distance, cross slope, superelevation, vertical clearance, and horizontal clearance (Harwood et al., 2014). Similarly, Binamarga (Audit Keselamatan Jalan, 2024) states fewer key aspects of road geometrics: horizontal and vertical alignment, sight distance, road curves, grades, and auxiliary road warnings/signs.

Geometric design consistency is defined as the ability of the geometric design to conform to the driver's expectations. It measures how well the road design aligns with most of the population's expectancy and experience. This is one of the most overlooked design criteria, although it heavily influences driver behaviors and safety. An anecdotal paper by Hauer (1999) argues that road networks designed strictly to standards are not necessarily safe, unsafe, or appropriate. They state that it is an ambiguous design safety that is safe and unsafe, according to the proper conditions. Hauer claims that road geometric design safety is always a matter of degree and can be improved upon by making changes to the road design. Good road design consistency makes it easier for the driver to control the vehicle and less likely for errors and unsafe maneuvers to occur.

Speed consistency is an aspect of road design and engineering that lets the driver maintain a constant and consistent velocity when traversing through a geometric alignment. This is especially important as it allows effortless driving and doesn't require the driver to put in extra effort while driving. A good road design that considers speed consistency ensures that drivers don't have to brake suddenly. This reduces the risks of accidents that are caused by driver errors. (Camacho-Torregrosa et al., 2013; Llopis-Castelló et al., 2018). Speed consistency minimizes the variability of the speed, which is a significant factor in traffic accidents of vehicles on the road at one time. By maintaining good speed consistency, drivers are less likely to be involved in accidents caused by sudden changes in speed. (Camacho-Torregrosa et al., 2013; Llopis-Castelló et al., 2018)

Methodology

This research starts by identifying and recognizing the problems occurring on the research object of observation, exit ramp 43 on the Cinere-Jagorawi Toll Road. By doing so, this research formulated a problem statement based on the occurring problem. Two research questions can be extracted from the formulated statement to determine the objective of this research. The two research questions are:

1. Is the geometric design on exit ramp 43, Cinere-Jagorawi Toll, safe according to the most recent Binamarga standards and regulations?
2. Is the speed consistency on exit ramp 43, Cinere-Jagorawi Toll, safe for drivers?

From these research questions, a literature study is conducted to gather relevant information from past similar research and other research that may have topics and information of interest. This is done so that this research can confidently talk and discuss this topic according to the definitive description of the subject. In this research, in particular, research question 1 talks about geometric design parameters that determine the level of safety of a specific road. Whereas research question 2 is heavily subjective as it talks about speed consistency.

Figure

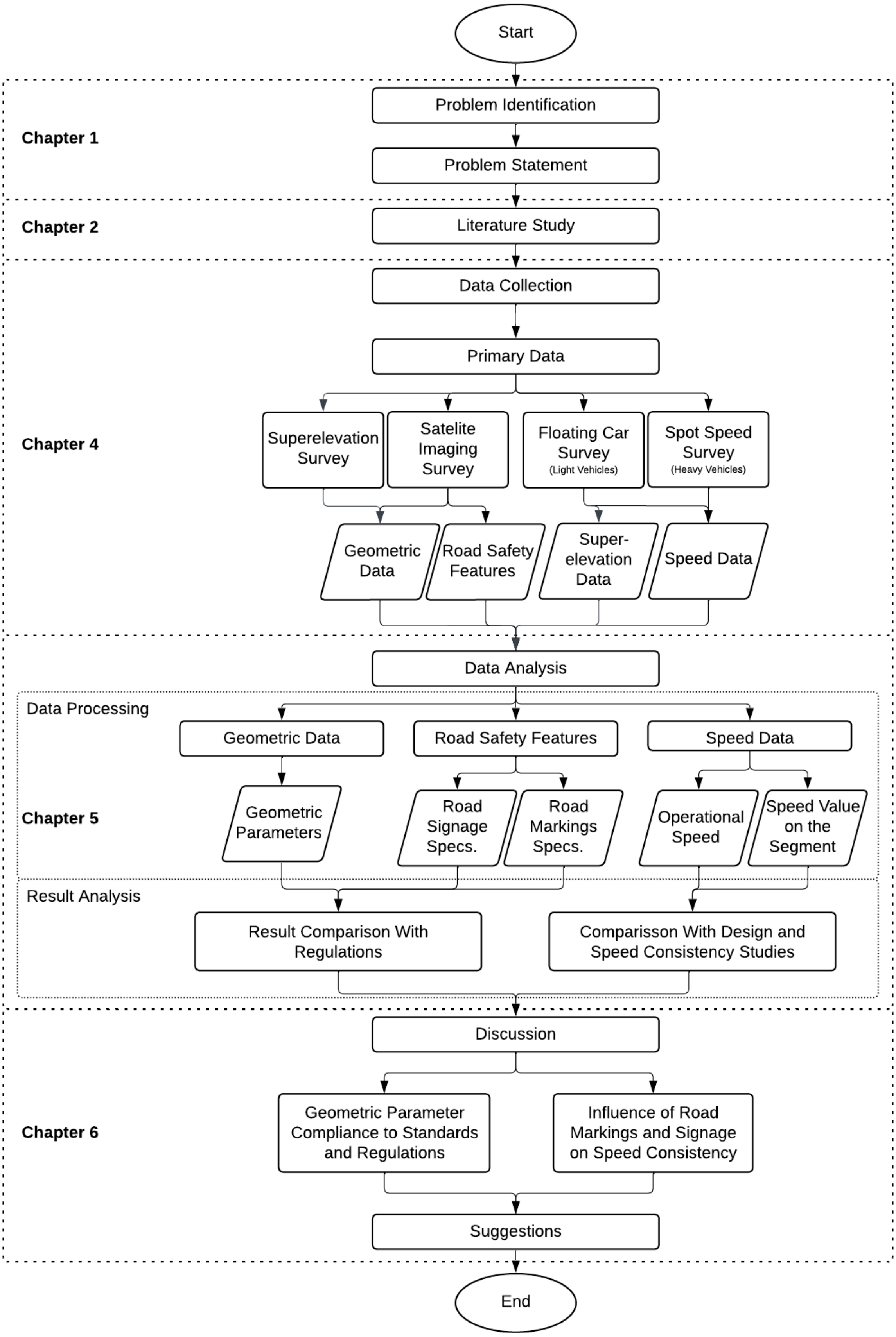

Figure 2 Research flowchart

Data Collection

1. Satellite Imaging Survey

   1.1. Off-ramp Geometric Alignment Data

   A trace of the off-ramp is made on Google Earth Pro; the coordinates point can then be exported and imported into ArcGIS and extracted and made into a scaled map for measurements in AutoCAD.

Figure

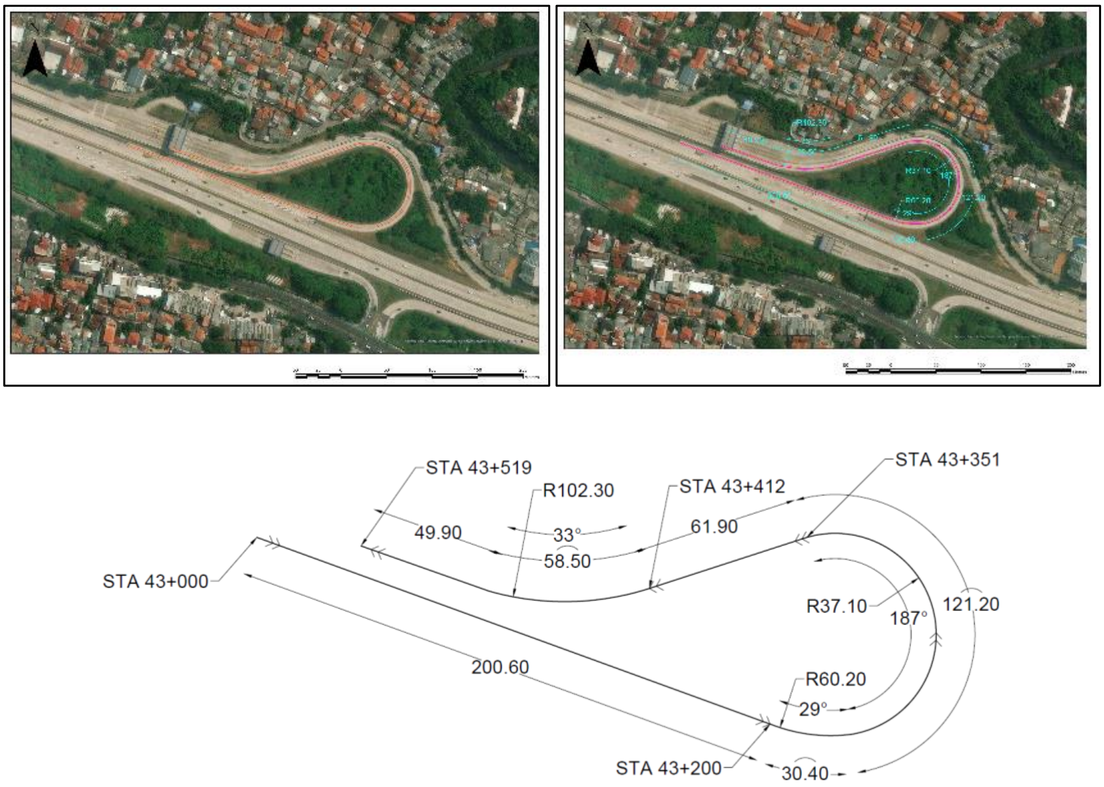

Figure 3 Off-ramp map and measurements

   1.2. Auxiliary Road Safety Features Data

   The survey was conducted by accessing the Google Street View (commonly known as *Street* View) feature inside the Google Earth Pro software. Firstly, the location of the *Street View* should be correct, and then the arrows should be used to navigate through the entire segments. A few necessary screenshots are taken to collect the data and specifications of the auxiliary road safety features.

2. Floating Car Survey

A floating car survey is a method used to collect speed data from an ongoing traffic flow along a road segment by recording the speed of a vehicle on a set interval of time or distance. This method helps collect traffic pattern data and speeds without requiring an intricate and time-consuming survey.

In this case, the survey uses a mobile smartphone app that records the vehicle's speed and GPS data in 1-second intervals. The result of this survey is the speed data tied with the coordinates, so each XY value is tied to the speed data. The data from the app can be exported into separate CSV and GPX data. The CSV files contain the time, speed, and coordinate data. Meanwhile, the GPX file contains only the geographical coordinates. Respectively, the CSV data are imported into Microsoft Excel, whereas the GPX data are imported into ArcGIS Pro. After being imported, each dataset is checked to determine whether it can be used in Microsoft Excel and ArcGIS Pro. If one of the two files is deemed unusable, then the whole dataset (both files) cannot be used in the data processing.

There are 8 points on the off-ramp, a reference point on where to record the speed. The details of the points are:

1. Off-ramp Entry / Converging point.
2. Beginning of curve 1
3. Middle of curve 1 (1)
4. Middle of curve 1 (2)
5. End of Curve 1
6. Beginning of curve 2
7. Middle of curve 2
8. End of curve 2

Figure

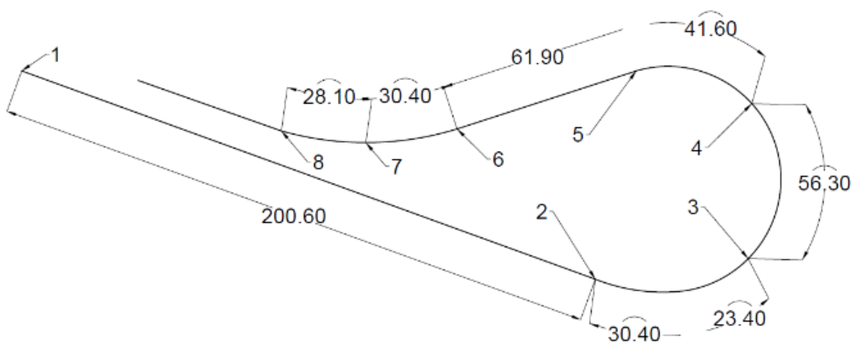

Figure 4 Points on the segment for the floating car survey

3. Spot Speed Survey

Spot speed survey is a speed survey similar to a floating car survey. A spot speed survey records the time needed for a vehicle to cover 2 points in a segment. This survey was done to determine the speed of heavy vehicles, as it is inaccessible for floating car surveys in this research.

Figure

Figure 5 Spot speed camera station location

The data is gathered by logging the time delta the vehicle requires to cover the distance between 2 points. The details of the points and distance on the off-ramp can be seen below:

1. 1-2 Off-ramp Entry / Converging Point
2. 2-3 Beginning of curve 1
3. 3-4 Middle of curve 1 (1)
4. 4-5 Middle of curve 1 (2)
5. 5-6 End of Curve 1
6. 6-7 Beginning of curve 2
7. 7-8 Middle of curve 2
8. 8-9 End of curve 2

Figure

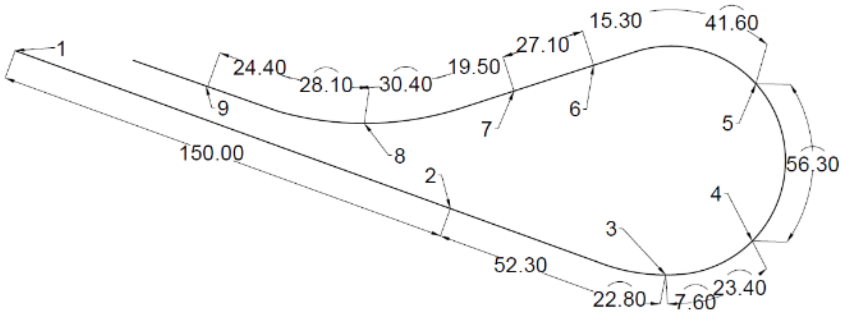

Figure 6 Points on the segment for the spot speed survey

4. Superelevation Survey

The superelevation survey aims to get the superelevation data manually. This is done by driving through the segment several times while logging the tilt degree of the vehicle. After that, the point and value of the superelevation are then determined. This survey was also done in tandem with the floating car survey. The survey result may vary for each attempt, so the results will be rounded off and averaged for each point. In this case, a positive value means a left roll, but a negative value represents a right roll.

Data Analysis

1. Speed Data

1.1. Speed Data Processing

The speed data is gathered and collected using two different surveys: the floating car survey and the spot speed survey. Respectively, one covers the data for passenger vehicles, and the other covers the data for heavy vehicles. As the floating car data already contains the speed values, the first thing to calculate is the speed value of heavy vehicles from the spot speed dataset. As the data from spot speed is in the form of time (s), the velocity can easily be calculated by $v = d/t$ Where v is velocity in Km/h, d is distance in meters, and s is time in seconds.

After all the necessary speed values are compiled, the next step is calculating the 85^{th} percentile speed or operating speed on the off-ramp. This value can also be used for the geometric design analysis. Additionally, the highway's 85^{th} percentile free-flowing operating speed can be calculated as 89.82 km/h

Figure

Table 1 85th percentile speed on the off-ramp

<table>
<tr><td>Point</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
<tr><td rowspan="3">85th Percentile Speed (Km/h)</td><td rowspan="3">76.42</td><td>54.32</td><td>43.73</td><td>41.84</td><td rowspan="3">46.57</td><td>53.05</td><td>51.05</td><td>49.73</td></tr>
<tr><td colspan="3">Curve 1</td><td colspan="2">Curve 2</td><td></td></tr>
<tr><td colspan="3">46.63</td><td colspan="2">51.28</td><td></td></tr>
</table>

1.2. Result Analysis

The speed consistency analysis is separated into 8 points across two curves and two straight sections. This way, the speed consistency scoring can be more thorough, and the specific problematic sections can be identified.

1.2.1. Acceleration Threshold Analysis

The acceleration threshold analysis uses the maximum deceleration value set by Binamarga on the Road Geometric Guidelines (2021), which states that the maximum longitudinal deceleration value of a moving vehicle through an alignment is a maximum of 3,4m/s2. The results of the analysis can be seen in the table below:

Table

Table 2 Acceleration threshold analysis table

Point	1	2	3	4	5	6	7	8
Acceleration (m/s^2)	-	-0.56	-0.74	-0.11	0.39	0.40	-0.27	-0.18
Threshold Check	-	OK	OK	OK	-	-	OK	OK

1.2.2. Significance Coefficient Analysis

The significance coefficient analysis uses Levene's Test results to determine whether the dataset groups are homogenous. The significance coefficient ranges from 0-1, and the value specifies the "level of homogeneity" of the dataset. Generally, a significance coefficient value that falls below 0.05 is considered inhomogeneous. The result analysis can be seen in the table below:

Table

Table 3 Significance coefficient analysis results

Curve	Sig.	Threshold Check
Curve 1	0.0125	Inhomogeneous
Curve 2	0.6737	Homogenous

1.2.3. Coefficient of Variance Analysis

This speed data analysis uses the relative variance value from the standard deviation analysis. The coefficient of variance is in the form of percentages. A smaller percentage would indicate a more consistent sample and vice versa. Conventionally, a CV value of 0-10% is considered small, 10-30% is moderate, and >30% is significant. The smaller the value, the smaller the relative variability of the data sample. The analysis can be seen in the table below.

Table

Table 4 Coefficient of variance analysis table

Point	1	2	3	4	5	6	7	8
Mean	64.14	46.33	37.59	37.64	41.46	45.57	44.81	45.06
Standard Deviation	13.51	7.33	4.31	5.14	4.49	5.61	4.99	5.33
Coefficient of Variance	21.06%	15.81%	11.47%	13.67%	10.84%	12.32%	11.13%	11.83%
Grade	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium

2. Geometric and Design Data

2.1. Geometric and Design Data Processing

The Geometric data collected before will be reviewed by the parameters and audited based on the Geometric Guidelines by Binamarga (Pedoman Geometrik Jalan, 2021). In this case, the speed in the equation is the 85th percentile operating speed that was calculated before. This is made to determine the safest geometric design based on the guidelines.

The data processing is done in 2 parts:

2.1.1. Existing Geometric Parameters

The existing geometric parameter measurements are done using the previously made AutoCAD drawing of the horizontal alignment. The entire horizontal alignment of the off-ramp can be sectioned into different parts with different specifications.

Table

Table 5 Alignment specifications

No.	Section	Point	STA Start	STA End	Length (m)	Radius (m)	Degree of Turn	e_{max}	Operating Speed (Km/h)
1	Straight 1	1-2	43+000	43+200	200,6	-	-	-	76,42
2	Curve 1.1	2-3	43+200	43+230	30,4	60,2	29	6,00%	54,32
3	Curve 1.2	3-4-5	43+230	43+351	121,2	37,1	187		44,05
4	Straight 2	5-6	43+351	43+412	61,9	-	-	-	49,81
5	Curve 2	6-7-8	43+412	43+470	58,5	58,5	33	-1,50%	51,28
6	Straight 3	8	43+470	43+519	49,5	-	-	-	49,73

Figure

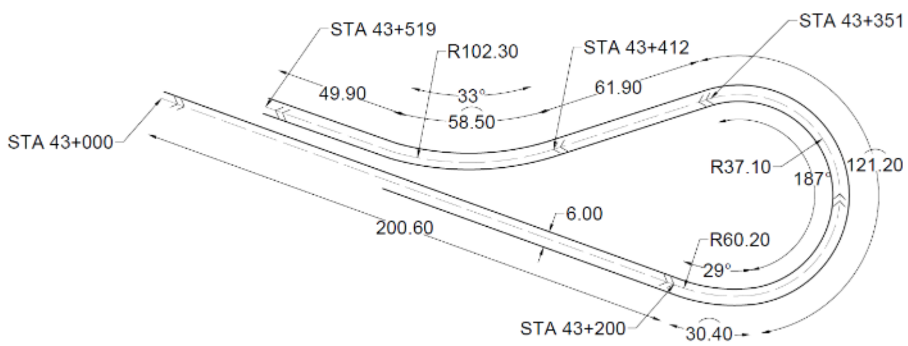

Figure 7 Off-ramp horizontal alignment

2.1.2. Geometric Parameter Requirements

According to the Geometric Guidelines by Binamarga, the highway toll road is classified as “Jalan Bebas Hambatan,” or a free-flowing road. From the parameters above, we can determine the minimum geometric parameters for the off-ramp. The curve radius can be calculated.

Table

Table 6 Minimum curve radius

No.	Section	Operating Speed (Km/h)	Fmax	Minimum Curve Radius (m) e = 2%	e = 4%	e = 6%
1	Straight 1	76.42	0.12	-	-	-
2	Curve 1.1	54.32		165.93	145.19	129.06
3	Curve 1.2	44.05		109.12	95.48	84.87
4	Straight 2	49.81		-	-	-
5	Curve 2	51.28		147.88	129.39	115.02
6	Straight 3	49.73		-	-	-

2.2. Result Analysis

The results are done by comparing the existing geometric parameters with the geometric parameters requirements by Binamarga.

Tables

Table 7 Curve parameters with operational speed

No	Section	Minimum Curve Radius (m) e = 2%	e = 4%	e = 6%	Existing Curve Radius (m)	Parameter Checking e = 2%	e = 4%	e = 6%
2	Curve 1.1	165.93	145.19	129.06	60.2	Not OK	Not OK	Not OK
3	Curve 1.2	109.12	95.48	84.87	37.1	Not OK	Not OK	Not OK
5	Curve 2	147.88	129.39	115.02	58.5	Not OK	Not OK	Not OK

Table 8 Operational speed with speed limit

No	Section	Minimum Curve Radius (m) e = 2%	e = 4%	e = 6%	Existing Curve Radius (m)	Parameter Checking e = 2%	e = 4%	e = 6%
2	Curve 1.1	89.99	78.74	69.99	60.2	Not OK	Not OK	Not OK
3	Curve 1.2	89.99	78.74	69.99	37.1	Not OK	Not OK	Not OK
5	Curve 2	89.99	78.74	69.99	58.5	Not OK	Not OK	Not OK

Upon further analysis, it is noticeable that the first curve counts as a compound curve, which is a curve that consists of 2 different radii with the specifications listed below:

Table

Table 9 Compound curve radii

No.	Section	Existing Curve Radius (m)
2	Curve 1.1	60,2
3	Curve 1.2	37,1

According to the geometric guidelines, a compound curve should have a bigger radius following a smaller radius. This means that the smaller radius should come first before the bigger radius. In this case, the first curve breaches that rule, resulting in a "*brokenback*" curve.

In the subject of sight distance, it is crucial to analyze it, especially on tight horizontal curves. The most important thing to check on horizontal curves is middle ordinate (Ms) values, which can be defined as the arch length that is equal to the stopping sight distance that must be visually cleared so that the line of sight is such that sufficient and adequate stopping sight distance is available.

Tables

Table 10 Middle ordinate calculation

No.	Section	Radius (m)	Speed Km/h	Speed m/s	Deceleration (m/s2)	Reaction Time (s)	SSD (m)	Middle Ordinate (m)
2	Curve 1.1	60,2	40,00	11,11	3,4	2,5	45,93	119,87
3	Curve 1.2	37,1	40,00	11,11	3,4	2,5	45,93	59,84
5	Curve 2	58,5	40,00	11,11	3,4	2,5	45,93	109,76

From the values, it can be quickly concluded that the only part of the section that complies with the minimum Ms value is the second curve. As stated before, the first curve's sight distance is heavily obstructed by vegetation, which can be seen in the images below:

Figure

Figure 8 Curve 1 middle-ordinate view

3. Road Safety Features

3.1. Road Safety Features Data Processing

The data processing of the road safety features data is then logged. Then, the inadequate road safety features will be extracted and logged from the compiled safety features data. From the table, it is concluded that only two inadequate road safety features are currently on the off-ramp alignment.

3.2. Result Analysis

The main problem with the posted speed limit is that it does not allow gradual deceleration as it is the only posted speed limit before the first curve. This is particularly dangerous as the operating speed of the highway is as high as 89.82 Km/h, and the operational speed of the first curve itself is 54.32 Km/h.

A study done by Garvey & Kuhn (2011) shows that there is average reading time and longitudinal displacement. Using this, we can determine the ideal distance of the signs. Using the reference above, we can determine the perfect position of the signs. The calculation can be seen below.

Table

Table 11 Posted speed limit sign placement calculations

Segment	i	ii	iii
Posted Speed Limit Sign	80	60	40
Before Sign			
Initial Speed - V0 (Km/h)	89,82	80,00	60,00
Initial Speed - V0 (m/s)	24,95	22,22	16,67
Sight distance (m)	28	25	18
After Sign			
Target Speed - Vt (Km/h)	80	60	40
Target Speed - Vt (m/s)	22,22	16,67	11,11
Deceleration - a (m/s2)	3,41	3,41	3,41
Distance - x (m)	19	32	23
Sign Placement			
Assumed Operating Speed (Km/h)	<89.92	<80	<60
Min. Reading Time (s)	4	3,5	3
Max. Reading Time (s)	5	4,5	4,5
Ave. Reading Time (s)	4,5	4	3,75
Longitudinal Sign Disp. (ft/s)	87,84	73,53	58,59
Longitudinal Sign Disp. (m/s)	26,77	22,41	17,86
Sign Position (m)	5,95	5,60	4,76
Sign Position Before Curve	68,05	49,40	18,24
Sign Position After Entry	131,95	150,60	181,76

The proposed solutions include three additional signs, one of which is a replacement. The full specifications can be seen in the table below:

Figure

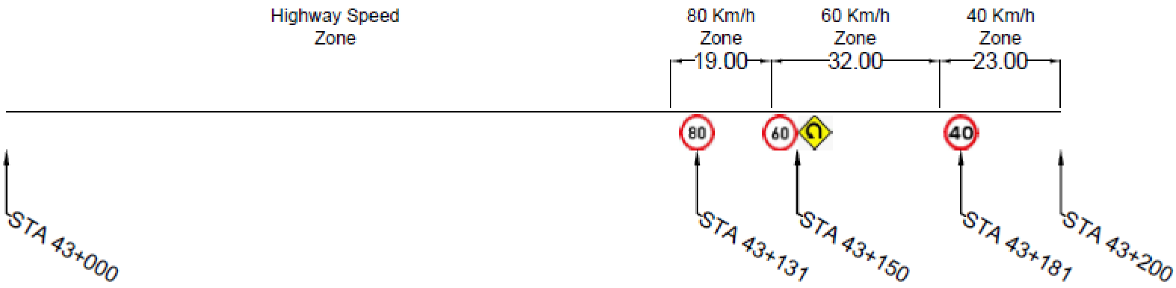

Figure 9 Illustration diagram for the road signs

Discussion

1. Geometric Parameter Compliance to Standards and Regulations
   From the results of the geometric and speed analyses, it can be concluded that the geometric alignment does not and cannot accommodate the speed of the vehicles going through the alignment. This choice of geometric alignment can be assumed to be caused by a restrictive workable land area. As this highway network is relatively the newest in the vicinity of Jakarta, significant land clearing needs to be done at the pre-construction phase. This may cause many disputes between the project owner and the surrounding population around the project. In the future, the possibility of such a thing happening is relatively high, especially on a national-scale project that needs a lot of land clearing and acquisitions.
2. Influence of Road Markings and Signage on Speed Consistency
   One of the most prominent findings from the data analysis is that the first curve has a terrible speed homogeneity value, which is 0,01. This part of the analysis compares the speed values of each point inside the curve with each other. Whether a coincidence or not, the first curve also has inadequate road markings and signage. The inadequate road signs have a high probability of causing the drivers to suddenly brake after entering the curve, whereas an ideal condition should be that the driver has already decelerated into the desired speed limit before the curve. This causes the first curve to have terrible speed consistency as many drivers reduce speed in the middle of the curve.

Conclusion

The conclusion of the road geometric safety and speed consistency analysis of Exit Ramp 43 on the Cinere-Jagorawi Toll Road highlights some significant findings regarding the current road design. The study results show that the geometric design applied to this exit ramp has several deficiencies that can affect driver safety. One of the main issues is the presence of sharp curves with a very minimal turning radius, which requires drivers to reduce their speed when approaching the curve drastically. This situation is hazardous when drivers are traveling from the main lanes of the highway at high speeds and are suddenly faced with road conditions that require significant speed reduction.

In addition, the current deceleration zone is considered too short to provide enough space for drivers to safely reduce speed before entering the curve. These short deceleration zones force drivers to brake abruptly, posing a potential crash risk, especially for those unfamiliar with the road conditions or who tend to drive at higher speeds than expected. This condition is further exacerbated by the lack of clear warning signs and consistent speed guidance along the exit ramp, which should help drivers adjust their speed better. It should be noted that even when going through the segment at a speed limit (40 Km/h), the curve radius and superelevation are still inadequate.

From this analysis, it is essential to review and revise the geometric design of this exit ramp to improve safety. One step that can be taken is to increase the existing curve's turning radius so drivers have more time to adjust their speed and vehicle position before reaching the curve. In addition, extending the deceleration zone will give drivers more room to reduce speed safely. More evident warning signs and more consistent speed guidance will also go a long way in reducing crash risk.

References

Abbas, S. K. S., Adnan, M. A., & Endut, I. R. (2011). Exploration of 85th percentile operating speed model on a horizontal curve: A case study for two-lane rural highways. Procedia - Social and Behavioral Sciences, 16, 352–363. https://doi.org/10.1016/j.sbspro.2011.04.456

Anna, V. A. B. K., & Chunchu, M. (2023). Determinants of speed variability on the horizontal curves of two-lane undivided rural highways passing through mountainous terrain. International Journal of Injury Control and Safety Promotion, 30(4), 652–665. https://doi.org/10.1080/17457300.2023.2252797

Audit Keselamatan Jalan (2024).

Babić, D., Babić, D., Fiolic, M., & Ferko, M. (2022). Road Markings and Signs in Road Safety. Encyclopedia, 2(4), 1738–1752. https://doi.org/10.3390/encyclopedia2040119

Bajaru, S., Nandimedala, T., Manikanta, M., & Chunduri, T. (2018). HIGHWAY ACCIDENT MODELING INFLUENCE OF GEOMETRICS. In JETIR1802117 Journal of Emerging Technologies and Innovative Research (Vol. 5). JETIR. www.jetir.org

Camacho-Torregrosa, F. J., Pérez-Zuriaga, A. M., Campoy-Ungría, J. M., & García-García, A. (2013). A new geometric design consistency model is based on operating speed profiles for road safety evaluation. Accident Analysis and Prevention, 61, 33–42. https://doi.org/10.1016/j.aap.2012.10.001

Cardell, J. E., Howarth, H., Boyce, E. C., Aldington, H. E., Lorenz, H., & Ranke, V. von. (1949). Vertical Alignment of High-Speed Roads.

Colombaroni, C., Fusco, G., & Isaenko, N. (2020). Analysis of Road Safety Speed from Floating Car Data. Transportation Research Procedia, 45, 898–905. https://doi.org/10.1016/j.trpro.2020.02.078

Divya, G., Anand Babu, Y., & Gopi, P. (2016). Highway Accident Modeling Influence of Geometrics.

Garvey, P. M., & Kuhn, B. T. (2011). HIGHWAY SIGN VISIBILITY. In Automobile Transportation—Traffic, Streets, and Highways.

Gastwirth, J. L., Gel, Y. R., & Miao, W. (2009). The Impact of Levene's Test of Equality of Variances on Statistical Theory and Practice. Statistical Science, 24(3), 343–360. https://doi.org/10.1214/09-STS301

Hardwood, D. W., Lamm, R., Guenther, A. K., Choueriri, E. M., Mak, K. K., Turner, D. S., Blaschke, J. D., Zegeer, C. V, & Council, F. M. (1995). Safety Effects of Roadway Design Decisions. National Academy Press.

Harwood, D. W., Hutton, J. M., Fees, C., Bauer, K. M., Glen, A., & Ouren, H. (2014). Evaluation of the 13 Controlling Criteria for Geometric Design. Transportation Research Board. https://doi.org/10.17226/22291

Haryadi, A. (2012). HARMONISASI RAMBU DAN MARKA DENGAN GEOMETRIK JALAN PADA JALAN LUAR KOTA.

Hauer, E. (1999). Safety in Geometric Design Standards.

Jayaratne, D. N. D., Pasindu, H. R., & Rathnayaka, L. M. K. (2024). Development of Capacity Estimation Models for Multi-lane Roads under Heterogeneous Traffic Conditions. Engineer: Journal of the Institution of Engineers, Sri Lanka, 57(1), 71–83. https://doi.org/10.4038/engineer.v57i1.7639

Khashbat.J, Tsevegjav.Ts, Myagmarjav.J, Bazarragchaa.I, Erdenetuya.A, & Munkhzul.N. (2013). Determining the Driver’s Reaction Time in the Stationary and Real-Life Environments.

Kozlowska, M. K. (2017). Consistency and certainty of the road marking system as a subject of protection based on the offence law. Analysis of the characteristics of the offence from article 85 -1 of offence code.

Krammes, R. A., Fitzpatrick, K., Blaschke, J. D., & Fambro, D. B. (n.d.). Understanding design, operating, and posted speed.

Liu, X. (2011). Road curve speed control engineering study. Applied Mechanics and Materials, 66–68, 793–797. https://doi.org/10.4028/www.scientific.net/AMM.66-68.793

Llopis-Castelló, D., Bella, F., Camacho-Torregrosa, F. J., & García, A. (2018). New Consistency Model Based on Inertial Operating Speed Profiles for Road Safety Evaluation. Journal of Transportation Engineering, Part A: Systems, 144(4). https://doi.org/10.1061/jtepbs.0000126

Moir, G., Edmonds, C., Walser, P., & Romberg, M. (2010). Construction Engineering of Phu My Cable-Stayed Bridge, Vietnam.

Omar, M. H. (2010). Statistical Process Control Charts for Measuring and Monitoring Temporal Consistency of Ratings. Journal of Educational Measurement, 47, 18–35. https://api.semanticscholar.org/CorpusID:35334209

Pedoman Geometrik Jalan, 2021 (2021).

Penempatan Marka Jalan (2004).

PERATURAN MENTERI PERHUBUNGAN REPUBLIK INDONESIA NOMOR PM 13 TAHUN 2014 (2014).

Ramon C., R. (2019). ANALISIS ARUS LALU LINTAS DAN KECEPATAN PERJALANAN RUAS JALAN A.A. MARAMIS DENGAN FLOATING CAR METHOD.

Schramm, A., & Rakotonirainy, A. (2010). Lane width: the effect on the safety of cyclists in urban areas. http://eprints.qut.edu.au/

Thakare, P. M., & Bawner, V. S. (2018). Computer-Aided Geometric Design of Road and Safety Evaluation Using Vehicle Simulation Model. International Journal of Scientific Development and Research, 3(4). www.ijsdr.org

Transport Agency, N. (2007). Curve Speed Management.

Turner, S. M., Eisele, W. L., & Benz, R. J. (1998). TRAVEL TIME DATA COLLECTION HANDBOOK (Vol. 7).

Zulkifli, I. T., Azhar, N. A., Mohamed Radzi, N. A., Md Aripin, M. F. S., Mohd Azmi, K. H., & Samidi, F. S. (2024). Electrical substations mapping for possible communication technologies using QGIS and Google Earth Pro. Jurnal Kejuruteraan, 36(2), 661–672. https://doi.org/10.17576/jkukm-2024-36(2)-25