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Design of Horizontal and Vertical Alignment for the Centerline of a Federal Highway

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Abstract

Highway engineering standards are constantly improving. In this study, a design has been done for a horizontal and vertical alignment for the centerline of a federal highway. The construction cost and pavement design have been done according to the Malaysian public works department for the federal roads system (JKR). The results indicate that the designed highway has an adequate, accurate, and economical system based on the proposed data. Accordingly, the objective has been achieved since the reliability of the designed highway was 94%.

Index Terms: Highway design; Highway system; Horizontal and Vertical alignment.

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1. Introduction

In the civil engineering program, there are many branches, and highway engineering is one of these disciplines which consists of planning, designing, constructing, maintaining roads, bridges, and tunnels. The above steps are to ensure the safety and the effectiveness of transportation for people and for goods as well. Highway engineering standards are constantly improving. Highway planners must take into account potential traffic flows, design of highway intersections/interchanges, geometric alignment and design, road surface materials and design, surface thickness structure and maintenance of pavements. Autobahn planning includes forecasting existing and potential levels of traffic on a road network. Highway engineers are committed to anticipating and evaluating all potential civil impacts of road systems. Some considerations include adverse environmental effects, such as noise emissions, air pollution, water pollution, and other environmental impacts. Developed countries are increasingly faced with high maintenance costs associated with aging motorways. The growth of the motor industry and subsequent economic growth have generated a market for cleaner, better-performing, less congested highways. In the past, the growth of trade, educational institutions, housing, and defence has drawn primarily from government budgets, rendering funding of public highways a challenge [1].

Highways are required to guarantee comfort and protection for users, allow efficient operation of traffic and at the same time attract the least possible construction and maintenance costs. Highways are often expected to inflict minimal environmental harm and to be ethically pleasing in the finished form. Geometric architecture is the way by which certain specifications are met. As the Nigerian Federal Ministry of Works (FMW) Highway Manual describes it, "geometric design focuses on practical measures providing for effective and sufficient road service, as well as providing for all the relevant information that makes roads secure and consistent with the social and environmental circumstances surrounding the route" [2].

Nevertheless, in recent years there has been a movement away from the segregation of traffic, driven by changes in design and urban planning. Instead, street design and traffic engineering saw a change in emphasis from cars to pedestrians as a means of creating a safer atmosphere, notably by allocating more space to the latter and eliminating features such as street furniture, signage, delineation and kerbs. Notable examples include the Complete Streets project in the US and the idea of public space in the UK [3].

Security management is a systemic mechanism that seeks to reduce traffic incidents and their severity [4]. The relationship between man/machine and road transport systems is unpredictable and presents a challenge to road safety management. The secret to increasing the safety of road systems is planning, building and maintaining them to be much more tolerant of the normal extent of this man/machine contact with highways. Over the years, technical advancements in road engineering have enhanced the design, construction and maintenance methods used. Such developments have provided for the latest advancements in road safety [5].

Through ensuring that all problems and opportunities are defined, addressed and enforced as appropriate, they can be evaluated at any level of road preparation, design, construction, maintenance, and operation in order to improve the protection of our highway systems.

Nowadays, road safety is a complex phenomenon depending on lots of different factors and interactions. In other words, in order to deliver the biggest possible impact, we need to ensure that safe vehicles are driven by safe drivers on safe roads. Therefore, the objective of this study is to design a safe, economical, and efficient highway system in order to decrease the road accidents, and the durations of the travel.

2. Literature Review

In 2002, about 25 percent of fatal accidents occurred in the United States at horizontal curves [6]. Moreover, past work has also shown that the average crash rate in the curve is around 3 times higher than that in tangents [6,7]. However, sharper curves have higher injury rates than those with longer radii [8]. Overall, almost three-quarters of the fatal horizontal curve accidents that took place in the United States in 2002 were all in rural areas and around the same proportion of those accidents were single-vehicle run-off-the-road incidents [6]. Many exit lanes and/or single-vehicle traffic accidents occur on or near horizontal curves. Approximately 32 per cent of road fatalities in Minnesota between 2001 and 2005 were single-vehicle run-off-the-road accidents. However, over 50 percent of the deaths in rural Minnesota (i.e. outside the metropolitan area of Twin Cities) were caused by lane departures. This percentage rises to over 60 percent along Minnesota's local rural roads. Overall, county roads in Minnesota suffer nearly half of the state's annual road deaths and have a fatal accident rate that is 20 per cent higher than comparable roads in the state highway system [9].

Recently, some new work on the horizontal curve related to crash prediction has also been published [10,11]. In 2009 Easa et al. introduced multiple crash prediction models that tried to take into account the three-dimensional existence of road curves [10]. The models built were based on crash data from the Highway Safety Information System (HSIS) for curved road segments with specific horizontal and vertical features or components. The horizontal curve characteristics represented by variables in the final crash prediction models included curvature degree and longitude. It should be noted that curve radii are inversely connected and diminish with curvature degree. Additionally, these findings generally agree with those mentioned above. The expected frequency of crashes along a roadway segment increased with curvature and curve length. Schneider, et al. have also recently built models for truck crashes along horizontal curves [11]. Such models also used curve length and curvature degree as statistically significant variables and, not surprisingly, the number of truck crashes forecasted to increase with both [11].

Bonneson, et al. conducted more recent research based on estimation of rural horizontal curve speed [12]. Nonetheless, there were very different findings and methodology than the ones used by Fitzpatrick, et al. [12,13]. Fitzpatrick et al. developed horizontal curve speed prediction models for various circumstances of vertical grade and used radius as the only variable model. On the other hand, Bonneson, et al.'s 85th percentile curve models were designed for multiple tangent approach speeds and included several variables. Bonneson, et al. (along with some other researchers) concluded that this aspect (i.e. approach speed) has a significant impact on the choice of horizontal curve speed. They also established that drivers with curve geometry or speed tend to change or alter their side friction demands. Drivers tend to have lower demands on side friction on more incremental higher velocity curves (i.e. greater radius) and are able to tolerate higher side friction on sharper curves. It was also concluded, however, that the effect of super-altitude on horizontal curve speed was not as important as the impacts of radius and tangent approach speed [12].

Overall, the Bonneson, et al. proposed parabolic horizontal curve speed prediction model provides over-altitude, radius and tangent approach velocity as input [12]. The model's projected 85th percentile horizontal curve speed increases with radius for a given overrise and 85th percentile tangent speed. However, it was found that the model's predictive capability also improved when the actual radius of the "vehicle course" was used instead of the curve radius built or constructed. A vehicle's actual route 5 around a circular curve is more like a spiral and vehicles are heading towards the middle of the road. The Bonneson, et al. model did not include the vertical grade impacts (such as Fitzpatrick, et al. above) because their database did not include curves with a large range of this feature [12,13,14].

3. Details of the Project

3.1 Illustration of the project

A federal highway is going to be constructed to join the points of A and B according to the topographic map that is given. The length of the proposed federal highway is designed depending on the geometric design guideline which is provided in the standard of JKR. As there are many classes of highway such as (U1a, U1, U2, U3, U4, U5, and U6) each referring to different speeds and from different types of Areas such as (Type l, Type ll, and Type lll). This highway project is designed referring to the highest design standard U6 Type l Area of 100 km/h. Vertical curve and horizontal curve were designed, in which the crest curve designed at the beginning of the highway and sag curve at the end of the highway. The radius we designed is enough to allow the driver move safely from one line and to curve without any problem or without any need to transition or curve. On our highway design, the lanes are wide enough so this allows the drivers to drive and move from one side of the lane to another side [15]. The geometric design of the highway is illustrated in Table 1 according to the Malaysian public works department for the federal roads system (JKR). The alignment design of the highway is shown in Fig. 1. The designed horizontal alignment of the highway is shown in Fig. 2. The Elevation of Highway - (Side – Front) is shown in Fig. 3. A Graph Sample Showing the Design of Highway Using AutoCAD is shown in Fig. 4.

Table 1. The Geometric Design of Highway [U6 Road, Type Area l] according to the Malaysian public works department for the federal roads system (JKR).

Design Criteria	JKR Standard	Proposed	Remark
Access control	FULL	FULL	OK
Design Speed	100 km/hr	100 km/h	OK
Lane Width	3.65 m	3.65 m	OK
Shoulder Width	3.00 m	3.00 m	OK
Median Width	4.0 m (minimum) 12.0 m (desirable)	4.0 m (minimum) 12.0 m (desirable)	OK
Marginal Strip Width	0.50 m	0.50 m	OK
Minimum Reserve Width	60 m	60 m	OK
SSD	205 m	350 m	OK
PSD	N/A	N/A	OK
Minimum Radius	465 m	470 m	OK
Maximum Superelevation	0.06	0.06	OK
Grade	Minimum: 0.5 % Desirable: 3% Maximum: 6%	Minimum: 0.5 % Maximum: 1.00%	OK
K value	60 (crest) 40 (sag)	333.33 (crest) 333.33 (sag)	OK

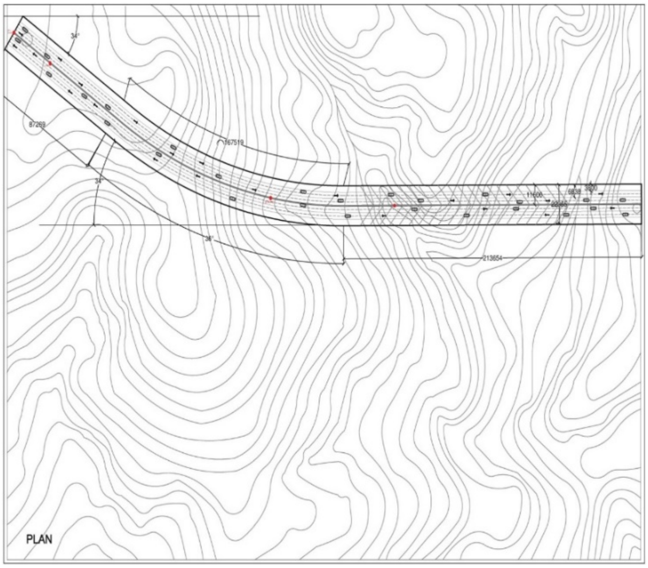

Fig.1. The Alignment Design of Highway – Plan.

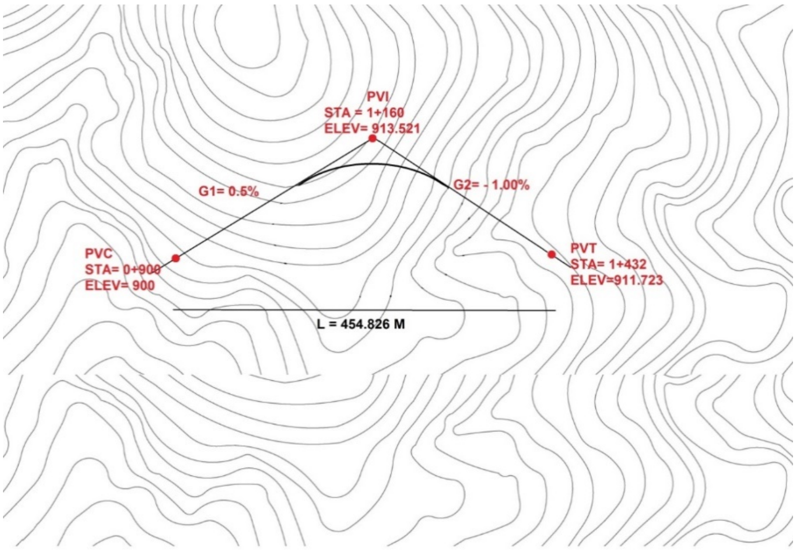

Fig.2. The Horizontal alignment and curve Design of Highway.

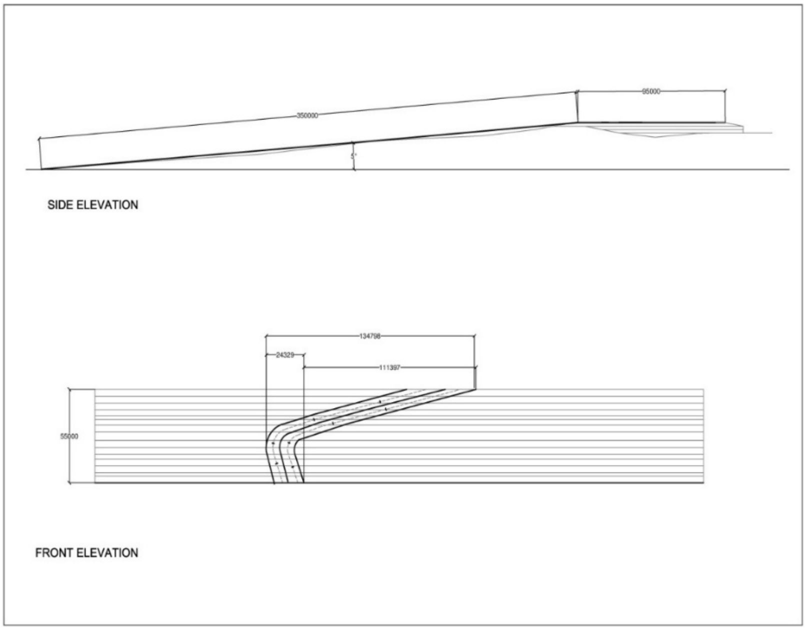

Fig.3. The Elevation of Highway - (Side – Front).

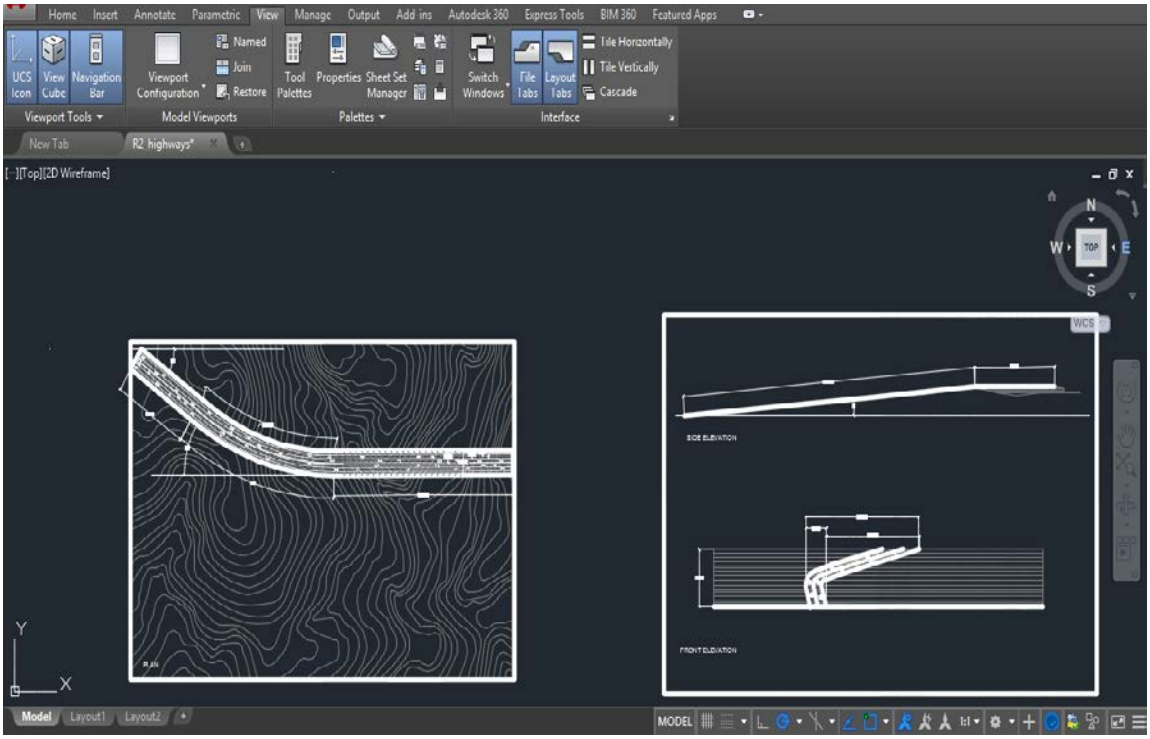

Fig.4. A Graph Sample Showing the Design of Highway Using AutoCAD.

3.2 Horizontal and vertical alignment

In order to plan horizontal and vertical alignment, requirements and parameters must be taken into account for integrating horizontal and vertical curves in the alignment of a roadway. A horizontal curve on a road refers to alignment, or how straight the segment of the road is. A vertical curve refers to the increase in elevation of a pavement, or the road's "flatness". Driver and motor vehicle operating characteristics put the greatest constraints on curvature. In certain cases, the implementation of motor vehicle safety controls follows safety controls for cyclists and pedestrians, including those with disabilities. This suggests that the standards for vehicles are more stringent than those for pedestrians and bicyclists because adding a bend or a slope in a section of the road that meets the design requirements for a motor vehicle would also likely fulfil the standards for pedestrians and bicyclists [16].

Roads are not necessarily smooth and straight-they have vertical and horizontal curves to avoid or be compliant with existing constraints. Typically, alignment constraints include topographical variability, natural resource areas, ownership of lands, land usage, costs, and the environment. Curvilinear alignments must be implemented when the model faces these constraints [17]. Good alignment design is crucial in the effort to balance road user needs and protection with the importance of protecting the environmental integrity [18].

It is important to note the effects of combining the two when using a combination of horizontal and vertical curves. Further incremental change may be required in each case to safely reach a distance of sight, acceleration, and other needs [19].

The process of integrating horizontal and vertical elements into the design of a roadway starts with the definition of the planned corridor and the position of vital constraints to be considered for protection during the design process. The crucial constraints that guide the design process include, but are not limited to: project boundaries, private property, pedestrian functions, accessibility for individuals with disabilities, significant cultural (historical/archaeological) areas and features, managed wetlands, natural drainage courses, endangered species habitat, the intersection of roads and driveways, underground and overhead utilities, and rain facilities [20]. Early in the process, a balanced design must define these constraints and coordinate the vertical and horizontal location of the road to protect, maintain or fulfill and the requirement to the degree practicable. The designed plan is shown in Fig. 5. The designed vertical alignment with (Crest - Sag Curve) is shown in Fig. 6.

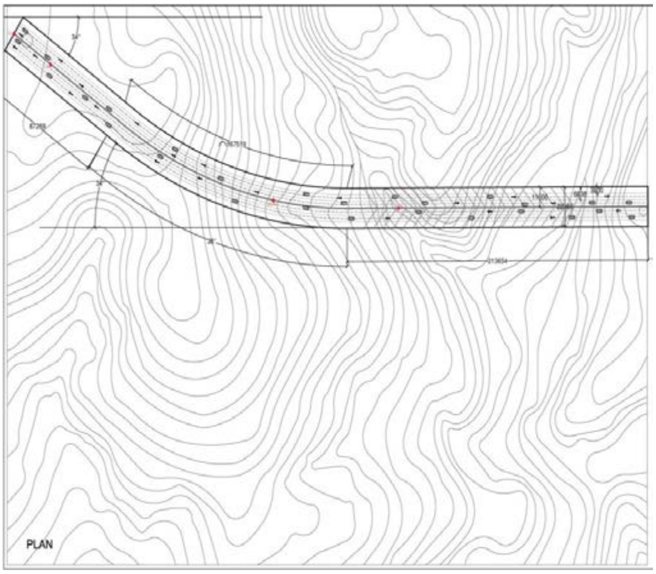

Fig.5. The designed highway plan.

3.3 Calculation of horizontal alignment design

Depending on JKR standard: minimum radius: 465 m
Proposed radius: 470 m
Based on the AutoCAD Drawing: Δ is 36°

$$T = R \tan\left(\frac{\Delta}{2}\right) \quad (1)$$

= 470 tan (36/2) = 152.712 m

$$L = \frac{\pi}{180 \; x \; R \; x \; \Delta} \quad (2)$$

= π / 180 *x* 470 *x* 36 = 295.31

Calculation of Stationing based on the AutoCAD Drawing:
Sta. PC = 5 + 152.000
Sta. PI = Sta. PC + T = 5 + 152 + 152.712 = 5 + 304.712
Sta. PT = Sta. PC + L = 5 + 152 + 295.31 = 5 + 447.31

3.4 Calculation of vertical alignment design

1: Crest Vertical Curve: According to Road Design Standard U6, and the speed design = 100 km/h.
Depending on JKR Standard: the minimum SSD = 205 m.
Proposed SSD: 350 m
G1 = +0.5% G2 = -1.00%
The total value of differences in both grades:

$$A = |G1 - G2| \quad (3)$$

= | +0.5 – (-1.00) |

= 1.5 %

Assume L < SSD

$$L = 2\,(SSD) - \left(\frac{404}{A}\right)$$

= 2 (350) – (404 / 1.5)
= 430.66 m > 350 m, SSD = 350 m, so our assumption was wrong.
Assume L > SSD

$$L = \frac{(A(SSD)^2)}{404} \quad (4)$$

= $(1.5\,(350)^2) / 404$

= 454.826 m > SSD = 350 m, so our assumption is RIGHT ✓

We will proceed the L = 500 m

- ➔ Sta. PVC = 0 + 900
- ➔ Elevation of PVC = 910 m
- ➔ $Sta.PVI = Sta.PVC + \frac{L}{2}$ (5)

= 0+900 + 500 / 2

= 450.000

➔ $Elevation\ of\ PVI = Elevation\ of\ PVC + G1\ (\frac{L}{2})$ (6)

= 910 + 0.005 (500/2)

= 911.25 m

➔ $Sta.PVT = Sta.PVT + \frac{L}{2}$

= 1150 + (500/2)

= 1400

= 1+400.000

➔ $Elevation\ of\ PVT = Elevation\ of\ PVI + G2\ (\frac{L}{2})$ (7)

= 913.521 + (-0.01) (500/2)

= 911.021m

➔ $K = \frac{L}{A}$ (8)

= 500 / 1.5

= 333.33 > K from JKR = 60 (for crest). So, it is accepted.

2: Sag Vertical Curve: According to Road Design Standard U6, and the speed design = 100 km/h.
Depending on JKR Standard: the minimum SSD = 205 m.
Proposed SSD: 350 m
G1 = -0.5% G2 = +1.00%
The total value of differences in both grades:
A = | G1 – G2 |
= | - 0.5 – (+1.00) |
= 1.5 %
Assume L < SSD
L = 2 (SSD) – (404 / A)
= 2 (350) – (404 / 1.5)

= 430.67 m > 350 m, SSD = 350 m, so our assumption is RIGHT ✓
Assume L > SSD
L = (A (SSD)²) / 404
= (1.5 (350) ²) / 404

= 454.82 m > SSD = 350 m, so our assumption is RIGHT ✓
We will proceed the L = 500 m

➔ Sta. PVC = 6+154
➔ Elevation of PVC = 862 m
➔ Sta. PVI = Sta. PVC + L / 2
➔ = 6+154 + 500 / 2
➔ = 6+404
➔ Elevation of PVI = Elevation of PVC + **G1** (L / 2)

= 862 + (-0.005) (500/2)

= 860.75 m

➔ Sta. PVT = Sta. PVI + L/2
= 6404 + (500/2)

= 6+654.00

➔ Elevation of PVT = Elevation of PVI + **G2** (L / 2)
= 860.75 + (+0.01) (500/2)

= 863.25 m

➔ K = L / A = 500 / 1.5 = 333.33 > K from JKR = 40 (for sag). So, it is accepted.

Fig. 6. Illustrates the designed vertical alignment with (Crest - Sag Curve), the PVC, and elevation values for vertical crest curve, and vertical sag curve are shown based on the calculated data.

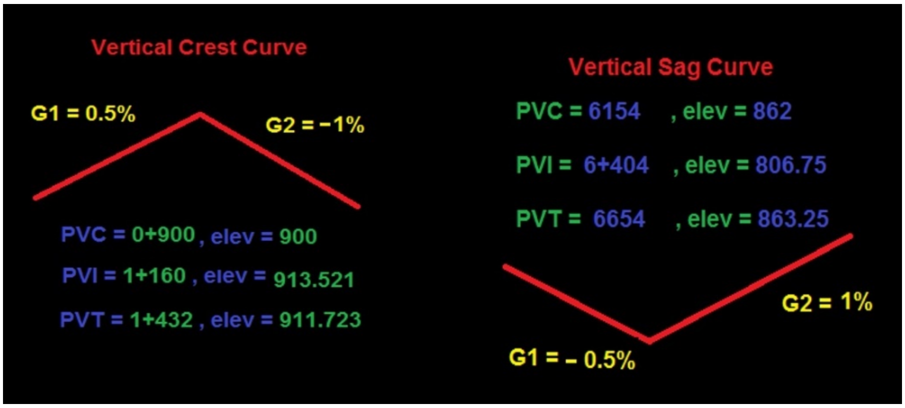

Fig.6. Vertical Alignment (Crest - Sag Curve).

3.5 Pavement design of road

Some of the most critical elements of project planning are efficient pavement planning. The pavement is the most visible part of the highway for the motorist. The quality and suitability of the road are also measured by the smoothness or roughness of the pavement. Deficient conditions of pavement can lead to increased user costs and travel delays, braking and fuel usage, vehicle maintenance repairs and the possibility of increased crashes. The number of heavy load repetitions applied, such as single, tandem, tridem and quad-axle trucks, buses, tractor-trailers, and vehicles, significantly affect the life of the pavement. A correctly built paving system takes account of the loading applied [21].

A road pavement is a structure consisting of superimposed layers of engineered materials above the natural soil subgrade, the primary purpose of which is to distribute the vehicle loads applied to the subgrade. The pavement system should be capable of providing a reasonable riding quality surface, sufficient skid resistance, desirable light-reflecting properties, and low noise pollution. The ultimate goal is to ensure that the transmitted stresses due to wheel load are sufficiently minimized so that they do not surpass the sub-grade bearing potential. Two types of floors are commonly recognized as serving this function, namely flexible flooring, and rigid flooring. Pavement architecture is the principal component of road construction. Nearly one-third or half of the overall building costs should be taken into account in pavement design [22].

3.5.1 Pavement requirements

O'Flaherty, (2002) [23] explained that an ideal pavement would fulfill the following demands:

- Enough thickness to spread the stresses of the wheel load to a secure value on the subgrade soil.
- Structurally sound to withstand the stresses put on it by all kinds.
- Adequate friction coefficient for stopping automobiles from skidding.
- Smooth surface offering comfort even at high speed for road users.
- Makes the least of the noise from moving vehicles.
- Dust confirmation surface so that the visibility loss will not affect traffic safety.
- Impermeable surface, so that the soil is well covered from subgrades.
- Long product life with low cost of maintenance.

3.5.2 Types of pavement

The pavements can be divided into two, flexible pavements and rigid pavements, depending on the structural performance. In versatile pavements, wheel loads are moved through the granular structure through grain-to-grain contact of the aggregate. Having less flexural energy, the flexible pavement works like a flexible sheet (e.g. bituminous road). On the contrary, wheel loads are moved to subgrade soil in rigid pavements by the flexural strength of the pavement, and the pavement serves as a rigid plate (e.g. cement concrete roads). Besides this, composite pavements are also available. The ideal pavement with the most desirable characteristics is a thin layer of flexible pavement over the rigid pavement. These pavements are, however, rarely used in new construction due to the high cost and complex analysis needed.

Pavings form the basic supporting framework for motorway transport. Each pavement layer has a multitude of functions that must be taken into account during the design process. Depending on the traffic conditions various types of pavements may be implemented. Improper design of pavements leads to early failure of pavements which also affect the quality of the riding [24].

There are various forms of pavement design, such as flexible pavement, rigid pavement and semi-rigid pavement. There are some factors influencing the selection of such pavements which are initial costs, the availability of good materials, maintenance costs, environmental conditions, the availability of industrial waste and the volume of traffic.

Design of a road pavement for a 2-lane highway will be calculated to the average daily traffic:
For our pavement design, we decided to select Flexible pavement design with unmodified bitumen and granular base.

3.5.3 Calculation of pavement design

Traffic Category: ESALYt (base year) = ADT x 365 x Pcv x LEF x L x T = 0.307 Million
Design Traffic over 20 years: ESALDES = ESALYS x TGF
= 0.307 x TGF
= 9.142 Million

Subgrade Category: Probability 85.3 %, Zr = 1.28
The Characteristics CBR value used for design = 13.1%
FULL DEPTH OF ASPHALT PAVEMENT
Traffic Category:
ESALYYt = 1.289 Million
The design traffic over 20 years: ESALDES = 40.44 Million
Reliability = 94 %

So, the Zr (Standard normal curve) = 1.555 %
Subgrade Category:
The used characteristics sub grade Modulus value for design = 121 MPa

4. Results and Discussion

Based on the topography map that is given, the federal highway project has been designed. To design the road, there will be cut or fill in building the project. In our project, both cut and fill were needed. As the beginning of our design, more excavation is needed because we designed the road in a lower surface. This is very economical and will reduce the cost of the project because if it has the opposite direction, we were in need to fill more with soil from the beginning and this will cost a lot.

4.1 Horizontal alignment of the designed highway which has the following data:

The station PC of the horizontal curve = 5+152.000
The station PI = 5+304.712
The station PT = 5+447.31

According to JKR standard, the minimum radius is 465m, however the radius for our horizontal curve design we propose 470 m which is greater than the minimum radius. Therefore, the horizontal curve’s radius is adequate for our design.

The circular length of the horizontal curve is 295.31m, and spiral or transition curve is 0 m, since JKR standard highway does not have transition curve and the lanes are wide enough.

4.2 Vertical alignments of the designed highway

The minimum SSD from JKR is 205m, however the SSD we designed is 350m. This indicates that the length is very suitable and sufficient to provide us with a safer stopping distance for the drivers in the transportation. Depending on the SSD, the length of the curve is 500 m and after the calculation the K value is 333.33. This indicates that the K value reaches the minimum requirement of standard K = 60 for the crust vertical curve and K= 40 for the sag vertical curve. The two vertical alignments have the following data:

4.2.1 The first vertical alignment (crest):

The station PVC = 0+900.000
The elevation PVC = 910.000 m
The station PVI = 1+150.000
The elevation PVI = 911.25 m
The station PVT = 1+400.000
The elevation PVT = 911.021 m
Initial Gradient, G1 = 0.5 %
Final Gradient, G2 = - 1.00 %

4.2.2 The second vertical alignment (sag):

The station PVC = 6+154.000
The elevation PVC = 862.000 m
The station PVI = 6+404.000
The elevation PVI = 860.750 m

The station PVT = 6+654.000
The elevation PVT = 863.250 m
Initial Gradient, G1 = - 0.5 %
Final Gradient, G2 = 1.00 %

The purpose of choosing low-value gradient is that we wanted to design a road with adequate and gentle slope for safer driving circumstances. For our pavement design, we decided to select Flexible pavement design with unmodified bitumen and granular base.

Traffic Category:
ESALYt (base year) = 9.142 Million
Subgrade Category:
Probability 85.3 %
Zr = 1.28
The Characteristics CBR value used for design = 13.1%
Full Depth of Asphalt Pavement
Traffic Category:
ESALYYt = 1.289 Million
The design traffic over 20 years: ESALDES = 40.44 Million
Reliability = 94 %
So, the Zr (Standard normal curve) = 1.555 %
Subgrade Category: The used characteristics sub grade Modulus value for design = 121 MPa

The road has been designed in a lower surface which is very economical and mets the objective of the study. Furthermore, the horizontal curve’s radius was adequate. The reliability of the designed highway was 94 percent which shows that the designed highway has an adequate, accurate, and economical system.

5. Conclusion

In the conclusion of this project, it's proven that the designed highway has an adequate, accurate, and economical system based on the proposed data. Through this highway design project, time-consuming travel, road duration, and the accident will be decreased. The construction cost and pavement design have been done according to the Malaysian public works department for the federal roads system (JKR). The reliability of the designed highway was 94 percent. Referring to the JKR standard and comparing our data to the highest standard highway system, this designed project met the designing requirements and fulfilled the goals and objectives of this project.

APPENDICES

JKR Standard Design of Highway U6

GENERAL SUMMARY - GEOMETRIC DESIGN CRITERIA FOR ROADS IN URBAN AREAS (METRIC)

s	1	DESIGN STANDARD	-	U6	U5	U4	U3	U2	Ui	Ula
O ~	2	ACCESS CONTROL	-	FULL	PARTIAL	PARTIAL	PARTIAL/NIL	NIL	NIL	NIL
	3	AREA TYPE	-	I II III	I II III	II III	I II III	I II III	I II III	I 11 III
0	4	DESIGN SPEED	Km/hr	100 80 60	80 60 50	70 60 50	60 50 40	50 40 30	40 30 20	40 30 10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	6 / 7	SHOULDER WIDTH / SHOULDER WIDTH STRUCTURES >1Wm	m / m	3.00 3.00 2.50 1.00	3.00 3.00 2.50 1.00	3.00 2.50 2.00 1.00	2.50 2.00 1.50 0.50 1	2.00 1.50 1.50 0.50 1	1.50 1.50 0.50 0.50 ~	1.50 1.50 1.50 0.50 1
	8	MEDIAN WIDTH (MINIMUM)	m	14.0 3.50 3.00	3.00 2.50 2.00	2.50 2.00 1.50	2.00 1.50 1.00	N/A	N/A	N/A
	9	MEDIAN WIDTH (DESIRABLE)	m	112-009- 6.00	9.00 6.50 4.00	7.50 5.00 3.00	6.00 4.00 2.00	N/A	N/A	N/A
v	10	MARGINAL STRIP (WIDTH)	m	0.50	0.50	0.25	0.25	0.00	0.00	0.00
	11	MINIMUM RESERVE WIDTH	m	60	50	40(30) b	30(20) b	20	11	12
	12	STOPPING SIGHT DISTANCE	m	205 140 85	140 85 65	115 85 65	85 65 45	65 45 30	45 30 20	45~ 30 20
	13	PASSING SIGHT DISTANCE	m	N/A	550 450 350	500 450 350	450 350 300	350 300 250	300 250 200	300 250 200
	14	MINIMUM RADIUS	m	465 280 150	280 150 100	210 150 100	150 100 60	100 60 35	60 35 15	60 35 15
	15	MINIMUM LENGTH OF SPIRAL	m	SEE TABLE 4 - 4B				N/A	N/A	N/A
	16	MAXIMUM SUPERELEVATION	RATIO	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	17	MAXIMUM GRADE (DESIRABLE)	%	3 4 5	4 5 6	5 6 7	6 7 8	7 8 9	7 8 9	7 8 9
	18	MAXIMUM GRADE	%	6 7 8	7 8 9	8 9 10	9 10 12	10 12 15	10 12 15	10 12 15
	19	CREST VERTICAL CURVE (K)	-	60 30 15	30 15 10	22 15 10	15 10 10	10 10 5	10 5 5	10 5 5
	20	SAG VERTICAL CURVE (K)	-	40 28 15	28 15 12	120 15 12	15 12 10	12 10 8	10 8 8	10 8 8

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