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Study on Geometric Design of Nay Pyi Taw-Mandalay Expressway and Possible Improvements; Sagarinn-Myinsain Portion

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Abstract**—**Geometric design is an important part of planning process design for physical highway to fill up basic function of roads, to give good traffic service. It is found that most of the road safety problems occur at the horizontal curves and complex-compound curves. In this paper, review on Sagarinn-Myinsain Portion of Nay Pyi Taw - Mandalay highway has been conducted in aspect of geometric design induced road safety condition. Horizontal alignment of geometric features and curve details are reviewed based on (AASHTO) standard and revised by Autodesk Land Desktop Software. Moreover, 85^{th} Percentile Operation Speeds (V85) with driver confidence on horizontal curves is evaluated in order to obtain the range of highway safety factor (FS). The length of the selected highway portion is 13.65 miles and 8 lanes. The results of this study can be used to investigate the possible hazardous locations in advance and to revise how design radius and super elevation should be for better road safety performance for the selected portion. Moreover, the relationship between highway safety and highway geometry characteristics can also be known.

Keywords**—**Geometric design; horizontal alignment; super elevation; 85^{th} percentile operation speed (V_{85}), safety factor (FS).

I. Introduction

THE goal of transportation is generally stated as the safe and efficient movement of people and goods. Due to the rapid growth of population, vehicles and traffic volumes, there are some negative impacts on highway safety such as traffic accident problems. Therefore, many traffic engineers are trying to find the best way to improve the highway transportation problems and road safety situations. It is found that most of the road safety problems occur at the horizontal curves and complex-compound curves. Globally, as many as 50 million persons are injured in road traffic crashes each year and about 1.2 million of them die (World Health Organization, 2004) [4].

It is a possible way to use highway *safety factor (FS)* like other civil engineering area as an indicator for geometric features induced road safety problems. Factor of safety must be at least 1. The evaluation of safety factor depends on the feasible speed and 85^{th} Percentile Operation Speed, V_{85} with driver confidence on horizontal curves. V_{85} speed is defined as the speed at which drivers choose to travel under free-flow conditions when they are not constrained by alignment features which can be examined by using basic formula [2].

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There are 85 percentile operating speed prediction equations are evaluated by using feasible geometric characteristics which are radius, curve length, central angle and degree of curvature. These are outcome of surveys conducted in United States, Europe and Australia [2]. It is found that radius or degree of curvature consistently tops the list of geometry variables that most significantly effect operating speeds on horizontal curves.

The advantages of the evaluation highway *safety factor(FS)* and 85 percentile operating speed are; it can be known the relationship between highway safety and highway geometry characteristics, it can be used to investigate the possible hazardous locations in advance and it can be used to revise how design radius and super elevation should be for better road safety performance.

II. Methodology for Evaluation of Safety Factor

This paper examines the highway *safety factor (FS)* depends on the 85 percentile operating speed, feasible speed and target speed or design speed. The target design-speed concept involves the selection of the design speed based on the topography, the adjacent land use, and the functional classification of highway. AASHTO defines *the design speed* as the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern. The design speed should be consistent with the speed a driver is likely to expect [8].

Furthermore, the design speed should be a high-percentile value in a cumulative distribution of vehicle speeds for that type of highway. The designer selects a radius for the horizontal curve and its respective super elevation rate. Super elevation is the banking of the pavement on curves to counteract the effect of the centrifugal force [11]. In this study, the design speed of Sagarinn-Myinsain Portion is 60 mph. The design speed is the main factor on which geometric design elements depend.

The *85th percentile of the distribution of observed speeds* is the most frequently-used measure of the operating speed associated with a particular location or geometric feature." Thus, V_{85} is the speed that is only surpassed by 15% of vehicles. 85^{th} percentile operation speed is defined as the speed at which drivers choose to travel under free-flow conditions when they are not constrained [2].

Then, the 85th percentile operation speeds for each segment of the selected road are evaluated by using the related designs of each geometry data into the well-known prediction 85th percentile operation speeds.

Finally, ranges of *factor of safety (FS)* are examined by comparing V_{85} feasible speed of each design and target design speed. *(FS)Factor of safety* must be at least 1 and sections with enough safety moving are defined as safer zone.

III. Location of Sagarinn-Myinsain Portion

The location of Sagarinn-Myinsain Portion is in Mandalay Region, which is a portion of Nay Pyi Taw-Mandalay Expressway. It connects Sagarinn, Aye Kyi Khone, Kan Chaw, Oo Min and Myinsain village which are near by Tadaoo Township in Mandalay Region.

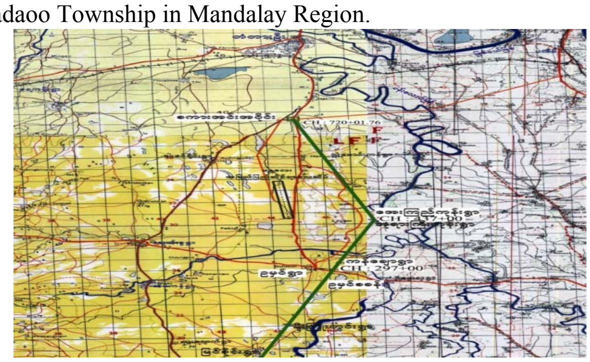

Fig. 1 Location of Sagarinn-Myinsain portion
Source: Public Works

In this study, 13.65 mile long with 8 lanes was taken into consideration. Location map of the selected portion of Nay Pyi Taw-Mandalay expressway from Public Works is shown in Fig. 1.

IV. Methodology

In the first stage, the total length (13.65 miles) of selected portion is divided into 28 segments and shown in Table I. The length of each segment is 2640 ft (0.5 mile). The total length is divided into two portions straight portion (segment no: 1 to 9 and 18 to 28) and curve portion (segment no: 10 to 12 and 16 to 28). Feasible speeds of highway according to design of Public Work for each segment of selected portion are calculated by reverse calculation using (AASHTO) design equations for horizontal curves. Feasible speeds of actual construction curves for each segment are also computed with reverse calculation approach. Then feasible speeds of proposed modified road are evaluated by adding super elevation e = 1.5 % at segment no: 10 and e = 6 % at segment no: 16. The next step, the author conducts design of selected road by Autodesk Land Desktop Software from all aspects of geometric characteristics. The V_{85} feasible speeds of highway according to design of Public Work for each segment of selected portion are calculated by using the related design of each geometry data into the well-known prediction equations. The V_{85} feasible speeds of actual construction curves for each segment are also computed with prediction equations approach. Ranges of *factor of safety (FS)* are examined by comparing the V_{85} feasible speed and target design speed. It can be used to investigate the possible hazardous locations in advance by depending on the value of range of factor of safety.

V. Estimation of Feasible Speed

In this paper, there are five types of design to calculate the feasible speed. They are Public Work design, actual constructed road condition, proposed modified road design (modification on super elevation e only), selected new design (Sagarinn-Myinsain Portion) and proposed modified new design (modification on radius R only). The geometry data on horizontal curves according to design of Public Works are summarized in Table I. The length of each segment is 2640 ft (0.5 mile). Type of portion for the selected portion is also shown in Table I.

TABLE I
Summary of Horizontal Curves (Public Work)

Segment No	Types of Portion	Curve Length (ft)	Central angle(Δ)	Tangent Length (ft)
1	Straight	116.18	1°19′53″	58.09
2	Straight	116.18	1°19′53″	58.09
3	Straight	116.18	1°19′53″	58.09
4	Straight	116.18	1°19′53″	58.09
5	Straight	174.58	2°0′0″	87.3
6	Straight	174.58	2°0′0″	87.3
7	Straight	174.58	2°0′0″	87.3
8	Straight	174.58	2°0′0″	87.3
9	Straight	174.58	2°0′0″	87.3
10	Curve	764.23	21°53′37″	386.83
11	Curve	174.58	2°0′0″	87.3
12	Curve	846.19	24°14′29″	429.52
13	Straight	174.58	2°0′0″	87.3
14	Straight	174.58	2°0′0″	87.3
15	Curve	145.36	1°39′57″	72.68
16	Curve	879.88	33°36′32″	453
17	Curve	305.65	5°50′15″	152.96
18	Straight	116.18	1°19′53″	58.09
19	Straight	116.18	1°19′53″	58.09
20	Straight	116.18	1°19′53″	58.09
21	Straight	116.18	1°19′53″	58.09
22	Straight	116.18	1°19′53″	58.09
23	Straight	116.18	1°19′53″	58.09
24	Straight	116.18	1°19′53″	58.09
25	Straight	116.18	1°19′53″	58.09
26	Straight	116.18	1°19′53″	58.09
27	Straight	116.18	1°19′53″	58.09
28	Straight	116.18	1°19′53″	58.09

From the survey data, there are seven horizontal curves on that road. Fig. 2 is showing some curves on selected portion of road.

Fig. 2 Some of curves on Sagarinn-Myinsain portion

The geometry data on horizontal curves of actual constructed road condition are summarized in Table II.

TABLE II
SUMMARY OF HORIZONTAL CURVES (ACTUAL CONSTRUCTED ROAD CONDITION)

Segment No	Types of Portion	Curve Length (ft)	Central angle(Δ)	Degree of curvature (D)
1	Straight	110.07	2°12′5.04″	1°5′23.63″
2	Straight	110.07	2°12′5.04″	1°5′23.63″
3	Straight	110.07	2°12′5.04″	1°5′23.63″
4	Straight	110.07	2°12′5.04″	1°5′23.63″
5	Straight	110.07	2°12′5.04″	1°5′23.63″
6	Straight	110.07	2°12′5.04″	1°5′23.63″
7	Straight	110.07	2°12′5.04″	1°5′23.63″
8	Straight	110.07	2°12′5.04″	1°5′23.63″
9	Straight	110.07	2°12′5.04″	1°5′23.63″
10	Curve	169.51	3°23′24.72″	3°2′22.43″
11	Curve	110.07	2°12′5.04″	1°5′23.63″
12	Curve	758.12	15°9′44.64″	2°59′31.01″
13	Straight	110.07	2°12′5.04″	1°5′23.63″
14	Straight	110.07	2°12′5.04″	1°5′23.63″
15	Curve	115.5	2°18′36″	1°5′23.63″
16	Curve	804.2	16°5′2.4″	4°2′5.7″
17	Straight	110.07	2°12′5.04″	1°57′19.76″
18	Curve	252.2	5°2′38.4″	1°5′23.63″
19	Straight	110.07	2°12′5.04″	1°5′23.63″
20	Straight	110.07	2°12′5.04″	1°5′23.63″
21	Straight	110.07	2°12′5.04″	1°5′23.63″
22	Straight	110.07	2°12′5.04″	1°5′23.63″
23	Straight	110.07	2°12′5.04″	1°5′23.63″
24	Straight	110.07	2°12′5.04″	1°5′23.63″
25	Straight	110.07	2°12′5.04″	1°5′23.63″
26	Straight	110.07	2°12′5.04″	1°5′23.63″
27	Straight	110.07	2°12′5.04″	1°5′23.63″
28	Straight	110.07	2°12′5.04″	1°5′23.63″

The feasible speeds can be calculated by reverse calculation using the (AASHTO 2004).

A. Design Speed

The overall design of geometrics of any highway is a function of the design speed. The design speed is the main factor on which geometric design elements depend [7]. The sight distances, radius of horizontal curve, super elevation, and length of horizontal transition curves are all depended on design speed. The relationship between R = radius (ft), V = design speed (mph), e = super elevation (max = 6%) and f= friction (0.12) are given by the following equations.

$$e + f = \frac{V^2}{15R} \qquad (1)$$

Thus, feasible speed can be calculated as

$$V = \sqrt{(15R(e+f))} \qquad (2)$$

B. Degree of Curvature

Most of the geometry data are developed by using degree of curvature instead of radius because that was the standard descriptor of horizontal curvature. The relationship between degree of curvature (D) and radius is given by the following where D = Degree of curvature in degree and R = radius (mph).

$$D = \frac{5729.58}{R} \qquad (3)$$

C. Length of Curvature

The relationship between central angle (Δ) and length of circular curve is given by the following where L = Length of curvature (ft) and Δ = central angle in degree.

$$L = 100\frac{\Delta}{2} \qquad (4)$$

In this study, the horizontal curves are revised by the author by applying Autodesk Land Desktop Software. The design speed, the radius of curve and the rate of super elevation are input data for the horizontal speed table of software (Fig.3). The result of geometry data on horizontal curves of selected highway are summarized in Table III.

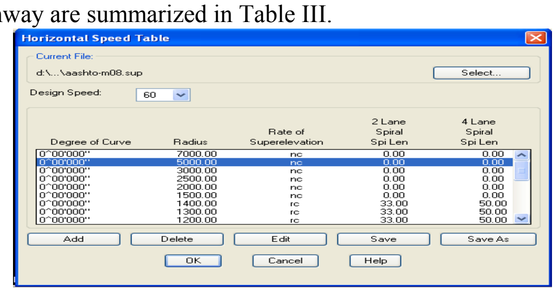

Fig. 3 Horizontal speed table of Autodesk Land Desktop Software

TABLE III
SUMMARY OF HORIZONTAL CURVES (NEW DESIGN)

Segment No:	Types of portion	Curve Length (ft)	Central angle(Δ)	Tangent Length (ft)
1	Straight	7. 89	0°05′26″	3.95
2	Straight	100.85	1°09′20″	50.23
3	Straight	30.41	0°20′54″	15.20
4	Straight	107.36	1°13′49″	53.48
5	Curve	176.32	2°01′14″	88.17
6	Straight	38.47	2°26′17″	19.24
7	Straight	63.69	0°43′47″	31.85
8	Straight	34.14	0°23′29″	17.07
9	Straight	34.61	0°23′48″	17.31
10	Curve	1093.11	20°52′37″	552.68
11	Straight	79.25	1°30′49″	39.63
12	Curve	1112.67	21°15′01″	562.8
13	Straight	98.71	1°07′52″	49.35
14	Curve	248.92	2°51′09″	124.49
15	Straight	125.67	1°26′24″	62.84
16	Curve	1245.19	28°32′15″	635.79
17	Curve	404.47	7°43′29″	202.54
18	Curve	295.63	3°23′16″	147.86
19	Straight	141.70	1°37′26″	70.86
20	Straight	107.27	1°13′45″	53.64
21	Straight	37.69	0°25′55″	18.85
22	Straight	7.78	0°05′21″	3.89
23	Straight	173.99	1°59′38″	87.01
24	Straight	195.54	2°14′27″	97.78
25	Straight	170.09	1°56′57″	85.05
26	Straight	91.79	1°03′07″	45.90
27	Straight	115.45	1°19′22″	57.73
28	Straight	86.36	0°59′23″	43.18

The length of each segment is 2640 ft (0.5 mile). Type of portion for the selected portion is shown in Table I. The total length is divided into two portions straight portion (segment no: 1 to 9 and 18 to 28, (9.33 miles)) and curve portion segment no: 10 to 12, (1.52 miles) and curve portion segment no: 16 to 28, (1.30 miles). There are seven horizontal curves in the selected road but curve no: 5, 14 and 18 are nearly the straight.

After dividing the total length into segments, the feasible speeds of selected design are also revised by back calculation from AASHTO design equation.

Then, feasible speeds of modified design are evaluated by modifying radius from 3000 ft to 5000 ft at segment no:10and12 and by modifying radius from 1500 ft to 2500 ft at segment no:16

VI. Estimation of Operation speed

The majority of researchers proposed determining the operating speed using the geometric characteristics of the alignment. Most model use a single variable, which is usually the radius of circular curves (R) or degree of curvature (DC) (Lamm and Choueiri 1987; Morrall and Talarico 1994). Lamm et al suggested a modal similar to the Gernan modal after studying 260 curves in New York State [8]. Some researchers use other variables, such as the central angle (Δ). In the modal devised by Krammes et al (1995a), in addition to the radius, length of horizontal curve and central angle (Δ).The study by Krammes et al. found that after studying 138 curves in New York, Oregon, Texas, Washington, the length of the horizontal curve and deflection also had a significant effect on operating speeds. Castro et al. modified the perdition on operating speeds of the Crammes et al method [2].

There are several modals that predict the operating speed on circular curves which are widely accepted as a measure of operating speed. This may be result of differences in driver behaviour from one place to another and. Radius, length, degree of curvature and deflection angle are other variables that have been used in some regression equations to predict operating speeds on horizontal curves. The relationship between highway safety and highway geometry characteristics can be known using it. Well-known regression equations to predict the operating speed on horizontal curves are as follow.

$$V85 = 94.39 - 3189/R \quad \text{[Lamm and Choueiri (1987)]} \quad (5)$$

$$V85 = \exp(4.561 - 0.0058 6D) \quad \text{[Morrall and Talarico(1994)]} \quad (6)$$

$$V85 = 120.16 - 5596.72/R \quad \text{[Castro et al (2006)]} \quad (7)$$

$$V85 = 102.44 - 2471.81/R + 0.012L - 0.1\Delta \quad \text{[Krammes (1995)]} \quad (8)$$

Where, V_{85} = operating speed (mph)
R = radius of circular curve (ft),
D = degree of curvature in degrees
Δ = central angle in degrees
L = length of curve length (ft).

In this study, V_{85} speeds for each segment of each road are evaluated by using the related designs of each geometry data into the well-known prediction equations.

VII. Findings

The goal of transportation is generally stated as the safe and efficient movement of people and goods. To achieve this goal, designers are trying to find the best way to improve the highway transportation problems and road safety situations. It is a possible ways to evaluate *highway safety factor* is evaluation of 85th percentile operation speed with driver confidence on horizontal curves.

Comparison between feasible speed for design geometry of Public Works and target design speed is shown in Fig.4. Feasible speed is less than target design speed at segment no16. It may have hazardous case if the driver drives even with 60 mph at segment no.16. Comparison between feasible speed of actual constructed road condition and target design speed is shown in Fig.5. The distance between segment no: 16 to17 is o.5 mile. The travel distance between that curves is 30 sec. So, it may have hazardous case if the driver drives even with 60 mph at that distance. Comparison between feasible speed of proposed modified road design (modification on super elevation e only), and target design speed is shown in Fig.6. Feasible speed is increased 58.24 mph to 61.78 mph by modifying super elevation e = 1.5 % at (segment no: 10) and from 50.559 to 61.91 mph by modifying super elevation e = 6 % at segment no: 16).

Comparison between feasible speed of selected new design (Sagarinn-Myinsain Portion) and target design speed is shown in Fig.7. Feasible speed is less than target design speed at segment no16. It may also have hazardous case if the driver drives even with 60 mph at segment no.16. Comparison between feasible speed of proposed modified new design (modification on radius R only) and target design speed is shown in Fig.8. Feasible speed is increased from 60 mph to 73.48mph by modifying radius from 2000 ft to 3000 ft at segment no: 12 and from 51.96 mph to 67.08 mph by modifying radius from 1500 ft to 2500 ft at segment no: 16.

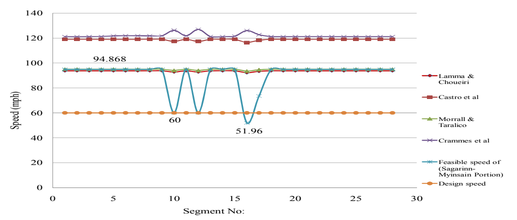

Fig. 4 Comparison between feasible speed for design geometry of Public Works and target design speed

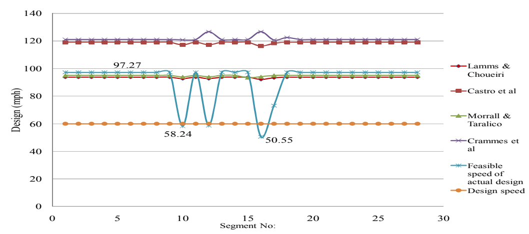

Fig. 5Comparison between feasible speed of actual constructed road condition and target design speed

Comparison between feasible speed of proposed modified road design (modification on super elevation e only) and target design speed is shown in Fig.6.

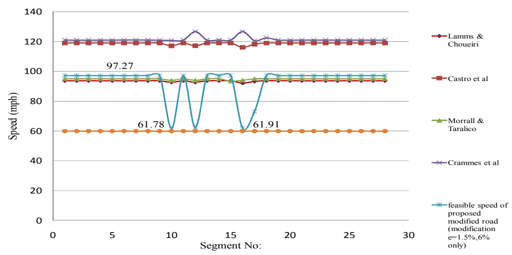

Fig. 6 Comparison between feasible modified speed of actual road (modification on e only) and target design speed

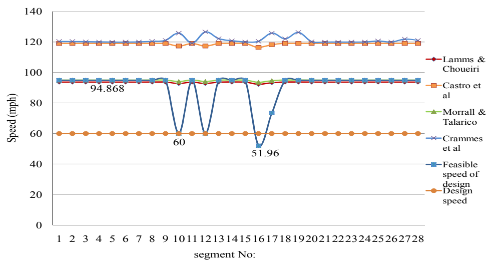

Fig. 7 Comparison between feasible speed of selected design and target design speed

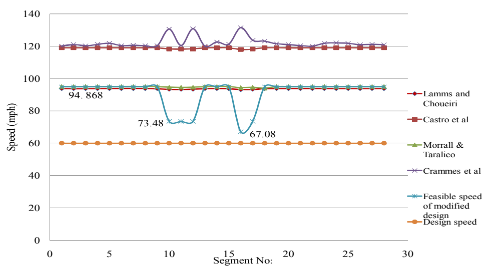

Fig. 8 Comparison between feasible speed of modified design (modification on R only) and target design speed

Ranges of Factor of Safety (FS) of Fig.4, Fig.5, Fig.6, Fig.7 and Fig.8 are shown in Table IV.

TABLE IV
RANGE OF FACTOR SAFETY

No. of Figure	List of item	Safety Factor (FS)	
		Straight portion	Curve portion
4	Public Work design	1.58	0.86
5	Actual constructed road condition	1.62	0.84
6	Proposed modified road design(modification on e only)	1.62	1.03
7	Selected new design	1.58	0.86
8	Proposed modified new design (modification on R only)	1.58	1.11

It is found that curves points have less than FS and segment no.16 is also most dangerous point in Public Works design and selected new design. Design radius should not be changed abruptly between straight and curve portion. If it is necessary, geometric modifications should be considered. It is also found that FS becomes better in curves points by adding super elevation. If it is not easy to add super elevation in curves points, speed management should be considered.

VIII. Conclusion and Recommendation

It can be conclude that target design speed cannot be satisfied in curve zone (2.82 mile long) of Sagarinn-Myinsain Portion of Nay Pyi Taw-Mandalay Expressway. Factor of safety (FS) is extremely low. These should be classified as potential hazardous zone where geometric management or speed management is necessary. The advantages of evaluation of highway safety factor (FS) is the relationship between highway safety and highway geometry characteristics. It can be used to investigate the possible hazardous locations in advance and it can be used to revise how design radius and super elevation should be for better road safety performance. The V_{85} speed should be revised by other 85^{th} percentile operating equation and survey on local driving speed for better prediction. The V_{85} speed should be evaluated by considering vertical alignment in order to know the effect of stopping sight distance on accident rate and the effect of grades on speed.

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