

# AN APPLICATION OF DIRECT METHOD AND BALL-BANK INDICATOR METHOD TO DETERMINE ADVISORY SPEEDS FOR HORIZONTAL CURVES IN VIETNAM

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## **Abstract**

Advisory speed signs on horizontal curves have been widely used in many countries over the world to improve traffic safety; however these road signs have not been applied in Vietnam. This paper aims to use the direct method and ball-bank indicator one to determine advisory speeds for 10 horizontal curves all with speed limit of 60 km/h on National Highway No. 4A in Lang Son province. The results showed that, advisory speeds were determined by the ball-bank indicator method ranging from 40 to 45 km/h for curves with radius of 70 m or less and from 50 to 55 km/h for curves with radius varying from 75 m to 120 m. As compared to the ball bank indicator method, advisory speeds determined by the direct method were 0 – 5 km/h higher if using 85th percentile speeds of cars, but 5 – 10 km/h lower if using average speeds of trucks.

**Keywords:** advisory speed limit; operating speed; horizontal curve; ball-bank indicator; traffic safety.

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## **1. Introduction**

When travelling on a horizontal curve, a vehicle will experience a lot of disadvantages as compared to travelling on a tangent section, therefore, horizontal curves often have higher traffic accident risks than normal tangent sections. According to the statistics in America, among about 33,000 fatalities occurring in the country nationwide each year, there are about 25 percent of these fatalities occurring on horizontal curves [1]. Improving traffic safety for horizontal curves therefore is very important on reducing road deaths in general.

According to Bonneson et al. [2], crash rate (crashes/million-vehicle-miles) increased with a decrease in horizontal curve radius; particularly the crash rate increased sharply for curves with a radius of less than 1000 ft [300 m]. The research also found that, crash frequency increased as side friction demand increased and the rate of increase was significant when side friction demand exceeded about 0.20. It should be noted that, this level of friction demand is about one-third of the friction supply

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available to passenger cars on wet pavements [3]. Therefore, it could be seen that a number of traffic accidents occurring on horizontal curves are not due to the side friction demand causing slide failure on pavement. The accidents may reflect that drivers might make more errors when the side friction demand is higher leading to more difficulties on maneuvering the vehicle.

To warn drivers to carefully drive and slow down when they pass through horizontal curves, in Vietnam at hazardous curves (the curves with a small radius and/or high deflection angle), curve warning signs are often installed such as: sign W.201 “Dangerous Curve” or sign W.202 “Winding Road” as stated in National Technical Regulation on Traffic Signs and Signals of Vietnam (QCVN41:2016) [4]. Besides using the curve warning signs as those used in Vietnam, a number of countries such as America, Canada, Australia, New Zealand also install an advisory speed sign (see an illustration in Fig. 1). According to the regulations in Australia [5], the advisory speed is the maximum speed at which a curve may be comfortably negotiated under a good road and weather conditions. The Manual on Uniform Traffic Control Devices of the American Federal Highway Administration [6] defines an advisory speed as a recommended speed for all vehicles operating on a section of highway and based on the highway design, operating characteristics, and conditions. These definitions imply that advisory speeds are recommended speeds. They are different from maximum speed limits at which the drivers have to compulsorily comply with.



(a) In England [7]



(b) In New Zealand [8]

Figure 1. Typical curve warning signage with advisory speed in England and New Zealand

In Vietnam, before horizontal curves or tangents in combination with curves which are traffic accident prone sections, in reality, besides using a curve warning sign, road authorities might install a warning sign with a message of “drive slowly” (sign W.245 according to [4]) or a maximum speed limit sign (sign R.127 according to [4]). However, because the warning sign with a message of “drive slowly” does not show any speed value that drivers should comply with, therefore drivers may make an error of choosing a speed that they consider “slow” but in fact this speed is higher than the safe speed under the driving conditions. In addition, using a maximum speed limit sign in some cases may not be suitable as this sign is not recommended to install for road sections with short lengths while most horizontal curves are rather short. An advisory speed sign, therefore is an alternative option that might overcome the disadvantages of the both aforementioned signs. Given that excessive speeds on rural roads are quite common in Vietnam as illustrated by Dinh et al. (2018) [9], the advisory speed sign may also act as a countermeasure for reducing a such dangerous driving behavior.

The horizontal curve signing with advisory speeds has been proved to have benefits on the traf-

fic safety. As an illustration, Hammer [10] conducted a before-after study on the safety benefits of installation of warning signs in advance of several curves. The author found that the implementation of advance horizontal alignment signs reduced crashes by 18 percent while the combined use of advance signing with an advisory speed plaque reduced crashes by a total of 22 percent. However, research indicates that the inconsistent use of curve warning signs, especially those with an Advisory Speed plaque, may have lessened the average motorists' respect for the message the signs convey. A study by Ritchie [11] showed that average curve speeds exceeded the advisory speed when the advisory speed was less than 45 mph [72 km/h]. The researcher also found that the amount by which the average speed exceeded the advisory speed increased with reduced advisory speeds. Specifically, for an advisory speed of 40 mph [64 km/h], the average speed exceeded the advisory speed by only 2 mph [3.2 km/h] (i.e., the average speed was 42 mph [68 km/h]); however, for an advisory speed of 20 mph [32 km/h], the average speed exceeded the advisory speed by 10 mph [16 km/h] (i.e., the average speed was 30 mph [48 km/h]). Therefore, appropriately determining advisory speeds is very important on ensuring the validity and the effectiveness of an advisory speed sign.

There are several methods that can be used to determine the curve advisory speed. According to Federal Highway Administration (USA) [12], there have been six main methods for establishing the curve advisory speed, including:

- Direct method: For this method, it is necessary to measure free-flow vehicle speeds on the field. The advisory speeds are then determined based on the measured average speeds or 85th percentile speeds of passenger cars or trucks.

- Compass method: This method is based on a single-pass survey technique using a digital compass, a distance measuring instrument and a ball-bank indicator placed in an experimental car to measure the subjective curve radius, deflection angle and superelevation. During the field measurement process, the test vehicle will stop or travel at low speed at two specified points on the subjective curve in order to measure compass directions at these points. Basing on the difference between the two compass directions and the distance between the two points, the curve radius and the deflection angle can be determined. The ball-bank indicator readings are used to calculate the superelevation rate of the curve. The advisory speed will be established based on the average speed or 85th percentile speed of passenger cars or trucks that are determined by using the available speed models (the models have been developed through experimental studies) with the curve radius and superelevation rate determined before.

- GPS method: As similar to the compass method, advisory speeds established by this method are based on average speeds or 85th percentile speeds of passenger cars or trucks. The speeds are calculated by using available speed models with the radius and superelevation rate of the subjective curve. The curve radius and superelevation rate in this method are determined through the data recorded by a GPS device with high accuracy and a ball-bank indicator equipment which are combined to a software installed in a laptop; the software is used to receive and analyze the data. All devices are placed in a test vehicle and the necessary data collection is implemented during the the test car travelling through the subjective curve.

- Design method: As similar to the compass method and the GPS method, advisory speeds established by the design method are also based on average speeds or 85th percentile speeds of passenger cars or trucks in which the speeds are calculated by using available speed models with the radius and superelevation rate of the subjective curve. The parameters of curve radius and superelevation rate are the input data that have been obtained in advance (from the shop drawings or field measurements).

- Ball-bank indicator method: According to this method, advisory speeds are based on the mini-

imum speeds of a test vehicle at which the readings of a ball-bank indicator exceeds a specified value. The readings of the ball-bank indicator device reflect the impact of lateral acceleration on a person sitting in the vehicle. In the other words, these readings account for the total impact of centrifugal force, superelevation rate of the pavement, and the rotation angle of vehicle body to a vehicle occupant. During the process of implementing this method, a test vehicle will be maneuvered to travel through the subjective horizontal curve with a constant speed and the readings displayed in the ball-bank indicator equipment will be recorded. The test vehicle speed will be increased until the ball-bank indicator readings exceeds a specified value.

- Accelerometer method: For this method, a high-precision electronic accelerometer with a built-in GPS receiver attached in a test vehicle is used to measure lateral acceleration that impacts on the vehicle and to measure vehicle speeds when the vehicle is travelling through the subjective horizontal curve. Advisory speeds are determined based on the speed of the test vehicle at which the readings displayed on the accelerometer exceeds a specified value (according to [13] the specified value is  $0.28g$  where  $g$  is the acceleration due to gravity,  $g = 0.98 \text{ m/s}^2$ ).

The six methods mentioned above used to establish curve advisory speeds are categorized into two general groups. The first four methods (including: direct method, compass method, GPS method, accelerometer method) determine advisory speeds based on measured or estimated operating speeds with given curve geometry. The last two methods (i.e., ball-bank indicator method and accelerometer method) determine advisory speeds based on lateral acceleration.

To apply the compass method, the GPS method and the design method, available speed models which are based on the local field speed data are needed. Although, there have been several speed models developed and used in USA [14], however these models may not suitable to the real operation of traffic flow in Vietnam. The accelerometer method requires to use specialized equipment that is not commonly available in Vietnam. The direct method and the ball-bank indicator method are quite simple; therefore, they are widely used all over the world. A ball-bank indicator can be obtained by using the app “BallBank” in Apple devices such as iPhone or iPad.

This paper, therefore aims to apply the direct method and ball-bank indicator method to establish advisory speeds for horizontal curves on National Highway No. 4A in Lang Son province, Vietnam in order to assess the feasibility of using these methods and evaluate the traffic safety of the curves with respect to vehicle speeds.

## 2. Methodology

### 2.1. Establishing advisory speeds for horizontal curves by direct method and ball-bank indicator method

#### a. Direct method

As mentioned in Section 1, to establish advisory speeds by using the direct method, it is necessary to measure vehicle speeds on the field. According to [12], at least, speeds of 125 vehicles for each direction are required. The speeds of free-flowing vehicles should be measured. A free-flowing vehicle will be at least 3 seconds behind the previous vehicle [6]. During the speeds being conducted, it should be minimized factors that affect drivers' speed behaviors by doing some solutions such as: properly hiding the speed measurement devices and surveyors; and data collection is discontinued to make the surveying periods not too long (not longer than 4 continuous hours).

From the collected speed data, average speeds and 85th percentile speeds of passenger cars or trucks for each direction of the subjective curve are calculated. In case of not conducting truck speeds,

according to Bonneson et al. [14] average speeds of trucks can be estimated by multiplying the average passenger car speed by 0.97.

To determine advisory speeds by the direct method, using either average speeds or 85th percentile speeds of passenger cars or trucks depends on the specific conditions and it should be determined by researchers. Normally, advisory speeds should be based on 85th percentile speeds of passenger cars or average speeds of trucks [14].

Furthermore, Bonneson et al. [14] proposed a rounding technique to determine the advisory speed. First add 1.0 mph [1.6 km/h] to the 85th percentile speeds of passenger cars or the average speeds of trucks based on the collected speed data; then round the sum down to the nearest 5 mph increment to obtain the advisory speed. Because of the rounding technique applied in USA where speeds are measured by mph, therefore to use (or apply?) the technique in Vietnam where the common unit of speeds is km/h, this paper proposes that advisory speeds will be rounded by the following way. First add 1.0 km/h to the 85th percentile speeds of passenger cars or the average speeds of trucks based on the collected speed data; then round the sum down to the nearest 5 km/h increment to obtain the advisory speed. For example, if the 85th percentile speed of passenger cars is 52.6 km/h, at which 1 km/h is added, a value of 53.6 km/h will be obtained, then this value will be rounded to the nearest 5 km/h increment to have an advisory speed of 50 km/h.

## 2.2. Ball-bank indicator method

The ball-bank indicator method is based on a set of field driving tests to record ball-bank indicator reading using a ball-bank indicator and a speedometer attached in a test car. The ball-bank indicator can be either mechanical or digital. The mechanical ball-bank indicator (see Fig. 2) consists of a curved glass tube which is filled with a liquid. A weighted ball floats in the glass tube. The ball-bank indicator is mounted in a vehicle, and as the vehicle travels around a curve, the ball floats outward in the curved glass tube. The movement of the ball is measured in degrees of deflection, and this reading is indicative of the combined effect of superelevation, lateral (centripetal) acceleration, and vehicle body roll. The digital ball-bank indicator is operated by simulating the movement of the ball in a mechanical ball-bank indicator.



Figure 2. A ball-bank indicator [11]

A ball-bank indicator can be used to measure the lateral acceleration on the vehicle's occupants. When properly mounted in the vehicle, the steel ball in the indicator moves laterally outward until its weight counters the centripetal acceleration acting on it and the vehicle. Analysis of forces acting on the steel ball, as shown in Fig. 3, yields the following relationship between centripetal acceleration, ball-bank reading  $\alpha$ , superelevation angle  $\phi$ , and body roll angle  $\rho$ .

$$\frac{V^2}{127R} = \tan(\alpha + \phi - \rho) \quad (1)$$

where  $V$  = Vehicle speed, km/h;  $R$  = Horizontal curve, m;  $\alpha$  = Ball-bank indicator angle (or “reading”), radians;  $\phi$  = Superelevation angle, radians;  $\rho$  = Body roll angle, radians.

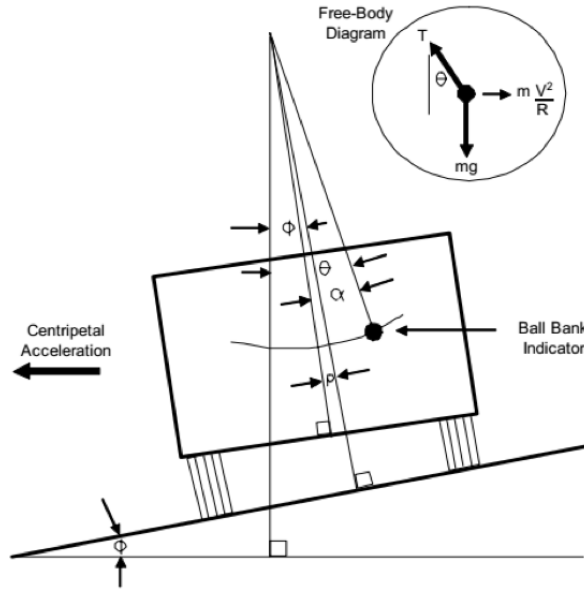


Figure 3. Diagram of forces acting on the ball-bank indicator [13]

It should be noted that, ball-bank indicator angle (or “reading”)  $\alpha$  normally has the unit of ° (degrees). However, to simplify expressions, in Formula (1) and the following relationships,  $\alpha$  is measured by radians.

The following two relationships can also be defined:

$$\phi = \tan^{-1} \left( \frac{e}{100} \right) \quad (2)$$

$$f_r = \tan^{-1} \left[ \frac{V^2}{127R} \right] - \tan^{-1} \left( \frac{e}{100} \right) \quad (3)$$

where  $f_r$  = Side friction angle, radian;  $\phi$  = Superelevation angle (see Fig. 3).

The side friction angle  $f_r$  corresponds to the lateral acceleration acting at the tire-pavement interface and equals the centripetal acceleration angle  $\theta$  less the superelevation angle  $\phi$ .

$$f_r = \theta - \phi \quad (4)$$

Combining the first three equations yields the following equation for estimating body roll angle:

$$\alpha = f_r + \rho \quad (5)$$

$$\text{or } \alpha = \theta - \phi + \rho \quad (6)$$

All the previous formulas from (1) to (6) and the accompanying expressions are extracted from [14]. As afore-mentioned, the ball-bank indicator angle  $\alpha$  corresponds to the lateral acceleration on the vehicle’s occupants. This acceleration is higher than the lateral acceleration acting at the tire-pavement interface because the body roll angle reduces the effectiveness of superelevation on vehicle body and vehicle’s occupants.



To establish advisory speeds by the ball-bank indicator method, it is necessary to drive a test vehicle through the horizontal curve with speeds ranging from low to high values (in general, vehicle speeds are rounded to 5 mph or 5 km/h and the speed of the test run will be higher than the speed of the current run). For each run, the test vehicle is maneuvered with a constant or nearly constant speed and ball-bank indicator readings are recorded. To ensure the accuracy of the measurement, for each vehicle speed value, the test run is replicated 3 times. It should be noted that, before the test run is conducted, it is necessary to adjust the location of the ball-bank indicator so that when the test vehicle is placed on a pavement with a lateral slope rate of 0 (%) then the readings of the ball-bank indicator will equal to 0 (degree).

According to the Manual on Uniform Traffic Control Devices of the American Federal Highway Administration (MUTCD, 2009) [6], the advisory speed is the vehicle speed on a horizontal curve corresponding to a ball-bank indicator reading as: 16 degrees of ball-bank for speeds of 20 mph [32.2 km/h] or less; 14 degrees of ball-bank for speeds of 25 mph [40.2 km/h] to 30 mph [48.3 km/h]; and 12 degrees of ball-bank for speeds of 35 mph [56.3 km/h] and higher.

### 2.3. Site selection and data collection

To initially assess the feasibility of applying the two methods introduced in Section 2 on establishing advisory speeds for horizontal curves in Vietnam, this current study conducted a survey on 10 horizontal curves with small radius on National Highway No. 4A in Lang Son province (the radius of these curves varied from 48 m to 120 m). In general, the road sections under the current study satisfied all the design criteria for roads classed IV for mountainous terrains according to the Vietnamese highway design standard (TCVN4054:2005, Highway - Specifications for design). The design speeds of these road sections are 40 km/h (except for one curve with a radius of 48 m less than the minimum curve radius of 60 m corresponding to the design speed of 40 km/h). The cross-sections of these sections consists of 2 traveled lanes ( $2.75 \text{ m} \times 2$ ) and has an embankment width of 7.5 m. The existing maximum speed limits of the curve P46 (at the station of Km11 + 949.33) is 50 km/h for trucks with weights of more than 3.5 tons and 60 km/h for other vehicles; the remaining road sections have the maximum speed limit of 60 km/h. All of these existing maximum speed limits were showed in the maximum speed limit signs posted before the road sections under study.

This research conducted a survey to investigate and measure parameters of the horizontal curves such as: radius, superelevation rate, longitudinal slope, length, and pavement width etc. In order to establish advisory speeds, the current study also measured spot speeds (free-flow speeds) of traffic flow at the middle point of the curves on each traffic direction by using an ATS II Stalker radar gun and performed a series of vehicle test runs to obtain the ball-bank indicator readings corresponding to each vehicle speed value. A digital ball-bank from the app “BallBank” installed in iPad was used in this current study. All the speed surveys and the vehicle test runs were conducted under the favorable weather and road conditions (i.e., dried and good pavements).

## 3. Results

Based on the collected data, this paper determined curve advisory speeds by the direct method and the ball-bank indicator method as described in Section 2. The main curve parameters and speed data are presented in Tables 1 and 2. The results on establishing advisory speeds are shown in Table 3. The detailed data on the recorded speeds and ball-bank indicators can be seen in [15].

The first application of the direct method and the ball-bank indicator method on establishing advisory speeds for horizontal curves in Vietnam has shown that these two methods are quite simple

Table 1. Main curve parameters and speed data for the traveling direction from Lang Son province to Cao Bang province

No	Survey location (Station/ name of stick)	Radius (m)	Superelevation rate (%)	Vehicle type	Number of surveyed vehicles	Average speeds $V_{tb}$ (km/h)	85th percentile speed $V_{85}$ (km/h)
1	Km8+499.44 - P5	80	5.0	Passenger car	67	46.63	52.90
2	Km10+600.47 - P30	80	3.0	Passenger car	49	48.47	55.03
3	Km10+763.87 - P32	90	2.3	Passenger car	53	51.20	57.11
4	Km11+749.33 - P46	48	6.3	Passenger car	60	42.64	47.88
				Truck	48	35.36	40.84
5	Km24+681.55 - P199	120	3.9	Passenger car	54	47.79	53.37
6	Km24+76.85 - P200	70	5.8	Passenger car	50	45.95	52.03
7	Km25+503.00 - P204	100	6.2	Passenger car	54	51.93	57.90
8	Km25+626.14 - P205	75	7.6	Passenger car	49	46.18	51.69
9	Km25+713.82 - P206	80	4.4	Passenger car	71	50.11	54.06
				Truck	65	42.14	47.15
10	Km25+912.69 - P208	80	5.0	Passenger car	51	49.49	55.48
				Truck	52	45.29	50.64

Table 2. Main curve parameters and speed data for the traveling direction from Cao Bang province to Lang Son province

No	Survey location (Station/ name of stick)	Radius (m)	Superelevation rate (%)	Vehicle type	Number of surveyed vehicles	Average speeds $V_{tb}$ (km/h)	85th percentile speed $V_{85}$ (km/h)
1	Km8+499.44 - P5	80	3.0	Passenger car	70	46.33	51.99
2	Km10+600.47 - P30	80	2.4	Passenger car	49	46.35	51.64
3	Km10+763.87 - P32	90	2.7	Passenger car	51	49.84	55.73
4	Km11+749.33 -P46	48	7.7	Passenger car	59	43.54	48.85
				Truck	54	38.91	42.60
5	Km24+681.55 -P199	120	3.0	Passenger car	51	51.41	56.84
6	Km24+76.85 -P200	70	5.4	Passenger car	51	47.19	54.21
7	Km25+503.00 -P204	100	4.4	Passenger car	51	50.19	58.31
8	Km25+626.14 -P205	75	5.6	Passenger car	49	47.37	54.22
9	Km25+713.82 -P206	80	5.5	Passenger car	80	51.70	58.27
				Truck	65	46.00	51.35
10	Km25+912.69 -P208	80	3.0	Passenger car	50	52.99	56.85
				Truck	50	45.17	52.33

and easy to use. However, when conducting test runs on the field to obtain ball-bank indicator readings, the surveyors are required to have a good driving skill in order to keep the test vehicle's speed constant and maneuver the test vehicle following a predefined trajectory while traveling through the curve. In addition, it should be noted that these two methods are only applicable for determining advisory speeds for existing road sections.

As shown in Table 3, advisory speeds determined by both methods vary from 35 to 55 km/h, and all lower than the existing maximum speed limit of 60 km/h for passenger cars. Advisory speeds



Table 3. Results on advisory speeds determined by direct method and ball-bank indicator method

No	Survey location (Station/ name of stick)	Vehicle type	Advisory speeds determined by direct method (km/h)		Advisory speeds determined by ball-bank indicator method (km/h)	
			Direction from Lang Son to Cao Bang	Direction from Cao Bang to Lang Son	Direction from Lang Son to Cao Bang	Direction from Cao Bang to Lang Son
1	Km11+749.33 - P46	Passenger car	45	45	40	40
		Truck	35	35		
2	Km24+76.85 - P200	Passenger car	50	50	45	45
3	Km25+626.14 - P205	Passenger car	50	55	50	50
4	Km8+499.44 - P5	Passenger car	50	50	50	50
5	Km10+600.47 - P30	Passenger car	55	50	50	50
6	Km25+713.82 - P206	Passenger car	50	55	50	50
		Truck	40	45		
7	Km25+912.69 - P208	Passenger car	55	55	50	50
8	Km10+763.87 - P32	Passenger car	55	55	55	55
9	Km25+503.00 - P204	Passenger car	55	55	55	50
10	Km24+681.55 - P199	Passenger car	50	55	55	55

established by the ball-bank indicator method range from 40 to 55 km/h. These advisory speeds have an increasing trend when the curve radius is higher, however these advisory speeds vary within a quite narrow range (from 50 to 55 km/h) when curve radius is from 75 m to 120 m. In general, the advisory speeds determined by the ball-bank indicator are 0 – 5 km/h lower than the advisory speeds established by the direct method with 85th percentile speeds of passenger cars being used.

Advisory speeds determined by the direct method with average speeds of truck being used are significantly lower than those calculated by the direct method using 85th percentile speeds of passenger cars because the average truck speeds are 7-10 km/h lower than the 85th percentile speeds of passenger cars at the same location. Therefore, using average truck speeds when determining advisory speeds by the direct method will be safety prone.

#### 4. Conclusions and recommendations

This paper is the first attempt to employ the direct method and the ball-bank indicator method to establish advisory speeds for 10 horizontal curves on National Highway No. 4A in Lang Son province, in Vietnam. All the curves have an existing maximum speed limit of 60 km/h for passenger cars. The results indicated that advisory speeds determined by the ball-bank indicator method are ranging from 40 – 45 km/h for the curves with a radius of 70 m or less and varying from 50 – 55 km/h for curves with a radius of from 75 m to 120 m. In general, as compared to advisory speeds determined by the ball-bank indicator method, advisory speeds established by the direct method are 0 – 5 km/h higher if using 85th percentile speeds of passenger cars but 5 – 10 km/h lower if using average speeds of trucks.

The results also showed that the advisory speeds determined in this current research are 5 – 25 km/h lower than the existing maximum speed limit. This findings imply that the current maxi-

mum speed limit does not reflect the safe speeds when travelling through the subjective curves in the present study. Therefore, it is recommended to install a warning sign with an advisory speed for sharp horizontal curves in Vietnam in order to improve traffic safety, especially for the curves where traffic accidents related to high speeds have occurred. The direct method and the ball-bank indicator method as illustrated in this paper could be used for determining the advisory speed.

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