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ANALISYS OF ROLLOVER RISK IN THE HIGHWAY PAMPLONA-CUCUTA

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ABSTRACT

The risk of accidents due to rollover of heavy vehicle is an issue that has always been studied in many countries, one of the most widely used factors to determine the vehicle's stability is the Static Rollover Threshold. For the calculation of this factor, the movement of the center of gravity is taken into account, which is affected by the vehicle and road characteristics. This is extremely important since through its use can predict how the behavior of certain vehicles will be in certain sections of a road, thus making it possible to establish safe speed limits for these vehicles. Taking into account this, and using the Static Rollover Threshold a rollover risk analysis is carried out in some critical points of the highway Pamplona-Cucuta to determine safe speed limits.

Keywords: heavy vehicles, stability factor, speed limits, road safety.

1. INTRODUCTION

The highway Pamplona-Cucuta is part of one of the most important highway corridors in the country and the Norte de Santander department - Colombia, this route transports most of the international trade with Venezuela, which makes this a very busy highway for many types of vehicles, especially the heavy goods transports [4].

On the other hand, the Colombian topography hinders the construction of fast highways due to the continuous level changes and successive curves, which in certain cases are very closed. This hinders the maneuverability of drivers, thus increasing the risk of accidents.

One of the accidents that occur due to the aforementioned conditions is the rollover of heavy vehicles, which is not so frequent, but given its effects (deaths, injuries, loss of merchandise, closure of the road, among others) they must be given special attention and care ([2]).

Taking these aspects into account, [9, 10] developed an interesting stability model for heavy vehicles, which allows determining the Static Rollover Threshold (SRT) of this type of vehicle, which is a factor that predicts how prone is a vehicle to rollover under certain conditions. This model includes vehicle and road characteristics, which allows to better predict the factor for each specific or critical point of a given road. In this sense, [11] in their study of accidents on the highway Pamplona-Cúcuta determine 11 critical points at which there may be a risk of heavy vehicle rollover on this road.

In this article, an analysis is carried out to predict the speed limits for heavy vehicles on this road, and a comparison is made with the limits established by the current traffic regulations ([7]), for this, Section 2 introduces the stability model developed by ([8]); Section 3 presents the critical accident points determined in the study carried out by ([11]), then, in Section 4 the stability factors for the different critical points are detailed through a case study and the speed limits for these are determined; finally, the conclusions of this study are given.

2. Stability Model

The Static Rollover Threshold (SRT) is one of the main factors to determine how prone a vehicle is to rollover; the classic model is based on a two-dimensional model of a completely rigid vehicle ([5]) (Figure-1), which, under the action of inertial force (ma_y) when the vehicle turns a corner, it makes all load at a certain moment be supported by the external wheel to the curve **(F_{z0}),** which is known as lateral load transfer or Lateral Load Transfer (LLT). When this occurs, the force on the inner wheel (F_{zi}) tends to zero, which is an indication that the vehicle is about to rollover.

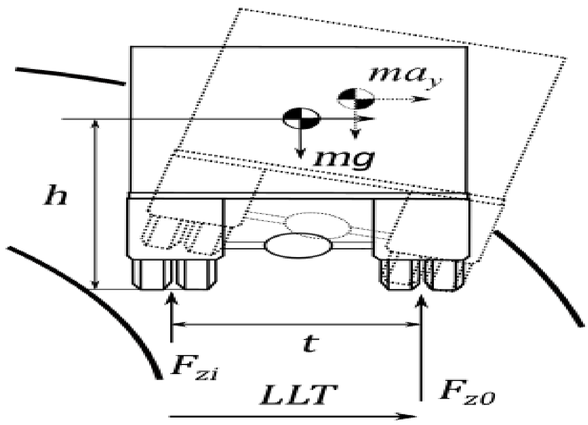

Figure-1. Classic stability model.

From Figure-1, taking momentum at the point of contact of the external wheel with the pavement, we have:

$$ma_y * h - mg * t/2 + F_{zi} * t = 0 \quad (1)$$

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Knowing that F_{zi} tends, rearranging Equation 1 we get:

$$SRT = \frac{a_y}{g} = \frac{t/2}{h} \quad (2)$$

where SRT represents the stability factor for the two-dimensional representation of a heavy vehicle. As can be seen, this factor depends on the location of the vehicle's center of gravity, which subsequently prompted countless investigations that included vehicle and road characteristics ([3, 12, 14]), which affect or allow the displacement of the center of gravity, which affects the stability factor.

In this sense, [8] developed a stability model for a heavy vehicle (Figure-2), which takes into account vehicle and road characteristics for calculating the Static Rollover Threshold (Equation 3).

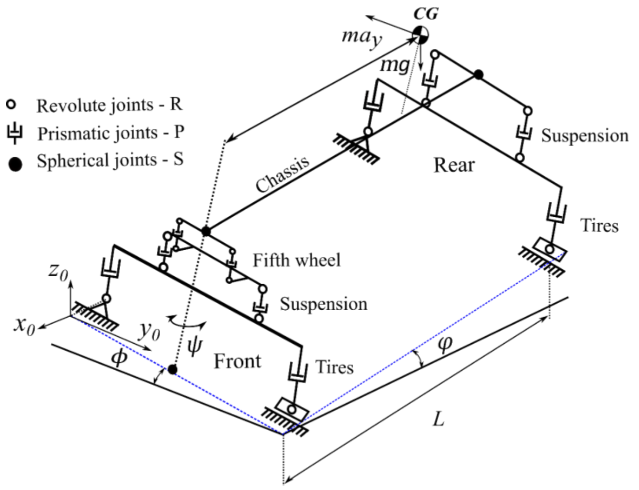

Figure-2. Trailer model of a heavy vehicle.

Adapted from [8]

$$SRT_{3D\phi\varphi} = \frac{a_y}{g} = \frac{h_1 \cos\varphi + h_2 e \cos\varphi}{h_2 - (h_1 + P_1)e}$$

$$SRT_{3D\phi\varphi} = \frac{a_y}{g} = \frac{h_1 \cos\varphi + h_2 e \cos\varphi}{h_2 - (h_1 + P_1)e} * \left(1 - \frac{P_1(F_{z17} - W\cos\phi\cos\varphi)}{W\cos\phi\,(h_1\cos\varphi + h_2 e\cos\varphi)}\right) \quad (3)$$

Where $SRT_{3D\psi\phi\varphi}$ is the three-dimensional stability factor of a heavy vehicle, h_1 is the lateral distance of the CG in reference to the coordinate axis, h_2 is the CG's height, e is the tangent of the lateral slope of the road, $P_1$is a system variable, $F_{z3}\ y\ F_{z17}$ are the normal supporting forces of the vehicle (F_{z3} external tire to the curve, front axle, F_{z17} inner tire to curve, rear axle), W is the vehicle weight, ϕ is the angle of lateral slope of the road, and φ is the angle of longitudinal slope of the road.

Additionally, since the stability factor (Equation 3) is a function of the lateral acceleration (a_y), and this is a function of vehicle speed (V) and the radius of curvature (r) from the sector under study, the vehicle speed for a curve can be calculated (Equations 4 and 5).

$$SRT_{3D\phi\varphi} = \frac{a_y}{g} = \frac{V^2/r}{g} \quad (4)$$

$$V = \sqrt{SRT_{3D\phi\varphi} * r * g} \quad (5)$$

The latter equation allows predicting the safe traffic speed limit with which a vehicle can travel through a curve, without risking an accident.

3. Critic Points of the Highway

According to work carried out by [11], through a survey of the road users, police, and journalistic reports, eleven critical points of the accident were detected on the highway Pamplona-Cucuta (Table-1); in each of these points the radius of curvature and the lateral, and longitudinal slopes were determined. These characteristics are necessary for stability calculations at each point.

Table-1. Geometric characteristics of critical points on the highway Pamplona-Cucuta.

ID number	Critical point	Location (km)	Lateral slope angle (ϕ)	Longitudinal slope angle (φ)	Curve radius (m)
1	The Adioses	1	12.2	8.3	26.5
2	Pamplonita	11	7.9	5.3	33.8
3	Rincón de los Caballos	12	10.3	3.8	30
4	S before of the Cocalinas 1	14	7.25	7.4	24.6
5	S before of the Cocalinas 2	14.5	12.4	6.87	13.8
6	The Cocalinas	16.5	10.25	7.96	82.3
7	The Miguelera	17	7.9	8.42	36.8
8	The Diamond	28	9.3	7.8	56.2
9	The Donjuana	39	9.5	3.85	78.95
10	Corozal 1	52	14	7.6	47.29
11	Corozal 2	54	12.56	7.17	34

4. Case Study

For this study, a heavy vehicle (tractor-truck type) was taken as a reference, which, as indicated by [11] is the one with the highest risk of accident due to rollover at the aforementioned critical points. Figure-3 and Table-2 show the main vehicle characteristics, which are necessary to determine the stability factors and the speed limits at each of the critical points. Additionally, for the determination of these measurements, the following standards were taken into account:

- ISO-14792 normative – Steady State Circular Tests ([6])
- As a road safety measure, the lateral load transfer of the rear axle of the vehicle cannot exceed 60% ([1, 13, 15]), since for larger transfers the vehicle is unstable, and it tends to tip over quickly.
- The stability factor calculations were made when the vehicle is descending since this modifies the load distribution of the vehicle and makes it lighter on the rear axle, facilitating the transfer of load on such axle ([8]).

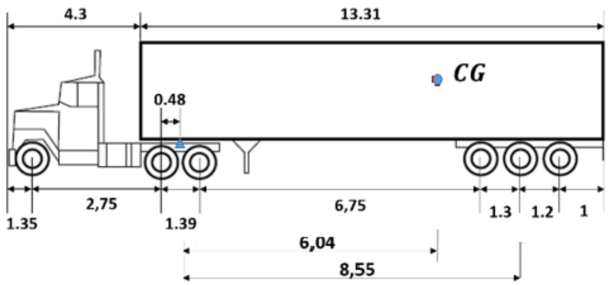

Figure-3. Tractor-truck (dimensions in meters).

Table-2. Vehicle characteristics.

PARAMETER	VALUE	UNIT
Tire height	0.499	m
Distance of the fifth-wheel to *CG* (*a*)	6.04	m
Distance of the fifth-wheel to the rear axle (*L*)	8.55	m
Height of the chassis to the *CG*	1.24	m
Suspension spring height	0.22	m
Vertical suspension stiffness	1800000	N/m
Number of frontal axles	2	
Number of rear axles	3	
Vehicle weight (*W*)	400000	N
Vertical stiffness of the tire	840000	N/m

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Using the road and vehicle parameters, the stability model was implemented in Matlab, and the inertial force (ma_y) was gradually increased until the lateral load transfer on the rear axle was recommended. Figure-4 shows the stability factors (*SRT*) and the speed limits obtained for each of the critical points determined on the highway Pamplona-Cucuta.

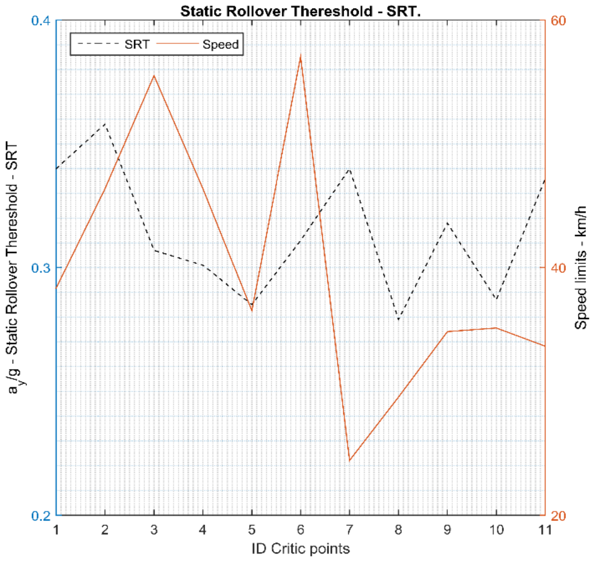

Figure-4. Stability factors and speed limits.

As can be seen, the calculated speeds are below the recommended transit speed limit for national and primary roads, which according to Artículo 107 del Código Nacional de Tránsito of Colombia should not exceed eighty kilometers per hour (80 *km/h*) ([7]), which is worrying, since for drivers who do not know the road the risk of an accident is quite high.

According to the inspection carried out, only the Corozal curves have adequate signage (Figure-5), with a traffic indication at 30 km/h of speed limit; however, in this sector, accidents due to vehicle rollover are frequent (Figure-6), which as observed, can be caused by overweight vehicles, which increases the height of the vehicle's center of gravity, decreasing its stability factor, or they can also be caused by the recklessness of the drivers, when exceeding the recommended speeds.

Figure-5. Corozal sector signage.

Figure-6. Accident in the Corozal sector.

Another important aspect that also increases the risk of an accident is the radius of curvature, since for curves with a low radius (Table-1) the lateral acceleration is high; therefore, it is necessary to travel at low speed in these sectors, so that centripetal acceleration is minimal, without putting the vehicle and its occupants at risk.

Additionally, in some critical points, the vegetation reduces the driver's visibility, which hinders the maneuverability of the vehicle when another vehicle is found, which causes unexpected maneuvers to be performed, thus increasing the risk of accidents.

5. CONCLUSIONS

It is important to highlight this analysis tool since it is possible to predict the speed limits of vehicles traveling on the roads, reducing accident rates due to these causes.

The highway Pamplona-Cúcuta is currently undergoing various infrastructure upgrades, which may improve safety in some of these sectors; however, it is important to re-evaluate these critical points in the future and implement the appropriate signs to minimize the risks of accidents due to rollover of heavy vehicles. Additionally, it is also important to evaluate other possible points that may generate this accident risk.

This is why this type of study is important, since through them aspects of the dynamics of vehicle movement will be better understood, and decisions that allow for better design of the roads may be made, or that transit authorities adopt road regulations and signs to minimize the risks that drivers may undergo when traveling through a certain sector of a road.

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