STABILITY OF HEAVY VEHICLES: INFLUENCE OF THE CHARACTERISTICS OF THE ROAD

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ABSTRACT

The study on the stability of vehicles when they make curves or evasive maneuvers allows us to identify how prone a vehicle is to have a rollover accident; taking this aspect into account, many studies identify the influence of the characteristics of the vehicle and the road on the calculation of the factor called Static Rollover Threshold (SRT); however, this factor depends largely on the location of the vehicle's center of gravity and the subsequent load distribution, in this sense, the load distribution can be affected by road conditions, such as are the lateral and longitudinal inclinations of this. Therefore, in this article, a bibliographic review of the main formulas developed to determine the SRT factor with the influence of the road is carried out, and a case study is developed to determine the influence of road in the calculation of the factor.

Keywords: static rollover threshold, heavy vehicle, safery.

1. INTRODUCTION

One of the main methods to determine the stability of a vehicle is the factor called Static Rollover Threshold (SRT); this factor allows for a balance of the forces acting on the vehicle in situations where it is prone to rollover, mainly when cornering.

In the determination of the SRT factor, the Newtonian model is used, by means of which the sum of moments around the external support point of the vehicle (Point A) is made when it makes a curve, according to Gillespie [1] when the classic two-dimensional model is used, we have:

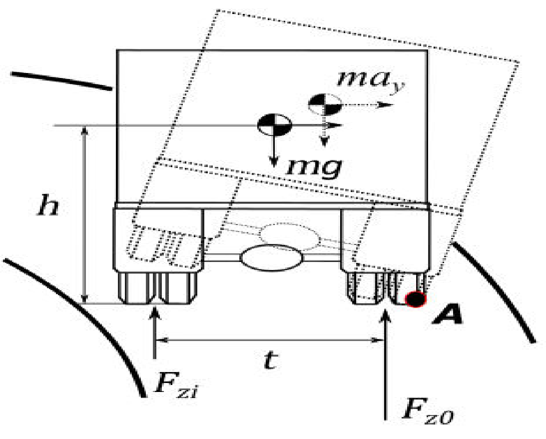

Figure-1. Classic stability model.

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

Where $mg - W$ is the vehicle weight, ma_y is the lateral inertial force, t is the vehicle track, h is the height of the center of gravity of the vehicle, and $F_{zi} and F_{z0}$ are the normal tire load of the vehicle. As indicated in Figure-1, in the rollover limit, the internal force (F_{zi}) tends to zero; therefore, and rearranging the equation, we have:

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

Where SRT is the stability factor of the vehicle, this equation tells us that this factor depends on the centripetal acceleration of the vehicle, which in turn depends on its speed, and is also dependent on the location of the vehicle's center of gravity.

Taking this methodology into account, in this article, the main models for calculating the stability of heavy vehicles used in the literature are detailed, and a case study is carried out to determine the influence of the characteristics of the road on the vehicle stability calculation.

2. STABILITY MODELS WHIT INFLUENCE THE CHARACTERISTICS OF THE ROAD

2.1 Chang Model

Following a similar development to the calculation of the stability factor of the classical model, authors such as Chang [2] and Moreno [3], in their two-dimensional models, include the effect that the bank angle of the road has on the stability factor of the vehicle. In his first model, Chang [2] only included the effect of the bank angle of the road in his heavy vehicle stability model (Figure-2 Eq. 3), then he developed another model which included the influence of the suspension (Figure-3 Eq. 4).

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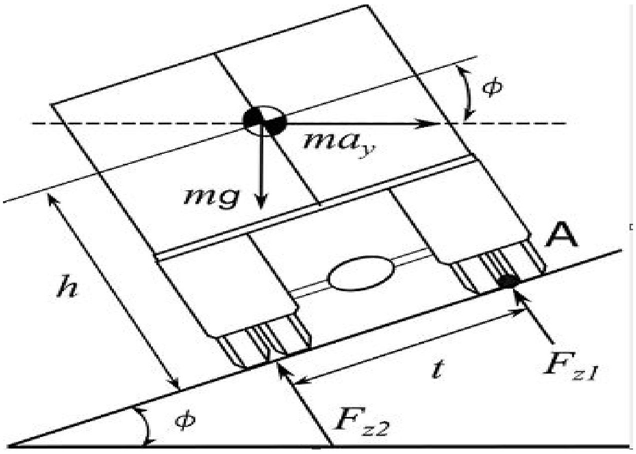

Figure-2. Chang model 1.
Source: Adapted from Chang [2]

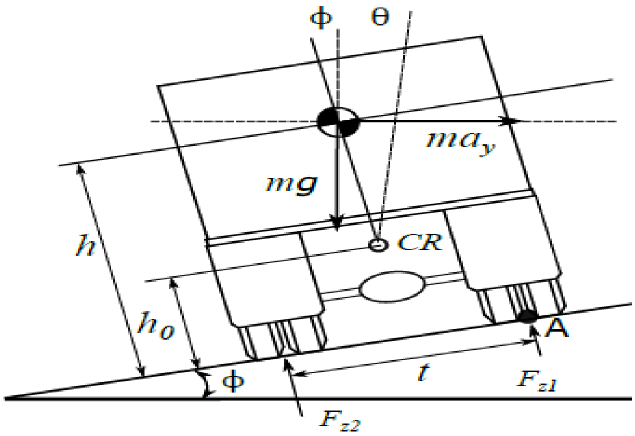

Figure-3. Chang model 2.
Source: Adapted from Chang [2]

$$SRT_{C1} = \frac{a_y}{g} = \frac{(t/2)}{h} + e \qquad (3)$$

$$SRT_{C2} = \frac{a_y}{g} = \frac{(t/2)}{h} + \left(1 - \frac{h_0}{h}\right)(\phi - \theta) \qquad (4)$$

Where e is the tangent of the bank angle ($e = \tan\phi$), h_0 is the roll center height, ϕ is the bank angle, and θ is the roll angle allowed by the suspension. In equations (3) and (4) it can be seen that the bank angle increases the SRT factor of the vehicle.

2.2 Two-Dimensional Moreno Model

Following the same methodology, Moreno [3] uses the analysis method called Davies Method; in our two-dimensional model, it includes the effects of the bank angle, the suspension and the tires, as shown in Figure-4 and Eq. (5).

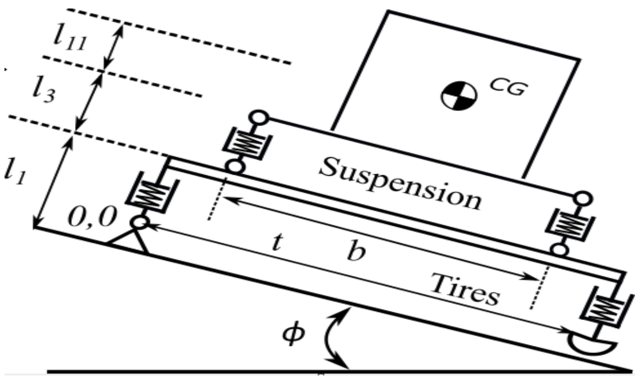

Figure-4. Moreno model 1.
Source: Adapted of Moreno [3]

$$SRT_{M1} = \frac{a_y}{g} = \frac{h_1 + h_2\, e}{h_2 - h_1\, e} \qquad (5)$$

Where h_1 is the instantaneous lateral distance between the zero-reference frame (0, 0) and the center of gravity, and h_2 is the instantaneous CG height. This model also shows that with increasing the bank angle, stability also increases.

According to Moreno et al. [4], the increase in the stability factor is because the load distribution in the vehicle is modified, which makes the internal part of the vehicle in the curve heavier, which partially hinders its rollover.

2.3 Three-Dimensional Moreno Model

Taking into account that modifying the load distribution of the vehicle can affect its stability, Moreno *et al.* [5] develop a three-dimensional stability model (Figure-5), which includes the effects of the suspension, the chassis, the fifth wheel, the tires, and the bank and slope angles of the road in the SRT factor calculation (Eq. 5).

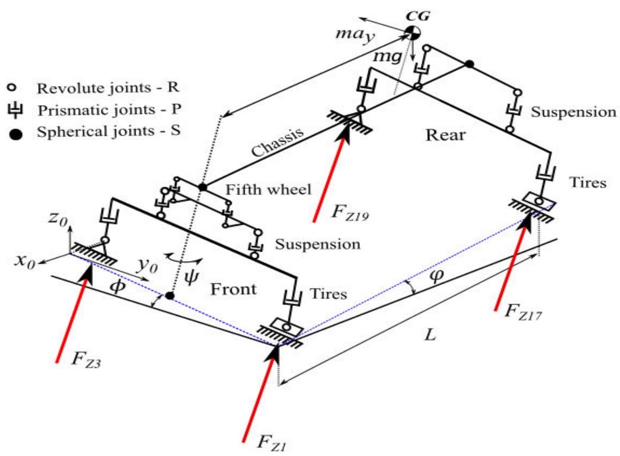

Figure-5. Moreno model 2.
Source: Adapted from Moreno *et al.*[4]

Where φ is the slope angle of the road, t_1 is the front track width of the trailer, and F_{z3} is the normal force of the tire.

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3. CASE STUDY

For this case study, the characteristics of the vehicle used by Ervin and Guy [6] are used.

$$SRT_{M2} = \frac{a_y}{g} = \frac{h_1 \cos\varphi + h_2\, e \cos\phi}{h_2 - h_1\, e}\left(1 - \frac{t_1 F_{z3}}{W \cos\phi (h_1 \cos\varphi + h_2\, e \cos\varphi)}\right) \quad (6)$$

Table-1. Parameters of the trailer model.

Parameter	Value	Units
Trailer weight - W	355.22	kN
Front and rear track widths - $t_{1,3}$	1.86	m
Front and rear axle widths - $t_{2,4}$	1.86	m
Number of axles at the front (trailer) (4 tires per axle)	2	
Number of axles at the rear (trailer) (4 tires per axle)	3	
Vertical stiffness per tire - k_T[7]	840	kN/m
Stiffness of the fifth-wheel - k_f	7500	kN/m
Initial suspension height - l_s	0.205	m
Initial dynamic rolling radius - l_r[8]	0.499	m
Initial height of the fifth wheel - l_f	0.1	m
Lateral separation between the springs - b	0.95	m
Fifth-wheel width - b_1	0.6	m
CG height above the chassis - l_{12}	1.356	m
Distance between the fifth wheel and the front axle - l_{13}	0.15	m
Wheelbase of the trailer - L	4.26	m
Distance from the front axle to the center of gravity - a	3	m
Bank angle	0 to 10	%
Slope angle - Uphill corner and Downhill corner	0, 5, 10	%

The SRT factor calculation was obtained using the steady-state circular test [9]; the load conditions include a load laterally centered. The simulation model was applied using Matlab®. To calculate the SRT factor, the inertial force was increased until the recommended maximum lateral load transfer ratio ($LLTr$) for the rear axle of 0.6 [10], and also include the recommended bank angle and longitudinal slope of the road [11], we can calculate the SRT factor for a trailer model on uphill and downhill corners.

Figure-6 shows the behavior of the SRT factor under the influence of the bank angle and longitudinal slope angle. In this figure, when the vehicle is uphill, the slope angle is specified as negative, and when it is downhill as positive.

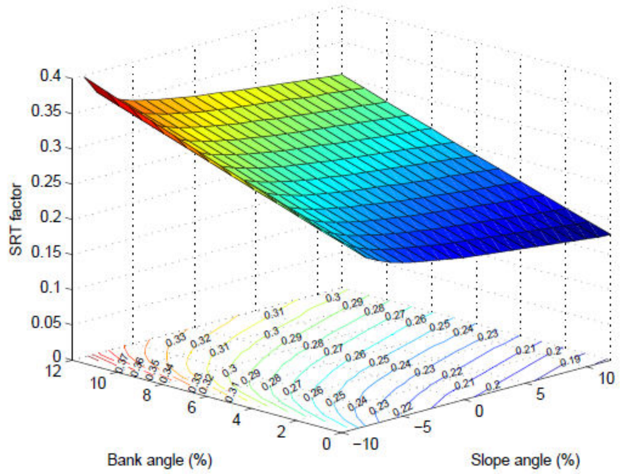

Figure-6. SRT factor under the influence of the bank angle, longitudinal slope angle.

Making an analysis of the Figure 6, the following conclusions are obtained:

- 1 % bank angle corresponds to again in the stability of around 0.01;
- when the trailer model is in downhill corners, a 1 % slope angle corresponds to a loss of stability of around 0.0021.

4. CONCLUSIONS

This study shows that both the characteristics of the vehicle and those of the road are important in calculating of the vehicle stability, since, when the load distribution in the vehicle is modified, stability can be favorable or not, in worst the cases, when vehicle is in downhill.

It is important to highlight that this is a point to be taken into account by road designers since very steep slopes make vehicles more likely to rollover; therefore, designers should include these recommendations in their calculations so that the roads are safer for their users.

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