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COLLISION BETWEEN MOTORCYCLE AND PASSENGER VEHICLE: ANALYSIS BY THE LINEAR MOMENT CONSERVATION METHOD

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Abstract: This work presents a detailed analysis, through the Physical Method of Linear Moment Conservation, of a traffic accident involving passenger vehicle and motorcycle, aiming to identify the culpability for the collision. The analysis methodology used here was based on the following elements: vehicle masses; speeds before and after the collision; at the entry and exit angles of vehicles at the impact site, among other elements. Thus, for the type of collision on screen, it was concluded that the motorcycle was the vehicle responsible for the collision under analysis, presenting an entry angle at the probable collision point (PPI) at 12.41° and an exit angle at 16°. Angles which corroborate the motorcycle immobilization position information present in the collision record by an official agency.
Keywords: Velocity, collision, entry angle, exit angle.

INTRODUCTION

In legal discussions involving traffic claims in which we act as Judicial Experts, with analyzes that are practically indirect, because when the discussion reaches the judicial sphere, some time has already passed and the elements of the claim site have already been overlooked or lost, the declarations, versions of the accident and documents attached to the records by the Parties involved are heavily used to assist in the reconstruction of the accidental event. In accidents in which the competent official body performs immediate analysis and with a survey of a suitable location, the work of Judicial Experts and Technical Assistants is facilitated (NEGRINI NETO, 2003). At the same time, reports of the accident by those involved in the accident must be carefully analyzed by the Auxiliaries of Justice (FEITOSA ARAGÃO, 2009).

The challenge is to clarify this traffic accident, considering the time elapsed from the accident to the completion of the Expertise, as well as the existence of completely opposite statements from the vehicle drivers regarding the event and cause of the collision.

Therefore, this work aims to evaluate, by the principle of linear momentum conservation, a real traffic accident, involving a passenger vehicle and a motorcycle, which occurred near the cities of Candelária-RS and Passa Sete-RS, thus determining the probable cause of the event.

MATERIAL AND METHODS

In this work, the physical method of the Linear Moment Conservation Law (DAYLI et al., 2006) was used to evaluate the accidental event that occurred near the cities of Candelária-RS and Passa Sete-RS.

The linear momentum conservation method considers the vehicle masses, speeds before and after the collision and the entry and exit angles at the impact point according to equation 1.

$$L = m^{*}v; \qquad \text{(Eq. 1)}$$

Where: L= linear momentum; m= vehicle mass; v= vehicle speed.

Dayli et al. (2006), states that the theory of conservation of linear momentum, when properly applied, is one of the most powerful tools used in the reconstruction of accidental events. Also, according to Dayli et al. (2006), and Feitosa Aragão (2009), the theory of conservation of linear momentum states that the linear moments before the collision are equal to the moments after the collision:

$$\vec{P}_1 + \vec{P}_2 = \vec{q}_1 + \vec{q}_2$$

In the present case, as the approximation of the vehicles involved is opposite and non-linear, a graphical analysis will be used (DAYLI et al., 2006 and FEITOSA ARAGÃO, 2009) to

Figure 1. Location of the collision.

Source: adapted from Google Earth.

Photo 1. Site of the accident.

Source: the authors.

identify which of the versions presented by those involved in the accident analyzed here is compatible with the immobilization position presented by the official body that attended the accident.

Decomposing the vectors along the x-axis (Candelária direction - Passa Sete) algebraically, according to Dayli et al. (2006) and Feitosa Aragão (2009), the expression as a function of velocity, represented by Equation 2.

$$v = m_1/m.u_1.sen(\beta - \alpha) + u.sen(\varphi - \alpha)/ sen(\psi - \alpha) \quad \text{(Eq.2)}$$

In which:

v= motorcycle speed before collision; u= motorcycle speed after collision; v_1= bus speed before collision; u_1= bus speed after collision; m= motorcycle mass + occupants; m_1= bus mass + passengers; ψ= motorcycle entry angle at the crash site; φ= motorcycle exit angle at the crash site; α= angle of entry of the bus at the collision site;β= exit angle of the bus at the collision site.

Using equation 2, and respecting the accident versions presented by the drivers of the vehicles involved, it was verified, according to the Linear Moment Conservation Law, in which version of the accident the motorcycle exit angle matches the angle found. according to the triangulation presented by the body that dealt with the occurrence of the claim in question, the 1st Pel. G Cachoeira do Sul Rv, State Highway Police-RS, BM (figure 2).

The characteristics of the vehicles involved are described in Table 1.

According to the statements of the drivers of the vehicles, Pedro (codename assigned to the driver of the motorcycle) and Paulo (codename assigned to the driver of the passenger vehicle), which appear in the case file 0XX/1.XX.0001XX7-0, which was processed at the Court Court of the District of the city of Candelária, in the state of Rio Grande do Sul, the event took place as follows:

Motorcycle Driver Version (Pedro): he moved in the opposite direction to the passenger vehicle, respecting the speed limit of the road when, in a curved section, at kilometer 25 of the RS-400, the bus would have invaded the motorcycle's roadway with its rear part and given cause to the accident.

Driver version of passenger vehicle (Paulo): he moved in the opposite direction to the motorcycle, respecting the speed limit of the road when, at kilometer 25 of the RS-400, the motorcycle would have invaded the carriageway of the bus and collided with the rear of the passenger vehicle, between the wheels back on the left side.

The official body that responded to the occurrence, BM, 1st Pel. G Rv of Cachoeira do Sul, State Highway Police-RS, developed the following positional triangulation of the accident site (Figure 2).

Mercedes Benz passenger vehicle	**Honda 125 motorcycle**
Year/model of manufacture: 1994	Year/model of manufacture:1984
Width: 2.600mm	Length: 1.935mm
Length: 13.150mm	Mass + passengers: 240 kg
Height: 380mm	Length between the axis: 1.270mm
Mass:11.080 kg	Year/model of manufacture:1984

Table 1. Characteristics of the vehicles involved

Source: Mercedes Benz (Certificate of Vehicle Inspection BR 0004285344); Honda (Honda manufacturer manual).

Photo 2. Motorcycle wrapped. Source: by the authors.

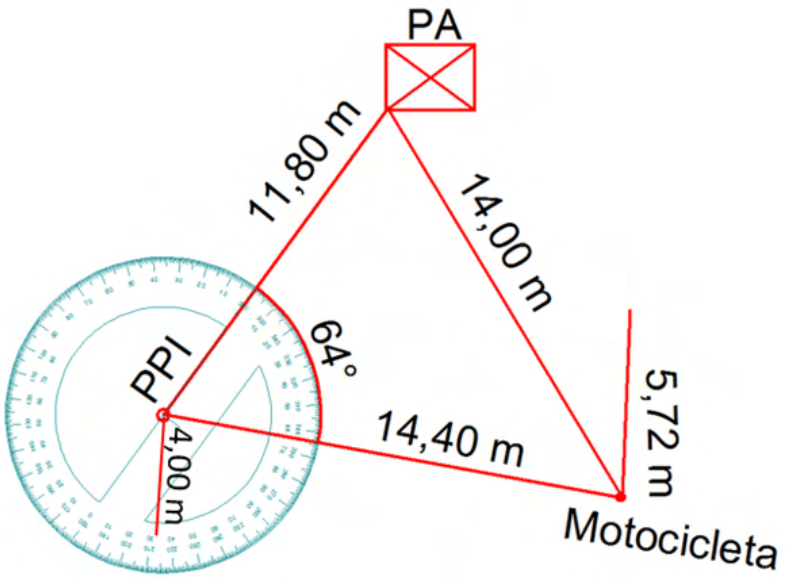


Figure 2. Positional triangulation established by an official body. Source: adapted from Graph of Accident N° 28 -CS- 2011 (BM, 1st Pel. G Rv of Cachoeira do Sul).

Where, PPI is "probable point of impact", located, according to BM, 1st Pel. G Rv of Cachoeira do Sul, on the roadway of the bus, and it was established because a residue of lubricating oil was observed on the roadway and an orifice in the motorcycle's engine block (photo 2). And PA is the "bus stop" present at the accident site (photo 1).

Using appropriate computational tools, Crash Zone version 10.1.21 and ImageJ version 1.52a, it was possible to transfer the triangulation (MERIAM, 1976 and DAYLI et al. 2006), identified by the State Highway Police-RS, BM, 1st Pel . G Rv of Cachoeira do Sul, and from the Expert and Documentary Examinations, to the place of the occurrence.

Based on the statement by Pedro, motorcycle driver, in the sense that the passenger vehicle that would have caused the accident, due to the dimensional characteristics of the vehicles and the carriageways, as well as the position of the likely point of impact, it was possible to establish the dimensional triangulation shown in figure 4.

The 10th was assigned to α, because, by the dimensions of the bus, for entry angle values (α) lower, the rear of this vehicle would not invade the roadway of the motorcycle.

Based now on the version of the accident presented by Paulo, driver of the passenger vehicle, in which the motorcycle that would have invaded the opposite lane and, therefore, caused the accident, due to the dimensional characteristics of the vehicles and the carriageways, and the position of the likely point of impact, it was possible to establish the dimensional triangulation shown in figure 5.

Since the passenger vehicle was on its lane, and considering that its mass is at least 46 times greater than that of the motorcycle (Table 1), a characteristic that makes the entry angle of the bus into the PPI is not changed by impact with the motorcycle, the entry angles (α) and outgoing (β) of the bus at the probable point of impact (PPI) are the same, 0°. The motorcycle's exit angle (φ) is known and measures 16° (figure 3), so the variable in this situation is the motorcycle entry angle (ψ) in PPI.

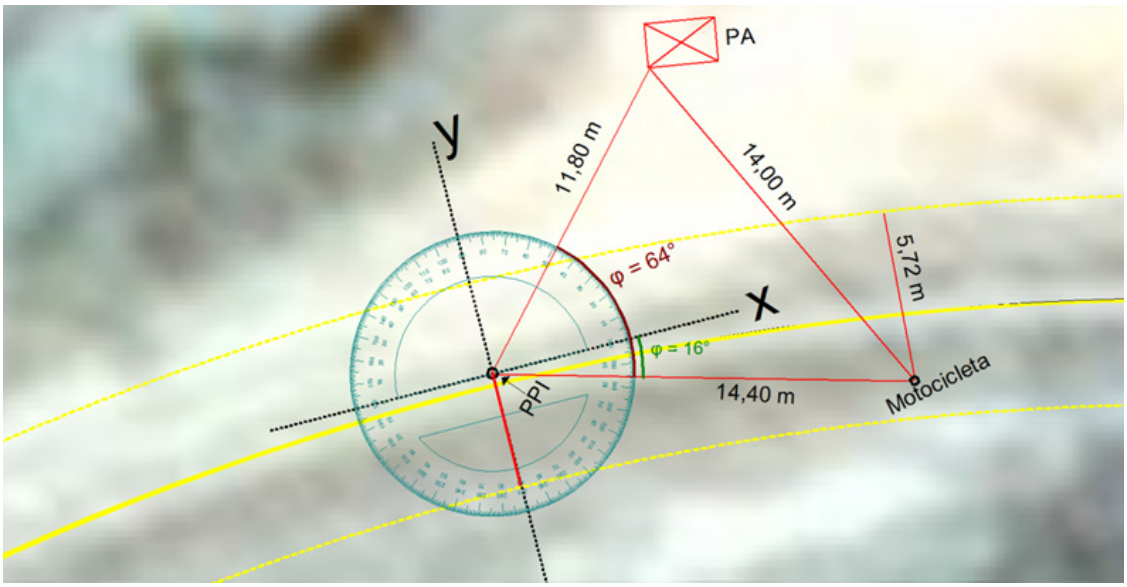
According to the motorcycle driver's report, he was traveling over the carriageway, heading towards Candelária - Passa Sete and, not, over the shoulder. Therefore, drawing a straight line from the PPI that touches the boundary between the motorcycle's roadway and the shoulder (dotted line, shown in figure 5), the maximum entry angle of the motorcycle at the time of impact. From careful graphic analysis, based on the fundamentals of Analytical Geometry (LEITHOLD, 1994), considering that the stretch of the likely point of impact (PPI in figure 2) is curvilinear (figure 5) and, respecting the version of the accident reported by Pedro, in the sense that he was traveling on the roadway, the value of the motorcycle's entry angle in the PPI must be at most 15.5° (figures 5 and 6), angles greater than this indicate, either that the motorcycle would be traveling along the shoulder, or that the collision would not have occurred. Figure 6 shows, in the detail of the superposition of the protractor with the triangulation developed by BM, 1st Pel. G Rv of Cachoeira do Sul (figure 2), carried out using the Crash Zone tool version 10.1.21 - a tool that allows dimensional adjustments, thus allowing the establishment of compatibility between the elements of the site of the occurrence, motorcycle, bus and lanes. bearing -, the possible angular range for ψ.

RESULTS AND DISCUSSION

Result of the accident analysis based on the statement of Pedro, motorcycle driver:

Initial speed of the motorcycle, in 60 km/h (16.66 m/sec).

Motorbike speed after the estimated collision, according to Negrini Neto (2003) or



Motocicleta = Motorcycle

Figure 3. Overlay of the collision point triangulation on the accident site figure. Source: adapted from Graph of Accident N° 28 -CS- 2011 (BM, 1st Pel. G Rv of Cachoeira do Sul).

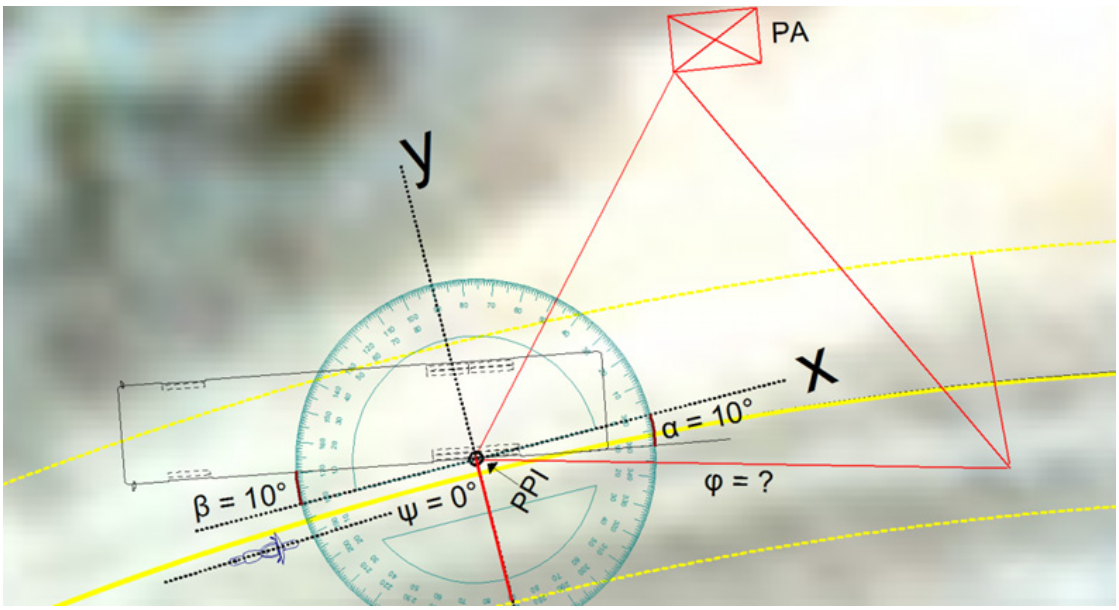
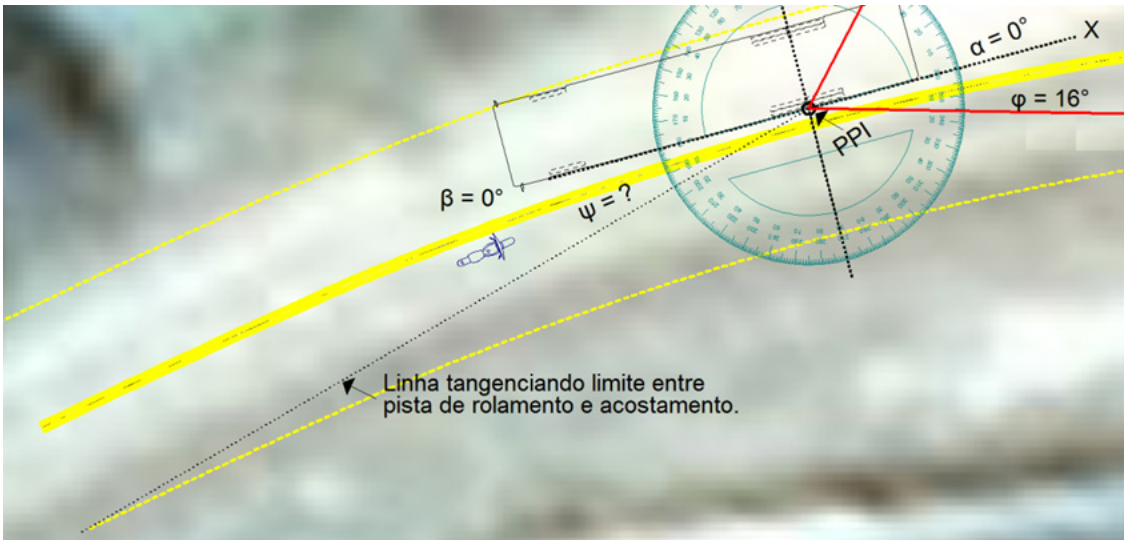


Figure 4. Dimensional triangulation with the rear of the bus invading the motorcycle lane. Source: adapted from Accident Chart N° 28 -CS- 2011 (BM, 1° Pel. G Rv de Cachoeira do Sul).



Linha tangenciando limite entre pista de rolamento e acostamento = Line tangent boundary between roadway and shoulder

Figure 5. Dimensional triangulation with the motorcycle invading the bus lane. Source: adapted from Graph of Accident N° 28 -CS- 2011 (BM, 1st Pel. G Rv of Cachoeira do Sul).

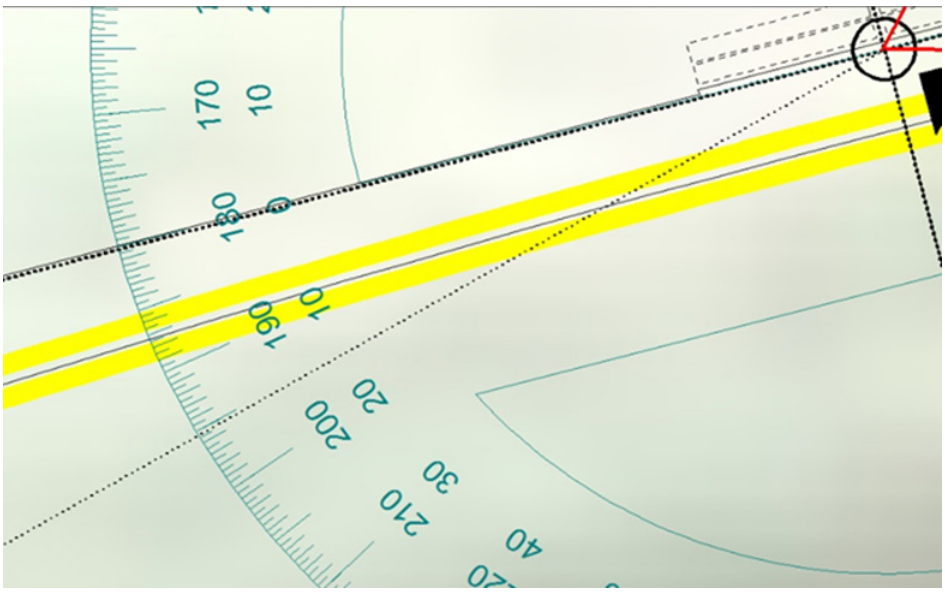


Figure 6. Detail of the tangent line to the shoulder of the motorcycle's roadway. Source: adapted from Graph of Accident N° 28 -CS- 2011 (BM, 1st Pel. G Rv of Cachoeira do Sul).

Feitosa Aragão (2009), by $V_p = (2.\mu.g.x)^{1/2}$ = 13,02 m/s (46,87 km/h).

Where:

V_p= vehicle speed after impact;

μ= friction coefficient (in this case, being conservative, 0.60 was adopted), of Dayli et al., (2006);

g= 9,81 m/s^2;

x= 14,40 m (figure 2).

Continuing, we have motorcycle exit angle (φ), after algebraic substitutions and manipulations in equation 02: 167,863.cos^{2}φ + 13,016.cosφ -154,44:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

in: cos φ = 0,921 e -0,998

The value -0.998 means that the motorcycle would have ended its trajectory after the accident on the bus's roadway, that is, the motorcycle would not have suffered any reaction to the impact and maintained its trajectory, moving towards the right side of the bus , a situation that is impossible - we reinforce that the mass of the bus is at least 46 times greater than that of the motorcycle.

Therefore, PPI motorcycle exit angle: φ = cos-1(0,921) = φ = 22,92°

Graphically (Figure 7).

Result of the accident analysis based on the statement by Paulo, driver of the passenger vehicle:

As mentioned above, the mass of the bus is at least 46 times greater than that of the motorcycle. A characteristic that, due to the collision location of the motorcycle on the bus - between the rear axles -, prevents changes in the exit angle of the PPI passenger vehicle in relation to the entry angle, that is,, α = β.

Therefore, we have as a variable in this situation, the angle of entry of the motorcycle into the PPI (ψ).

By equation 02, we have to:

16,66 = 0 + 13,02.sen(16°)/sen(ψ) =
sen(ψ) = 0,215 = without^{-1} 0,215.

Therefore, the entry angle of the motorcycle into the PPI (ψ) is 12.41°. Angle that, based on the fundamentals of Analytical Geometry (LEITHOLD, 1994), as well as the dimensional overlap using the Crash Zone software, is within the range identified between 0° and 15.5° (figures 5 and 6).

Graphically, we have (Figure 7).

CONCLUSION

Based on the expert examinations carried out, on the fundamentals of analytical geometry, on the geography of the site of the accident, on the dimensional triangulation carried out and on the principle of conservation of linear momentum, it was certainly the motorcycle that invaded the carriageway of the passenger vehicle (with entry angle in PPI (ψ) de 12,41° and exit angle (φ) 16°), being, therefore, the cause of the traffic accident in question.

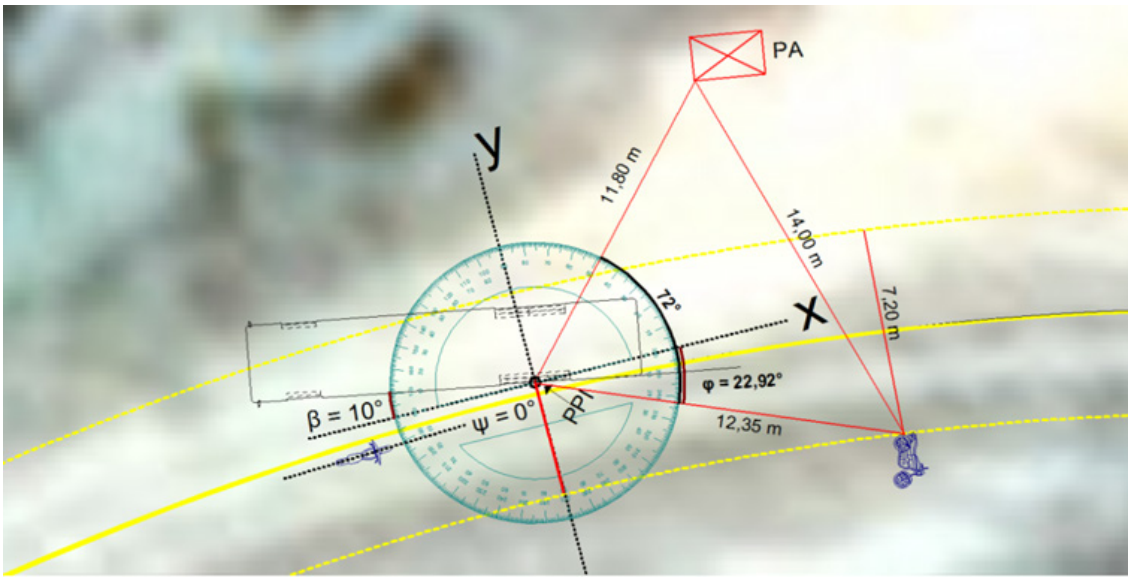


Figure 7. Motorcycle immobilization position according to the version of the motorcycle rider. Source: adapted from Graph of Accident N° 28 -CS- 2011 (BM, 1st Pel. G Rv of Cachoeira do Sul).

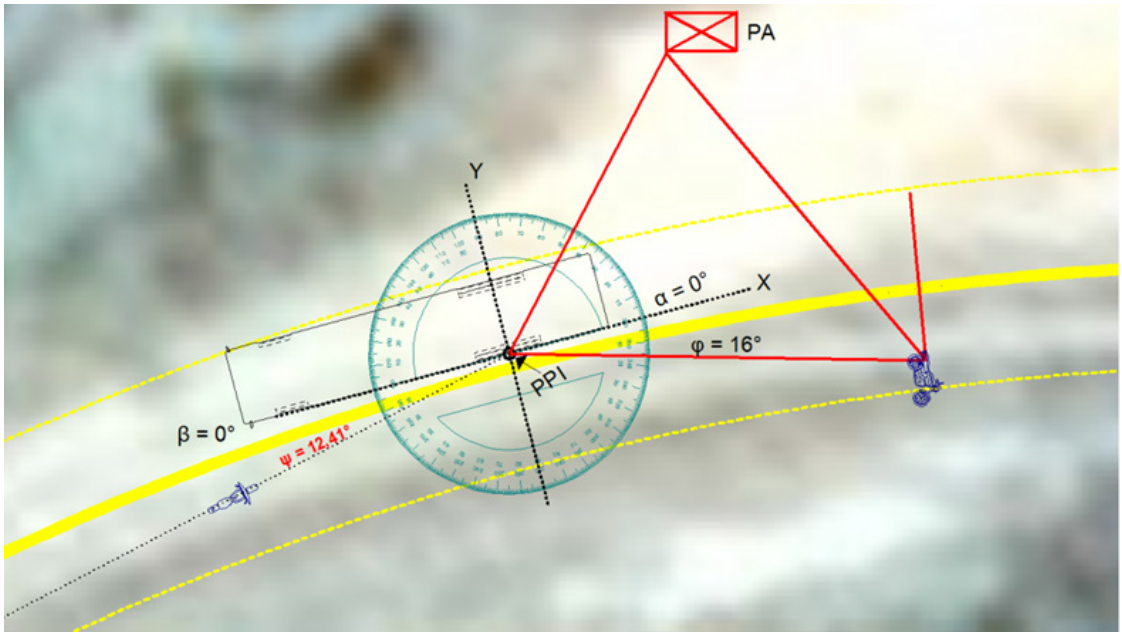


Figure 7. Motorcycle immobilization position according to the bus driver's version. Source: adapted from Graph of Accident N° 28 -CS- 2011 (BM, 1st Pel. G Rv of Cachoeira do Sul).

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