ACCELERATION IMPACT INVESTIGATION FOR CONTROL ROAD GEOMETRY PARAMETERS

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ABSTRACT

The research addresses the acceleration impact in vehicle safety during tractive mode for control road geometry parameters and vehicle speeds at and below the suggested relevant design speed values. Instrumented field measurements on speed distance data and pavement friction supply were collected utilizing a FWD C-Class passenger car and correlated against an existing dynamic model in order to examine the interaction between vehicle dynamics and road geometry.

Aiming to quantify the potential safety hazard during vehicle acceleration at impending skid conditions on curves, the analysis revealed that the conventional approach of addressing vehicle safety based on posted speed management seems inadequate. Even when the speed of the vehicle is less than the relevant posted value, the acceleration effect which depends on the utilized horse power rates may result in vehicle skidding.

Among other important findings, stands also the necessity for monitoring friction supply as well as the fact that vehicles equipped with excessive amounts of horse power rates must be driven very conservatively, especially on sharp curves combined with poor friction supply.

The authors believe that besides data on speed, pavement friction and road geometry, the provision of additional information on vehicle horse power utilization, incorporated in more sophisticated intelligent speed adaption (ISA) process of vehicle advanced driver assistance systems (ADAS) in the near future, will deliver integrated and more comprehensive, in terms of safety, guidance to drivers.

INTRODUCTION AND PROBLEM STATEMENT

In existing road design practice (e.g.1-4), vehicle motion during curve negotiation is examined under steady state cornering conditions. Moreover based on a rather simplified approach, the vehicle is simulated as a point mass, following the curve centerline, where from the equilibrium in the lateral direction of travel the minimum horizontal radius is derived.

In terms of potential safety violations, the above generalization actually fails to assess the impact of the acceleration effect during cornering.

During the past 20 years, a number of research studies addressing vehicle safety considerations with varying analysis levels have been released. In one of these, Harwood and Mason (5), utilizing the point mass approach concluded that regarding passenger vehicles, existing design policy provides adequate margins of safety against both skidding and rollover. However more recently, many researchers have pointed out the necessity of more sophisticated models to simulate vehicle's cornering process (6-10) especially in cases where steep grades are present (11-15). Regarding vehicle motion under tractive mode, research (e.g. 11, 15-16) revealed that steep upgrades reduce the margin of safety. Moreover, the superelevation impact of a steep upgrade road section under certain conditions may be critical as well (17).

Since road crashes are the result of three contributing factors, despite the above simplified or more advanced interaction of road – vehicle parameters, drivers' behavior characteristics should be assessed as well. Therefore, driving operation ability and driving workload should be adequately considered in order to reduce the possibility of driving operation errors (18). Design consistency, defined as the balanced relationship between the geometric characteristics of a highway and those conditions the driver expects to encounter can serve this requirement. A number of researches (e.g. 19-22) have pointed out that if design consistency is present, the successive elements of a highway system act in a coordinated way and therefore, road safety may be improved significantly.

The most common means utilized to assess the design consistency of a road is the operational speed (23), which consists a crucial parameter in road geometric design since it is quantifiable (it can be measured). Substantial differences between operational speeds or between design and operational speeds in successive design elements, especially between approaching tangents to horizontal curves (24), may increase erratic maneuvers and crashes (23, 25).

However, in terms of assessing safety during vehicle motion on curved paths, solely the examination of the vehicles' speed variations before entering the curve seems inadequate. For most models, through field measurements, spot speed values are collected at specific and/or random points during the vehicle motion on the approach tangent to the curve, but on the curve steady state cornering conditions are assumed. This assumption has been proved false by many researchers since acceleration – deceleration rates are present on curves as well (26-28). Moreover, certain studies (29, 30) have concluded that deceleration and acceleration rates increase with curvature on two-lane rural roads and that their determination based on operating speed profiles underestimates the actual rates experienced by the drivers (31).

In most of the aforementioned research, although an appreciable effort was made to assess the interaction between road geometry and vehicle dynamics, the determined vehicle speed was not related to the vehicle's actual ability since the following conditions should apply concurrently:

- incorporate in the equations, but also define, the vehicle's acceleration at impending skid conditions for different speed values as a function of road, vehicle and tire friction parameters
- calculate the longitudinal and lateral friction demand for each tire and associate these values to the friction supply in order to prevent skidding
- associate the vehicle motion to the available horse power rate on the wheels and more specifically to a horse power utilization factor (%/100) since a vehicle cannot always be driven at its nominal horse power rate

The above concerns have already been addressed in previous research of the authors (15, 32) where aiming to assess vehicle safety from the highway engineering point of view, vehicle skidding conditions were simultaneously associated to vehicle acceleration as well as its horse-power utilization rate.

The objective of the present paper is to assess the acceleration impact in vehicle safety during tractive mode and more specifically quantify the potential safety hazard at impending skid conditions for control road geometry parameters and vehicle speed at and below the suggested relevant design speed value. Moreover, the authors intend to highlight the importance of vehicle horse-power utilization in order to incorporate such information in a more sophisticated intelligent speed adaption (ISA) process of vehicle advanced driver assistance systems (ADAS) in the near future.

For this purpose, in order to assess and further clarify aspects related to vehicle acceleration, field measurements were carried out on a curved graded road section, where besides geometry elements, data related to vehicle dynamics as well as tire – road friction values were collected and correlated against an existing vehicle dynamics model. As a second step the authors deliver upper values of horse power rates for various control road geometry parameters, vehicle speed and tire - pavement friction values.

METHODOLOGY

A previous vehicle dynamics model developed by the authors (14, 15) was utilized where all forces and moments applied to the vehicle were analyzed into a moving three dimensional coordinate system, coinciding at the vehicle gravity center and formed by the vehicle's longitudinal (X), lateral (Y) and vertical (Z) axis respectively (Figure 1a). Through these axes, the influence of certain vehicle technical characteristics, road geometry and tire friction were expressed.

The model takes into account variables related to vehicle steering and tire sideslip angles (33), the actual wheel load due to the lateral load transfer as well as the corresponding alteration of the lateral force on each wheel, thus creating a four-wheel vehicle dynamics modelling (33-35). The model's outputs were validated against the known data derived by two other distinct cases: the final climbing speed of a truck travelling on a grade (14) and the output data from the well-known CARSIM Simulation Software (32). Both cases revealed a satisfying match.

In order to assess the ability of the vehicle to negotiate a curved path and moreover define the breakpoint where safety violation occurs, certain considerations should be further clarified. The following paragraphs provide a brief discussion on how these concerns were addressed. Further details are available through references (14, 15, and 32).

The available tractive effort of the vehicle (driving force minus rolling resistance) acting on the front or rear axle (depending on the driving configuration) should be associated to the vehicle's speed as well as the net power available at the driving wheels. Since a vehicle cannot always be driven at 100% of its available horse-power rate, and having in mind that the actual percentage of the horse-power ratio delivered by the driven axle is around 94% of its nominal value (5), the vehicle's tractive force and horse-power utilization factor (n), are related as follows:

$$F_x = 745.6 \frac{P}{v} n \tag{1}$$

where :

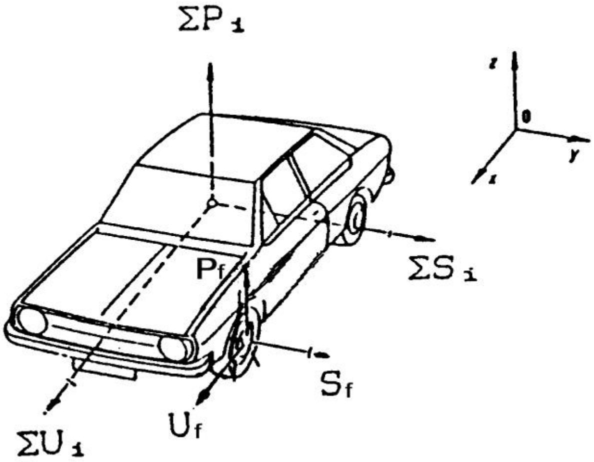
F_x : tractive force (Nt)

P : net engine horse-power available at the driven axle, 94% of the nominal value (hp)

v : vehicle speed (m/sec)

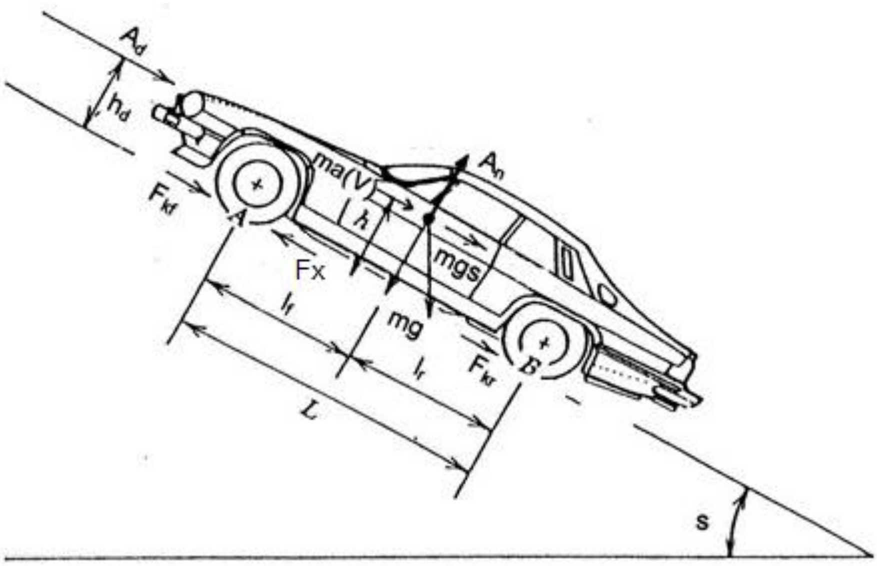
n : horse-power utilization factor (%/100)

In order to understand the interaction between the vehicle's tractive force and acceleration, the example of a front wheel drive (FWD) vehicle on a tangent (not curved) but inclined surface is utilized (Figure 1b), where it is assumed that the vehicle's drag (A_d) and rolling resistance (F_{kf}, F_{kr}) forces are negligible (36).



Note: Ui (longitudinal forces); Si (lateral forces); Pi (vertical forces); Uf, Sf (forces in front axle)

(a) Vehicle Coordinate System



(b) Vehicle Motion on a Tangent and Inclined Surface

FIGURE 1 (a,b) Vehicle Coordinate System and Vehicle Motion on a Tangent and Inclined Surface

By taking moments around the front and rear vehicle axles, the vertical forces acting on the front and rear axle are as follows:

$$P_f = mg\left(\frac{l_r}{L}\cos s - \frac{h}{L}\sin s\right) - ma(V)\frac{h}{L} \qquad (2)$$

$$P_r = mg\left(\frac{l_f}{L}\cos s + \frac{h}{L}\sin s\right) + ma(V)\frac{h}{L} \qquad (3)$$

where ($\sin s \approx s$, $\cos s \approx 1$):

P_f , P_r : vertical forces acting on front and rear axle respectively (Nt)

m : vehicle mass (kgr)

h, l_f, l_r : distances of position of gravity from the road surface, the front and the rear wheel axle respectively (m)

L: wheelbase distance (m)

s: grade (%/100)

dv/dt = a(v) : acceleration (m/sec^2)

The Newton's equation on the longitudinal axis is expressed as follows:

$$\sum U_i = ma(V) \quad (4)$$

$$F_x - mgsins = ma(V) \quad (5)$$

The vehicle's tractive force at impending skid conditions is achieved when the whole longitudinal friction is utilized:

$$F_{x,skid} = P_f f_{T,max} \quad (6)$$

where:

$f_{T,max}$: maximum longitudinal friction

From Equation (2), Equation (5) and Equation (6), the vehicle's acceleration reaches its impending skid value as follows:

$$\frac{a(V)_{skid}}{g} = \frac{l_r f_{T,max}}{(L+hf_{T,max})} - s \quad (7)$$

By utilizing Equation (2), Equation (6) and Equation (7), the tractive force of the vehicle at impending skid conditions can be expressed as follows:

$$F_{x,max} = mgf_{T,max}(\frac{l_r}{L+hf_{T,max}}) \quad (8)$$

As a result it can be seen that although the impending skid vehicle acceleration is grade dependent, the relevant impending skid tractive force on the driven axle (F_x) is independent to the road's longitudinal grade.

The same applies for a vehicle motion on a curved path, where assuming the proposed vehicle dynamics model, the equations from the interaction of the forces in both lateral and longitudinal direction are far more complicated. By taking moments about the front and rear vehicle axles and by using the equilibrium around the vehicle's longitudinal (X) axis, the vehicle's longitudinal acceleration (dv/dt) can be expressed as a four degree polynomial equation, for which the parameters A through E are expressed as functions of vehicle technical characteristics and road geometry values as follows (14, 15):

$$A\left(\frac{dv}{dt}\right)^4 + B\left(\frac{dv}{dt}\right)^3 + C\left(\frac{dv}{dt}\right)^2 + D\left(\frac{dv}{dt}\right) + E = 0 \quad (9)$$

On the other hand, pavement friction reserves are distributed to the longitudinal and lateral direction of travel (37). During a curve negotiation, the portion of friction experienced in the longitudinal direction, is engaged by the friction demanded laterally and the following equation applies, the upper value of which is known as impending skid conditions:

$$(\frac{f_T}{f_{T,max}})^2 + (\frac{f_R}{f_{R,max}})^2 \leq 1 \quad (10)$$

where:

f_T : longitudinal friction demand

$f_{T,max}$: maximum longitudinal friction

f_R : side friction factor

$f_{R,max}$: maximum side friction

By applying laws of mechanics, the vehicle's instant deceleration can be expressed as a function of vehicle's instant speed as well as driven distance, thus forming the following differential equation which is resolved by applying numerical Runge-Kutta method (38).

$$a(v) = \frac{dv}{dd} v \tag{11}$$

where:

a(v) : acceleration (m/sec^2)
v : speed (m/sec)
d : distance (m)

The solution of Equation (11) delivers the vehicle speed variation as a function of the required distance. This procedure takes place at impending skid conditions utilizing Equation (10) both in longitudinal and lateral direction of travel for every wheel by adapting each time the horse-power utilization factor ‘n’ from Equation (1).

As already stated above, based on the proposed vehicle dynamics approach, during vehicle cornering under acceleration mode, although the equations describing the vehicle motion are far more complicated, still the tractive force reflecting impending skid conditions is independent to the road’s longitudinal grade. However, as expected in this case the longitudinal friction engaged is less than its peak value.

The critical wheel in the examined vehicle motion was always the inner front wheel to the curve (FWD vehicle), which means that the vector sum of the longitudinal and lateral demand in friction for this wheel were at the limit of the peak friction utilized. In other words since the vehicle’s speed variation is performed at impending skid conditions, the model delivers for every integration the vehicle’s “best” possible performance. It must be stressed that under the term “impeding skid conditions”, the model delivers data for the critical wheel. This means that not necessarily vehicle skidding will occur; instead a transition to an unstable vehicle motion is evidenced, which is in every case undesirable.

As a result, by accelerating the vehicle at impending skid conditions, the vehicle’s horse-power utilization can be defined. This approach is far more complete compared to the conventional according to which on a given curve the driver should solely comply with the posted speed limit. Even if a driver negotiates a curve with speed values below the design speed, depending on the acceleration rate, which is a result of the horse power utilization, critical safety concerns might rise.

Such an assessment is carried out in the following sections where the vehicle motion is examined for a range of control design parameters and vehicle speed at and below the suggested relevant design speed values.

FIELD MEASUREMENTS AND PARAMETERS DESCRIPTION

The field measurements were carried out on a steep upgraded (s=7%) 2-lane service road section of the major PATHE motorway located at Agios Stefanos area near Athens (Figure 2). The horizontal alignment was formed by a right curve of R=95m, followed by a left curve of R=190m.

Moreover, instrumented speed distance data were recorded solely inside the circular arcs for various initial speed values under free flow conditions. The objective was to drive aggressively, beyond driver’s comfort, in terms of utilizing as much as possible the available horse power of the vehicle without braking. In order to avoid errors due to vehicle handling, all runs were performed by the same driver. When the driver felt uncomfortable, he was asked to release the acceleration pedal. There were cases where the driver felt some kind of lateral drifting. Cases with braking were also reported but excluded from the analysis.

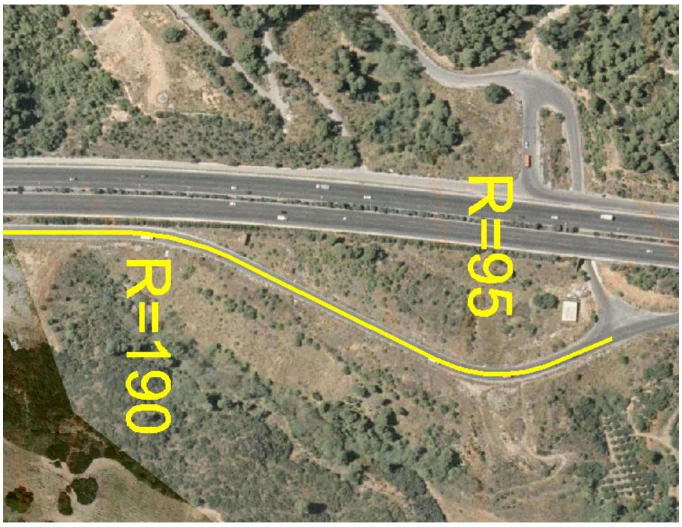


FIGURE 2 Plan View of the Curved Road Sections

In total 4 runs per curve were adopted satisfying the above criteria (no braking, driver feeling uncomfortable). The 8 in total runs more or less revealed the same findings. In order to make sure the recorded runs were inside the circular arcs, every run had different starting and ending points.

The recording device for the speed distance data was the Vericom VC4000 accelerometer (39). The device was also utilized to measure the peak pavement friction, based on the braking performance for various runs of the test vehicle; a C-class, ABS equipped passenger car (KIA Proceed). For this purpose, the tangent road section between the two curves, which retained the constant grade value of 7% was selected.

The friction supply for the entire road section was measured on the upgrade tangent area between the two curves, under dry road surface conditions, where f_{MAX}=0.78 was delivered as peak friction. More information regarding both speed distance and friction recording procedures can be found in a similar research of the authors (15).

The parameters inserted in the model from the vehicle point of view, are shown through Table 1. Although an effort was made to provide the utilized vehicle parameters from the vehicle industry, most of them were taken from the literature (34). In Table 1 the parameters inserted in the model, from the vehicle's manual are bolded. Please note that although the actual horse-power rate available on the wheels is slightly higher, the 100hp were used in order to have a more clear view of the utilized rates as a percentage as well.

TABLE 1 Vehicle Parameters Inserted to the Model
NOTE: The Parameters in Bold Refer to the Vehicle's Manual.

L (m)	**2.650**	Wheelbase
t_f (m)	**1.538**	Front track width
t_r (m)	**1.536**	Rear track width
m (kgr)	**1300**	Vehicle mass
l_f (m)	1,161	Position of GC from front axle
h (m)	0,620	Position of GC from surface
$K_{\varphi f}$ (Nm/rad)	27502	Suspension roll stiffness (front)
$K_{\varphi r}$ (Nm/rad)	14324	Suspension roll stiffness (rear)
C_{af} (kp/rad)	2295.7	Cornering coef. (front)
C_{ar} (kp/rad)	2120.7	Cornering coef. (rear)
m_{uf} (kgr)	92	Unsprung mass (front)
m_{ur} (kgr)	120	Unsprung mass (rear)
h_{Rf} (m)	0,020	Roll center height (front)
h_{Rr} (m)	0,410	Roll center height (rear)
r_{dyn} (m)	0,290	Dynamic radius
A_f (m^2)	1,850	Frontal area
c_N	0,280	Lift drag
c_d	0,360	Aerodynamic drag
P (hp)	**100**	Horse power

VEHICLE PERFORMANCE AGAINST MODEL'S OUTPUTS

Vehicle runs with various speed values were performed on the selected upgrade road sections under free flow conditions. The runs were performed only at the upgrade section, since in a recent research (15), steep upgrade road segments were found to be more critical at impending skid conditions. The reason is that on upgrades more friction is engaged in the longitudinal direction of travel resulting to less friction availability in the lateral direction.

The objective of the vehicle runs was to negotiate the curves by exceeding driver's comfort and utilizing as much as possible the available horse power of the vehicle without braking. Therefore, cases of impending skid occurred where lateral drifting was reported.

Figure 3 shows various runs performed for both curves where the measured speed distance data (V_{RUNS}) are compared against the relevant data from the model's outputs (V_{model}). It can be seen, as expected, that since the model's data are extracted at continuous impending skid conditions, the relevant vehicle speed values are always greater. However, in certain cases the speed values from these two different approaches seem rather close implying that the vehicle was driven near impending conditions too.

In order to make certain all the measured speed data were inside the curve, the relevant recorded distances per run had different starting and ending points. Therefore, the data shown on the distance axis (horizontal) are informative only. From the speed distance correlation between the model's outputs and the measured data, it can be seen that the measured speed values referring to the curve with the higher radius value (R=190m) seem more conservative. The reason is that in addition to the posted speed (V_{limit}=50km/h), the driver didn't feel comfortable from the speeding point of view and not due to potential vehicle skidding.

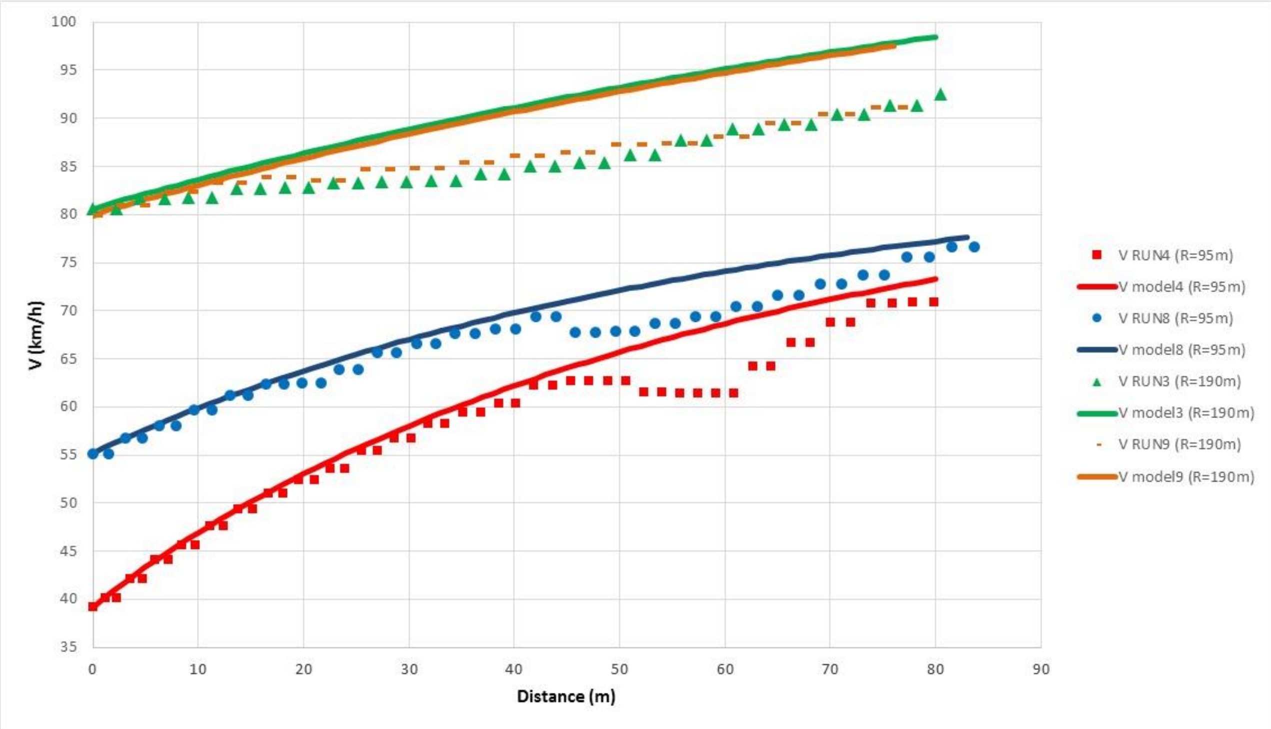


FIGURE 3 Speed – Distance Data Measurements against Model's Outputs

On the other hand, the speed distance correlation between the model's outputs and the measured data on the sharp curve, (R=95m, lower set of curves in Figure 3), revealed that the driver experienced impending skid conditions from the entrance up to the middle of the curve, where the vehicle's speed was slightly decreased.

Based on the latter correlation it is interesting to analyze in more detail the variation of certain vehicle dynamic characteristics extracted from the model. In order for the findings to be more clear, although this investigation was carried out for all the 8 runs (4 and 4 runs for both curved road sections), in Figure 4 only 2 runs regarding the sharp curved road section (R=95m) are analyzed. The reason is that for the curve with R=95m, the vehicle was driven at impending skid conditions from different initial speed values where the only common parameters were road geometry and friction supply of the pavement.

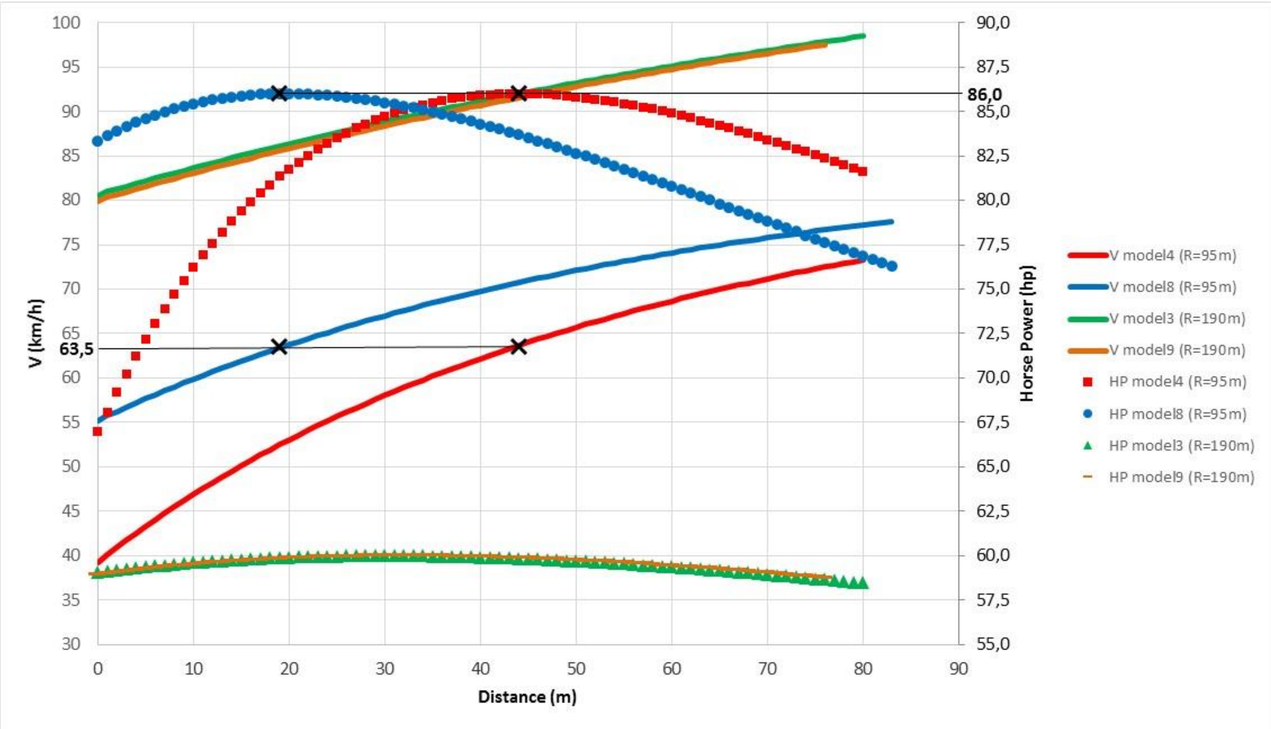
Figure 4a and Figure 4b illustrate the (same) model's speed distance outputs on the primary (left) vertical axis, where the variation of the vehicles' horse power utilization and acceleration are shown on the secondary vertical axis respectively. More specifically in Figure 4a it can be seen that the horse power utilization, which has a parabolic variation, reaches its peak value (86.0hp) for the same vehicle's instant speed value of 63.5km/h. At the same time the acceleration seems continuously decreasing, which is not surprising since speed is increasing, and reaches the value of 1.75m/sec^2 at the same peak horse power utilization value of 86.0hp (Figure 4b).

As a result, it can be concluded that during vehicle acceleration on curved road sections and continuous impending skid conditions, every speed value can be paired to a certain horse power utilization rate. This assessment is mostly critical in terms of safety, since beyond this rate vehicle skidding occurs. Moreover, there is a certain point where the vehicle reaches a peak horse power utilization, where even though it decreases after, the vehicle's speed still increases until the acceleration reduction reaches zero [point of vehicle's maximum attainable constant speed (15)].

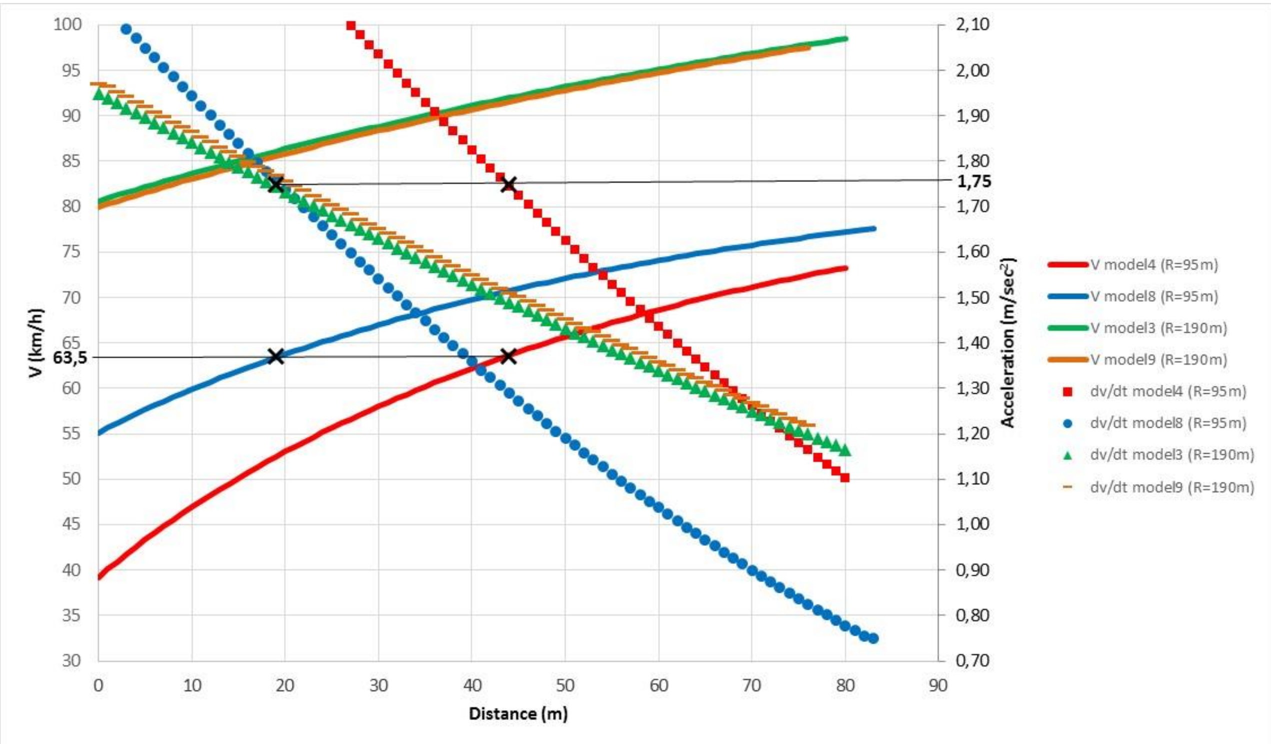
Therefore, it is essential to investigate the acceleration impact in current practice by quantifying the potential safety hazards for control road geometry parameters and vehicle speed at and below the suggested relevant design speed value.

The conventional approach of addressing vehicle safety on curves based on posted speed management seems inadequate, since, even when the speed of the vehicle is less than the relevant posted value, the acceleration effect which depends on the utilized horse power rates may result in vehicle skidding.

Such information incorporated in more sophisticated intelligent speed adaption (ISA) process of vehicle advanced driver assistance systems (ADAS) in the near future will provide integrated and more comprehensive in terms of safety guidance to drivers.



(a) Speed and Horse Power Utilization Variation vs Distance



(b) Speed and Acceleration Variation vs Distance

FIGURE 4 (a,b) Speed, Horse Power Utilization and Acceleration Variation vs Distance

ACCELERATION IMPACT INVESTIGATION IN CURRENT PRACTICE

The impact of vehicle acceleration during cornering was examined for design speed values ranging from 50km/h – 90km/h and the corresponding control horizontal radii based on AASHTO 2011 Design Guidelines, where the superelevation rate was set to 6% for all examined cases (Table 2).

TABLE 2 Control Horizontal Curvature based on Design Speed Values

V_{design} (km/h)	R_{min} (e=6%) (m)
50	79
60	123
70	184
80	252
90	336

As far as pavement friction values are concerned, besides the values adopted by AASHTO, it is evident that the sliding friction coefficient and consequently the relevant peak value are subject to marginal variations in terms of wet-dry pavement conditions as well. For this reason, in the present analysis the vehicle motion was examined under 3 values of peak friction coefficients (supply friction) for each of the above design speed values, namely; 0.35, 0.50 and 0.65 in order to assess pavements with poor friction performance under both wet (0.35) and dry (0.65) pavement conditions.

In order to assess more sufficiently the acceleration impact during vehicle cornering, besides vehicle motion under the design speed, speed values of 10km/h and 20km/h below the design speed were used as well for every set of control parameters, in accordance to Table 2. As already stated, during an accelerated curve negotiation at impending skid conditions, the tractive force reflecting impending skid conditions is independent to the road's longitudinal grade.

In the present analysis, the breakpoint where the vehicle reaches a peak horse power utilization, after which it decreases, was found for speed values beyond the design speed and therefore it was not further investigated.

The vehicle's horse power rates for the examined cases are shown through Figure 5. For every colored set, the three different shapes (box, partial pyramid and cylinder) represent horse power rates extracted for vehicle motion under the design speed, 10km/h below and 20km/h below (V_{design}, V_{design}-10km/h, V_{design}-20km/h) respectively. This process was performed for every utilized value of peak friction coefficient.

During vehicle cornering on control alignments under the above conditions, if the driver attempts to utilize more horse power rates compared to the values shown in Figure 5, the vehicle will skid.

From Figure 5 it can be seen that vehicle acceleration at impending skid conditions under speed values below the respective design speed are more critical. As a result, during curve negotiation the safety performance of a vehicle may be violated if the driver attempts to accelerate the vehicle more aggressively at such speed values.

When the vehicle accelerates at impending skid conditions under the design speed value and on poor wet friction pavement (f_{max}=0.35) the horse power rates are 1hp-3hp and 6hp-8hp higher compared to speed values 10km/h and 20km/h respectively below the design speed. For f_{max}=0.65, the respective horse power rates range between 7hp-9hp and 19hp-20hp.

Another interesting finding is that vehicle performance in terms of horse power utilization for pavements with friction supply between f_{max}=0.35 and f_{max}=0.65 can be increased by approximately 80%. Therefore, it is very important to monitor friction supply and schedule friction improvement programmes on a regular basis.

Moreover, as already stated on a similar research of the authors (15), among the most important findings is the fact that vehicles equipped with excessive amounts of horse power rates must be driven very conservatively, especially on sharp curves combined with poor friction supply.

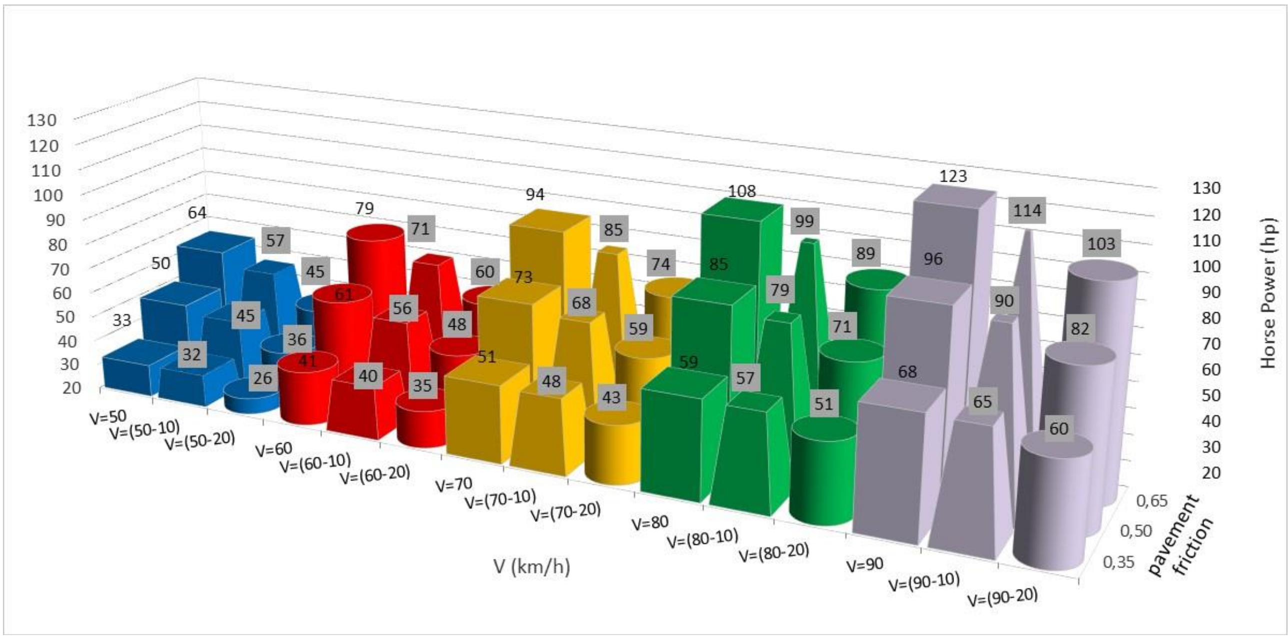


FIGURE 5 Horse Power Utilization at Impending Skid Conditions for Control Values

CONCLUSIONS

The present paper investigated the acceleration impact in vehicle safety during tractive mode for control road geometry parameters and vehicle speeds at and below the suggested relevant design speed values.

Speed – distance of a C-class FWD passenger car along with pavement friction supply were collected on two upgraded curved road sections and correlated against an existing dynamic model in order to examine the interaction between vehicle dynamics and road geometry. The vehicle runs were performed on the basis of exceeding driver's comfort and utilizing as much as possible the available horse power of the vehicle without braking. As a result, in certain runs the driver experienced impending skid conditions. This finding was confirmed from the speed distance correlation between the model's outputs and the measured data on the sharp curve.

Aiming to quantify the potential safety hazard during vehicle acceleration at impending skid conditions, the authors examined alignments with control road geometry parameters based on AASHTO 2011 Design Guidelines and vehicle speeds at and below the suggested relevant design speed values which ranged from 50km/h to 90km/h. This assessment was performed for three values of peak friction coefficients in order to assess pavements with poor friction performance under both wet and dry pavement conditions. The analysis delivered specific horse power rates for every examined case, beyond which the vehicle will skid.

Among other important findings, stands the necessity for monitoring friction supply and scheduling friction improvement programmes on a regular basis as well as the fact that vehicles equipped with excessive amounts of horse power rates must be driven very conservatively, especially on sharp curves combined with poor friction supply.

The conventional approach of addressing vehicle safety on curves based on posted speed management seems inadequate, since even when the speed of the vehicle is less than the relevant posted value, depending on the utilized acceleration cases of vehicle skidding may occur.

Such information incorporated in more sophisticated intelligent speed adaption (ISA) process of vehicle advanced driver assistance systems (ADAS) in the near future will provide integrated and more comprehensive in terms of safety guidance to drivers.

Although the contribution of more specific driver assistance systems on road safety and traffic efficiency is something still under consideration and research, such integrated systems may support a closer collaboration between "intelligent" roads and "intelligent" vehicles.

However, since only a certain passenger car type was examined which definitely is not a representative of the passenger car fleet, further investigation for the entire vehicle fleet (SUVs, heavy vehicles etc.) is required. In addition, it should not be ignored that the human factor during the acceleration process, might impose additional restrictions and, consequently, affect vehicle's safety performance.

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