Analysis of Driving Safety Criteria Based on National Regulations for the Suspension Systems of NGVs
Ronald Martinod, German René Betancur, Leonel Castañeda

To cite this version:
Ronald Martinod, German René Betancur, Leonel Castañeda. Analysis of Driving Safety Criteria Based on National Regulations for the Suspension Systems of NGVs. Acta Universitatis Agriculturae Et Silviculturae Mendelianae Brunensis, 2015, 63 (1), pp.253-261. 10.11118/actaun201563010253 . hal-02181091

HAL Id: hal-02181091
https://hal.archives-ouvertes.fr/hal-02181091
Submitted on 11 Jul 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
ANALYSIS OF DRIVING SAFETY CRITERIA BASED ON NATIONAL REGULATIONS FOR THE SUSPENSION SYSTEMS OF NGVS

Ronald Mauricio Martinod¹, German René Betancur¹, Leonel Francisco Castañeda¹

¹ Mechanical Engineering Department, Engineering School, Universidad EAFIT, Cra. 49 N° 7 Sur-50 Medellín, Colombia

Abstract


The work analyses the technical evaluation process of the suspension system for vehicles that have been adapted to natural-gas-fuelled engines from power light-duty gasoline, and diesel vehicles; this evaluation is done through a mechanical review established by national regulations. The development of this analysis is focused on establishing the relationship between the natural-gas-fuelled equipment and the dynamic effect caused by the extra-weight, according to two measuring criteria that determine the safety and driving comfort, these are: (i) tire-road adhesion index; and (ii) tire excitation phase angle. The paper also proposes new elements that can be added to the current national regulations and that are currently applied to assess the suspension of natural gas vehicles, recorded using a test standard benchmark for the evaluation of the suspension.

Keywords: adhesion index, EuSAMA, phase angle, natural gas vehicle, suspension system, viscous damping ratio

INTRODUCTION

Natural Gas-fuelled Vehicles (NGVs) with spark-ignited engines can either be ‘bi-fuel’ indicating the possibility to switch back and forth between gasoline and natural gas, or ‘dedicated’ which means that the gasoline fuelling hardware is completely removed and the engine can only work with natural gas. There are many motivations to replace gasoline or diesel-fuelled engines with NGVs engines in different countries (see Tab. I), in most of the cases because of the following reasons:

i) potential fuel cost savings,

ii) reduced dependence on imported foreign oil, and

iii) reduced engine emissions e.g. carbon dioxide, nitrogen oxide, etc. (Daziano, 2012); NGVs are actually helpful for the increase of energy conservation and also for the decrease of gas emissions.

The weight and volume of NGVs containers storage are considered significantly greater when compared to gasoline/diesel tanks. Gasoline can be stored on a vehicle at approximately atmospheric pressure in a thin-walled, light-weight tank (~1 lb/gal depending on the construction). The shape of the tank can be adjusted as needed to fit the available space, thus decreasing the impact on cargo space. Regular gasoline has a density around the 6.1 lb/gal. Diesel fuel is stored as easy as the gasoline and has a density of about 7.1 lb/gal. A full 10-gal tank of gasoline/diesel will hence weigh a bit more than 71/81 lb and will employ a slightly greater space than the fuel volume (Keoleian et al., 1998).

On the other hand, Compressed Natural Gas (CNG) is stored on a vehicle in a high pressure cylinder that is able to resist pressures up to 3600 psig. CNG are constructed in different ways, almost 90% of cylinders that are use nowadays,
Type-1 tanks weight 4 to 5 times more than the same capacity gasoline tank (compared with full tanks), and occupies a roughly three times larger volume inside the vehicle. Using Type-3 tanks, the weight is a half in comparison with the weight a gasoline tank, but the volume exceeds 4 to 5 times the size of the gasoline tank (Whyatt, 2010).

The modified vehicles’ suspension technical condition has physical thresholds (e.g. stiffness, damping, and overload) that cannot be exceeded, for any vehicle, even for the newest design vehicle. The thresholds are defined by the designers, factories or assemblers, of each type of vehicle. Furthermore, there is a great contribution of the ten countries with the highest number of NGVs, they has a meaningful participation, equivalent to 87.1% of NGVs globally (NGV Global, 2012a); most of these countries are non-developed countries that do not have the ability to design, redesign or manufacture some kind of these commercial vehicles (e.g. Pakistan, Argentina, India, China, Colombia, Thailand, etc.). Then in the actual field the workshops that switch vehicles from gasoline/diesel to natural gas; or the ones that make structural changes through refurbishing the power source to get ‘bi-fuel’ fuelled old vehicles, do not consider the design or the thresholds values. The workshops are restricted only by the state regulations.

The paper discusses the national regulations that are currently applied to evaluate the suspension of NGVs, it also will be focused on the analysis of the technical condition of the suspension system in the case that the vehicle is subject to switch from power light-duty gasoline/diesel vehicles to NGVs. Later, the paper will refer to studies about the relation between the storage tanks and the suspension technical condition. Displaying the following NGVs types are specifically considered in this paper:

i) gasoline-fuelled, light-duty, vehicles used primarily for private transport; and

ii) gasoline-fuelled (e.g. cars, pickups, small vans, taxis, etc.) or diesel-fuelled (e.g. scholar vans, delivery trucks, station wagons). The necessity of including additional criteria for the safety/comfort evaluation in NGVs has been identified in this paper since the extra-mass, due to the storage tank, affects the tests’ results defined by the state regulations.

The state regulations of the European Union country members, United States, Japan, Colombia, among others; establish that there must be a periodic technical review for the different systems that vehicles possess (see Tab. III):
Analysis of Driving Safety Criteria Based on National Regulations for the Suspension Systems of NGVs

i) suspension system,
ii) state of the bodywork,
iii) gas emission level, among others.

This regulation establishes two types of periodic reviews for the suspension system:

i) visual inspection, examines the state of: fixations and suspension components, presence of fissures, corrosion symptoms, existence of welded repairs, and presence of damages, deformations, and oil leakage (MITC, 2006); and

ii) mechanical review, identifies the suspension condition according to the method denominated EuSAMA (EuSAMA, 1976), which has been a fundamental document about studies about the equipment for the evaluation of vehicles suspension system conditions (SAE, 1996; SAE, 2000); and national standards.

The current evaluation of NGVs suspension system is done following the guidelines of the original method established by EuSAMA (EuSAMA, 1976; Koláček and Dostál, 2013). While there has been a significant increase in the amount of consumers’ interest in the driving safety/comfort issues of privately owned vehicles, the role played by this method in the purchasing consumers decisions is poorly understood (Koppel et al., 2008), specially the one relative to NGVs.

EuSAMA regulation uses a criteria in function of the vertical oscillation frequency of the tire \( \omega \), denoted adhesion index \( A(\omega) \), which is critical to basic safety, it is therefore very important that the levels of \( A(\omega) \) are measured. In the case that a vehicle has a reduced level of adhesion, then it has a high potential driving accident due to the skid effect (Robinson, 1997; Buczaj et al., 2007; Martinod et al., 2013). NGVs incorporate an extra-mass \( m_a \) to the design mass of the vehicle \( m_v \), and causes an increase in the total mass of the vehicle \( m_t = m_v + m_a \), where \( A(\omega) \mu m_t \). The present study proposes to include the phase angle \( \psi(\omega) \) criterion, where \( \psi(\omega) \mu m_t^{-1} \), this criterion has been defined by SAE (SAE, 2000).

Besides, another state regulation that is related to NGVs is the equipment size/weight, thus the manufacturers must follow the international

---

1: ¼ model of 2-Degrees of Freedom (DoF) vehicle

<table>
<thead>
<tr>
<th>Country/region</th>
<th>Periodelity</th>
<th>Regulatory entity</th>
<th>Issue date</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Union</td>
<td>Biennial</td>
<td>Council Policy 96/CE</td>
<td>1996</td>
</tr>
<tr>
<td>United States</td>
<td>Biannual/annual</td>
<td>Office of the Law Revision Counsel</td>
<td>2006</td>
</tr>
<tr>
<td>Japan</td>
<td>Biennial</td>
<td>National Agency of Vehicle Inspection</td>
<td>--</td>
</tr>
<tr>
<td>Colombia</td>
<td>Biennial</td>
<td>Transit and Transport Ministry</td>
<td>2002</td>
</tr>
</tbody>
</table>

* Varies according to the laws of every state.

---

1 Adhesion index \( A(\omega) \), ratio of the vertical force exercised by a tire in respect to the load in the contact surface of the road, during a vertical oscillation of an tire (SAE 960735, 1996).

2 Phase angle \( \psi(\omega) \), measure of the angular difference between the contact force of the tire and the position of the excitation platform for each instant in time (SAE 960735, 1996).
regulations (NFPA, 1996; ISO/DIS, 2000; ANSI/CSA, 2000), the storage tanks are standardized according to the tank size (FMVSS, 2012), which is defined by the volume capacity in terms of the equivalent water volume capacity \( v_c \), then \( v_c \) is defined by the range values \( v_c = \{30, \ldots, 150\} \) L (see Tab. VII).

### MATERIAL AND METHODS

The proposed procedure to evaluate the suspension performance of NGVs considers two measurement criteria:

i) \( A_{min} \)

and

ii) \( \psi_{min} \) which can be recorded by a standard commercial suspension tester machine.

The tester machine consists of hardware (sensors + transducers) with processing software, and a mobile oscillating platform in a metal frame on which are mounted casters and handle; the platform is on one side connected to electric motor with an eccentric shaft and the opposite side is stored in the pivot, an oscillating circular cam lifts the platform with an wheel up to a frequency of 25 Hz, under the platform, there is installed a load cell, which is sensing the wheel load on the platform (Buczaj et al., 2007; Koláček and Dostál, 2013).

To the present work is used a suspension tester for cars and vans (series VL T 3673/M) with display accuracy 1% of end value, supplied by Van Leeuwen Test Systems from Holland, applied to a MacPherson non-semiactive suspension installed in a Nissan Sentra vehicle, with a tire type 185/70 R13, which has a load index of 84, equivalent to 450 kg with a pressure of 2.2 bar (Reimpell et al., 2001).

The laboratory tests have been designed from the power sampling to obtain a high significance level in the tests, the estimation of the power sampling is based on the stochastic method proposed by W. Cochran (Cochran, 1977). The control of the parameters associated with the variables of each laboratory test yielded a power value of 80% (see Tab. V), with two sets of test treatment, to each treatment was done ten repetitions as minimum, it allows to achieve a suitable reliability level of study (Tab. VI), which is considered valid for the scope of the experimental study.

\[ A_{min} = \frac{F_{23}}{P} \times 100 \% \] (1)

\( A_{min} \) is defined as the ratio between the minimum vertical force, \( F_{23} \), see Fig. 1, in the contact surface of a tire (unsprung mass \( m_2 \)), and the static wheel load on the platform \( P \), exercised by the corresponding \( m_2 \) (SAE, 1996), this is

\[ \psi_{min} \] is defined as the minimum angular difference between the vertical position of the excitation platform \( x_3 \), and the vertical position of \( m_2 \) in relation to the platform \( x_{23} \) (SAE, 1996); \( x_3 \) is expressed as a sinusoidal function based on the movement equation

\[ x_3(t) = a \times \sin(\omega_3 \times t + \phi_3), \] (2)

where

\( t \) .......Instant in time domain of the test,

\( a \) .......Amplitude of the platform displacement,

\( \omega_3 \) .......Platform excitation frequency at instant \( t \), and

\( \phi_3 \) .......Phase.

\( x_{23} \) is indirectly found using the magnitude of the tire-platform contact force \( F_{23} \), expressed as a sinusoidal function

\[ F_{23}(t) = F_0(t) \times \sin(\omega_{23} \times t), \] (3)

where

\[ \omega_{23} \]
Analysis of Driving Safety Criteria Based on National Regulations for the Suspension Systems of NGVs

VII: CNG storage cylinder Type-1 tank based on European-Indian factory

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>244</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>838</td>
<td>30</td>
<td>10</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>1270</td>
<td>50</td>
<td>17</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>1529</td>
<td>60</td>
<td>20</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>279</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>895</td>
<td>40</td>
<td>14</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>1016</td>
<td>50</td>
<td>17</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>1270</td>
<td>60</td>
<td>20</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>1633</td>
<td>80</td>
<td>27</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>324</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>970</td>
<td>64</td>
<td>22</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>1016</td>
<td>70</td>
<td>24</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>1191</td>
<td>80</td>
<td>28</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>1450</td>
<td>100</td>
<td>34</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td>356</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>841</td>
<td>64</td>
<td>22</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>899</td>
<td>70</td>
<td>24</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>1021</td>
<td>80</td>
<td>28</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>1461</td>
<td>120</td>
<td>41</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td>1755</td>
<td>140</td>
<td>48</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>406</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1229</td>
<td>125</td>
<td>43</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>1440</td>
<td>150</td>
<td>51</td>
<td>167</td>
<td></td>
</tr>
</tbody>
</table>

$F(t)$ amplitude of the force, and
$\omega_2$ response frequency of the unsprung mass.

Expressing the platform displacement angle as
$\psi_1(t) = \omega_1 \times t$, and the displacement angle of $m_2$, as
$\psi_2(t) = \omega_2 \times t$ and joining the equations (2) and (3),

$$\psi_1(t) = \sin^{-1}\left(\frac{x_1(t)}{a}\right),$$

$$\psi_2(t) = \sin^{-1}\left(\frac{F_2(t)}{F_1(t)}\right),$$

therefore, the phase angle for the unsprung mass $m_2$, can be expressed as
$\psi(t) = \psi_1(t) - \psi_2(t)$.

Then the evaluation is performed independently to each unsprung mass (to each tire of NGVs) with a suspension tester machine where (SAE, 1996):

i) the machine registers the wheel load on the platform, $P$;

ii) the platform has an initial oscillation frequency $\omega_3 = 0$ Hz increasing the frequency to $\omega_3 = 25$ Hz, with a constant amplitude of 6 mm; and

iii) the equipment registers $F_2(\omega_3)$, and the position of the platform $x_1(\omega_3)$.

Previous studies (Tsymberev, 1994; SAE, 1996; Buczaj et al., 2007) have established four (4) acceptance states that clearly qualify the evaluation of vehicle suspension systems, according to the values obtained for $A_{min}$ and $\psi_{min}$ (see Tab. IV).

RESULTS AND DISCUSSION

The weight of NGVs fuel storage tank $w_s$ is given in function of $v_c$, where $w_s \propto v_c$. There are some vehicles with refurbished storage that have twins tanks installed in order to achieve long-range travels (Bhattacharjee et al., 2010). This type of modifications is classified as changes in the physical environment, while the modifications and changes in the availability of products are considered structural modifications (Lund and Aarø, 2004). Therefore, it is possible to establish the following range relation $w_s = (40, \ldots, 320)$ kg. $w_s$ is relatively close to $m_s$, $w_s \approx m_s$, therefore, the mathematical model considers that the elements and accessories of the natural-gas-fueled engines has a despicable mass, i.e. $w_s$ and $m_s$ are equivalent, $w_s = m_s$. In the case that $m_s$ value exceeds the maximum design load $C_{max}$ of a standard vehicle, it means $m_s > C_{max}$, NGVs requires a modification in the suspension system to conserve the design safety standards.

The model represents the dynamic behaviour equivalent to ¾-car (Gáspár et al., 2007), through 2-DoF and considering a system of 3-masses (Haroon and Adams, 2008; Pourqorban et al., 2010):

i) $m_1$ - platform mass;

ii) $m_2$ - tire or unsprung mass; and

iii) $m_3$ - sprung mass.

The relation of the masses is

$$m_s \approx \sum_{i=1}^{4} m_i,$$

where $r = (1, \ldots, 4)$ symbolizes a standard vehicle with four wheels. Assuming the storage tank is installed on the rear-end vehicle, then $m_1$ is distributed in the rear tires. Then, the study is focused on the performance of the rear tires, because the sprung mass is added the half of the weight of the fuel storage tank.
where $\frac{\omega_c}{2} = [20, \ldots, 160] \text{ kg}$. 

The numeric model has been subject of a validation process remaining previous experimental study (Arbeláez and Marín, 2007). The experimental study consisted in a set of laboratory tests, in a test’s bed (see Appendix B, Fig. 4), for the analysis of adhesion to suspension evaluations of light vehicles based on the EuSAMA principles. The model with mechanical properties of a commercial vehicle is denoted by a reference model, the general parameters of ¼-NGVs model are the following: $m_1 = 173 \text{ kg}$; $m_2 = 35 \text{ kg}$; $k_2 = 18.71 \text{ kN/m}$; $k_{23} = 127.20 \text{ kN/m}$; $c_{12} = 1.30 \text{ kNs/m}$; $x_3 = 6E^{-3} \text{ m}$; $\omega_3 = \{0, \ldots, 25\} \text{ Hz}$; and the model has been structured in two stages:

i) Modelling of NGVs with a range of storage tank capacity $v_c = \{30, \ldots, 250\} \text{ L}$, keeping the features of the commercial standard vehicle suspension system; and

ii) Modelling of NGVs with a range of storage tank capacity $v_c = \{30, \ldots, 250\} \text{ L}$, and with a modification of the suspension system properties:

a) the loss of properties (ageing of the elements); and

b) the improvement of the damping properties.

The results of the two modelling stages are shown above:

**NGVs with Standard Vehicle Suspension**

The parametric space of the extra-mass is equivalent to incorporating different storage tanks cylinders, $v_c = \{30, \ldots, 250\} \text{ L}$. Fig. 2 exposes the dependence of criteria $A_{\text{min}}$ and $\psi_{\text{min}}$ to the variation of $m_a$. $A_{\text{min}}$ has a directly proportional tendency, obtaining a 2-order polynomial regressive model with a correlation coefficient of $\sqrt{R^2} > 0.99$,

$$A_{\text{min}}[\%] = -0.0003 m_a^2 + 0.1394 m_a + 65.598. \quad (5)$$

The regressive model is considered valid knowing that the $\sqrt{R^2}$ value represents the association measure of the statistic model with the obtained data, which has an acceptable level for the scope of this study.

The maximum design load equivalent to ¼-car is $C_{\text{max}} \approx \frac{500}{4} \text{ kg}$; this represents the limit value to which the vehicle can be loaded with extra-weight without requiring modification in the suspension system. However, Fig. 2 shows if the extra-mass is in the range $m_a = \{C_{\text{max}}, \ldots, 170\} \text{ kg}$ then $A_{\text{min}} \geq 79\%$, such relation expresses that: the evaluation criterion for the standard suspension of NGVs as excellent, even in cases in which the maximum design load $C_{\text{max}}$ is exceeded. Furthermore, the criterion $A_{\text{min}}$ indicates that the suspension state for NGVs improves indefinitely with the increase of extra-mass $m_a$. Therefore, it is possible to assure that the criterion $A_{\text{min}}$ is not enough for evaluating the suspension state of NGVs.

$\psi_{\text{min}}$ presents an inversely proportional behaviour, obtaining a linear regressive model

$$\psi_{\text{min}} = -8.2E^{-3} m_a + 86.36, \quad (6)$$

with correlation coefficient of $\sqrt{R^2} > 0.97$, which is considered valid for the scope of this study. The evaluation criterion for the suspension behaviour $\psi_{\text{min}}$ presents a coherent relation to the suspension state of NGVs, where it is possible to propose it as limit evaluation value of suspension state for NGVs ($\psi_{\text{min}}$) = 85 deg, this limit value is highly sensitive to the maximum design load, for that reason it is enough for NGVs evaluation of suspension state.

---

2: Regressive models $A_{\text{min}}$ and $\psi_{\text{min}}$, in function of $m_a$. 
NGVs with Variation of Suspension Properties

The parameter $m_a$ is defined by $v_c$. The parameter $c_{12}$ has parametric space $c_{12} = \{0.3, \ldots, 2.3\}$ kNs/m considering the extremes damping values: defective and excessively rigid (see Fig. 3). Four areas that classify the suspension state are observed, $RE = \{RA, RB, RC, RD\}$, according to the Tab. VI, where $R_E$: excellent, $R_{E0}$: good, $R_{E1}$: fair, and $R_{E2}$: deficient.

The analysis result of criterion $A_{min}$ shows that each $RE = \{RA, RB, RC, RD\}$ area has a boundary parametric function, which possess an inverse relation $c_{12} \propto m_a^{-1}$:

- for $RE_A$: $c_{12} = -1.90 m_a + 955.46$, with $\sqrt{R^2} = 0.97$;
- $c_{12} = f(m_a)$; $\sqrt{R^2} = 0.97$;
for \( R_{(0)_n} \rightarrow c_{12} = -2.19m_s + 708.91 \), with \( \sqrt{R^2} = 0.99 \); and

for \( R_{(0)_n} \rightarrow c_{12} = -2.57m_s + 533.70 \), with \( \sqrt{R^2} = 0.99 \).

Considering the parametric space \( (0, \ldots, 170), (0.3, \ldots, 2.3) \), each RE area possesses the following proportion: \( R_1: 77\% \), \( R_2: 13\% \), \( R_3: 7\% \), \( R_4: 3\% \). This criterion \( A_{m_n} \) is permissive in relation to parametric variables. Additionally, \( A_{m_n} \) qualifies the behavior of NGVs standard suspension as excellent (even allowing a reduction of suspension of the dynamic properties), still in cases in which the maximum design load \( C_{max} \) is exceeded. Note that criterion \( A_{m_n} \) qualifies the behavior of NGVs suspension as excellent, with a damping ratio \( c_{12} \) that has values lower than the 60% of the studied nominal property. This decrease of the damping ratio value is equivalent to 60% of damping wear. Thus, once again it is possible to affirm that \( A_{m_n} \) is not enough for evaluating the suspension state of NGVs.

The analysis result of criterion \( \psi_{m_n} \) shows that each area has a 2nd-order boundary parametric function:

\[ \text{for } (R_{(0)_n} \rightarrow c_{12} = -0.013m_s^2 + 4.37m_s + 885.97, \text{ with } \sqrt{R^2} = 0.94}; \text{ and } \]

\[ \text{for } (R_{(0)_n} \rightarrow c_{12} = -0.029m_s^2 + 8.47m_s + 359.35, \text{ with } \sqrt{R^2} = 0.96}. \]

Considering the entire possible parametric field, each area has the following proportion: \( R_1: 65\% \), \( R_2: 19\% \), \( R_3: 16\% \). However, criterion \( \psi_{m_n} \) is sensitive to the extra-mass \( m_s \).

CONCLUSION

The current evaluation of the technical conditions of the suspension system to NGVs based on EuSAMA principles, that have been adopted by state regulations, although this does not guarantee an accurate diagnostic of safety/comfort driving.

The main goal of the present work is establish a suitable procedure to the suspension system assessment for NGVs, which considers the evaluation via two criteria: \( A_{m_n} \) and \( \psi_{m_n} \) providing an accurate diagnostic of the state of NGVs suspension systems focused on the safety/comfort driving issues.

The established procedure can be integrated with the procedures used in periodic vehicle revisions in countries that include a technical inspection into the state regulation [European Union, United States, Japan, Colombia, among others]. The proposed method can be implemented maintaining the same installed technical capacity to perform mechanized technical inspection, and without requiring adding new infrastructure neither requiring additional technical elements.

As another remaining conclusion, the paper shows that the structural modification through refurbishing storage to get a long-range travel via twin tanks is not an appropriate solution, due the study found that \( m_s \geq C_{max} \) then, NGVs require a modification in the suspension system to conserve the design safety/comfort standards.

The present study can be a reference point for different cases of vehicle suspension analysis, when extra-load has been added to the nominal standard design. Therefore, this methodology can be applied for other studies on suspension systems, where the mass of the vehicle has been modified.

Acknowledgement

The research has been supported by the project “Criterios de Evaluación del desempeño de vehículos automotores (Criteria for performance evaluation of motor vehicles)” financed by Universidad EAFIT.

REFERENCES


FMVSS 304. 2012. Compressed natural gas (CNG) fuel container integrity. US Department of...
Analysis of Driving Safety Criteria Based on National Regulations for the Suspension Systems of NGVs


Contact information

Ronald Mauricio Martinod: rmartino@eafit.edu.co
German René Betancur: gbetanc4@eafit.edu.co
Leonel Francisco Castañeda: lecasta@eafit.edu.co