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METHODS FOR THE CALCULUS OF THE ROAD WHEEL VERTICAL LOAD

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Abstract - *The static vertical load of the wheel roads plays a key role in the optimization of the suspension. The input criteria for set up the suspension include the clearance of the vehicle, the longitudinal inclination of the vehicle as well as the stiffness of the suspension resulted from ride comfort optimization. Additional calculus difficulties occur for vehicles with more than 3 road wheels on each side.*
The paper presents an analytical model for calculus of the vertical load of the road wheels applied to a tracked vehicle with 7 independent torsion bars suspension on each side. For a similar vehicle, the vertical loads are estimated using multi-body based software, such as Recurdyn. Neglecting the influence of the track, the methods may be extended for wheeled platforms with independent suspensions.
Key words*: tracked vehicle, road arm, torsion bar suspension, static load*

1. INTRODUCTION

The suspension of the tracked vehicles plays an essential role in the stabilization of the hull, providing ride comfort and firing accuracy. Due to the large mass of the vehicle, the optimization of the suspension rises difficulties in balancing the "softness" required by the ride comfort incentives with the rigidity required by a the firm position of the hull and by the rapid dissipation of the hull oscillations.
A key step in design of the military tracked vehicle suspension is the evaluation of the vertical loads of the road wheels. The vertical load of the road wheels must balance the total weight of the vehicle and has to provide a horizontal position of the hull.
The mobility of military vehicles crossing terrains with soft soil is limited by the power needed to overcome the rolling resistance and by the thrust of soil. Both limitations depend on the vertical pressure exerted by the track on the deformable soil. As result of the pressure of the track, the soil beneath the track changes its mechanical characteristics, influencing accordingly the traction. The existing models dealing with the interaction between track and soft soils can be grouped into two large categories.
On one side there are analytical models based on Bekker's equation for describing the relationship between the sinkage and pressure [0]:

$$z = \left[\frac{p}{k_c / b + k_\phi} \right]^{\frac{1}{n}} . \tag{1}$$

The friction modulus, cohesion modulus and the exponent of soil deformation are determined by experiments using a special device, the bevameter. A relatively narrow list of values for pressure – sinkage parameters exists for consideration in mobility assessment [[6]], despite the fact this list was implemented in multi-body specialised software as RecurDyn. The relation (1) proves the importance of the estimation of the road wheel vertical load.

2. THE STATICS OF THE INDIVIDUAL SUSPENSION

The large majority of the military tracked vehicles use torsion bars independent suspensions. The running gear of such type of vehicles is schematized in Figure 1 and offers a fast view of the existing interaction between the suspension and the track.

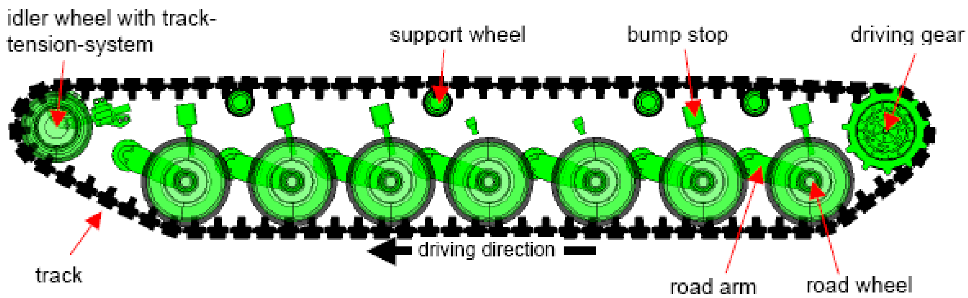

Figure 1 Schematic representation of the tracked vehicles running gear

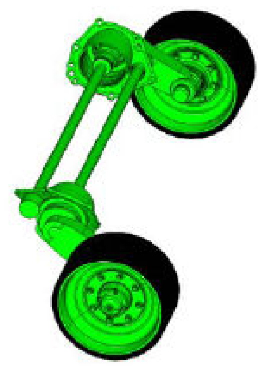

Figure 2 Torsion bar individual suspension

The individual torsion bar suspension is represented in Figure 2. The initial angle of the road arm, noted β_0 represents the design element which determines the value of the road wheel vertical load for the static situation of the vehicle. The actual position of the road arm, corresponding to the static position of the vehicle, is defined by the value of the angle of the road arm measured to the horizontal, noted β_s. The aim of the individual suspension statics is to determine the relations between the vertical load of the road wheel and the design parameters of the suspension. The schematization of the road arm is presented in Figure 3.

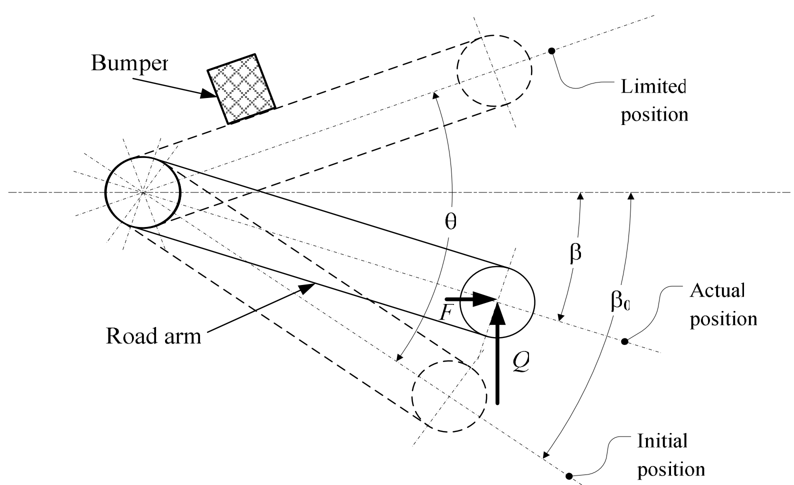

Figure 3 The schematization of the road arm

Finally, the following relation results for the stiffness of the individual suspension:

$$c = \frac{\pi \cdot G \cdot d^4 \cdot (\beta_0 - \beta)}{32 \cdot L_a \cdot b^2 \cdot (\cos\beta + f \sin\beta)(\sin\beta_0 - \sin\beta)} \quad (2)$$

where: G – transversal elasticity modulus, d – diameter of the torsion bar, L_a – length of the torsion bar, f – rolling resistance coefficient of the road wheel on the track, b – road arm length.
The relation (2) indicates a non-linear dependence of the stiffness versus the actual position of the road arm expressed by the angle β.

Meanwhile, because the initial position of the road arms differs, the stiffness characteristics of the road arms differ too. If the road wheel rolling resistance is neglected, the relation (2) becomes:

$$c = \frac{\pi \cdot G \cdot d^4 \cdot (\beta_0 - \beta)}{32 \cdot L_a \cdot b^2 \cdot (\sin\beta_0 - \sin\beta) \cdot \cos\beta}. \quad (3)$$

The stiffness of the individual suspension, calculated for the static position results by imposing $\beta = \beta_s$:

$$c_s = \frac{\pi \cdot G \cdot d^4 \cdot (\beta_0 - \beta_s)}{32 \cdot L_a \cdot b^2 \cdot (\sin\beta_0 - \sin\beta_s) \cdot \cos\beta_s} \quad (4)$$

The stifness for the actual position may be expressed taking into consideration the relations (3) and (4) as follow:

$$\frac{c}{c_s} = \frac{(\beta_0 - \beta) \cdot (\sin\beta_0 - \sin\beta_s) \cdot \cos\beta_s}{(\beta_0 - \beta_s) \cdot (\sin\beta_0 - \sin\beta) \cdot \cos\beta}. \quad (5)$$

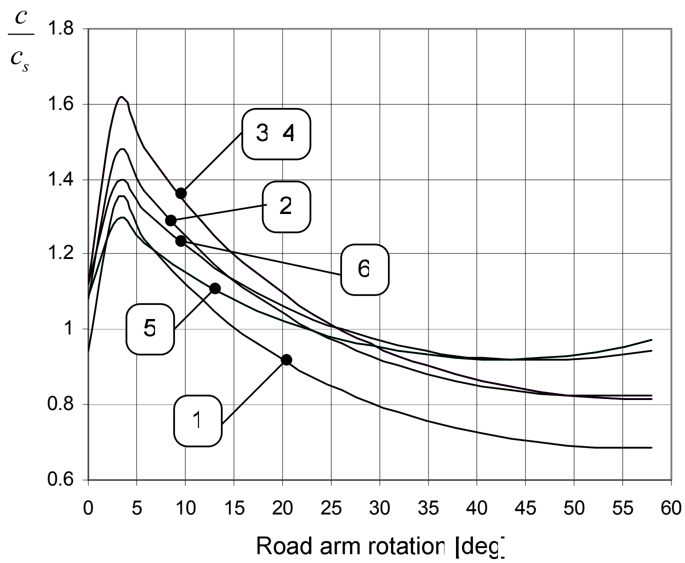

Figure 4 Variation of the rated stiffeness of the individual suspensions

The graphical variation of the ratio given by (5) is given in Figure 4.
An important variation is observed around the static position of the road arm, for which the plotted ratio becomes equal to 1.
The main conclusion of the study regarding the statics of the individual suspension is that is mandatory to take into consideration the variation of the stiffness with respect to the position of the road arm in order to calculate the vertical load of the road wheels.

3. THE STATICS OF THE SUSPENSION ASSEMBLY

Taking into consideration the whole suspension consisting of 7 individual suspensions on each side, the balance of the forces and moments acting on the hull which is aslope with the angle φ, the following system of simultaneous equation results:

$$\begin{cases} \sum_{i=1}^{N} \frac{G\pi d^4}{32L_a} \frac{(\beta_{0i} - \beta_i)}{b\cos(\beta_i - \varphi)} - G_s = 0 \\ \sum_{i=1}^{N} \frac{G\pi d^4}{32L_a} \frac{(\beta_{0i} - \beta_i)}{b\cos(\beta_i - \varphi)} \left[l_i \cos\varphi + (H_g - h_i)\sin\varphi \right] = 0 \\ H_0 = l_i \sin\varphi - H_g(1 - \cos\varphi) + h_i \cos\varphi + b\sin(\beta_i - \varphi) \\ i = 1, \dots, N \end{cases} \quad (6)$$

Solving by successive iterations the simultaneous equations (6) in order to obtain the horizontal position of the hull ($\varphi = 0$), the values of the static angles result. The iterations are generated by adjusting the initial angles β_{0i} . Consequently, the road wheel vertical loads are calculated using the following relation:

$$Q_{mi} = \frac{G \cdot \pi \cdot d^4}{32 L_a} \frac{(\beta_{0i} - \beta_i)}{b \cdot \cos\beta_{si}} . \quad (7)$$

Table 1 presents the results of the experimental data compared with calculated data.

Table 1 Vertical load of the road wheels – experimental versus calculated data

Road Arm	Experimental data			Qcalc [N]
	Q_{left}[N]	Q_{right} [N]	$Q_{average}$ [N]	
1	22143	24805	23474	24385
2	32762	31328	32045	32973
3	38218	36196	37207	37272
4	38804	37125	37964	36116
5	31381	32265	30658	30658
6	31428	31302	31365	30658
7	35686	35063	35374	35308
Total	**230422**	**228084**	**229253**	**228526**

It is mentioned that this model is directly applicable for suspension using only the torsion bar as elastic element. The spread of hydrogas suspension requires an especially dedicated model with respect to the non-linear characteristic of the individual suspension.

Despite the high accuracy of the calculated values, the main disadvantage of this analytical model cannot be ignored.

4. VERTICAL LOADS OF THE ROAD WHEEL FOR HYBRID SUSPENSIONS

The individual hybrid suspension consists of a road arm acted by both the torsion bar and the hydrogas element. The study of this type of suspension is convenient to be done using the multibody system approach. Thus, the specialised software Recurdyn (derived from ADAMS by the addition of several toolbox with pre-defined elements of the tracked vehicle running gear) represents a valuable option. The schematization of the hybrid suspension performed under Recurdyn is presented in Figure 5.

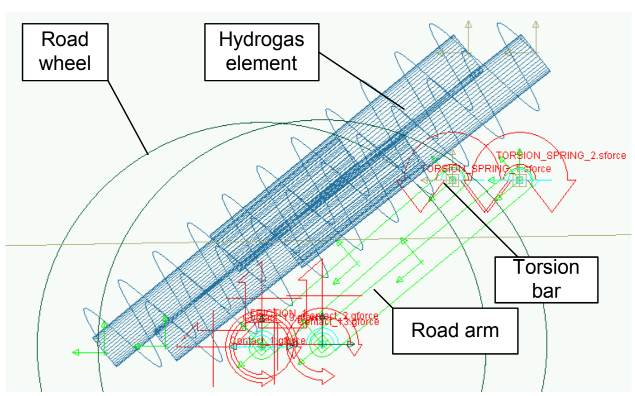

Figure 5 Individual suspensions of the virtual model (right and left road wheels)

The simulations include the study of the static position of the vehicle on a flat surface. The data obtained through simulation were compared with the data obtained by experiments.

5. MEASUREMENTS OF THE ROAD WHEELS LOAD AND THE PRESSURE DISTRIBUTION

The experiments were performed on a heavy tracked vehicle with 6 road wheels and double pin track. The method consisted of replacing a track pad with the device presented in Figure 6.

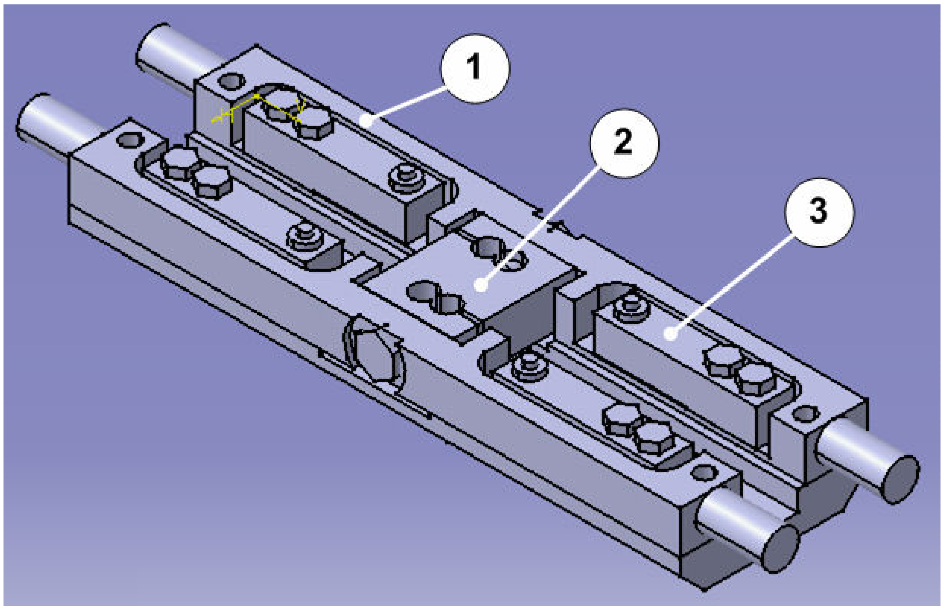

Figure 6 General view of the instrumented track pad

The geometry of the track pad was reproduced by the two pins, marked 1, interconnected through the strain gauge tension sensor, noted 2. This sensor allows the measurement of the longitudinal tension of the track.
The beam strain gauge sensors, marked 3, allow the measurement of the vertical force acting on the platform. If the weighting platform is placed upside, the vertical load of the road wheel is measured. In the situation for which the platform is placed downside, in direct contact with the soil, the pressure exerted by track on soil is measured.
Additionally, the platform (not represented in Figure 6) was equipped with two strain gauge diaphragm pressure sensors for direct measurement of the pressure.

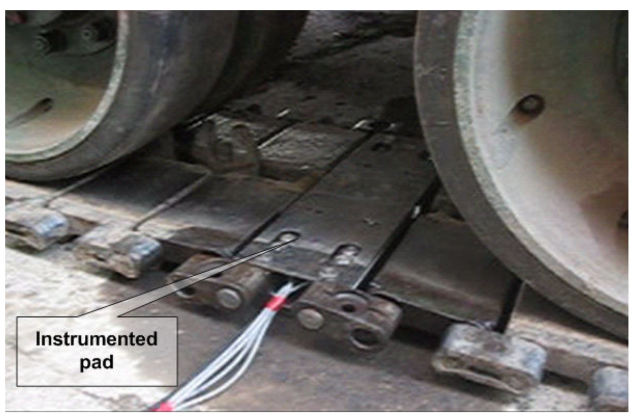

Figure 7 View of the instrumented pad insterted into the vehicle track

The instrumented pad was intercalated into the track (Figure 7) using the regular links; consequently, the longitudinal tension of the track was setup accordingly.
The signal collected from the stain gage sensors were recorded using a data acquisition system assisted by a portable computer.
The results are summarized in Figure 8, emphasising a good correlation of the measured data with data obtained through simulation. A narrow difference exists between the experimental data and the results obtained by using multibody approach.

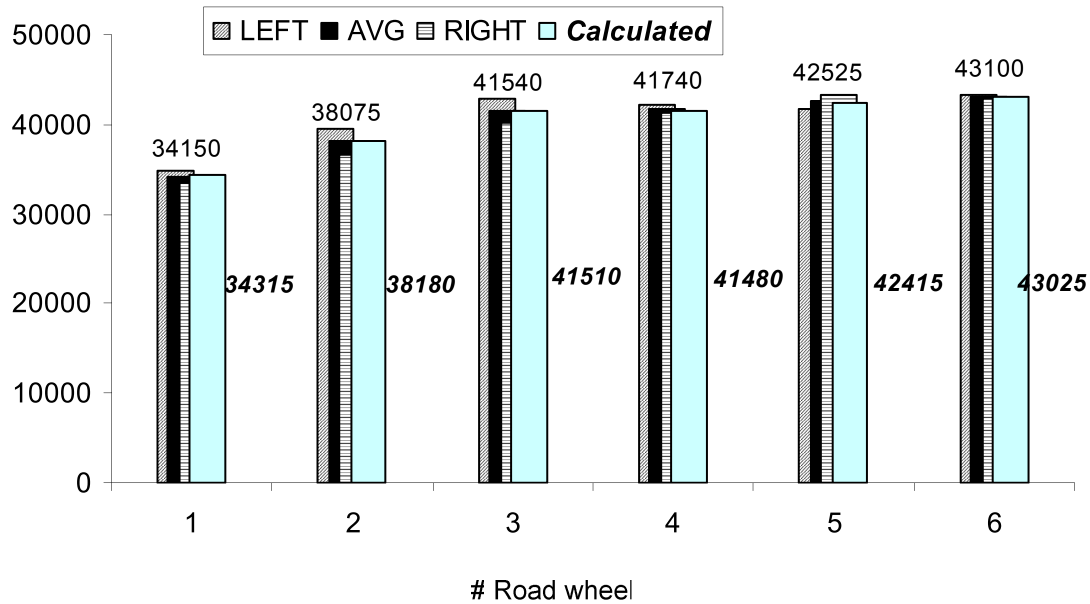

Figure 8 The vertical load of the road wheels - comparison of the measured data with the results of the simulation

As result of the above presented studies, the vertical load of the road wheels may be accurately calculated using adequate approaches.

6. CONCLUSIONS

The approach based on the multybody theory offers the best estimation of the vertical load of the road wheels. The usage of this method is facilitated by the release of several commercial specialised programs which allow enough flexibility in setting up the design parameters. Meanwhile, these programs are very useful in taking into consideration the structure of the modern suspensions.

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