THE RESEARCH ON THE DOUBLE SPRING EFFORT IN BRAKING PROCESS

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Abstract

A prototype double spring, consisting of the main four-leaf spring and the auxiliary two-leaf spring, designed for a truck (van) vehicles of a gross weight of app. 3,5 tons, makes the subject of considerations. This structural design is characterized by a clearance between the main and the auxiliary springs. The main objective of this work is to define the double spring strain during intense vehicle braking. A spatial FE shell double spring model has been proposed and it has been used for effort and deformation research on its selected elements, at combined load (vertical, horizontal forces and braking moment). Numerical tests have been performed within the quasistatic operation loads. The numerical analysis using those loads allows evaluating the braking force impact on the double spring operation and cooperation of the main and auxiliary spring leaves. Modelling and analysis issue, including contact issue, have been solved by means of the software package for engineering computation by MSC.Software. Results obtained from simulations allow evaluating the deformation of individual leaves of the double spring, stress concentration areas and preliminary identification of the suspension (drive axle) kinematics, particularly to define axis trajectory of the wheel. Selected numerical test results have been compared to the experimental test results.

Keywords: *FEM, numerical models, double multi-leaf spring, truck suspension, load in braking process*

1. Introduction

In design practices applied so far, an elementary theory of bending straight rods of variable section have been used for the spring calculations. It has been limited to vertical loads, excluding the impact of complex loads resulting from e.g. intense vehicle braking [9, 10]. Resistance computations for complex loads have been introduced only for the so-called safety leaf (master leaf). Development of computation technology, including general access to advanced computing systems, provides new possibilities of facilitating motor vehicle suspension design. This work presents the use of finite element method (FEM) for geometrically non-linear numerical analysis of a double spring for various load variants: vertical, horizontal and load torque. That kind of loads can be observed during intense vehicle braking or acceleration [8-10]. A prototype double spring (Fig. 1), combined of a four-leaf main spring and a two-leaf auxiliary leaf, designed for a group of trucks (vans) with a gross weight of app. 3.5 tons, makes the subject of considerations. Clearance (Fig. 1 and 2) between the main and the auxiliary springs makes the specific feature of this design solution. The tests carried out in the frames [1-3, 12] have confirmed that resulting stiffness of a complete spring depends on stiffness factors of the component springs, clearance size [2, 3] and relation between the lengths of the shortest leaf of the main spring and the longest lead of the auxiliary leaf. The studies presented in this work make a continuation of the double spring resistance analyses, discussed in works of the authors from the Military University of Technology [1-3, 6, 7, 12]. Presented models and results have been obtained due to the use of more advanced modelling and analysis techniques including contact issues that can be performed by means of the

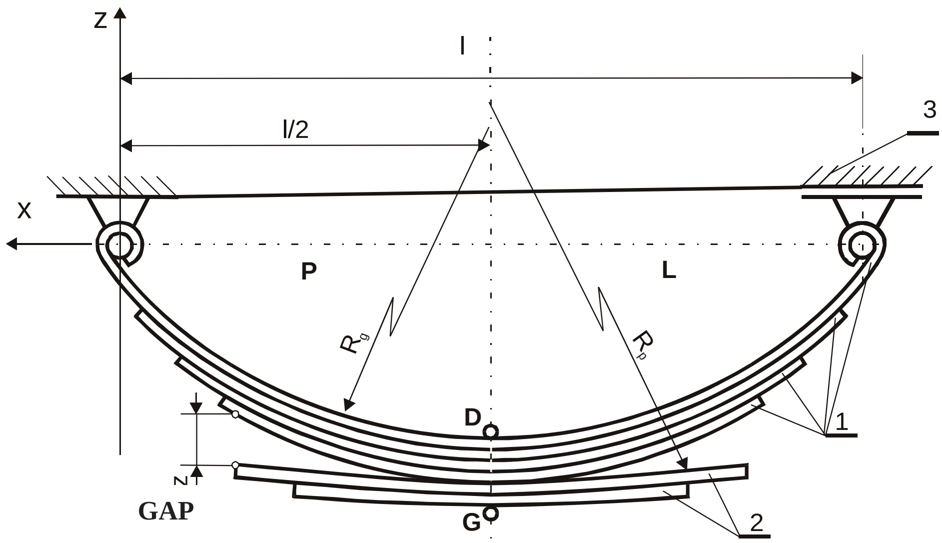

Fig. 1. A diagram of a rear suspension equipped with a double spring (without a hydraulic damper): 1 – main spring leaves, 2 – auxiliary spring leaves, 3 – vehicle frame, L(P) – left (right) spring side, D(G) – lower (upper) theoretical points of contact between the rear axle and the spring

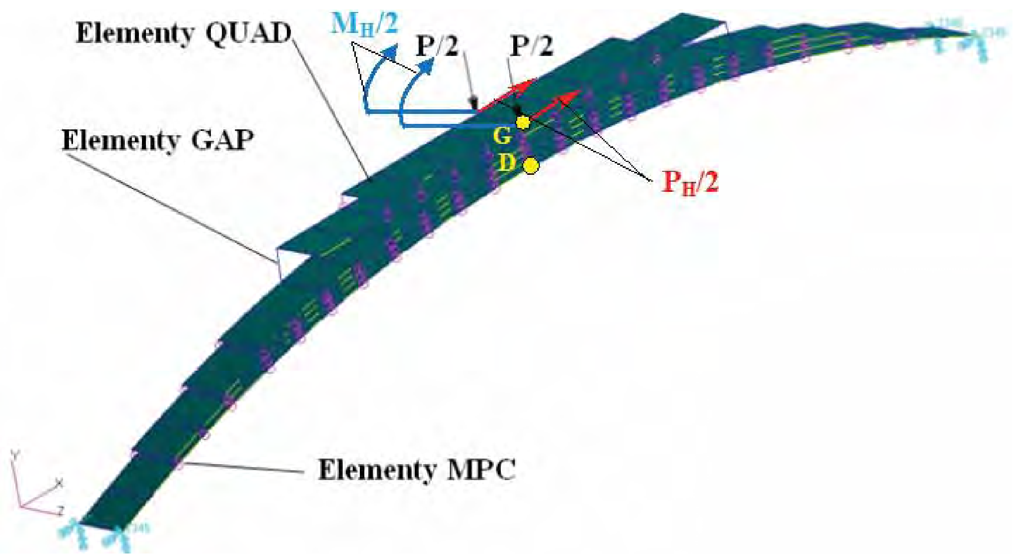

Fig. 2. Spatial shell double spring model with complex load diagram

engineering computation software package by MSC.Software [11]. A spatial FE model, described in the authors‘ publications [6, 7] that have analyzed various numerical FE model variants of a double spring and selected aspects of displacements and deformations of selected structure elements, has been used in this work. Various approaches in modelling the phenomenon of contact between individual spring leaves and their impact on the analysis results. Selected model test results have been compared to the experimental test results.

2. Numerical FE double spring model

On the basis of the test results presented in the authors' works [1, 6, 7] it has been decided that the use of the most simple beam spring models, requiring the smallest work expenditure at the preparation stage, leads to satisfactory results. The solid model, requiring the highest work expenditure at the numerical simulation preparation stage and the longest computation time, allows a detailed deformation analysis and straining individual leaves of a double spring. Spatial models provide better consistence of elasticity characteristics defined in numerical and experimental ways in their folding points i.e. in the spring bending section, when the auxiliary spring is engaged. This work uses a 3D model made of shell elements which combines the advantages of spatial solid models and the most simple beam models due to its simple structure and low 'numerical costs' related to the expenditure of work on modifications and short analysis times within the non-linear scope. Due to a need to make many computation variants with various load models, it has been decided to use the aforementioned 3D shell model. Examined numerical models discussed in this section of the work were made as deformable discrete models intended for the analysis by the finite element method (FEM) [1, 4, 5]. The models have been built by means of MSC.Patran processor [11]. QUAD4 type 4-node shell elements have been used for leaf digitalization, available in the MSC.Nastran software library [11]. The main and auxiliary leaves have been mapped by means of 1211 shell elements spread on a grid with 251 nodes. Beam elements of properly selected substitute characteristics have been used for mapping the screws pulling off individual leaves of the double spring. They have been spread on the nodes of extreme elements modelling individual leaves in the spring symmetry plane. Assumed elements modelling the pull-off spring screw have been 10-times stiffer than the auxiliary spring components.

Clearance between the main and the auxiliary spring leaves (Fig. 1 and 2), resulting from the geometrical and technological features of the examined spring, have been modelled by inserting 2-node GAP type elements between the nodes of adjacent spring leaves. Conditions of cooperation between the leaf tips and the adjacent leaves in two component springs have been mapped, as in case of a beam model, by means of special kinematic MPC type elements. It has been assumed that linear vertical displacements of adjacent spring nodes correlated with kinematic dependences are identical.

3. Numerical analysis – results

The numerical analysis of a double spring in 3D models has been made within a scope of non-linear statics by means of MSC.Nastran software [11]. Boundary conditions corresponding to the spring mounting in the vehicle suspension are shown on Fig. 1. A possibility of linear displacement along Y and Z-axes has been eliminated in the model nodes corresponding the edges of the longest leaf. Complex load in the spatial shell model has been defined in a form of a set of dense forces ($2*0.5P$, $2*0.5P_H$) and bending moments ($2*0.5M_H$) applied in the nodes of the crosswise symmetry plane of a spring of identical values (Fig. 2). Resultant vertical force value (P) has been changed within a scope of 0–10 kN. Dense forces $P_H=\mu*P$ have been defined for the maximum adhesion coefficient (dry concrete μ=0.7-0.8), while the braking moments $M_H = r_S * P_H$ have been defined for a static wheel radius (6.5R16C) r_S=0.34 m. Tab. 1 presents individual computation variants.

Tab. 1. Values of the load caused by the vertical force and forces occurring in the braking process for individual computation variants

P [kN]	P_H [kN]	M_H [Nm]
0	0	0
1	0.8	272
2	1.6	544
3	2.4	816
4	3.2	1088
5	4.0	1360
6	4.0	1632
7	5.6	1904
8	6.4	2176
9	7.2	2448
10	8.0	2720

Analyzed numerical models have been loaded only with vertical forces or complex load including components of the vertical and horizontal forces and the braking moment. The numerical analysis using those loads allows to evaluate the braking force impact on the double spring operation and cooperation of the main and auxiliary spring leaves. Fig. 3 presents a comparison of deformations, displacements and distribution of reduced stress defined according to the Huber-Mises-Hencky strain hypothesis (H-M-H) in a spring loaded only with vertical forces or complex load (vertical forces with corresponding forces and braking moments). Presented results have been determined in a load variant with the maximum vertical force P = 10 kN and in a variant with identical vertical force with corresponding maximum braking forces (Fig. 3). Taking the braking forces into account results in asymmetrical deformations of the examined spring. For the considered load variant, the auxiliary spring contacts the surface of the upper leaf of the main spring on the right side of the double spring and it is loaded with forces caused by the vehicle braking. This is the most strained area on the reduced stress diagrams and the maximum reduced H-M-H stress amounts to about 930 MPa.

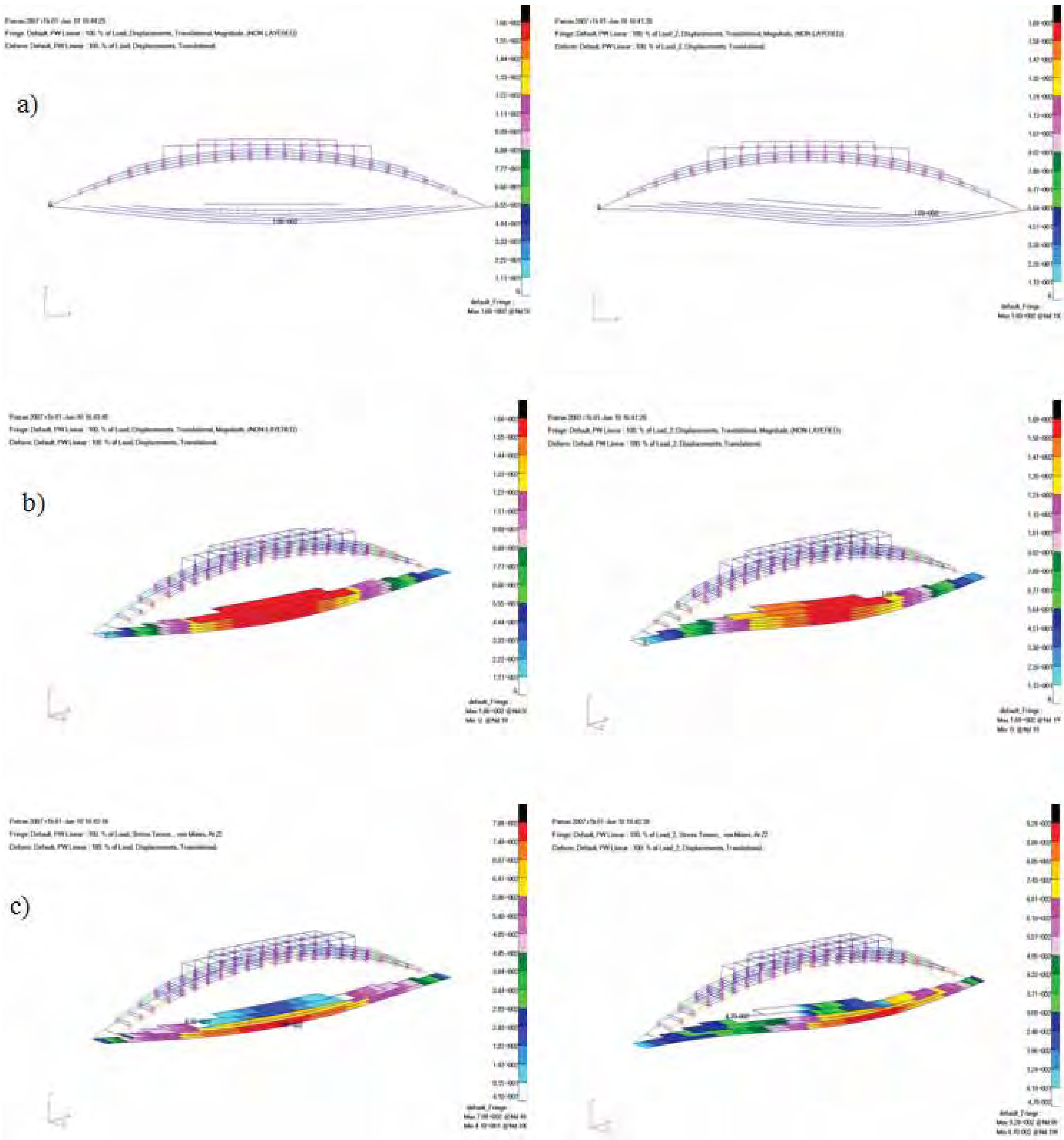

Fig. 3. Comparison of the numerical spring analysis results in two examined numerical load variants: vertical force P=10.0 [kN] and the vertical force with the braking forces P=10.0[kN], P_H=8.0 [kN], M_H=2720 [Nm]: a) deformations, b) resultant displacements, c) H-M-H stress

Figure 4 shows the comparison of the maximum reduced stress value variations according to the H-M-H hypothesis, determined in the leaves of the double spring loaded with vertical forces as well as vertical forces with braking forces. The maximum reduced stress values determined in the load variant with vertical forces and braking forces are higher all examined numerical cases. Relative differences of the maximum stress are higher at the first load stage when only the main spring is engaged. They obtain the value of almost 40% in case of the vertical load amounting to 4 kN. When the auxiliary spring is engaged, the relative differences of the reduced spring values are decreased for examined load variants (within a scope of vertical forces amounting to P = 6-8 kN). In case of the vertical load P = 10 kN the reduced stress values increase again, determined in the variant including the braking forces. The relative difference of compared values amounts to app. 16%. This effect should be interpreted because of generation of significant normal component stress values in the area of contact between the leaves of two component springs. It mostly refers to the area of the highest spring overload i.e. in the contact area where the auxiliary spring imposes a load on local leaves of the main spring assembly. Details have been illustrated on Fig. 5, where a fragment of the double spring model is shown in the leaf contact area for two load states.

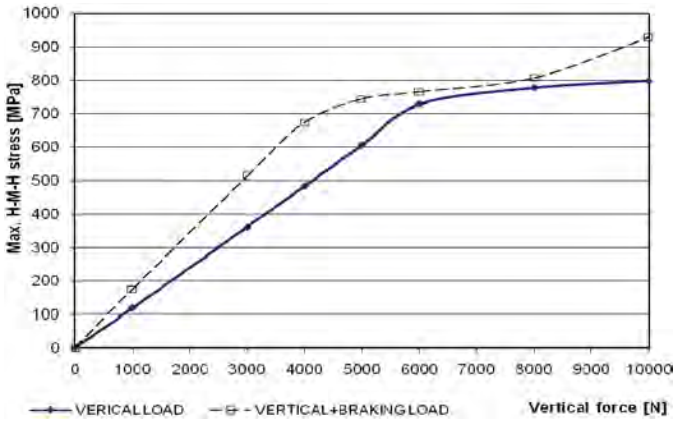

Fig. 4. Comparison of the maximum reduced stress value variations according to the H-M-H hypothesis in the double spring leaves loaded with vertical forces or complex load (vertical forces with the braking forces)

a)

b)

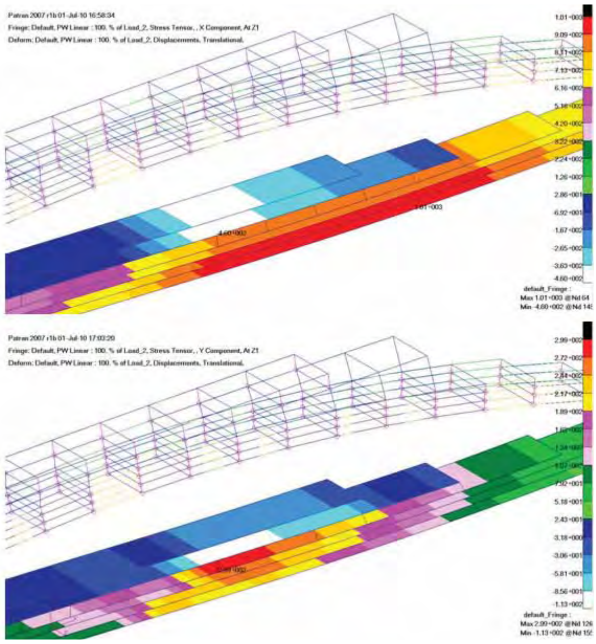

Fig. 5. Normal stress in the contact area of the auxiliary and the main spring leaves in the vertical load variant P=10 kN and corresponding braking forces: a) component σ_x , b) component σ_y

Normal stress σ_x and $\sigma_{y,}$ shown on Fig. 5, significantly differ as far as the value, signs and extreme location are concerned and can decide on local increase of the maximum reduced stress value, observed on the chart shown on Fig. 3.

Figure 6 presents the comparison of the maximum vertical displacement value variation for the double spring loaded with vertical forces as well as vertical forces and braking forces. The middle chart line describes the maximum vertical displacements, registered in the symmetry plane of the double spring loaded only with vertical forces P, variable within the scope 0-10 kN. The extreme curves on Fig. 6 correspond to the maximum vertical displacements registered in the left and the right end of the longer leaf of the auxiliary spring. Those curves have been determined based on results obtained in the load variants that also include the braking forces, apart from the vertical forces. The maximum vertical displacements defined for the right end of the auxiliary spring leaf (Fig. 1) are higher within the whole scope of examined loads. It means that the area, identified on Fig. 5 as the most strained one in the examined spring, is subject to significantly higher deformations. This conclusion can be also confirmed by the curve comparison, presented on the diagrams on Fig. 7, describing the variation of the clearance values between the auxiliary spring leaf ends and the surface of the upper leaf of the main spring.

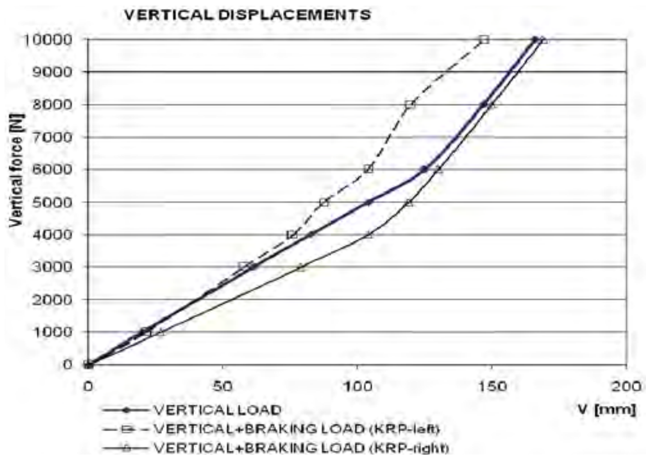

Fig. 6. Comparison of the maximum vertical displacement value variation for the double spring loaded with vertical forces as well as vertical forces and the braking forces.

The curves describing the clearance values (GAP) on Fig. 7 between the left end (L) and the right end (R) of the auxiliary spring leaves and the surface of the upper leaf of the main spring, loaded with the vertical and braking forces, have been mapped on the curve determined numerically in the spring loaded only with the vertical force (marked with V) and the experimental curve (marked with EXP) to show the clearance variations registered at the spring testing station [7]. Clearance variations illustrated by the curves L and R on Fig. 7 confirm that the clearance between the right end of the auxiliary spring leaf and the main spring is fully used up when the vertical force increases over 4 kN. However, the clearance between the left end of the auxiliary spring leaf and the main spring is not fully used up within the examined scope of load. This fact decides on forming a mechanism applying extra load on the contact area of the right end of the auxiliary spring and the main spring (Fig. 3-5).

Figure 8 presents a comparison of the wheels axis motion trajectories, determined as the envelopes of its further positions in the spring loading process, depending on the position of the wheel axis fixing node in point G or D (Fig. 1 and 2). It has been shown that the wheel axis fixing in the upper position (point G) affects the elongation of the wheel axis motion trajectory cooperating with the double spring during the braking process. For example, for the horizontal displacement V_{max} = 120 mm, difference between the point G and D amounts to app. 15 mm and has a growing tendency (Fig. 8).

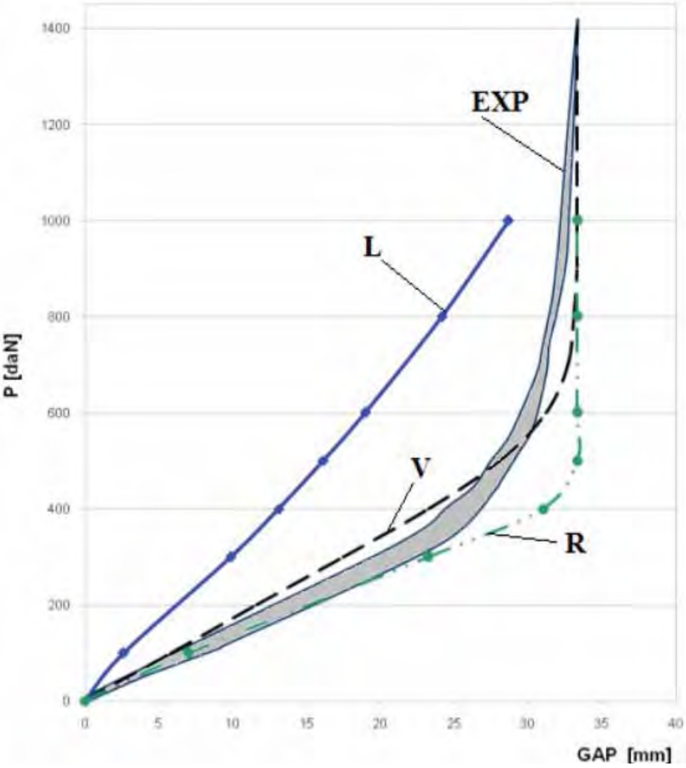

Fig. 7. Comparison of the maximum clearance value variation registered between the longer leaf ends of the auxiliary leaf and the surface of the main spring in various load variants: EXP – experiment results obtained for the spring loaded with vertical forces, V – model research results for the loads as in the experiment, L(R) – model research results for the complex load (vertical forces with the braking forces for the left (L) and right (R) spring size, GAP – clearance according to Fig. .1

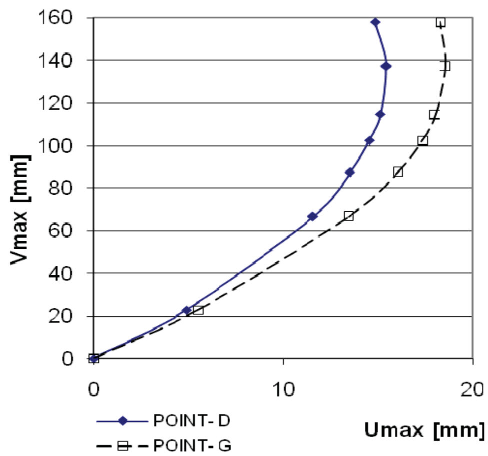

Fig. 8. Comparison of the wheel axis motion trajectories in the complex load process for the double spring depending on the position of the wheel axis fixing node according to point D or G (Fig. 1 and 2)

4. Final conclusions

Numerical test methodology presented in this work and applied FE shell model allow to examine the braking force impact on the double spring operation. Analyzed parameters describe the mechanism of cooperation between the auxiliary and the main spring leaves. Numerical tests have been performed within a scope of quasistatic operational loads and obtained results allow to evaluate the effort and deformation of individual leaves of the double spring, stress concentration areas and preliminary identification of the suspension (drive axle) kinematics, particularly to define axis trajectory of the wheel cooperating in that type of vehicle suspension.

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