MODELLING OF THE SYSTEM BRIDGE SUPERSTRUCTURE – MOTOR VEHICLE FOR THE COMPUTER SIMULATION

N. MALCOCI[1], B. CUTICO[2]

Rezumat. *Lucrarea prezintă metoda modelării dinamice: modelarea inerţială, elastică şi disipativă a motorului unui vehicul. Sistematizarea modelării este realizată cu scopul de a afla comportarea dinamică a ansamblului format de suprastructura punte şi motorul autovehiculului. Această modelare permite exprimarea echilibrului dinamic între două subsisteme principale: vehiculul în mişcare şi suprastructura punte.*

Abstract. *The work presents the methodology of dynamic modelling: the inertial, elastic and dissipative modelling of motor vehicles. Modelling systematization is performed in order to find out the dynamic behaviour of the ensemble formed by the bridge superstructure and a motor vehicle. This modelling allows to express the dynamic balance formed by two major subsystems: the vehicle in movement and the bridge superstructure.*

Keywords: Elastic coefficients, Composite materials, Elastic properties, Industrial domains

1. The dynamic modelling of the motor vehicle on wheels.

In special literature one can find extremely detailed analyses referring to the dynamic modelling of motor cars on wheels [1, 2, 3, 6, 7]. In fig. 1. [1] an idealized dynamic model of a motor vehicle which is composed of a suspensive mass, a frame and the body (considered as rigid structures); unsuspensive masses composed of wheels, bridges and the mechanisms connected with them is presented. The model also includes springs and dampers, interposed between the suspensive mass and unsuspensive masses and springs that represent auto tires mounted in model between the unsuspensive masses and the carriage body.

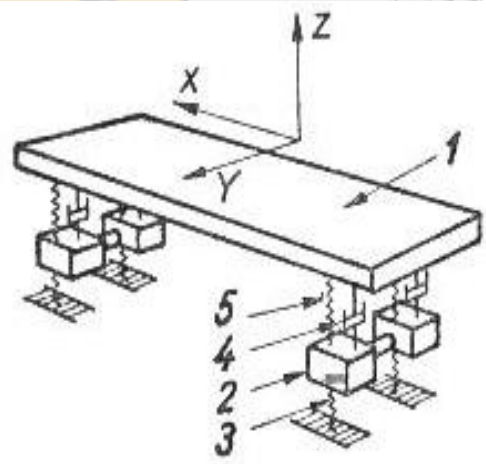

Fig. 1. The dynamic model for the motor vehicle [1]: 1 suspensive mass, 2 unsuspensive mass, 3 spring – (pneumatic) tyre, 4 spring - suspension, 5 damping - suspension.

[1] Ministry of Transport and Communication of the Republic of Moldova, (nicmalcoci2002@ yahoo.com).
[2] Technical University of Moldova.

Such a dynamic model has much more grades of freedom and the dynamic balance implicitly may be expressed during the moving of the motor vehicle by a system of equations with a great number of unknowns.

The specialists in the dynamics of the motor vehicles on wheels specify the following vibratory phenomena characteristic to a motor vehicle:

- vertical vibrations called jumps;
- longitudinal vibrations called throbs;
- rotational vibrations around the transversal axis of the motor vehicle called rocking vibrations;
- rotational vibrations around the longitudinal axis called rolling vibrations or rocking vibrations;
- turning vibrations around the vertical axis called gyrations or rotations.

These forms of vibrations are specific both the unsuspensive and those suspensive. Taking into consideration that at present the suspensions of motor vehicles hinder some vibrations which were described before, for example: the relative movement from the suspensive mass and the unsuspensive masses on a longitudinal and transversal direction, the gyration movement of a suspensive mass, the rocking and gyration vibrations of the unsuspensive masses as well as the fact that only the vertical vibrations of the body and the wheels and the rocking and rolling vibrations are important for the regime of vibrations of the motor vehicle, the reduction of the number of grades of the dynamic freedom and implicitly the reduction of the mathematical model are achieved.

2. The dynamic model used in the study of the vibrations of the motor vehicles.

When the analysis of the motor vehicles vibrations brought about by the differences in the level of the carriage road when moving with a constant speed is required, adequate dynamic models are achieved. Although the motor vehicle masses are continuously distributed, as a rule, in order not to complicate extremely the numerical calculations concentrated masses are used while achieving the dynamic model [5]: the suspensive mass – frame and body and non-suspensive masses for the wheels. In the case of a motor vehicle with four wheels an accessible model is presented in fig. 2.

Such a model stimulates the following motor vehicles:

- with an independent suspension in front and with a rigid suspension behind;
- with an independent suspension in front and behind;
- with suspensions on the rigid bridges in front and behind.

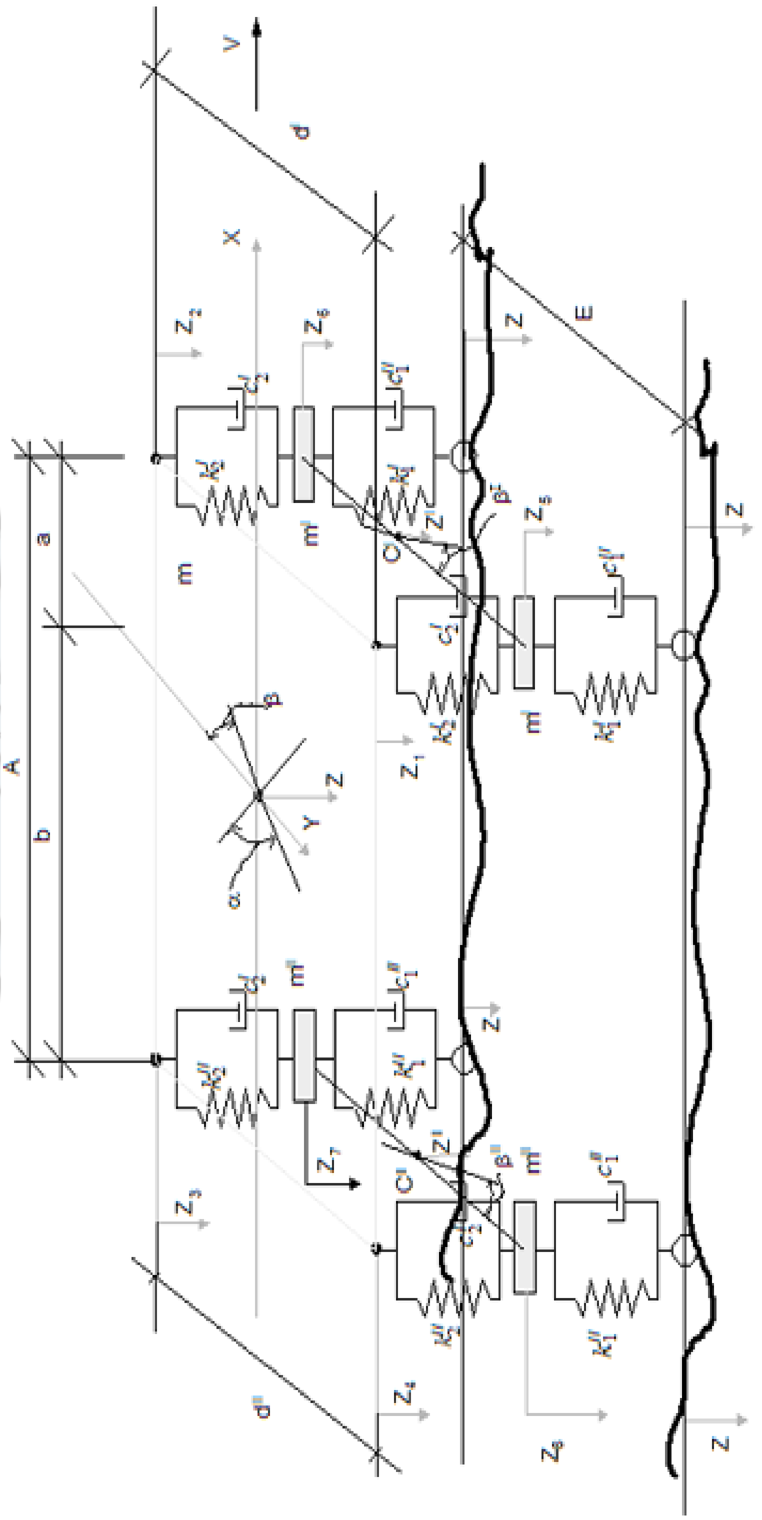

Fig. 2. The dynamic model of a motor vehicle.

At the motor vehicles with independent suspensions the notion of half-bridge is utilized by which the wheel and the elements which compose the non-suspensive mass from the right or left sides are understood.

Dynamic coordinates. The dynamic system in fig. 2. has seven grades of freedom marked with q_i (i = 1, 2, 3,...,7) changes of places expressed in generalized coordinates. If we mark with Z_r, α, β, β^I, β^{II} the changes of places in the system of coordinates *XYZ* then in accordance with the type of motor vehicle the following connecting relations are set up.

The motor vehicle with independent suspension in front and suspension on the rigid bridge behind (case 1):

$$q_1 = Z,\ q_2 = Z_5,\ q_3 = Z_6,\ q_4 = Z^{II},\ q_5 = \alpha,\ q_6 = \beta,\ q_7 = \beta^{II} \tag{1}$$

The motor vehicle with suspension on the bridge rigid both in front and behind (case 2):

$$q_1 = Z,\ q_2 = Z^I,\ q_3 = Z^{II},\ q_4 = \alpha,\ q_5 = \beta,\ q_6 = \beta^I,\ q_7 = \beta^{II} \tag{2}$$

The motor vehicle with independent suspension (case 3):

$$q_1 = Z,\ q_2 = Z_5,\ q_3 = Z_6,\ q_4 = Z_7,\ q_5 = Z_8,\ q_6 = \beta^I,\ q_7 = \beta^{II} \tag{3}$$

In the hypothesis of the small angular changes of places, among the changes of places Z_1, Z_2, ... , Z_8 and the generalized coordinates q_1, q_2, ... ,q_7 the following linear relations can be written.

$$\{Z\} = [A]\{q\} \tag{4}$$

where [A] represents the transformation matrix.

$$\{Z\} = [Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7 Z_8]^T \tag{5}$$

$$\{q\} = [q_1, q_2, q_3, q_4, q_5, q_6, q_7]^T \tag{6}$$

The rigidity and damping characteristics. The rigidity coefficients k_2^I, k_2^{II} as well as the damping coefficients c_2^I, c_2^{II} of the front and back suspensions can be determined experimentally. For this the centres of the motor vehicle wheels are fixed rigidly and after the production of a shock to the suspensive part (unexpected rising) the free vibrations of the suspensive mass are registered. The frequency of the vibrations f and the logarithmic decrement of the damping Δ are determined from the vibration registration. If we mark with m^I the suspensive mass that is recurrent to the front suspension then the rigidity and damping coefficients are calculated from:

$$k_2^I = 0.5 m^I f^2 (\Delta^2 + 4\pi^2) \tag{7}$$

$$c_2^I = m^I f \Delta \tag{8}$$

The rigidity coefficients of the tires $\left(k_1^I \text{ si } k_1^{II}\right)$ can be determined by attempts to compression, starting from the loading forces corresponding to the position of static balance of the motor vehicle. In situations when the loading is performed in dynamic regime, the coefficients of damping as functions of frequency loading can be determined from the curves of hysteresis. Functions are recommended:

$$c_1^I = \frac{0.1k_1^I}{2\pi f} \quad \text{and} \quad c_2^I = \frac{0.1k_1^{II}}{2\pi f} \tag{9}$$

3. Modelling of the construction systems (of the bridges).

At present it is known that the principles of the modelling of the construction system represent fundamental requirements in the construction dynamics, because these principles can't be generalized. In many cases an inadequate model can bring to satisfactory results if we take into consideration the economic aspects of the analyses on one hand, and, on the other hand, if this modelling was certified practically in time as well. Therefore, in case of modelling of a construction structure as a result of achieving a dynamic analysis, there exist many subjective situations that stick to the experience of the person that performs the analysis or the scientific limits achieved at a given moment in this domain. Taking into consideration the physical properties, the dynamic models may be linear and non-linear systems. Handbooks on specialty largely present models of system behaviour in close connection with the properties of the materials from which these consist of, for example; linear systems, non-linear systems, linear-elastic systems, non-linear-elastic systems. From the point of view of inertia we shall analyze the systems with the mass continually distributed and the systems with discrete mass obtained by corresponding modelling of those with distributed mass. As concerns the elastic modelling of the systems we shall use the method of evaluation of the rigidity properties proportionally to the dynamic characteristics. The method of calculation is the method of dynamic rigidity matrix, the equations of balance express, in fact, the condition of the simultaneous dynamic balance on the direction of GLD. Practically the method of the finite element is used. Consequently, the specificity of the method consists in the substitution of the continued structure with a model of calculus formed from an ensemble of discrete elements, finite elements connected in a finite number of points. As the calculus concerns it is necessary to set up a model configuration through a geometric definition defining more accurately the coordinates of the nodes in proportion with a certain system of reference and through a topologic definition for every bar defining the nodes between which it is found. It is necessary to define more accurately with initial data the geometric characteristics of the sections of the bars, the structure connections with the outside (parts) and the loadings. In the spirit of the method of changing places the unknowns are represented by the changing of places of the nodes, and the basic system is obtained by the blocking of the nodes.

The general equation of the method of changing places is [4]:

$$[k]\cdot[D]=\{P\}, \tag{10}$$

where [k] is the matrix of rigidity of the structure; [D] – the vector of the nodal changes of places; $\{P\}$ - the vector of forces.

The dynamic analysis of the construction supposes the achievement of a mathematical model constituted by entities that will point out the elastic and inertial characteristics of the system from the equations of balance by means of which we must determine the proper ways of vibrations. The proper throbs are the solutions of the algebraic equations:

$$\det([k]-\omega^2[m])=0, \tag{11}$$

where [k] is the rigidity matrix of the system, and [m] the matrix of inertia.
The system of equation (11) are *n* real positive and distinct roots: $\omega_1^2,\ \omega_2,\ \ldots,\omega_i^2,\ \ldots,\omega_n^2$.
A proper form corresponds to each own throb ω_1^2 a proper vector $\{w_i\}$ with real elements w_i, so as the matrix relation be satisfied.

$$([k]-\omega_i^2[m])\{w_i\}=0 \tag{12}$$

Own vectors $\{w_i\}$, named also modal vectors, are unique in the sense that the proportion between two arbitrary w_{ji} and w_{si} is constant. The value of the elements is relative because equation (18) is homogeneous.
The analytical modelling is realized at present by means of the electronic computer utilizing calculating programs of extremely performance: ANSYS, ALGOR, COSMOS, SAP etc.

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