NUMERICAL STRENGTH ANALYSIS IN VEHICLE DESIGN

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Abstract: The methodical bases of numerical strength analysis of body frame arrangement in vehicle design have been developed which make it possible for a designer to reach a scientifically proven decision on geometrics of vehicle styling subsequent to the results of body frame arrangement evaluative research.
Hardware and software which are used in design and preproduction of industrial goods and vehicles are continuously being upgraded. Features of software tools with regard to electronic geometrical modeling and numerical reverse engineering are widening. Advanced software systems for engineering research have simplified the problem of initial data preparation and carrying out some numerical studies to the extent possible. There is a real possibility to apply numerical engineering evaluations in preconceptual design works at the early designing stages. That may be demonstrated by the example of frame arrangement design of light vehicles, such as tricycles and all-terrain vehicles. Frame arrangement functions as load-carrying elements, and it bears great aesthetics load in terms of development of original and attractive exterior of the vehicle.

Under aggravated competition in the field of design at car market and hard time constraints as to performance of design works, frame structural solution of vehicle body stipulates a particular approach to its styling. The approach is associated with solving the design problems and production of complex exterior styling of the body with prompt potential modification of body style provided at the same time in line with constantly changing demands of car market. In order to solve the problem it is required to arrange the system of CAD components so that a designer could handle the posed problems as efficiently as possible. Rod-shaped frame geometrics provides means for a designer to make evaluative strength calculations already at the designing stage via modern finite-element calculation packages that is available through use of rod-shaped finite-element model. The model is simply and quickly generated, and number of the model units is by one order lower compared with surface finite-element model applied when modeling the body made of sheet metal. Rod-shaped elements in finite-element model provide ease of variation of the model geometrics and physical specification of the materials that is important in the search of a satisfactory combination of styling composition characteristics and strength characteristics of the structure. All that reduces time expenditures on preparation of initial data, performance of numerical strength studies and making an efficient decision of the structure.

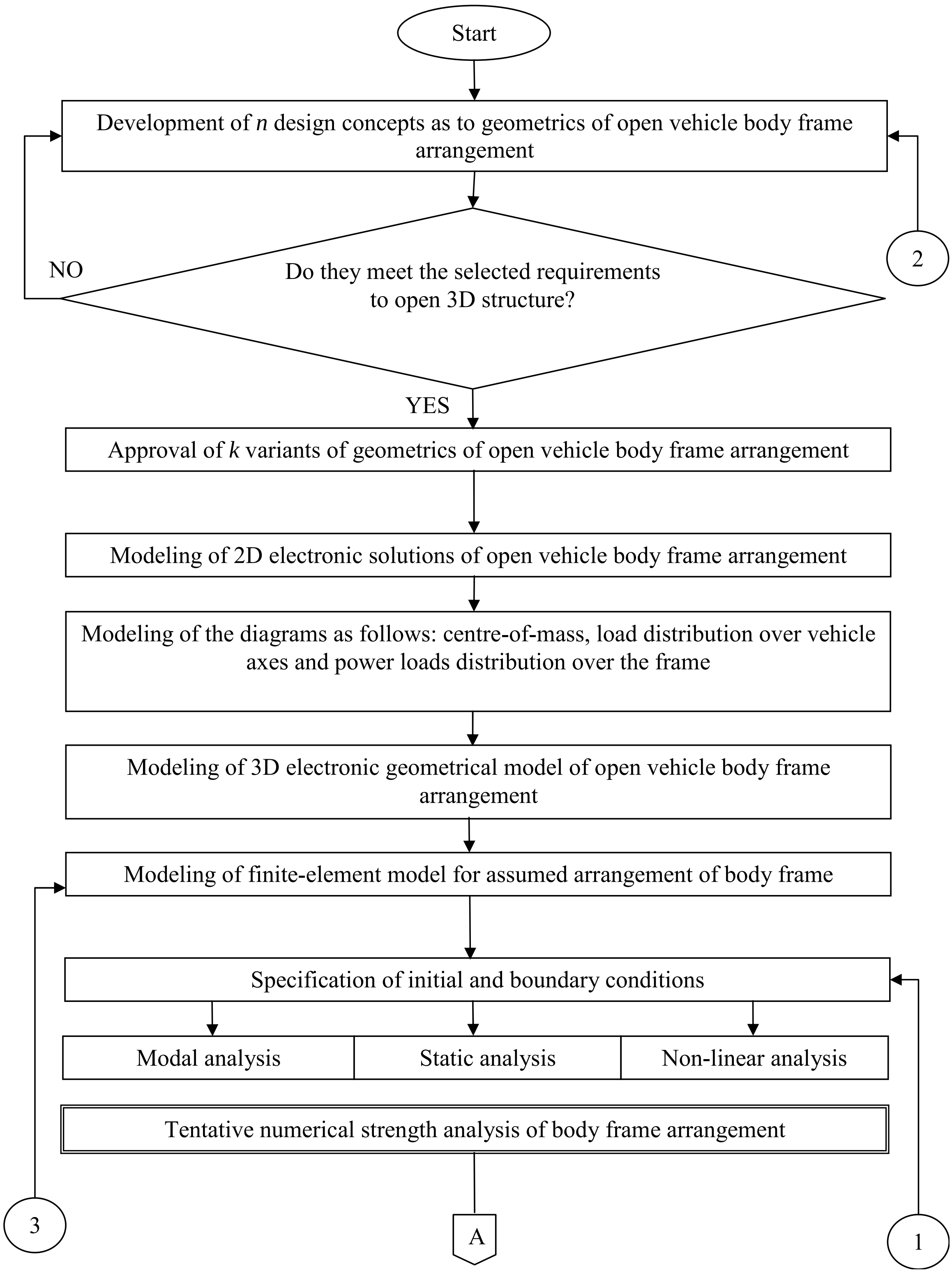
Flow diagram for design of vehicle body frame arrangement using evaluative strength analysis is shown in figure 1.

Based on the data of performance specification, researches, structure and ergonomics solutions of the vehicle, the designing stage [1 to 3, etc.] shall begin with development of *n* concepts as to geometrics of vehicle body frame arrangement that is embodied in numerous sketches and drafts. For the further working the project on, *k* body frame solutions shall be approved which shall meet the selected requirements to open 3D structure [4], such as, organized nature, information content, expressiveness, singularity, imagery, conformity to style and fashion, order and sequentialization of the parts. Overall parameters of frame arrangement shall be determined with due consideration of harmonization of proportional and rhythmic characteristics.

On the basis of hand-made sketches electronic vector representation of vehicle body frame shall be generated. By means of frame representation its 3D electronic geometrical model (EGM) shall be built up, as well as centre-of-mass diagram and diagram of assumed operating loads distribution (points of support, load application, anchorage of engine and power plant and passenger seats, etc.) shall be developed [5, 6].

For accelerated design of vehicle frame with potential active modification of the structure it is efficient to perform evaluative numerical reverse engineering of EGM generated using CAD systems (CATIA, UNIGRAPHICS, SolidWorks, etc.) and corresponding calculation and analytical tools of CAE systems (ANSYS, NASTRAN, etc.) [7, 8]. In order to make evaluative strength analysis of vehicle load-bearing frame based on frame arrangements the application of rod-shaped elements is seemed to be effective and sufficient to make adequate calculations. Simplicity of electronic mathematical (parameter-oriented) and design finite-element models of vehicle rod-shaped frame makes it possible to obtain for analysis the target displacement, stress and strain fields within small period of time already at the designing stage provided accurate specification of initial and boundary conditions [5].

While preparation of vehicle body frame arrangement EGM to strength analysis and interpretation of calculation results the following technical guidelines are to be taken into account.



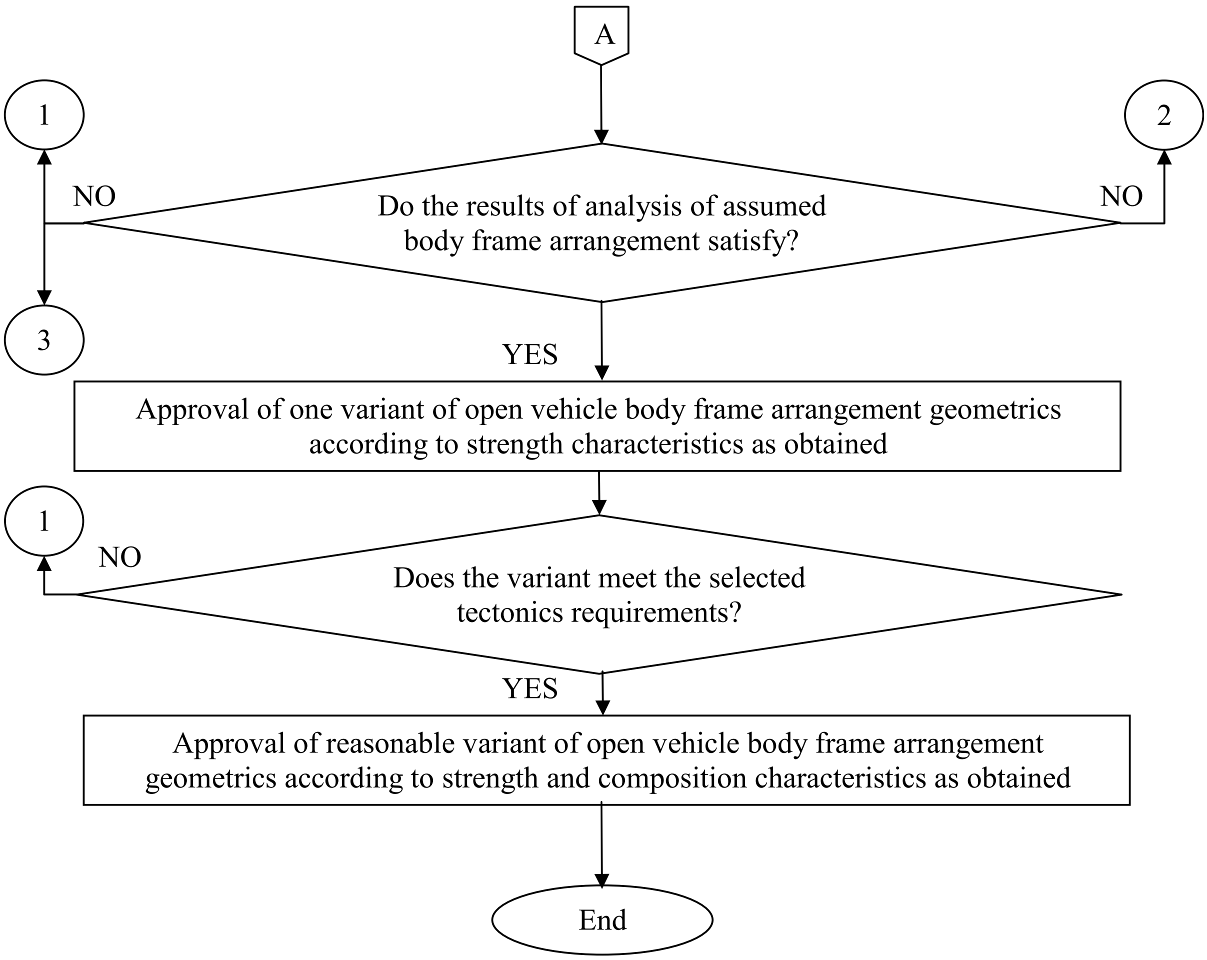


Figure 1: Flow diagram for design of vehicle body frame arrangement

1. Requirements to general geometrics of mathematical (parameter-oriented) model [7, 8]**:**

1.1) the model shall meet the requirements of ISO 10303 Production automation systems and their integration. Product data representation and the data exchange;

1.2) type of the model - frame (curve);

1.3) software applied for model generation – CAD-systems;

1.4) model parameters:

1.4.1) standard graphic display – format of software system, the model has been generated with, and IGES, STP formats (common international standards for storage of electronic information);

1.4.2) units of measurements – mm;

1.4.3) working scale – 1:1;

1.4.4) model accuracy parameters – linear and angular tolerances of 0.005 mm and 0.1° respectively;

1.4.5) max dimension of the model – 20,000 mm;

1.4.6) the model designed by outsourcers shall be used for further development with inherent parameters;

1.5) the model file size shall be the smallest possible:

1.5.1) geometrically coincident elements of the plotting within the range of linear and angular tolerances shall not be applied;

1.5.2) active elements of the geometry analysis and filling of geometry elements of the model are not allowed;

1.5.3) the model shall have consistent topology (i.e. it shall have sharp main generating surfaces, fillets and chamfers);

1.6) quality of the model topology shall be as follows;

1.6.1) breaks and uneven generating lines shall not be used (save specific cases);

1.6.2) the models shall not have breakthrough between elements and self-intersection of the elements;

1.6.3) the model geometry shall not have breakthrough with linear and angular tolerances of 0.005 mm and 0.1° respectively;

1.6.4) divergence between the model and measurement results shall not exceed 0.02 mm;

1.6.5) divergence between setting (check) points of the model and drawings as provided shall not exceed 0.02 mm;

1.6.6) consistent model topology;

1.7) as a global coordinate system of the vehicle model a coordinate grid used for design of the vehicle arrangement shall be applied where coordinate axes are the intersection of three surfaces: vehicle plane of symmetry (ZOX); vertical plane (ZOY); horizontal plane (YOX);

1.8) in software system format, the model has been generated with, some specific schemes of layer-based distribution of the information on different variants of the configuration in EGM structure shall be applied;

1.9) specific schemes of the model file designation according to corporate requirements shall be applied.

2. Requirements to procedure of model poly-element generation for further finite-element breakdown:

2.1) minor structural elements which have no significant influence on calculation results shall be removed;

2.2) geometric primitives shall be structurally reconfigured (without change in general model shape) with the primitive junction points created strictly based on their end points that is required in order to provide secured generation of corresponding general units while finite-element breakdown.

In terms of strength analysis a vehicle body frame arrangement shall be designed as non full-strength over different force impact vectors, that is stipulated by service environment and requirements to driver and passenger's safety. At vehicle operation the basic operating loads act at right angle to road surface (Z-axis of vehicle system of coordinates), therefore, in this direction the pipe-shaped frame shall have the highest structural strength. Along the vector of vehicle movement direction, non full-strength of the frame complies with generally accepted driver and passenger passive safety principles. In order to provide damping of short-term force impact when accident a rigid central load-bearing chamber and less rigid front and rear areas of the body frame are to be built up.

While operation frame arrangement of a vehicle is under static and vibration loads and short-term impact force actions in the event of crash. Type of the strength analysis to be performed and, therefore, initial and boundary conditions are determined by expect data which are to be received as a result of calculations.

The simplest type of calculations which can be used with regard to body frame arrangement is modal analysis. After the spectra of free frequency for different variants of the structure are defined and one variant with the highest free frequency is selected it may be preliminary concluded which frame of the considered variants has the most strength.

The initial data for static strength analysis are mass loads which act at the body from engine and power plant, driver, passenger and hanging-on parts. The boundary conditions are reaction of the supports acting on the frame from roadway and transmitting to the frame through suspension. The feature of modeling such loads in case of body frame arrangement is that they may be considered as point loads, since they act through auxiliary reinforcement anchorage points. Static analysis may reveal already at the designing stage which frame areas are subject to the most strain and required to be modified. With regard to frame arrangement a non-linear strength analysis of response to impact loads may be used. This is more complex research which requires a lot of time for data preparation and sufficient knowledge on assumed physics of the process.

In the course of evaluative analysis of strength research results there is a possibility to make prompt changes into frame model geometrics within integrated environment of CAE-systems by means of standard procedures for obtaining satisfactory results.

The results of finite-element modal analysis (initial vehicle mass parameters for the analysis are shown in Table 1) of five different variants of small-size vehicle frame with regard to the first four modes of the structure free frequency are shown in Tables 2 to 6.

Table 1: Mass parameters of vehicle units

Name	Mass, kg
1. Engine and power plant	50
2. Seats	18
3. Rear wheels	20
4. Front wheels	20
5. Passenger (95 %)	96.5
6. Driver (95 %)	96.5

Table 2: Wagon-type vehicle frame

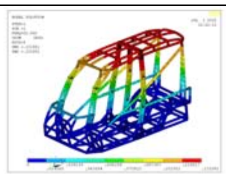
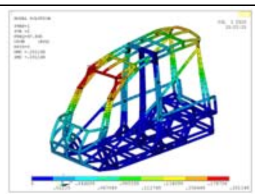
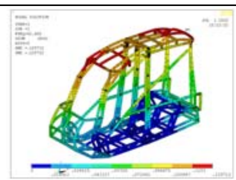
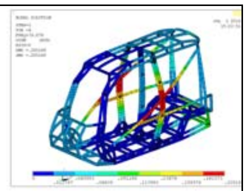
Visuali-zation				
Mode No.	1	2	3	4
Freque n-cy, Hz	22.043	47.845	61.663	76.078
Max displac e-ment, m	0.131	0.201	0.12	0.205

Table 3: Wagon-type vehicle frame

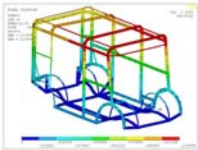
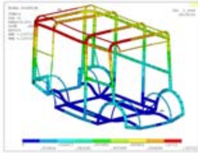
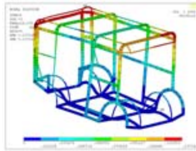
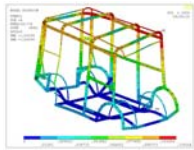
Visuali-zation				
Mode No.	1	2	3	4
Frquen-cy, Hz	12.29	19.872	26.078	34.374
Max displac e-ment, m	0.113	0.121	0.137	0.116

Table 4: Automobile-type vehicle frame

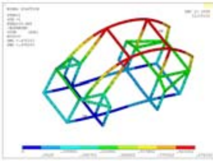
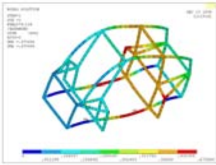
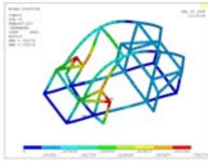
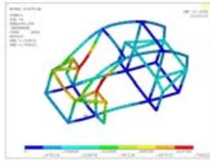
Visuali-zation				
Mode No.	1	2	3	4
Freque n-cy, Hz	25.486	74.124	87.627	88.258
Max dislace -ment, m	0.476	0.471	0.755	0.704

Table 5: Automobile-type vehicle frame

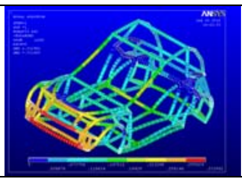
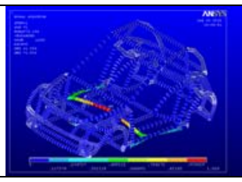
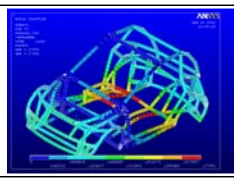
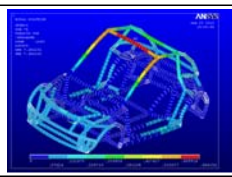
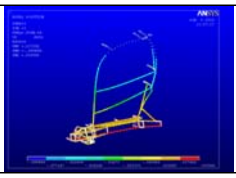
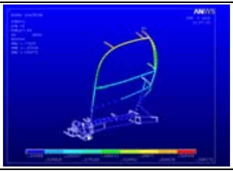
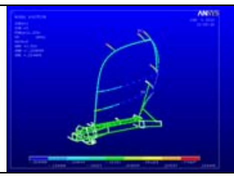
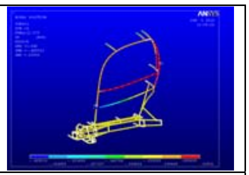
Visuali-zation				
Mode No.	1	2	3	4
Freque n-cy, Hz	53.452	76.196	81.042	94.968
Max displac e-ment, m	0.332	1.056	0.38	0.686

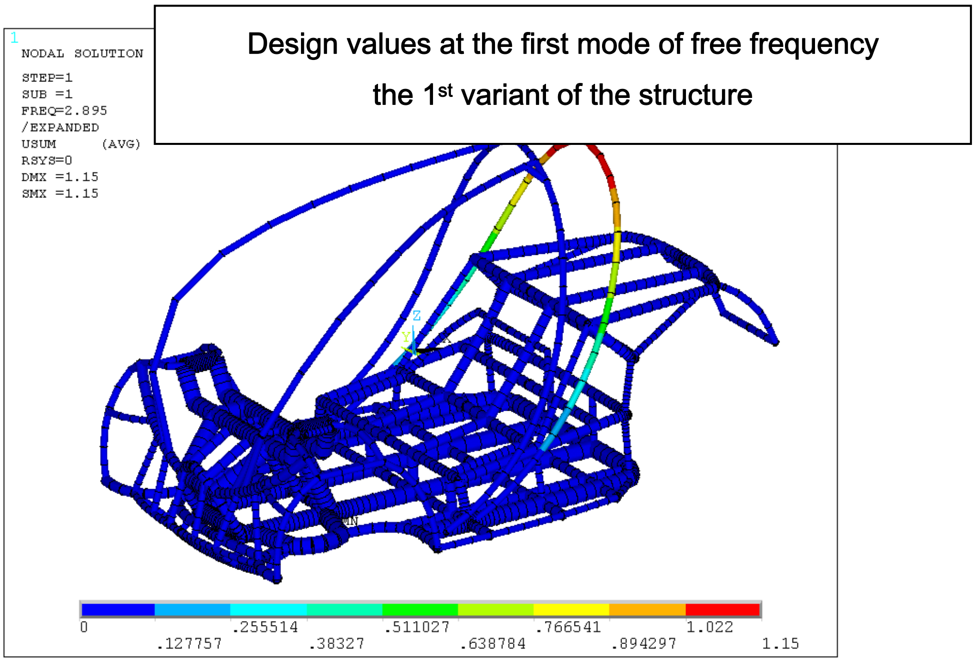
Table 6 – Automobile-type vehicle frame
(for the purposes to simplify the analysis a half of symmetrical frame is used)

Visuali-zation				
Mode No.	1	2	3	4
Freque-n-cy, Hz	0.904e-4	7.84	11.294	12.975
Max displac-e-ment, m	0.537	0.776	1.501	1.642

Modal analysis can be used in order to detect underreinforced areas of the structure. Fig. 2 shows the results of the modal analysis performed for two variants of the structure with non-reinforced and reinforced upper rear forming arc of the vehicle frame. The arrows point at design values to which a designer shall pay attention when making a comparative analysis:

– value of the first mode of free frequency for compared variants of the structure (the higher frequency, the higher total rigidity of the structure);

- max values of local strain at the first mode of free frequencies and their localization over the structure.



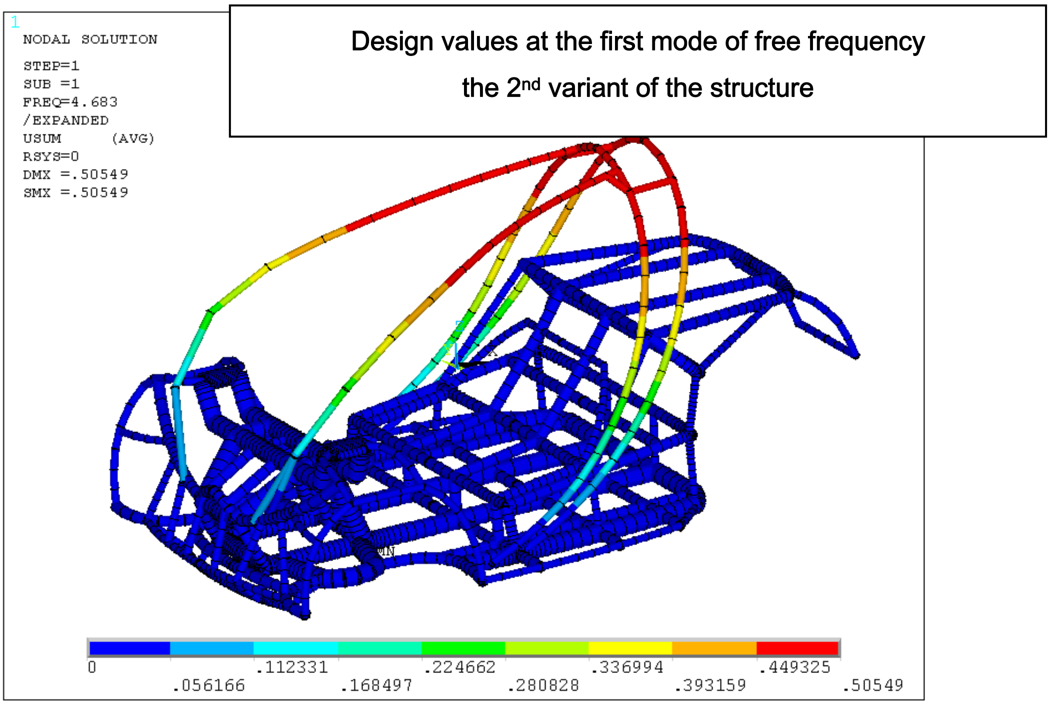


Figure 2: Results of comparative evaluative modal analysis of frame arrangement

Table 7: Design values of modal analysis

Variant	Free frequency, Hz	Max strain, m
1	2.895	1.15
2	4.683	0.5

Comparative evaluative analysis of the design values has revealed (refer to Table 7) that after the upper beam has been added between forming arcs the rigidity of the structure greatly increased that can be judged due to:

– increased first mode of free frequency (from 2.895 to 4.683);

– decreased max strain (from 1.15 to 0.5);

– involvement of much more area of the structure into strain resistance (3D color diagram of the structure strain distribution).

The developed method of body frame arrangement strength analysis in vehicle design made by means of CAD components makes it possible for a designer to reach a scientifically proven decision subsequent to the results of body frame arrangement evaluative research regarding vehicle styling geometrics; also, it improves the total efficiency of design works for further research and reduces the number of engineering faults at designing stages.

The data of strength calculations for the assumed variants of frame arrangement are the ground for making changes or approving design proposals as to vehicle body geometrics. Information about strength response of the structure to the loads implied provides a means to alter or specify geometrics of vehicle body frame under the selected tectonics requirements [4], such as, tectonics, ductility, functional and design conditioning, and to specify the parameters of the body frame as well. These evaluative procedures as to meeting the geometrics of open vehicle body frame to the requirements of open 3D structure and tectonics are interchangeable, and a designer can determine their sequence through initial design data and final results achieved.

Conclusion

Following the results of the research performed a designer can reach a scientifically proven decision on styling geometrics of the vehicle body frame arrangement at the designing stage which is determined by composition characteristics based on results of evaluative strength research. Synthesis of design and technical approaches used while selection of geometrics of vehicle body frame arrangement provides a means to reduce the number of engineering and technological faults which arise while designing, to improve the efficiency of research and development, and considerably cut time and material expenditures for their performance.

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