Migration of Computational Models in Virtual Prototyping of Complex Mechanical Systems

Jarosław Tokarczyk

Abstract—**The method of creation of computational models using the Multibody System (MBS) as well as the finite element method (FEM), is presented on the example of virtual prototyping of the mechanical system used in underground coal mining industry. Arch yielding support together with highly loaded bearing systems for suspended monorails, generating dynamic loads during passage, is one of such systems. The results of dynamic loads to the support, tested in the laboratory according to the PN-92/G-15000/05 Standard, were compared with the selected criterial state, which includes support arches overload i.e. emergency braking of the transportation set, which carries large-size materials. The limit overloads causing local loss of arch support stability have been calculated.**

Index Terms— **Virtual prototyping, finite element method, Multibody system, dynamic load**

I. INTRODUCTION

BUMPING initiated by rock quake is the most dangerous natural hazard in Polish hard coal mines. Sudden reduce of roadway cross-section i.e. deformation of arch support can be the result. The load to arch support coming from rock mass is a subject of the research. There are the methods for simulation or calculation how the rock mass behave itself during a seismic quake [1]. For that purpose the special software using Discrete Elements Methods: UDEC, 3DEC or FLAC is used [9]. As regards the strength criterion [8], it is possible to generate impact load in the special testing facility [4] due to the problems of identification of dynamic load of arch supports in in-situ conditions. The requirements, which the testing facility has to meet as well as the method of loading the support, are given in standards [5].

In Poland, in all the mining underground plants the roadway yielding supports, which are made of steel arches connected with fasteners and clevises, are used. The support task is to keep stability of the roadway in a given time, what means keeping required dimensions of roadway cross-section as well as protection working people and machines against falling rock pieces and against roof falls. In Fig. 1 3D geometrical model of yielding arch support, created in CAD software environment, is given.

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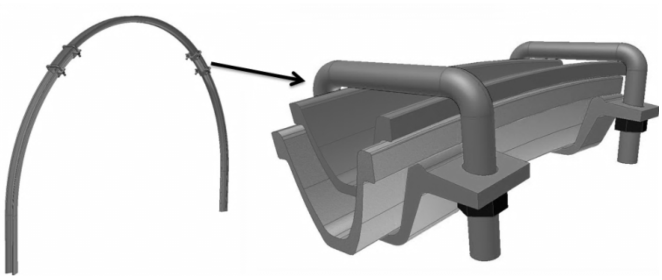

Fig. 1. Geometrical model of yielding arch support.

The arches of the support are pressed to each other by clevises generating static friction force between them. Possibility of suspension of additional equipment like hoisting winches or suspended monorail tracks, which cause dynamic load, is another function realized by the yielding arch supports. The Multi-Body System was used for simulation of load values.

In Poland, according to current regulations the amount of static load to single frames of arch support cannot exceed 40 [kN] [6]. Identification of dynamic overload, in a result of suspended monorail passage, acting on a single frame of arch roadway support, is one of simulation objectives. The monorails are used for transportation of materials and miners. They became dynamically developing technical mean used in the Polish underground mining industry [2]. However, increasing weight of transported large-size loads causes increase of overloads to suspended monorails tracks, what means higher load to rail joints, suspensions and finally to the frames of arch supports.

Identification of places of the highest strain, where damage can happen during operation, is the objective of virtual prototyping for the strength criterion at the stage of designing or verification of the mechanical system consisting of such components as a transportation unit, a railway route and arches of roadway support. Active forces and reaction forces during machine operation should not result in yielding of the material, which the machine components are made of. That is why in calculation models linear models of materials are most often used. Non-linearity of calculations is a result of contact phenomenon as well as due to complex load state of the computational model. General procedure of strength calculations is given in Fig. 2.

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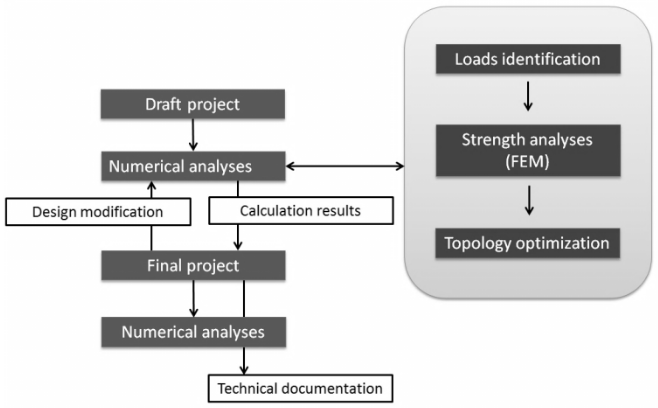

Fig. 2. Diagram of operations during virtual prototyping of mechanical system.

Designing process starts from a development of preliminary design, which is then verified using the special software tools. At this stage improvement of a design, except of elimination of design errors, is very important. For the selected criterial states the load conditions are identified. In the case of complex load conditions, additional initial calculations are made. In the case of dynamics problems, the Multibody System method (MBS) is used. It enables determination of such amount as: force (*F*), force momentum (*M*), acceleration (*a*), speed (*v*). In the case of elastic-damping joints, it is necessary to determine stiffness coefficient (*c*) as well as damping coefficient (β), which will be used in the computational model. Then the results as input data are entered as boundary conditions for strength calculations, Fig. 3.

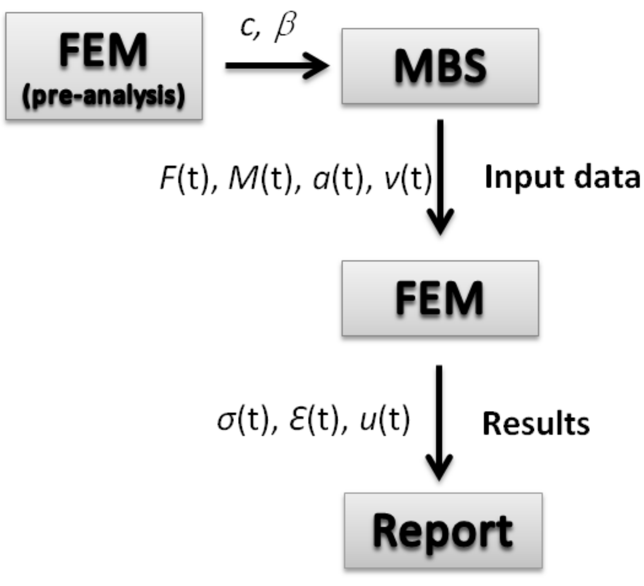

Fig. 3. Data flow between MBS and FEM software.

The obtained results of the strength calculation enable to optimize the design. Most often minimization of weight, at limitation of maximal reduced stresses and limitation of maximal displacements at selected points of the structure is the target function. Then current design is modified. In many cases the process has feedback loop character. After achievement of required parameters the mechanical system is designed, which is the base for development of design documentation.

II. Simulation of Emergency Braking of Suspended Transportation Set

The simulation was made using the MBS method. To determine action of high-loaded bearing units to arch support frames, the simulation of emergency braking of the transported load was made for the following parameters:

--Weight 15 [t].

--Speed at the moment of starting braking 3 [m/s].

--Static braking force: 60 [kN].

--Inclination 10º.

Computational model for the railway route includes rails of the suspended monorail track connected with spherical and rotational joints, Fig. 4.

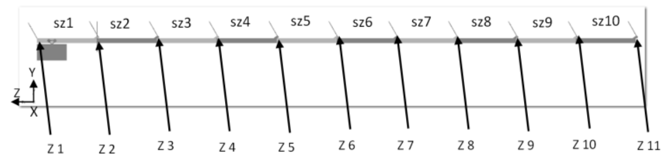

Fig. 4. MBS global model of suspended monorail track.

Totally the computational model consists of: 64 rigid bodies, 4 rotational joints, 44 spherical joints, 2 translational joints, 3 fixed joints, 22 elastic-dampening elements, 60 models of contacts. The model has 188 degrees of freedom (DOF), Fig. 5.

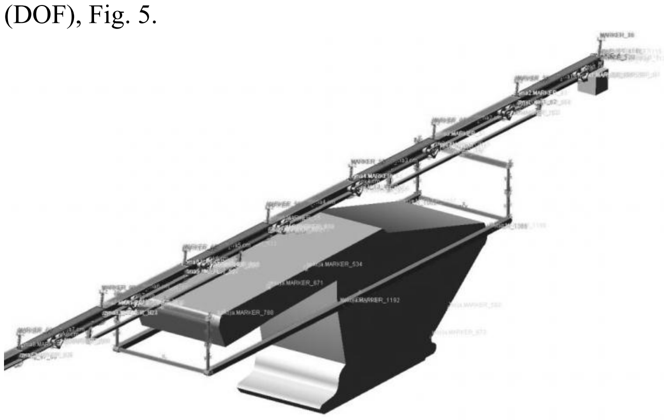

Fig. 5. MBS computational model of transportation set.

Then a single braking car with actuating components of the braking system was placed on the track, Fig. 6.

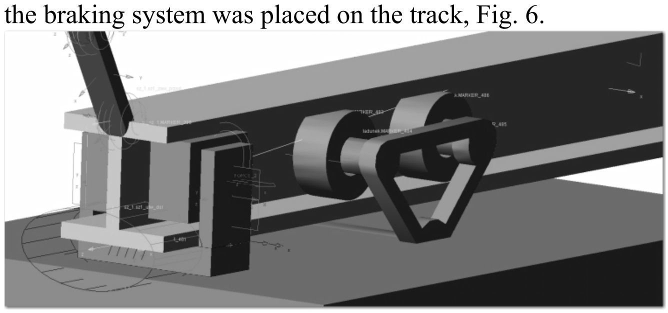

Fig. 6. Isometric view of transportation car with braking components.

The simulation was carried out in two stages:

--Determination of so-called stable equilibrium.

--Acceleration of the bearing set and its braking.

After reaching a speed of 3 [m/s], the force pressing brake blocks to the rail is released causing sudden braking of the transported load and in consequence overload to the suspensions of the track. In the result of rapid release of brakes in the braking car unstable dislocation of large-size load starts, Fig. 7.

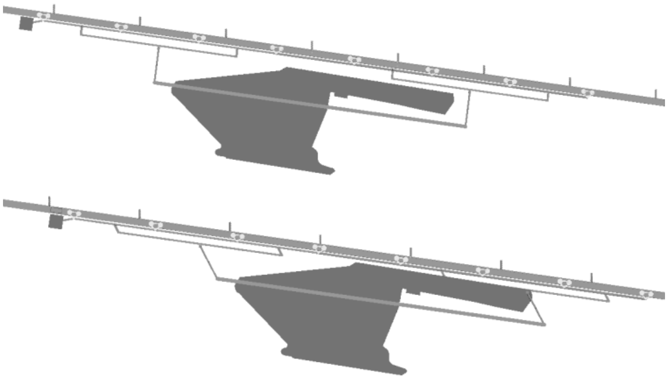

Fig. 7. Unstable behavior of load during emergency braking.

On the basis of MBS calculations the forces in suspensions in function of time were identified. In Fig. 8 time process of forces in the suspension No. Z4 is given.

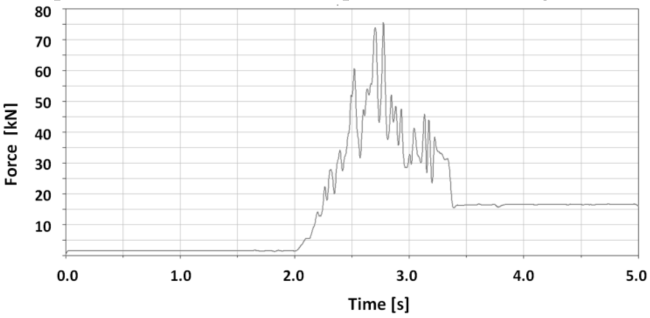

Fig. 8. Unstable behavior of load during emergency braking.

From the above diagram it results that maximal force in the suspension was 75 [kN], what means 50% of dynamic overload. Then the diagram of the force in suspension was exported as input data to the FEM pre-processor environment and it was defined as so-called time dependent field.

III. Simulation of Impact Load to the Yielding Arch Support

Calculations objective was to compare dislocation of single arch of roadway support under dynamic load from the following sources:

--In the stand test for testing support frames [7].

--Emergency braking of the transportation set.

As the load is dynamic and of short duration, MSC.Patran/Dytran software, which enables explicit numerical analyses [3], was used in strength calculations. Possibility of arch support yielding, i.e. possibility of movement of side wall arch against roof arch, was introduced to the computational model. Such a movement is possible after exceeding frictional forces between the arches. For that purpose the models of contacts between side wall arch and roof arch were added. In the computational model the following models of contacts, presented in Fig. 9, were added:

--Side wall arch – side wall (1).

--Clevis – arch of the support (2).

--Rod element – arch of the support (3).

--Testing rig (beater) – arch of the support (4).

--Weight – testing rig (beater) (5).

--Side wall arch – roof arch (6).

--Rod element – clevis (7).

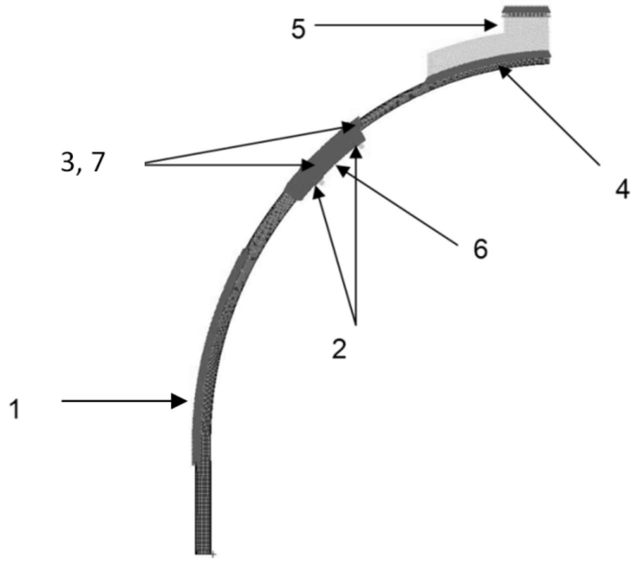

Fig. 9. Computational model of yielding arch support [7].

The results of total displacement of arch support frame have proved that impact load from falling mass in the testing facility had more severe effects (PHASE I) than load from emergency braking of transported mass (PHASE II). This can be seen in Fig. 10.

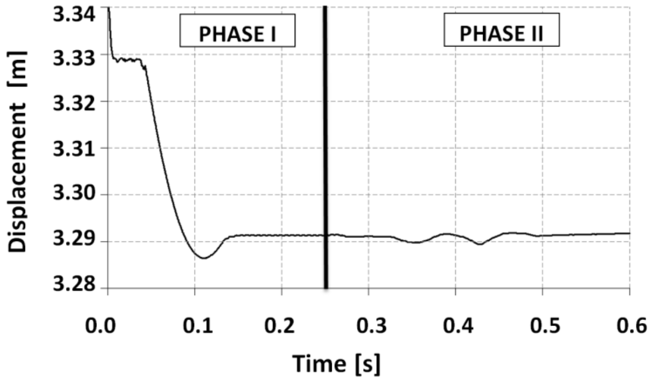

Fig. 10. Computational model of yielding arch support.

Maximal total displacement of the support after impact was about 40 [mm], what resulted in yielding the frames against each other as well as plastic strains in roof arch. Emergency braking caused support displacement of 2 – 3 [mm]. Only elastic strains occurred.

IV. Simulation of Damage of Arch Yielding Support under Impact of Dynamic Load

Identification of dynamic critical load, from emergency braking of the transportation set, acting symmetrically on the frames of arch support, causing local loss of stability, i.e. arch buckling, was the simulation objective. Numerical calculations of explicit type were made to multiply (1, 2, 3 and 4) the load obtained from MBS analysis. The analysis was made using MSC.Patran/Dytran software.

In the computational model the following elastic-and-plastic material model with linear hardening was assumed:

--Density: 7850 [kg/m^3].

--Elastic modulus: 205 [GPa].

--Hardening modulus: 2.7 [GPa].

--Poisson ratio: 0.3.

--Yield stress: 340 [MPa].

--Max. plastic strain: 17%.

In Fig. 11 diagrams of displacements of the node which is in the arch support axis for overloads 1,2 and 3 are given.

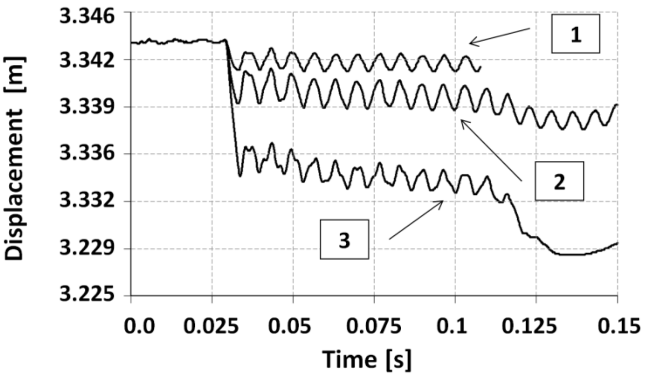

Fig. 11. Maximal displacements of arch of the support for impact overloads 1, 2 and 3.

Overload 4, at which the maximal loading force reaches about 300 [kN], causes local loss of stability of side wall arch (buckling) what leads to loss of load-bearing capacity of the support arches and collapse of the support, Fig. 12.

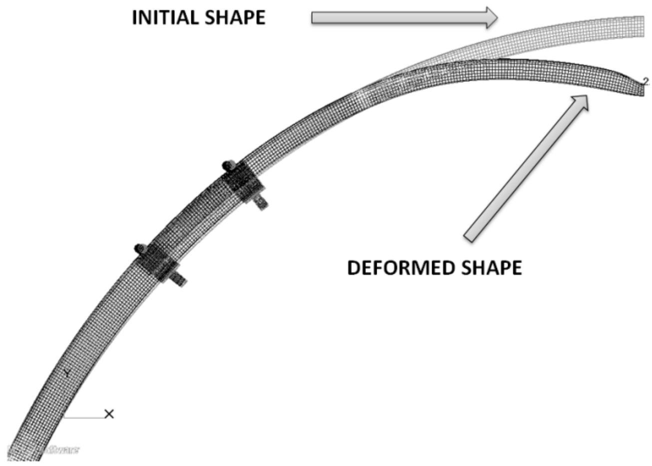

Fig. 12. Deformation of the arch yielding support for overload "4".

V. Summary

Use of dispersed software environment for virtual prototyping of mechanical systems causes the necessity of data transfer between computer programs. It is also necessary to select dedicated software programs, which enable numerical simulations which will include the required physical phenomena. Additionally number of calculation tasks requires their parameterization and computer programs enabling at least partial automation of import/export operations between the calculation programs.

For the presented example the results clearly indicate that impact loads of energy about 30 [kJ] cause movement of the support frames against each other what results in reduction of the support height. The permissible load which, according to the regulations, can be applied to a single arch of the support i.e. 40 [kN] does not cause yielding the material of which the support is made. Overloading over 3.5 causes exceedance of yielding point and in consequence collapse of the support. Impact load can also lead to buckling of the support arches. State-of-the-art programs of class CAE enable defining any model of material and its verification in the investigated problem. They are broadly used in process of designing of new machines and equipment.

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