NUMERICAL ANALYSIS OF IMPACT LOAD OF ARCH YIELDING SUPPORT

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Abstract

Bumping is one of the natural hazards that occur in Polish collieries. It is a common phenomenon but difficult to predict and very often it causes huge losses in mining equipment and roadway structure. Death of miners working underground is most severe result of bumping. To reduce or even to eliminate results of bumping, especially fatal cases, many safety measures have been used. Frame of arch support is one of the measures applied to reduce dangerous results of bumping.

Simulation test of impact load of arch yielding support was presented in the paper. The simulation of support load was realized in two stages. Static load of frame of yielding arch support was simulated at the first stage. Among others simulation of assembly of arch support components was carried out. Non-linear simulation, including contact phenomena, was conducted for that purpose. First stage of the task was realized in MSC.Marc/Mentat software Structure of yielding arch support was dynamically loaded at the second stage. The forcing corresponded to real dynamic loads that were found in mine workings. Second stage of the task was realized in MSC.Dytran software The results of simulations carried out at the KOMAG Institute of Mining Technology were compared with the results of tests of arch supports, which were realized at the Central Mining Institute

***Keywords**: virtual prototyping, finite elements method, mining, impact analysis, experimental test*

1. Introduction

Bumping initiated by rock bursts are one of most significant natural hazards in Polish hard coal mines. The knowledge of static and dynamic loads in rock mass is required for reliable assessment of seismic hazard and bumping hazard. While static loads are well known and it is possible to calculate them in a reliable way, dynamic loads caused by rock bursts, especially close to their source, are known rather slightly. Analysis of recorded materials, which refer to bumping in mines of Upper Silesia, showed that most of bumps were caused by bursts, centres of which were 100 m from the place of the results that appeared in workings [7].

Rock bursts in hard coal mines in Upper Silesia Coal Region are recorded continuously from 1950ties. Upper Silesian Regional Seismological Network is recording all bursts of seismic energy above 10^5 J. From mid 1970ties in collieries that have seismic activity all rock bursts are also recorded by local mine seismic stations. To record all of these phenomena local mine seismic networks are established. These networks consist of 10 to 20 single-stand, vertical seismometric stations. Mine inspections are mainly carried out for assessment of local seismic hazard in a region of mining.

Bursts generated by mining, which result in bumps in coal mines, become more common, especially in roadways [8]. In longwall faces, which are protected with powered-roof support of high load bearing capacity, relatively less bumps than in roadways are recorded. A problem of protection of longwall support against dynamic load caused by rock bursts requires further studies [9, 11].

Yielding roadway supports, which consist of arches of steel profiles connected by locks and sprags with additional net lining, became popular and used from many decades in Polish coal mines.

The support has to secure roadway stability within determined time, i.e. it has to maintain dimensions of roadway cross-section and to protect people, machines and equipment against rock parts falling down from walls and roof or against roof falls, Fig. 1. There are the following features that yielding arch support should have:

- stability, i.e. support should not displace or its components should not be displaced in a result of rock mass pressure, what could cause its total damage,
- strength, i.e. each support component should not be plastically deformed; each support component should be designed with a proper safety factor.

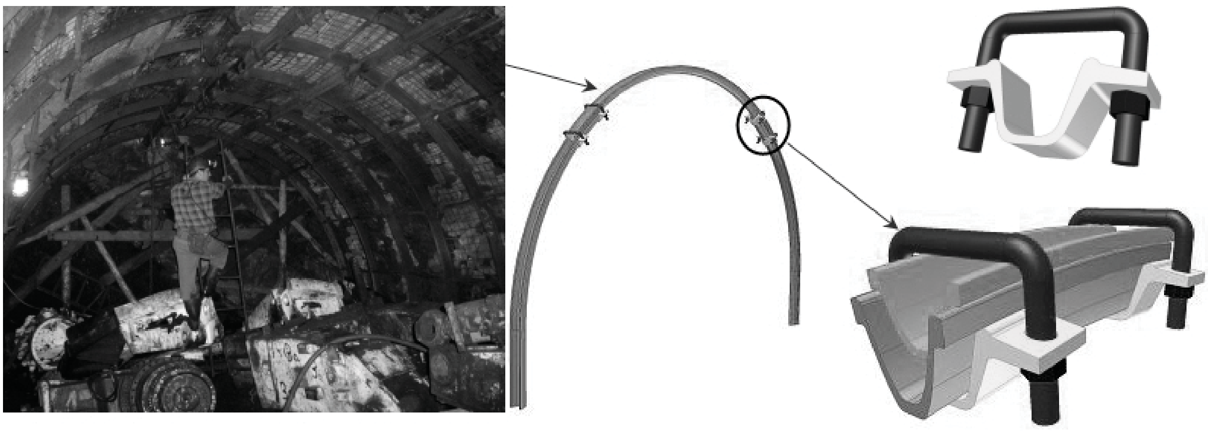

Fig. 1. Yielding arch support

However, dynamics of instrumentation, which is used in mine networks, is small and at present recording of vibrations only of velocity amplitude of order up to several millimetres per second, without changing of accuracy range, is possible. Thus mine instrumentation is not suitable for testing the characteristics of vibrations in a short distance from a seismic source, where velocity amplitudes reach the values of ten or so and even up to few hundred millimetres per second. Specialistic measuring instrumentation enables to get acquainted with real characteristics of vibrations, which are near to the seismic source, but it is necessary to take measurements of vibrations close to the centres of bursts, what is not easy in practice. Many-time recording of strong burst from a short distance requires many months of waiting and sometimes it is not possible at all. First successful measurements were made in Polish coal mines at the turn of 1980s and 1990s by Mutke and Dubinski [1, 2, 6], while first successful recordings of strong mining bursts close to the source were made in 1978 in the deep colliery East Proprietary Mines in South Africa [5].

So far input data, describing dynamic loads, for prediction of stability of underground roadways in coal mines of Upper Silesia were assumed on the basis of empirical relationships developed for the bursts caused by blasting operations [3]. Use of this solution was implied by lack of real data about characteristics of vibrations caused by mining bursts in close distances from their centres. Mechanism of rock bursts in their centres, which result from using of explosives, is generally different from the mechanism of rock bursts activated naturally [7].

Analysis of the results caused by rock bursts, centres of which were located in the near area, showed that bursts which caused bumps generally have some characteristic features. Frequency (small) of vibration and length of seismic wave in rock mass, which is associated with frequency, are one of them. Vibrations recorded in a close distance from the centre reveal that very often they have a form of oriented impulse, especially in the case of high-energy bursts. Such form of vibrations close to burst centre means that dynamic loads are strongly oriented and in suitable conditions they can cause damages in a roadway.

2. Numerical strength calculations of yielding arch support in a rigid state

Few field tests consisting in in-situ measurements of dynamic loads of roadways support that are caused by rock bursts do not give sufficient representation of rock burst characteristics that result in bumps. So the studies aiming at numerical simulation of rock bursts with use of Distinct Element Method (DEM) were carried out. The method enables obtaining the characteristics of rock burst in a centre located near the modelled roadway, Fig. 2.

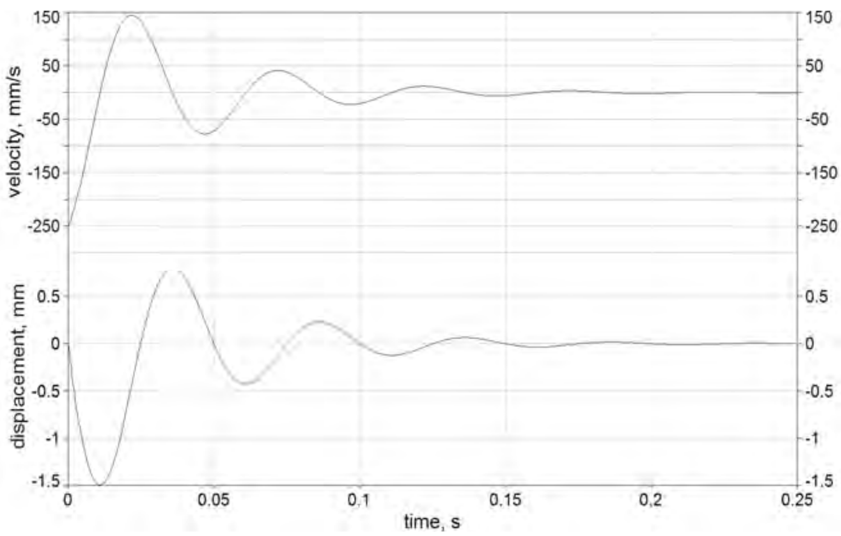

Fig. 2. Exemplary characteristics of rock burst (displacement and vibration velocity)

Such a rock burst can (potentially) result in support damage and in a bump. For example one of the most tragic rock burst that had happened in recent years in coal mines in Silesian region – rock burst that happened in 11th September 1995 at 13[57] in Nowy Wirek Colliery had vibration acceleration of order 20-50 g [4, 10].

Rock displacement and velocities obtained from DEM simulation do not reflect the real displacement of falling rock fragments directly over the roadway, so in FEM calculations of results of impact load of arch yielding support, the boundary conditions of testing rig were recreated.

Numerical calculations were divided into three following stages:

- simulation of screwing arch components together – non-linear static analysis,
- simulation of impact load of yielding support's frame in a rigid state,
- verification of calculations by impact test in a test rig,
- simulation of impact load of yielding support's frame in a yielding state.

Dynamic analysis of model of rigid arch support

Calculation model of ŁP8_v25 yielding arch support was created. Rigid state means the blockage of support's arches movement against each other, so there is no so called yield of the support.

Finite elements meshing consists of the following:
- wall arch – 4890 elements of QUAD4 type, 192 elements of HEX8 type, 5814 nods,
- canopy component – 2068 elements of QUAD4 type, 2268 nodes,
- stand model – 1661 elements of QUAD4 type, 3548 nodes,
- loading components – 58 elements of HEX8 type, 180 nodes.

View of finite elements meshing was presented in Fig. 3. Symmetry of arch support in relation to two planes was used to shorten calculations, so in the calculations ¼ of real yielding arch support was used.

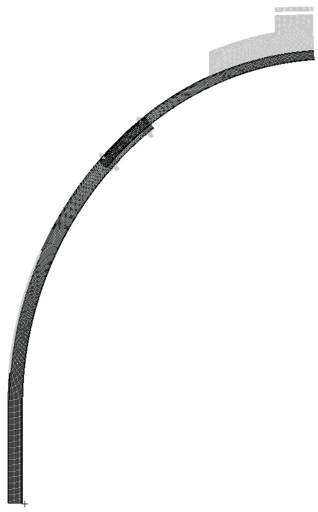

Fig. 3. View of finite elements meshing of ŁP8_v25 arch support

Two following isotropic elastic perfectly plastic material models were used in the calculation model:
- for support's arches and clevises:
  - Density ρ=7850 [kg/m^3],
  - Modulus of elasticity E=205 [GPa],
  - Poisson modulus ν=0.3,
  - Yield point Re=590 [MPa],
- for loading component:
  - Density ρ=31967500 [kg/m^3],
  - Modulus of elasticity E=205 [GPa],
  - Poisson modulus ν=0.3,
  - Yield point Re=200 [MPa].

Density for a loading component was selected in such way that its weight is equal 25% of the weight that has to load the arch support. Amount 25% as ¼ of support's model is calculated. Increase of material density enabled reaching the required impact energy without increasing of deadweight dimensions.

Boundary conditions of the calculation model were given in Fig. 4. Rigid fixation of wall arch model to the floor and contact support in wall direction was used. Possibility of moving the support towards a roadway is an advantage of the contact supporting method. Action of the rest part of the calculation model was included in calculations by making the nods move possible only on symmetry planes. Wall arch and canopy arch were connected with each other in a rigid way (joint nodes).

Initial velocity of the weight loading support arches was calculated according to the following formula.

$$v = \sqrt{2 \cdot g \cdot h}\ ,$$

$$v = \sqrt{2 \cdot 9.81 \cdot 0.12} = 1.534\ [m/s].$$

The weight should be falling freely from the height 0.15 m, but to shorten calculation time the weight was placed at height 30 mm from the intermediate component (see Fig. 7) and its initial speed that the weight would have when falling freely from the height 0.12 m was attributed to it. In Fig. 5 a map of reduced stresses for the maximal support deflection was given.

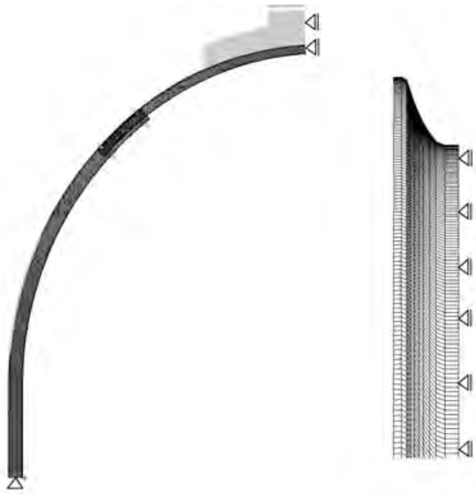

Fig. 4. Boundary conditions and position of contact places in the calculation model

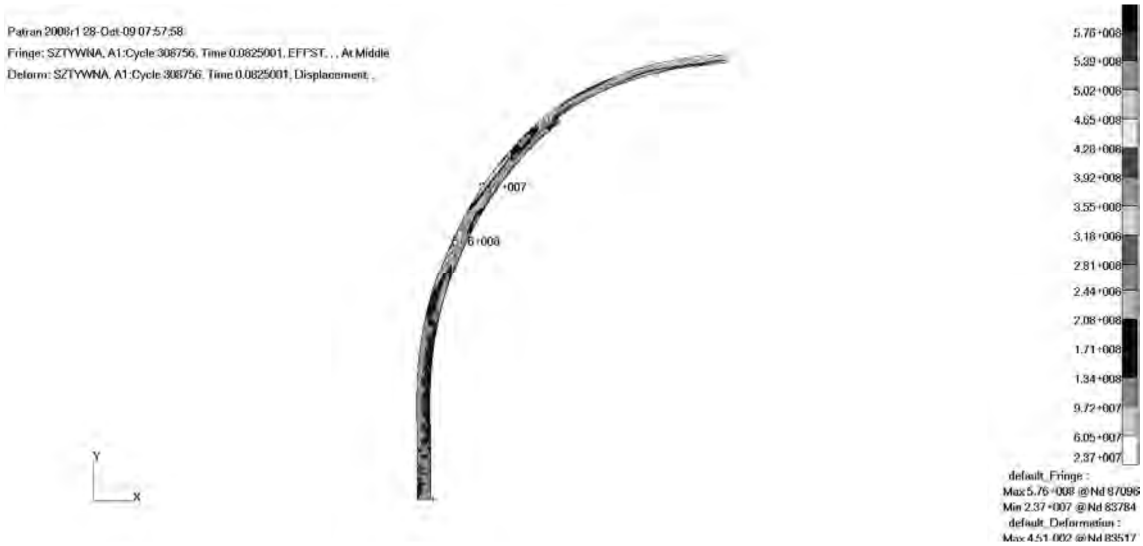

Fig. 5. Map of reduced stresses for the ŁP8_v25 arch support

Map of plastic deformation of ŁP8_v25 arch support presents part of canopy arch and wall arch, Fig. 6.

Fig. 6. Map of plastic deformation of part of ŁP8_v25 arch support

3. Verification of computational model

Obtained results of numerical calculations were compared with the results of experimental tests carried out in the laboratory stand at the Central Mining Institute (GIG) in Katowice.

Description of the stand

Arch support was installed and loaded at the laboratory stand according to PN-92/G-15000/05 Standard. Frame of support was made rigid, i.e. its smooth joints were blocked to make its yield impossible. View and diagram of the test stand are presented in Fig. 7.

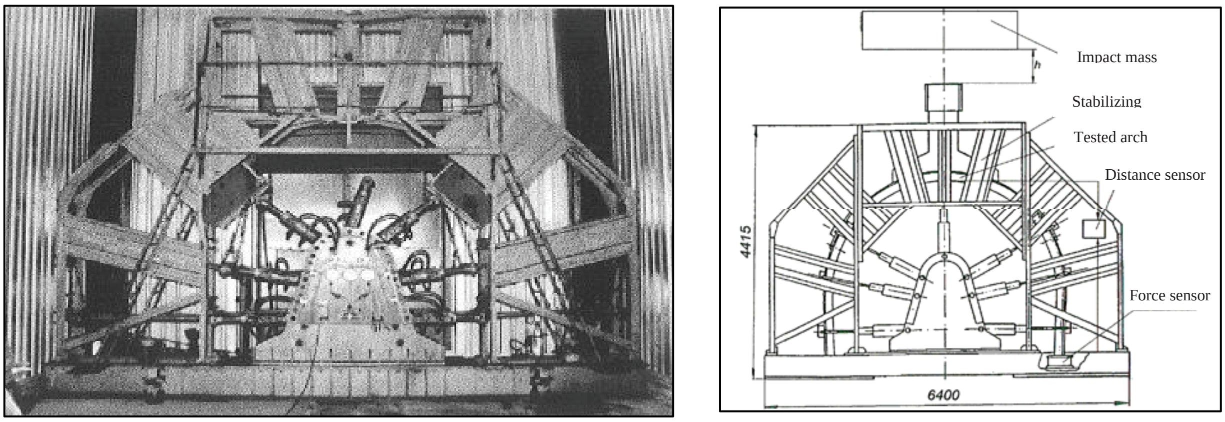

Fig. 7. Stand for testing a frame of arch supports used at the Central Mining Institute in Katowice

The test was conducted for the following conditions:

- impact weight – 20 [t],
- height of weight fall – [0.15] m,
- impact energy – 0.02943 [MJ],
- maximal deflection – 0.04 [m],
- ultimate strength of material – 782 [MPa],
- yielding point of material – 599 [MPa].

Comparison of results of experimental tests and FEM calculations:

Maximal dislocation of upper part of canopy arch equal to 0.04 [m] was obtained during laboratory tests.

The same conditions of load bearing capacity and of arch support load were included in numerical model (compare with item 2). Dislocation of node in the upper part of canopy arch was monitored during simulation. Diagram of node dislocations is presented in Fig. 8. Real time of simulation was equal to 0.25 s.

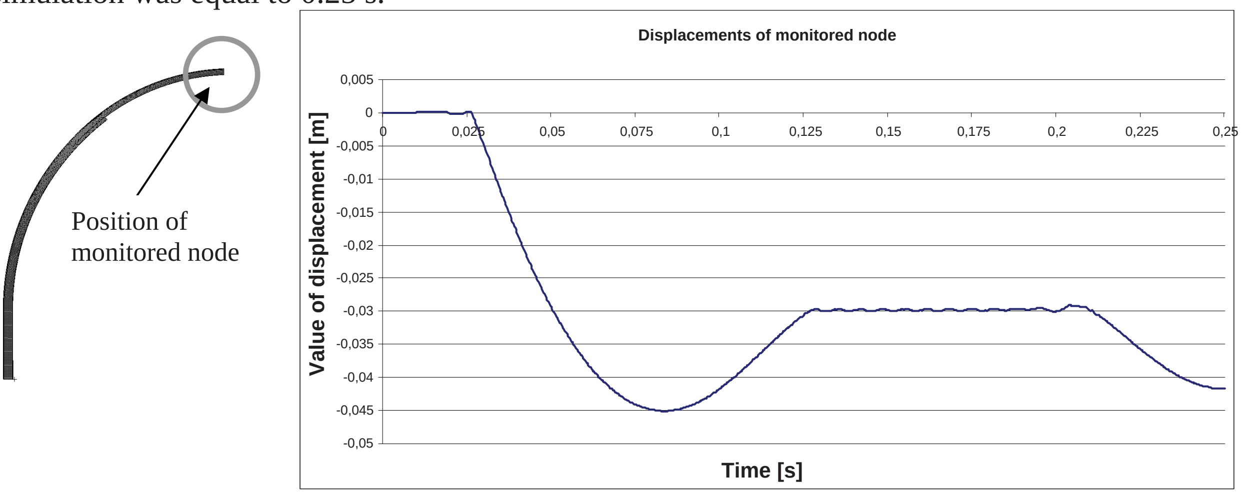

Fig. 8. Diagram of dislocation of monitored node for the support in a rigid state

Observed relative error can result from resistance during fall of deadweight, which was not included in the computational model.

4. Numerical strength calculations of yielding arch support in a yield state

Static analysis of yielding arch support model

Static analysis of yielding arch support consisted in a simulation of screwing together support arches using clevises. Results obtained in this way were the initial stresses for further dynamic analysis. Due to symmetry of the system the part of joint presented in Fig. 9 was selected for analysis. Calculations of process of screwing together of support's arches were made in MSC.Marc/Mentat software.

Created discreet model included 27876 spatial components of HEX8 type (modelling support's arches) and 10317 components of Tet10 type (modelling clevises). Boundary conditions that were used for analysis included both the symmetry of support and the compressing forces caused by screwing down. Additionally contact boundary conditions between each component of joint were assumed in a computational model.

The following isotropic elastic perfectly plastic material model was used in the calculation model:

- Modulus of elasticity E=210 [GPa],
- Poisson modulus v=0.3,
- Yield point Re=590 [MPa].

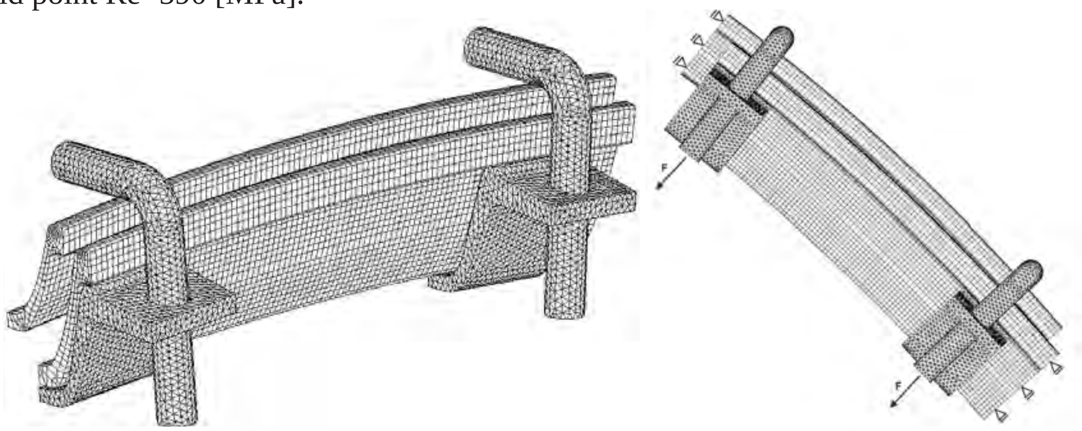

Fig. 9. Computational model for static analysis – screwing together the support's arches

Force caused by screwing down was determined with the use of the following equation:

$$F = \frac{F_1 \cdot 2 \cdot \pi \cdot L}{s},$$

where:

F - force stretching the screw,
F_1 - twisting force,
L - arm length,
s - screw pitch.

Among others stresses in components of screwed joint were obtained after the simulation, Fig. 10.

Static analysis showed that in a result of screwing down of components of arch support, stresses reach yielding point value, what causes permanent deformation of joining components (clevises) at the stage of assembly. This phenomenon is positive as we can obtain the required rigidity of the support directly after assembly.

Dynamic analysis of model of yielding arch support

Static analysis was the starting point for simulation of impact load of initially screwed and complete yielding support. For that purpose, a computational model of yielding arch support of ŁP8_v25 type in a yielding state.

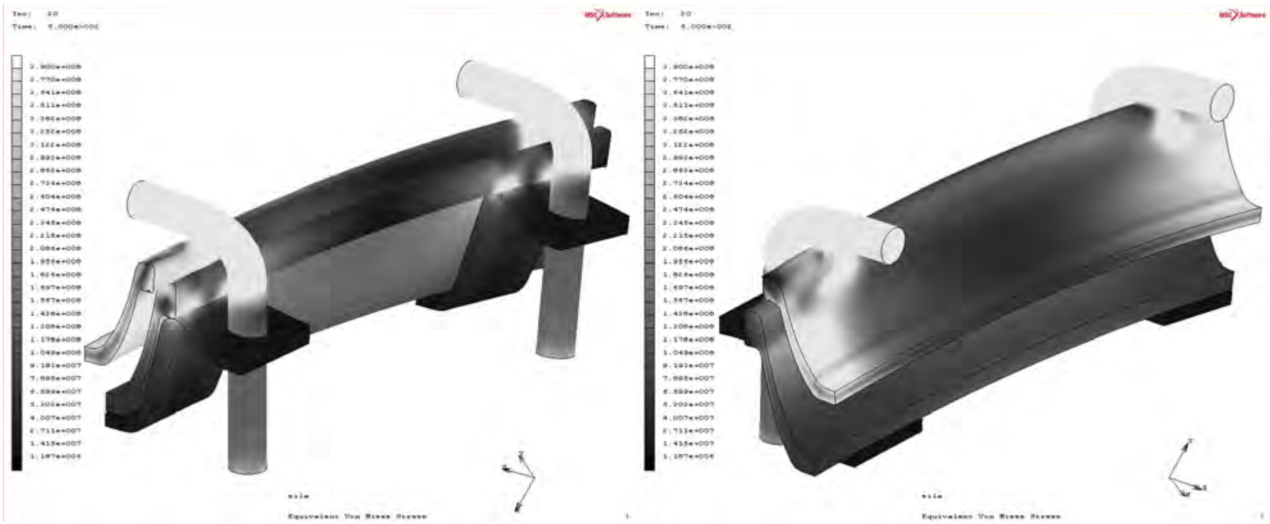

Fig. 10. Map of reduced stresses [Pa]

Yielding arch support enables movement of support frames against each other when overcoming friction forces between screwed support arches. For that purpose a contact between wall arch and canopy arch was added, blocking at same time movement against each other. Model of contact in a model of yielding support is presented in Fig. 11:

- wall arch – wall (1),
- clamp – support arch (2),
- bar – support arch (3),
- intermediate component – support arch (4),
- deadweight – intermediate component (5),
- wall arch – canopy arch (6).

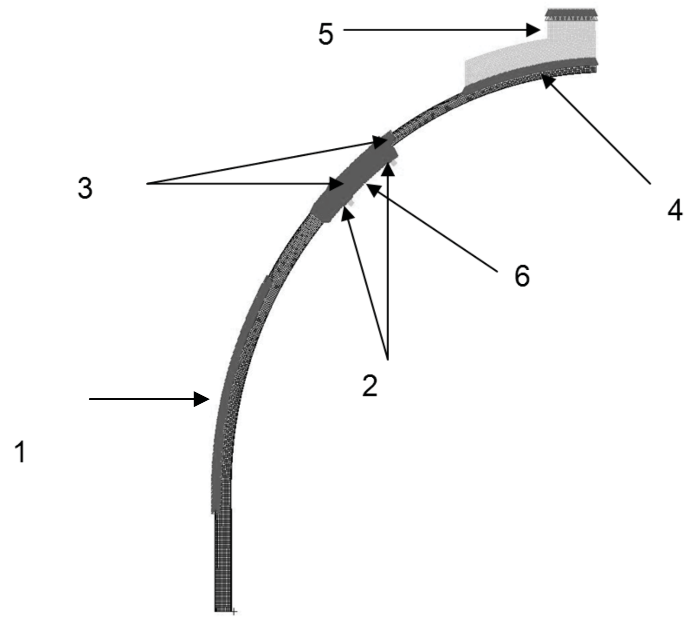

Fig. 11. Computational model of yielding arch support

Results of simulation show that use of yielding arch support does not reduce load bearing capacity, quite the contrary – by reducing a material's yielding point to 340 MPa, the values of maximal deflection are similar with those as in a rigid arch support made of material of yielding point 590 MPa, Fig. 12.

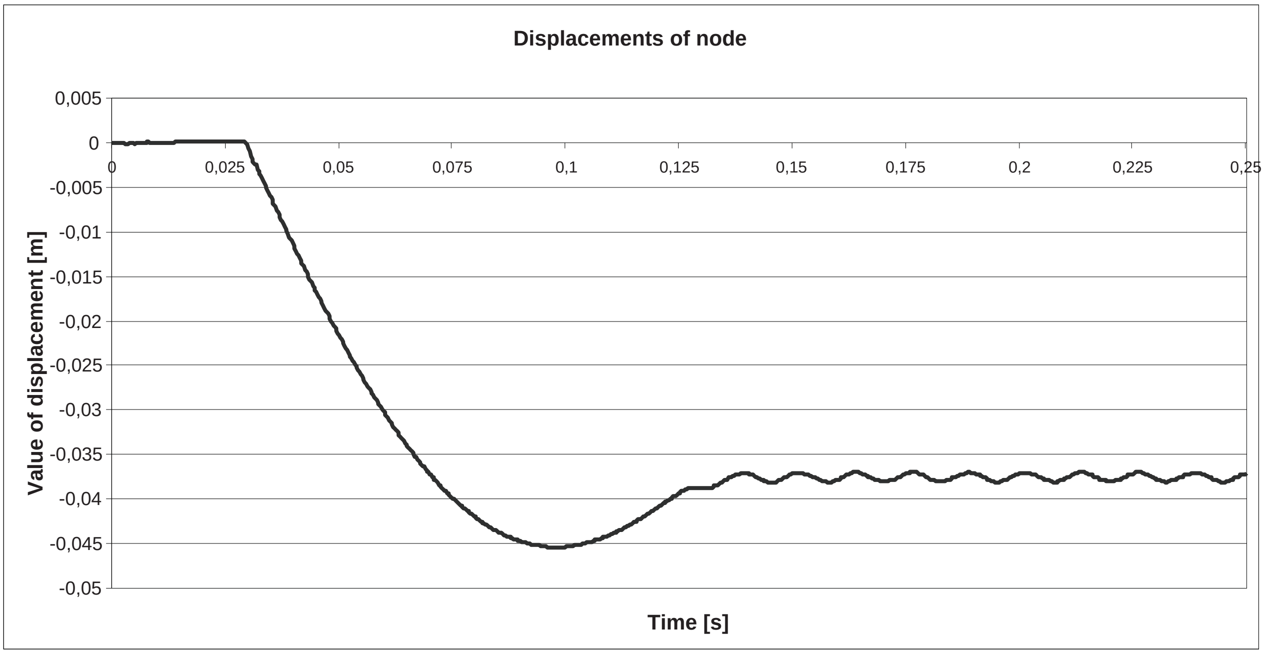

Fig. 12. Diagram presenting displacements of monitored node in a yielding support

5. Summary

Verified numerical tests of yielding arch supports enable drawing the following conclusions:

- arch support in a yielding state is much more resistant to impact loads in comparison to support in a rigid state,
- each impact load, which acts on yielding arch support causes its yield, what leads to continuous decrease of roadway cross-section surface,
- a shape of profile has influence on contact forces between frames of arch support,
- optimization of shape of V profiles in future arch supports is possible with the use of numerical analyses,
- further studies as regards cooperation of arch support with rock mass are indispensable – recorded characteristics of rock mass burst cannot be directly used for loading of yielding arch support.

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