VERSITA

Arch. Min. Sci., Vol. 58 (2013), No 2, p. 411–432

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.2478/amsc-2013-0028

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USE OF CAD SYSTEMS IN TESTING THE COLLISION OF UNDERGROUND TRANSPORTATION MEANS

ZASTOSOWANIE SYSTEMÓW CAD W BADANIACH KOLIZYJNOŚCI ŚRODKÓW TRANSPORTU PODZIEMNEGO

A concept of use of CAD systems in testing collision of underground transportation means is presented. Reasons for undertaking this problem are given with end users identified. The concept of the system for collision analyses of transported loads is described. Examples of collision analysis during transportation of powered roof support are given.

Presented system is designed to aid planning, organizational and training activities undertaken in management of transportation safety in mines. It will be also possible to use software resources, developed within the system as the didactic material as regards safe transportation process, which include hazards to the employees working in the area of transportation operations.

Developed prototype of a system for testing the collision of underground transportation means was positively assessed by employees of the Coal Company, JSC – industrial partner of KOMAG. This prototype is continuously improved and adapted for commercial implementation in the selected coal mines.

Keywords: underground transportation, collision analysis, CAD

W pracy przedstawiono koncepcję zastosowania systemów CAD w badaniach kolizyjności środków transportu podziemnego. Określono przyczyny podjęcia tematu oraz zidentyfikowano końcowych użytkowników. Zaprezentowano koncepcję systemu do analiz kolizyjności transportowanych ładunków. Pokazano przykłady analizy kolizyjności podczas transportu sekcji obudowy zmechanizowanej.

Przedstawiony system przeznaczony jest do wspomagania działań planistycznych, organizacyjnych i szkoleniowych podejmowanych w zarządzaniu bezpieczeństwem transportu w zakładach górniczych. Opracowane w ramach systemu zasoby programowe będzie można również wykorzystać jako materiał dydaktyczny z zakresu bezpieczeństwa pracy w transporcie, uwzględniający zagrożenia dla pracowników pracujących w bezpośredniej strefie prac transportowych.

Opracowany prototyp systemu do badania kolizyjności środków transportu podziemnego został pozytywnie oceniony przez pracowników Kompanii Węglowej S.A. – partnera przemysłowego KOMAG-u.

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Prototyp ten jest w chwili obecnej ciągle udoskonalany oraz przygotowywany do komercyjnego wdrożenia w wybranych kopalniach węgla kamiennego.

Słowa kluczowe: transport podziemny, analiza kolizyjności, CAD

1. Introduction

Mine transportation of materials in underground mine workings is realized by mine underground railways (on the main transportation routes) as well as by suspended monorails or floor-mounted railway (in a department transportation). Transportation is realized on tracks placed on the floor of working (floor-mounted rail transportation) or on rails suspended to roadway support (suspended rail transportation). Increasing dimensions of transported equipment and materials can cause hazard to the personnel and force the designers of transportation systems to make analyses of transportation routes as regards possibility of collision between transported loads and roadway support components, equipment or other machines that can be the obstacles or that can cause hazard during transportation. Collision free transportation of load depends on proper designing of the track and proper selection of the transportation system. Research work aiming at a development of tools aiding verification of designs of transportation systems in the light of safety criterion is carried out at the KOMAG Institute of Mining Technology (MINTOS, 2007-2010; ITG KOMAG, 2010). Analyses of collision of large-size loads and long loads, which are transported in roadways by mine underground railway, floor-mounted railways and suspended monorails are significant part of the verification procedures. Collision analysis on transportation routes is especially important in the case of designs of transportation system, in which reduction of area of roadway cross-section in a result of impact of surrounding rock mass should be considered.

At present analysis of transportation route as regards possibility of collision is realized in AutoCAD programme by positioning of load in the selected points of route and visual assessment of collision possibility. This task is especially difficult and labour-consuming with use of suspended monorails, where load-carrying system is usually the transportation machine. Kinematics of load-carrying system on a bend causes deflection of load trajectory from the axle of railway route, what significantly extends the time required for collision analysis. Examples of collision analyses in AutoCAD programme are presented in Fig. 1 (transportation by floor-mounted railway) and in Fig. 2 (transportation by suspended monorail). Drawing documentation of transportation system was obtained from Ziemowit Colliery (KWK ZIEMOWIT, 2010-2011).

Employees of Departments of Production Preparation in mines develop the designs of transportation systems. At present most of drawing documentation of these designs is created with use of AutoCAD programme, which is one of the Computer Aided Design software. Possibility of writing own, author's applications, running inside CAD system, which automate certain tasks or make additional calculations, is one of advantages of these systems. These are so-called external applications, which run inside the CAD system and which extend the possibilities of its use in different branches of industry.

Collision analyses on transportation routes can be made with use of author's software developed at the KOMAG Institute of Mining Technology, which is written in VisualLISP programming language (AUTODESK, 2010) and runs in AutoCAD programme environment. Collision analyses are mainly made at transportation of large-size and long loads transported by

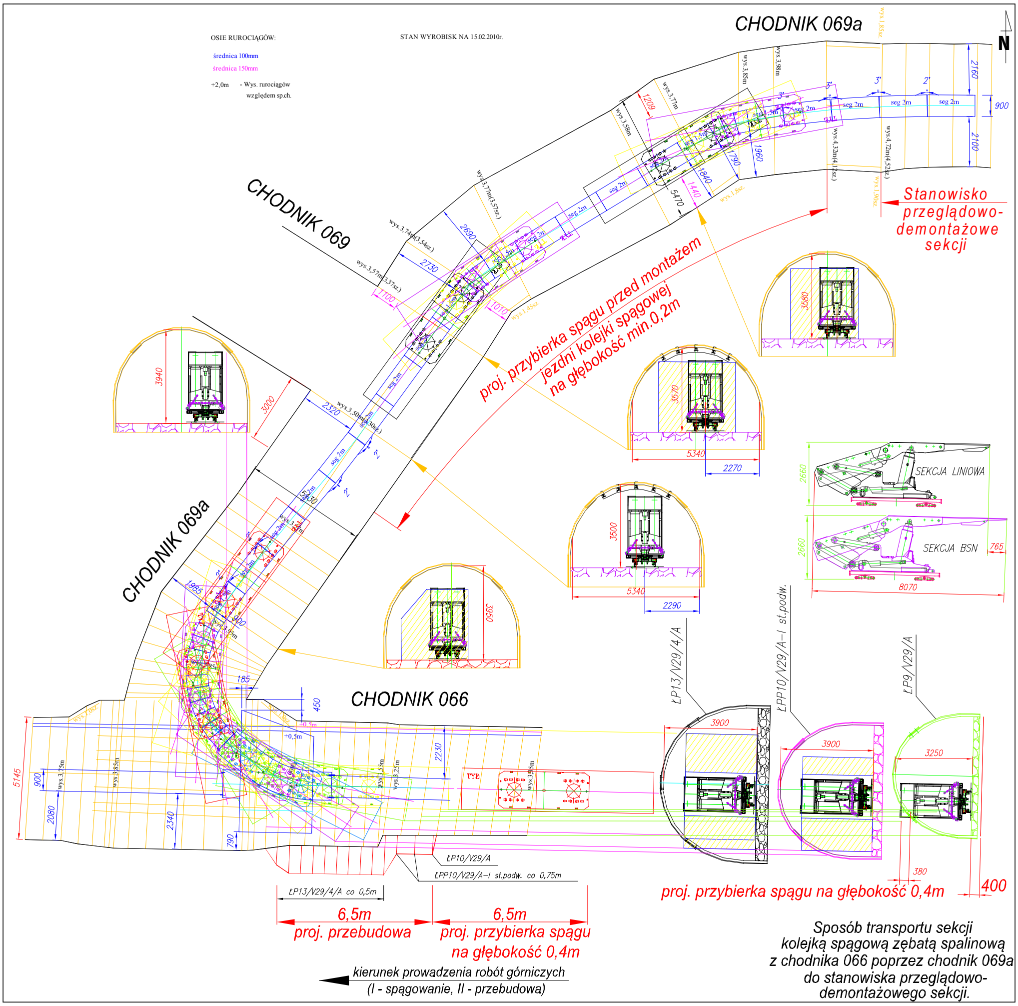


Fig. 1. Example of present testing the collision during transportation by floor-mounted railway. The drawing made by KWK Ziemowit mine is a part of transportation documentation

mine underground railway, floor-mounted railways or suspended monorails. The analyses can be made at the stage of designing the roadways for transportation or at the stage of development of documentation of transportation system in which the roadways can be verified for their transportation usefulness. At the stage of designing the roadways, the collision analyses are made to check roadway cross-sections and localization of railway route in the roadway (verification of passes on roadway cross-roads, bends, forks, etc.). At the stage of verification, i.e. during development of transportation system documentation, the collision analyses are made to take into account decrease of roadways cross-sections in a result of rock mass action.

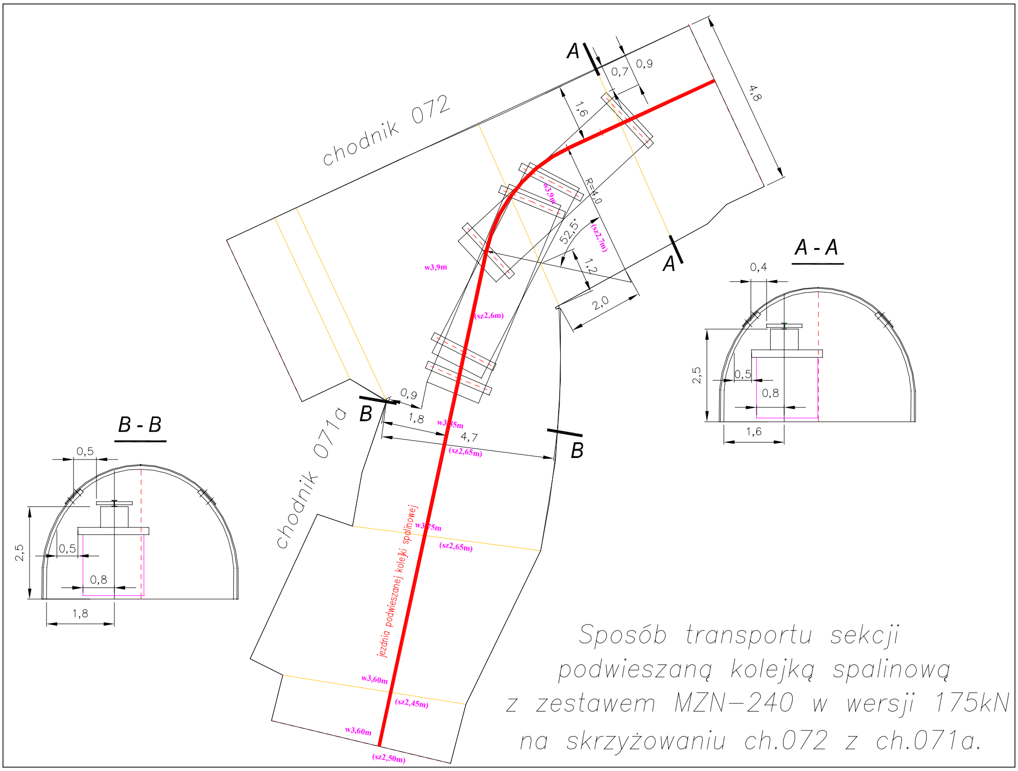


Fig. 2. Example of present testing the collision during transportation by suspended monorail. The drawing made by KWK Ziemowit mine is a part of transportation documentation

2. Assumptions to the system for collision analyses in underground horizontal transportation

Supporting the designer in creation of new route of transportation system or in verification of the existing route of transportation system is the main task of computer system for collision analyses in underground transportation. The system for collision analyses (Fig. 3, Fig. 4) consists of the following components:

- AutoCAD (Client) programmes to formulate input data and to analyse the results obtained from AutoCAD Server ,
- AutoCAD (Server) programme with author's software programme for downloading input data, collision analyses and making the results of analyses available to AutoCAD Client programmes,
- internet application, which completes input data and is the link between AutoCAD Client programmes and AutoCAD Server programme.

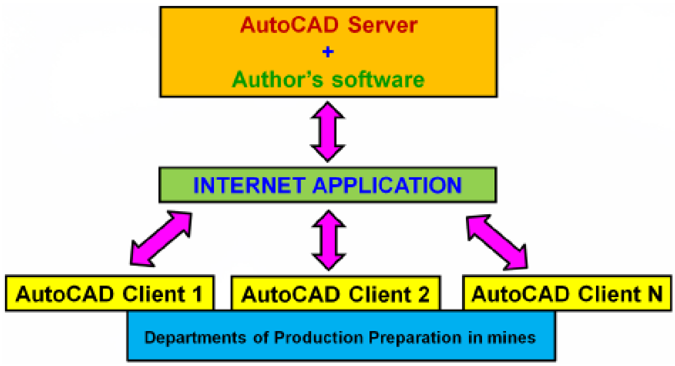


Fig. 3. Concept of the system for collision analyses on transportation routes

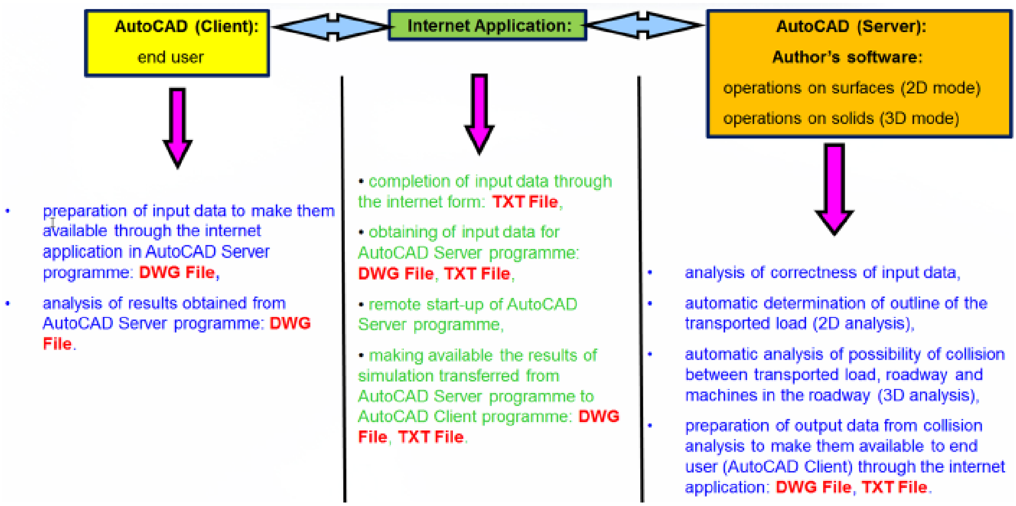


Fig. 4. Structure of Client – Server application for collision analyses on transportation routes

There are the following assumptions for the programme for collision analyses, which runs in AutoCAD Server programme environment:

- programme is helpful for the designer of transportation system in testing the collision on the selected section of the route of mine underground railway, floor-mounted railway or suspended monorail,
- design of transportation system and drawing documentation developed in AutoCAD Client are input data to the programme for collision analysis,
- programme for collision analyses is started in Client – Server mode,
- collision analyses can be made for flat models (2D mode) and for spatial models (3D mode),

- programme automatically analyses possibilities of collision of transported load and transportation machine with a roadway as well as with machines, which are in a roadway,
- results of collision analysis are documented in a form of graphical and textual files.

Acquisition of input data for AutoCAD Server programme, their completion, remote start-up of AutoCAD Server programme to analyze collision automatically and to make results of collision analysis available to AutoCAD Client programme are the tasks of the internet application. It was assumed that internet application should enable realization of the following tasks:

- acquisition of data on roadway dimensions,
- acquisition of data on route localization,
- acquisition of data describing arrangement of machines and equipment, which can be the obstacles during transportation operations, in a roadway,
- acquisition of data on transportation machine,
- acquisition of data on transported load: its dimensions and position in relation to transportation machine (transportation platform, load-carrying system, …),
- making the results of collision analysis available to AutoCAD Client software.

3. Formulation of input data of collision analysis in participatory mode

Maintaining regular contact among the specialists from external companies and designers of transportation system in mine is important in supporting the designing process of transportation system. So-called participatory designing mode (Winkler et al., 2009) was used in the MINTOS project for the purposes of verification of the solutions developed in dispersed designing environment. It consists in a joint participation of designers of transportation system and external specialists in internet sessions during which the same maps, drawings, computer models or documents are analyzed, Fig. 5.

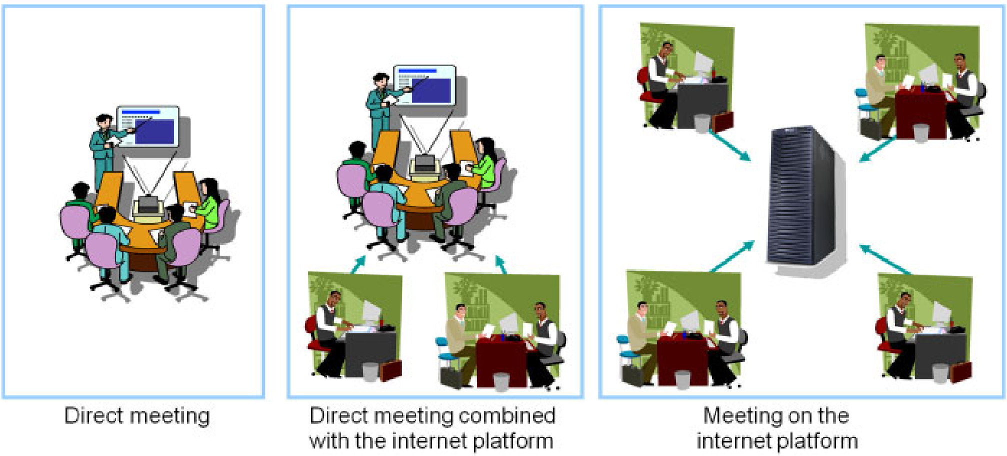
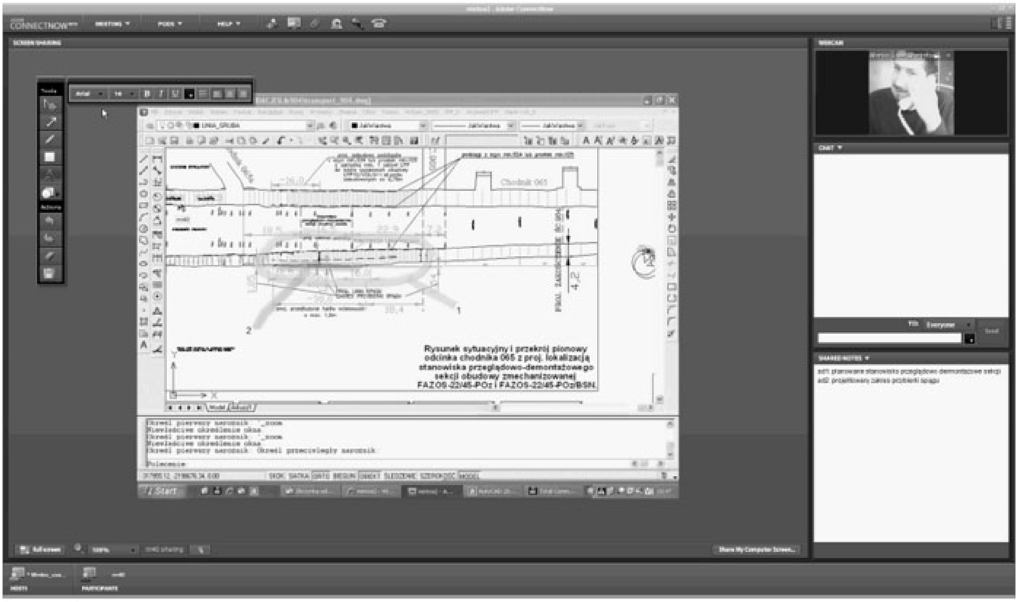


Fig. 5. Forms of formulation of verification criteria in a participatory designing mode

Due to the fact that AutoCAD programme is widely used by the designers of transportation systems for development of drawing documentation of designs of transportation system, it was decided to use this documentation as input data for the participatory mode of construction of selected part of roadway with transportation route and equipment installed on this route.

Analysis of transportation route as regards selection of these sections where collision might occur is the first stage of formulation of input data for testing the collision. Most often these are route bends, crossroads or roadways forks. Software programme aiding exchange of information is used during the internet session. The screen on the side of designer of transportation system with a section of railway route is visible in Fig. 6. The same route section is visible on the screen of external monitor at the specialist site. Route sections, on which collision during transportation operations is possible, are selected during the session.



a) b)

Fig. 6. Formulation of verification criteria in a participatory designing mode on the internet platform: a) screen during realization of the session, b) report from the session

Analysis of transportation system as regards selection of load, which can cause a risk of collision during transportation work, is the next stage of formulation of input data. These are mainly large-size loads or long loads. Input data come from a drawing prepared in AutoCAD programme, after formation of transportation set. For example, in the case of transportation with use of suspended monorail, load-carrying system, traverses and transported loads are identified in a participatory designing mode (Fig. 7). These are the next input data to the programme for collision analysis.

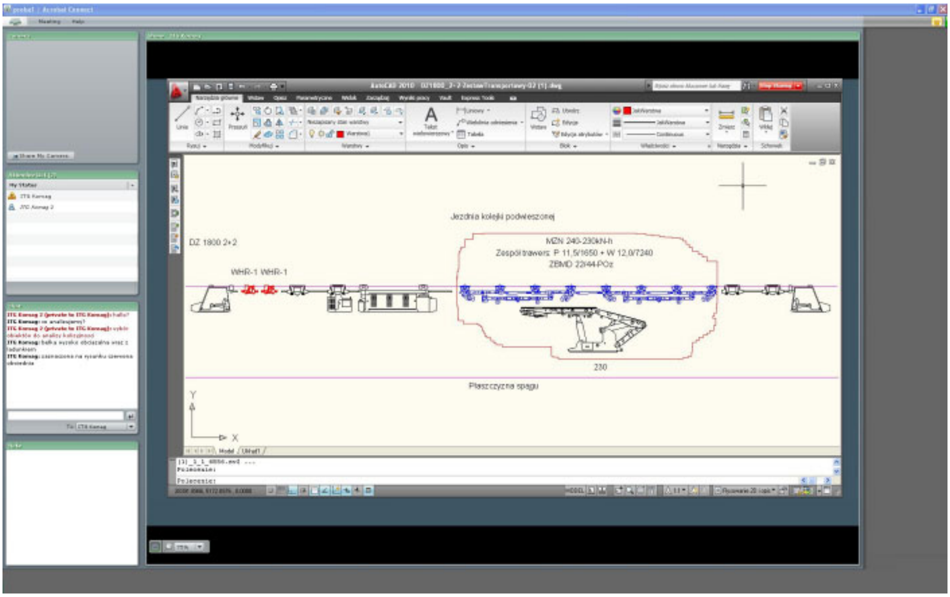


Fig. 7. Exemplary configuration of transportation set – participatory mode for selection of type of transportation machine, system of traverses and the load

4. Examples of collision analysis

Examples of creation of simulation models as well as collision analyses for transportation with use of floor-mounted railway and suspended monorail are presented below, using technical data of the following machines and equipment:

- transportation platform of load-bearing capacity 320 kN, for transportation with floor-mounted railway,
- modular load-carrying system developed by FAMA Company, type MZN-240-175kN (FAMA, 2008), for transportation with suspended monorail,
- system of P11,5/1650 transverse traverses and W12,0/7240 (FAMA, 2008) longitudinal traverses, for transportation with suspended monorail,
- powered roof support: line support (basic support used in a longwall) of Fazos-22/45-POz type of pitch 1750 mm and weight about 24600 kg and the support of Fazos-22/45-POz/BSN type (support used at the longwall end) of pitch 1750 mm and weight about 27200 kg, transportation of complete support with use of diesel rack floor-mounted railway, at rails of maximal length 2000 mm and rail space 900 mm – Fig. 8,
- powered roof support: Fazos-15/31-POz-Zt of pitch 1500 mm and weight 14130 kg, transportation with suspended diesel railway without advance system, hydraulic base lifter and without face front shield, with rails of maximal length 2250 mm

Collision analysis can be made both for 2D models (2D mode – operations on surfaces – determination of outline of transported load) and 3D models (3D mode – operations on solids – determination of collision solid).

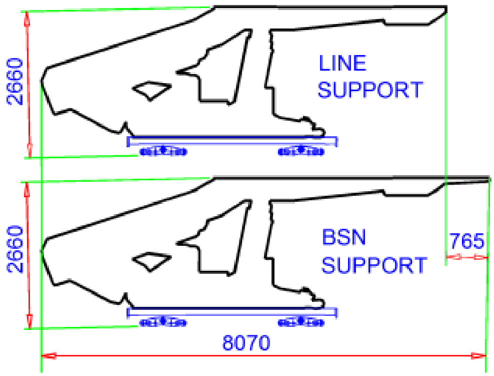


Fig. 8. Load transported by floor-mounted railway – external outline

4.1. Example of 2D collision test – floor-mounted railway transportation

In the case of 2D collision analysis, in floor-mounted railway transportation, input data are as follows:

- selected route section,
- cross-sections of roadways in which the transportation route runs,
- transportation machine – transportation platform,
- transported load and its arrangement on the transportation platform.

Input data used in a discussed example come from drawing documentation of KWK ZIEMOWIT design of transportation system, which is presented in Fig. 9 (KWK ZIEMOWIT,

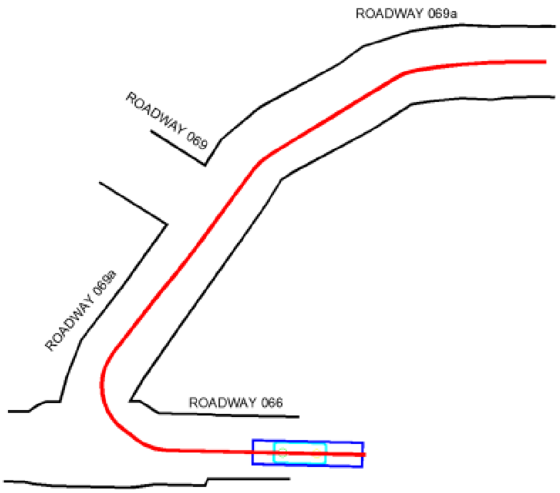


Fig. 9. Testing 2D collision – transportation by floor-mounted railway. Input data

2010-2011). The drawing presents the method of powered roof support transportation with diesel rack floor-mounted railway from roadway 066, through roadway 069 to the support inspection-and-disassembly stand. FAZOS-22/45-Poz powered roof support presented in Fig. 8 is the transported load. Transportation of support is realized on the transportation platform as the entire machine.

Using the input data, a simulation model (Fig. 10), which consists of the following 2D models, was prepared in the same drawing file, on the proper layers:

- roadway,
- route of floor-mounted railway,
- transportation machine,
- transported load.

The simulation model was modified to make automatic analysis of collision by a simulation programme possible. Modification of model consisted in placing the transportation machine with load in the roadway space (Fig. 11).

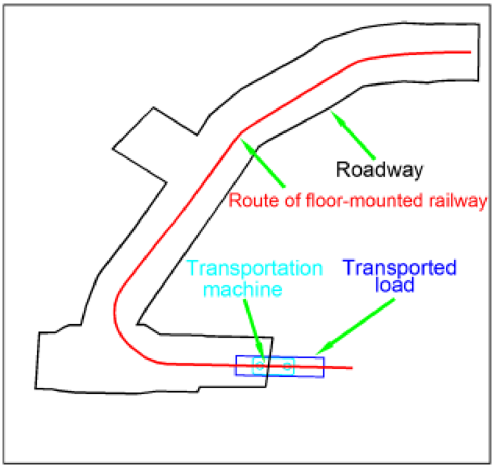


Fig. 10. Components of simulation model – drawing documentation

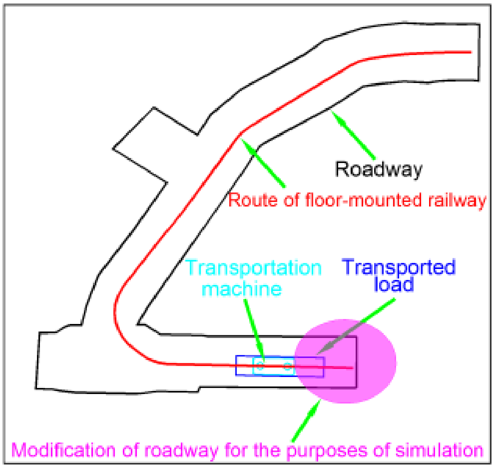


Fig. 11. Components of simulation model – for the purposes of simulation

Simulation programme automatically realizes pass of transportation platform with load on a railway route according to set simulation steps. After each step the programme leaves a "trace" of transported load (Fig. 12). After the simulation the "traces" of load are combined in one outline, which shows the surface that is occupied by transported load in a roadway during pass of transportation platform.

The following two simulations of pass of transportation platform with load, on the floor-mounted railway route, were made for such prepared model (presented in Fig. 11):

- rearward facing transportation of powered roof support, Fig. 13,
- forward facing transportation of powered roof support, Fig. 14.

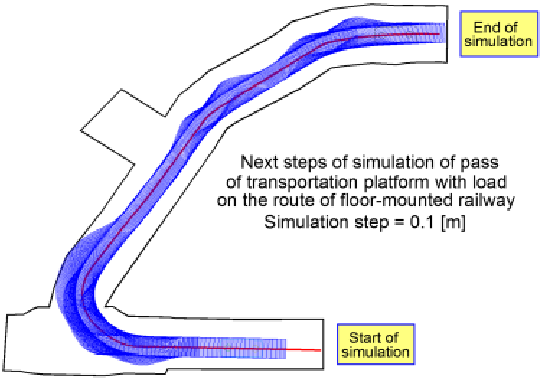


Fig. 12. Exemplary simulation test. Next steps of simulation of pass of transportation platform with load on route of floor-mounted railway

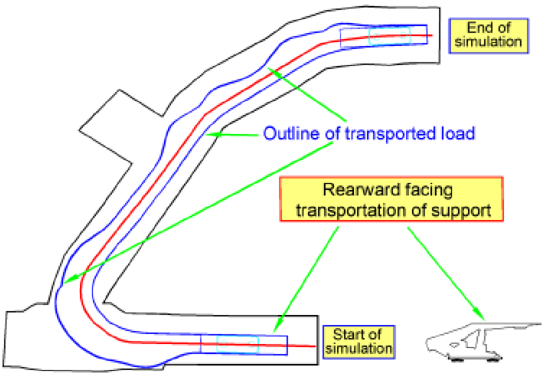


Fig. 13. Exemplary simulation. Determination of outline of transported load. Rearward facing transportation of the support

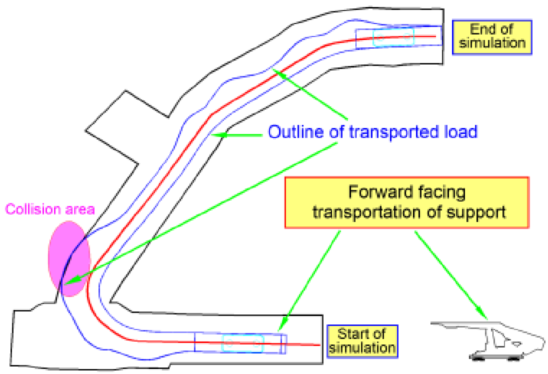


Fig. 14. Exemplary simulation. Determination of outline of transported load. Forward facing transportation of the support

Analysis of the simulations enabled to find out that during forward facing transportation of powered roof support collision of transported load with roadway support can occur. Additionally, reduction of roadway cross-section in a result of rock mass action should be considered in collision analysis. It is presented in Fig. 15 where the outline of transported load is inscribed in the contour lines of longitudinal section of the roadway. The contour line of longitudinal section of the roadway at the height 2660 mm from the floor was especially important in collision analysis as it is the maximal height of transported support placed on the transportation platform.

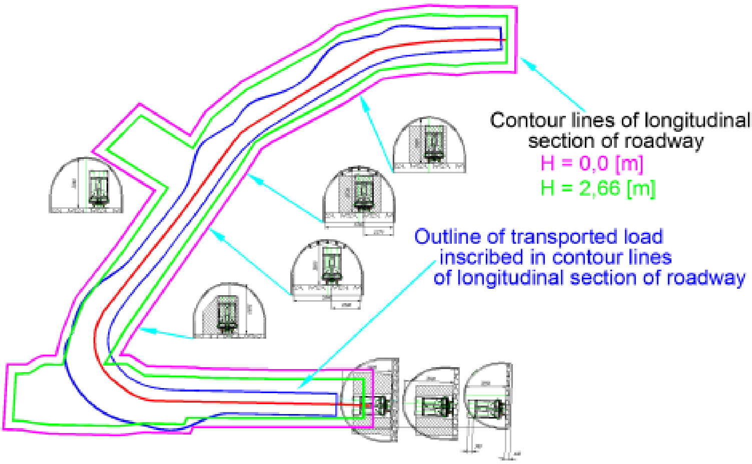


Fig. 15. Exemplary simulation. Contour lines of longitudinal section of roadway

4.2. Example of 2D collision testing – suspended rail transportation

In the case of 2D collision analysis, in suspended rail transportation, input data are as follows:

- selected section of a railway route,
- cross-sections of roadways in which the railway route is located,
- transportation machine – high-loaded beam,
- system of transverse and longitudinal traverses,
- transported load and the method of its fixation to the transportation machine.

Input data used in a discussed example come from drawing documentation of the project of KWK ZIEMOWIT transportation system, presented in Fig. 16 (KWK ZIEMOWIT, 2010-2011). The drawing presents the method for transportation of support by suspended diesel railway with MZN-240 system in version 175 kN, at the crossroad of roadway 072 with roadway 071a. The support is fixed to MZN-240-175 kN transportation system by the system of transverse traverses. Transportation of support is forward facing.

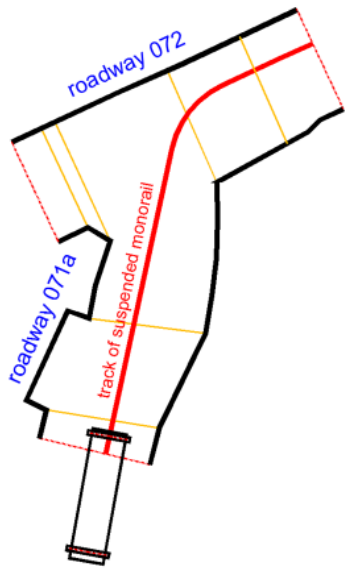


Fig. 16. Testing 2D collision – suspended monorail. Input data

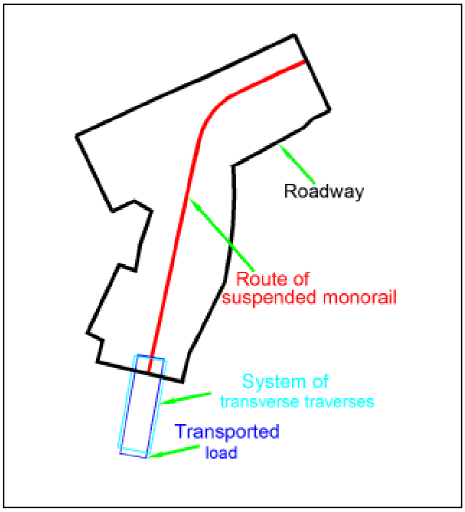


Fig. 17. Components of simulation model – drawing documentation

Using the input data, a simulation model (Fig. 17), which consists of the following 2D models, was prepared in the same drawing file, on the proper layers:

- roadway,
- route of floor-mounted railway,
- system of transverse traverses,
- transported load.

In the case of transportation of large-size and long materials with suspended monorail the modular load-carrying systems – high-loaded beams are – most often used as transportation machines. Examples of such machines are presented in Fig. 18 (FAMA, 2008). Modular load-carrying systems consist of interconnected segments. During transportation with use of modular load-carrying system on a bend, the transported load is approaching to the roadway side wall, what can cause a collision between load and roadway support or between system of traverses and roadway support. The examples of behaviour of selected modular load-carrying systems on a bend are presented in Fig. 19.

As in the case of floor-mounted railways, the simulation model underwent indispensable modifications to enable automatic analysis of collision. Modification of the model consisted in such elongation of the beginning and the end of analyzed route of the suspended monorail at which transported load, transportation machine and system of traverses are whole in the roadway area (Fig. 20).

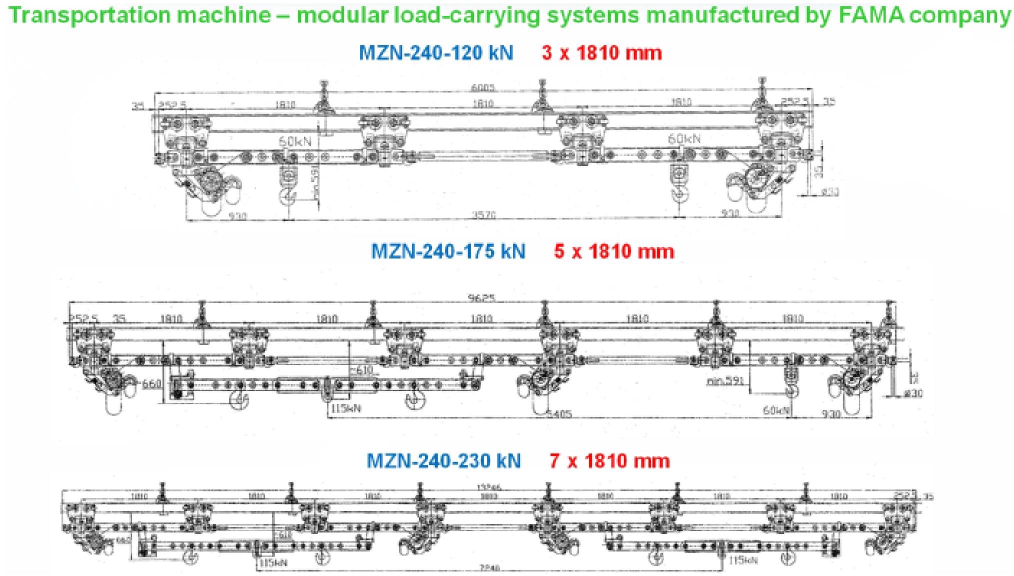


Fig. 18. Components of simulation model – modular load-carrying systems

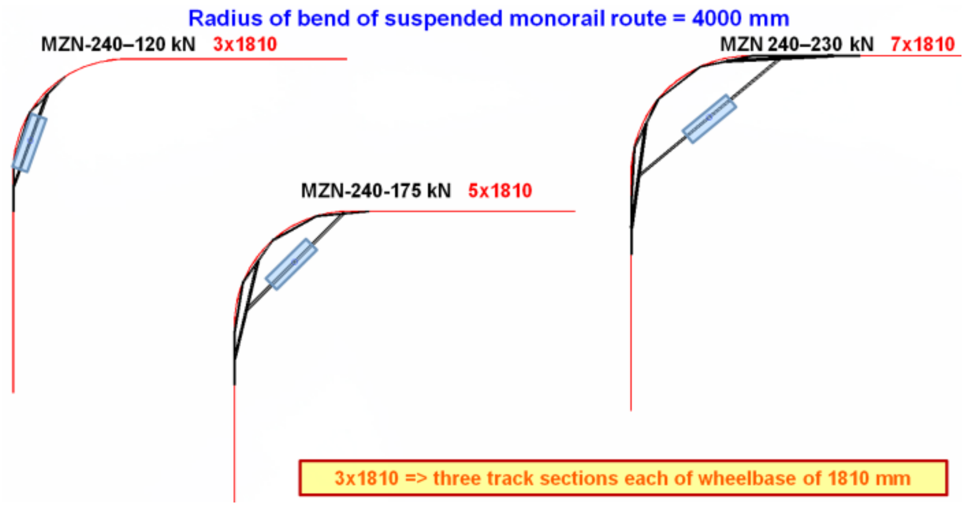


Fig. 19. Kinematics of modular load-carrying systems on a bend

The outline of transported load and the outline of traverses system were obtained in a result of simulation (Fig. 21). These outlines can be additionally inscribed in contour lines of longitudinal section of suspended monorail route (Fig. 22), what is a further assistance to a designer during analysis of possibility of collision occurrence on a selected route section.

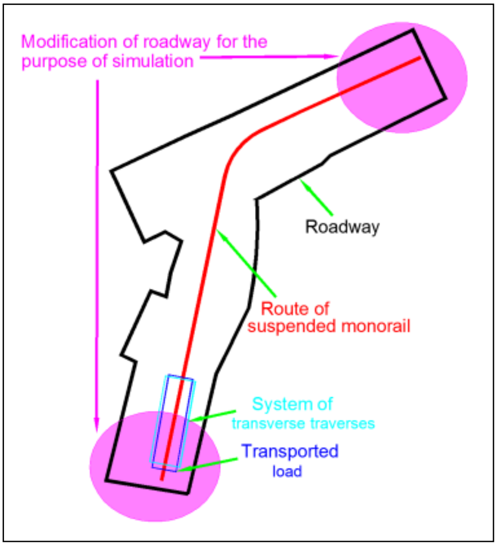


Fig. 20. Components of simulation model – for the purposes of simulation

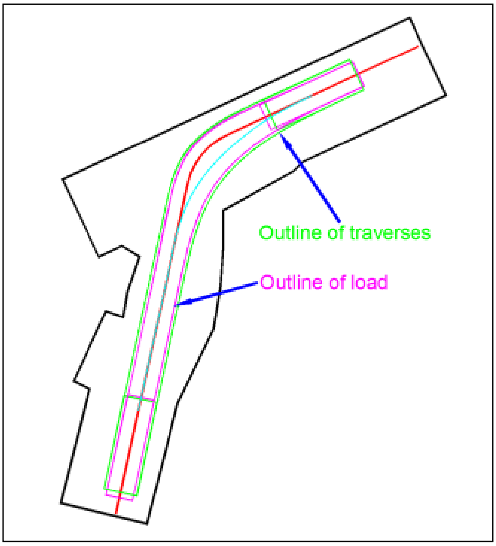


Fig. 21. Exemplary simulation. Determination of outline of transported load and outline of traverses. Forward facing transportation of the support. Fixing of load by the system of transverse traverses (without longitudinal traverses)

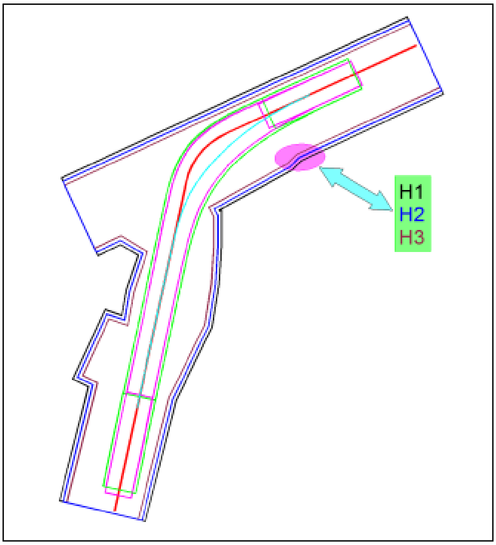


Fig. 22. Exemplary simulation. Outline of transported load and outline of traverses inscribed in contour lines of longitudinal section of suspended monorail route

4.3. Example of 3D collision analysis – suspended rail transportation

Building the model of the selected roadway section, in which collision of transported load with the surrounding can occur, is the first step of preparation of input data for the programme for 3D collision analysis. The roadway section is most often selected in a participatory mode with use of input data delivered by the Department of Production Preparation in a mine. Usually, during transportation of large-size or long loads, collision can occur on bends, crossroads of any type or roadways forks. Input data for building the model of selected roadway section are then as follows:

- cross-sections of roadways,
- position of route of suspended monorail in a roadway cross-section,
- machines and equipment installed in a roadway, which can be the obstacles during transportation operations.

Example of analysis of collision during transportation of powered roof support by suspended monorail is presented below. The selected section of suspended monorail route is the crossroad of roadways, where the belt conveyor transporting run-of-mine from the longwall panel is additionally installed. Transportation of powered roof support in the area of crossroad is realized on a bend of radius equal to 4 meters.

Roadway 3D model was created in AutoCAD programme. The roadway was developed in a solid coal of the following dimensions: 60(X) * 60(Y) * 30(Z) metres, where XY is a plane of longitudinal section of the roadway, while XZ and YZ are the planes of roadway cross-section.

2D polyline, which lies on the plane oriented to the roadway, is the route of suspended monorail. Exemplary orientation of the road in relation to the roadway cross-section is presented in Fig. 23, while orientation of the road plane with its position in relation to roadway is presented in Fig. 24.

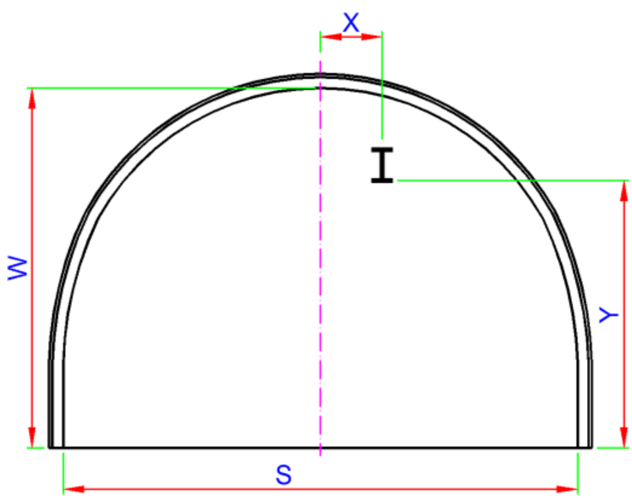


Fig. 23. Orientation of suspended monorail track to cross-section of the roadway

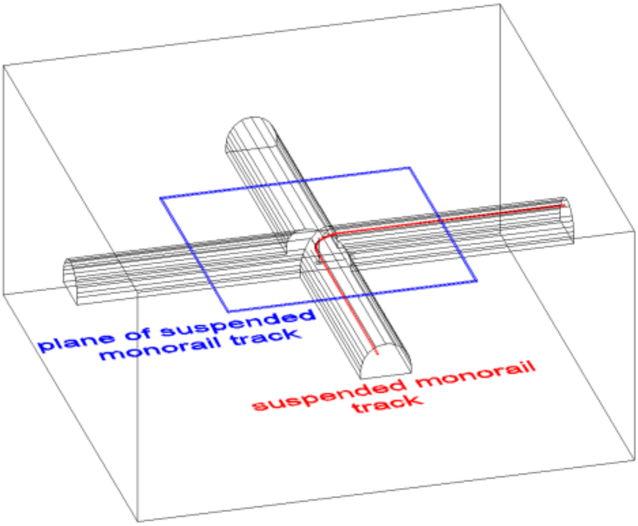


Fig. 24. Suspended monorail track in relation to solid model of the roadway

The discussed roadway model can include additional machines, equipment and materials, which can be the obstacles during run of suspended monorail and should be considered during analysis of possibility of collision. Models of obstacles on transportation route are also created in AutoCAD programme as 3D solid models.

Exemplary model of belt conveyor installed in a roadway, which crosses the route of suspended monorail, is presented in Fig. 25. It is a solid model, which describes maximal dimensions of the conveyor.

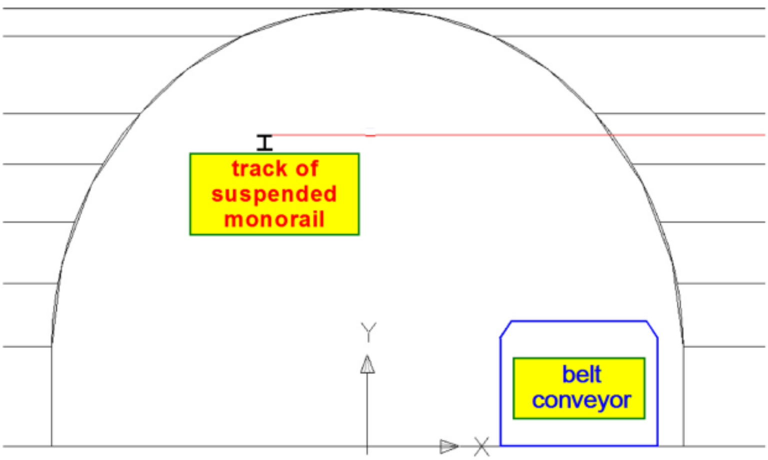


Fig. 25. Exemplary model of belt conveyer on suspended monorail track

Transportation machine is selected from the list displayed in a window of internet application for preparation of input data for collision analysis programme. On the basis of selected transportation machine the programme automatically creates its kinematic chain at a given point of suspended monorail route and determines coordinate system and point of inserting the model of transported load and the model of traverses system. MZN-252-252kN modular load-carrying system was the transportation machine in the analyzed example, Fig. 26 (FAMA, 2008).

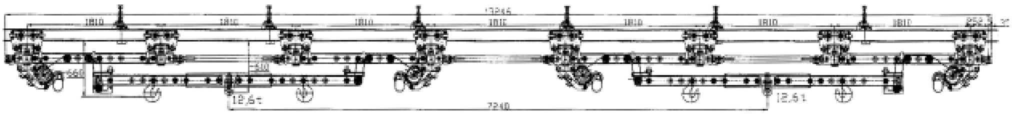


Fig. 26. Transportation machine – MZN-252-252kN modular load-carrying system

Transported large-size load is usually fixed to the transportation machine and stabilized by the system of longitudinal and transverse traverses. The system of traverses is made as a separate 3D solid model to enable analysis of collision of this system with a roadway support and machines in the roadway. A simplified 3D solid model of the system of longitudinal and transverse traverses is presented in Fig. 27. Orientation of XYZ coordinate system of 3D model of the system of traverses and its point of insertion, which overlaps AutoCAD global coordinate system, are marked in the figure.

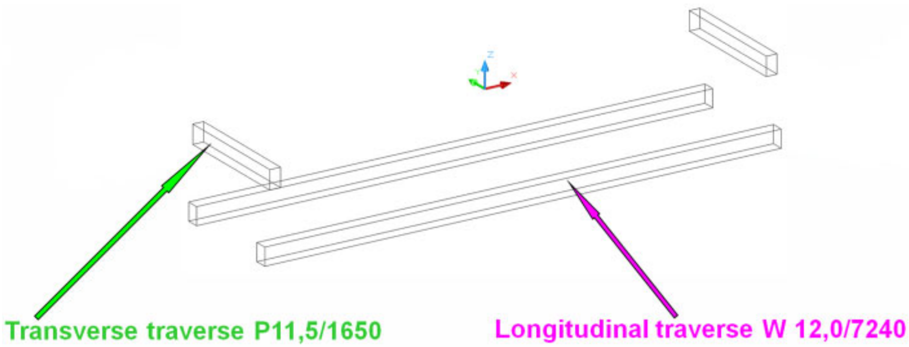


Fig. 27. Simplified 3D solid model of the system of transverse traverses P11,5/1650 and longitudinal traverses W12,0/7240

The model of transported load was made in AutoCAD programme as a solid model. It is automatically read in by the simulation programme and oriented to the kinematic chain of used transportation machine. Exemplary 3D model of ZBMD-22/44-Poz longwall support is presented in Fig. 28. Orientation of XYZ coordinate system of the model and its point of insertion, which overlaps AutoCAD global coordinate system, are shown.

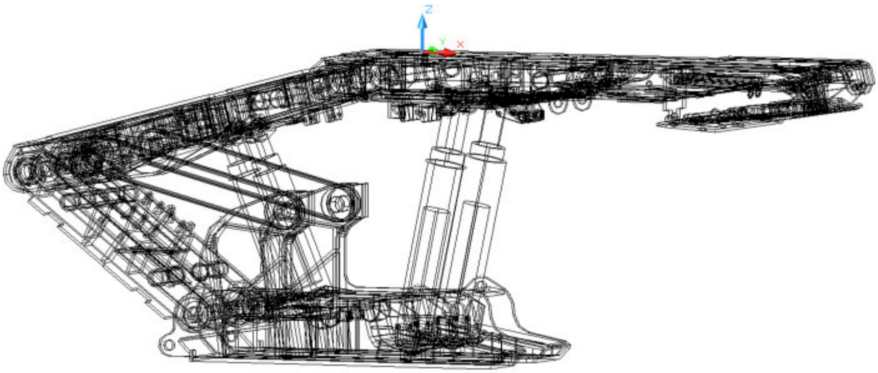


Fig. 28. Exemplary detailed 3D model of transported load

Due to the fact that 3D models of transported load are of high precision, they have to be prepared in a simplified version to make the collision analysis possible. Then they become the solids recreating external dimensions of the load. It is shown for ZBMD-22/44-Poz lonwall support model in Fig. 29. Fig. 30 shows the model of transported load and model of the system of traverses put together.

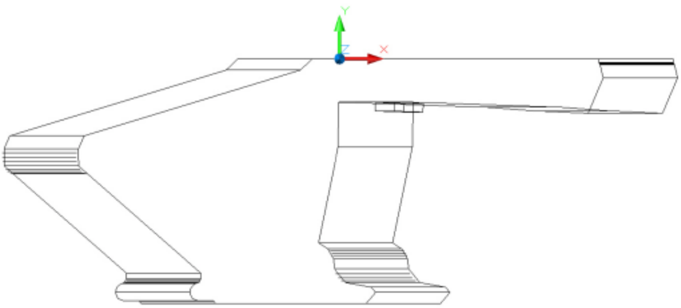


Fig. 29. Simplified 3D model of transported load

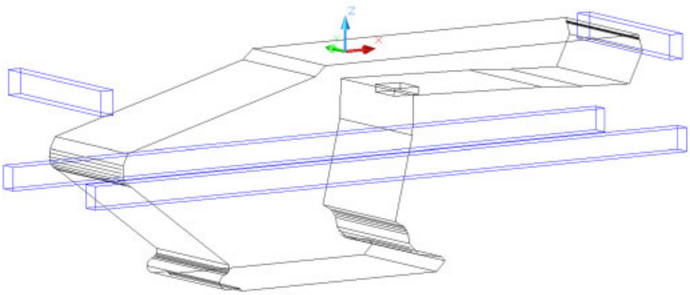


Fig. 30. Simplified 3D model of transported load with a model of traverses system

For such prepared input data, the analysis of possibility of collision occurrence was made for the selected section of suspended monorail route – transportation of the support on a bend on a roadways crossroad. Starting point of simulation is presented in Fig. 31a, while Fig. 31b shows the movement of the load centre of gravity (blue line) in relation to the suspended monorail route (red line).

The programme makes analysis of possibility of collision at each simulation step. Solid of collision is automatically created in the case of collision. This solid, after the simulation, can be analyzed to suggest the measures for elimination of collision. Selected steps of the simulation of overcoming the bend are presented in Fig. 32a, and Fig. 32b is a top view of exemplary simulation step. Additionally, solid of collision between powered roof support and belt conveyor is visible on both figures.

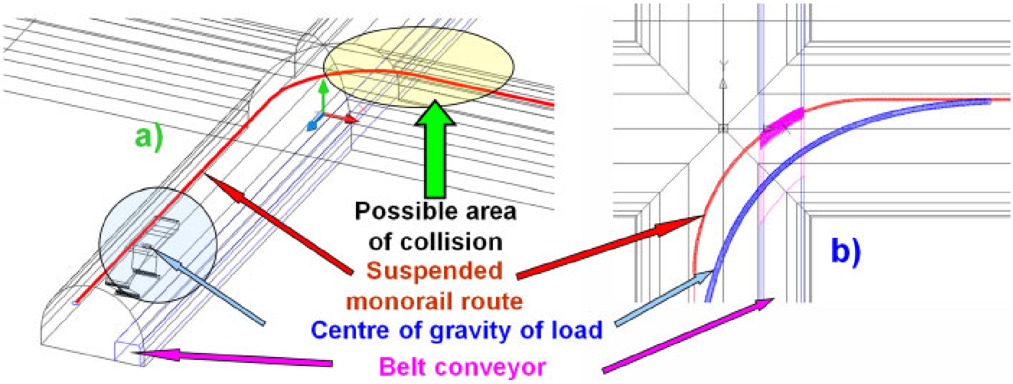


Fig. 31. 3D model of suspended monorail route – transportation of powered-roof support by MZN-252-252kN modular load-carrying system on a route curve: a) view of route bend, b) movement of the centre of gravity of load (blue line) in relation to suspended monorail route (red line) on a bend

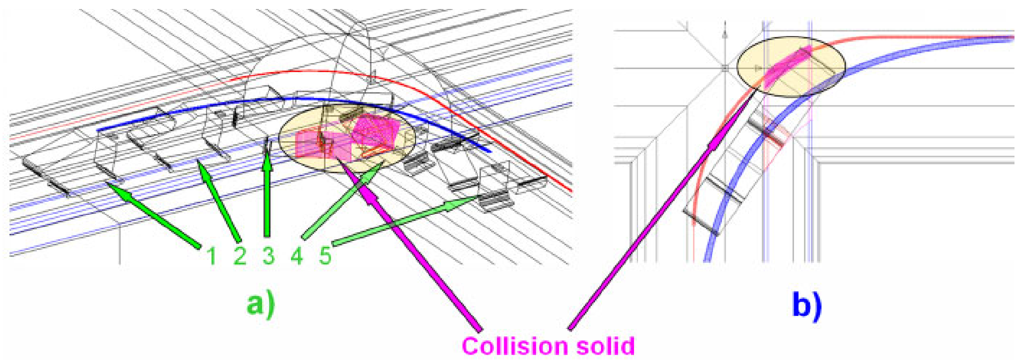


Fig. 32. Simulation of transportation of powered-roof support by MZN-252-252kN modular load-carrying system on a route bend: a) next selected steps of simulation of bend overcoming, b) exemplary simulation step – collision solid of support and belt conveyer – top view

5. Summary

Available internet tools for acquisition of input data entered to the popular Computer Aided Design software (AutoCAD) as well as author's software developed at KOMAG, operating within AutoCAD programme is the essence of the computer system for collision analyses. The developed system can be used in collision analyses of transportation routes of mine underground railways, floor-mounted railways and suspended monorails.

Use of the programme from CAD group for collision analysis provides the designer of transportation system with the following benefits:

- possibility of multiple analyses of collision for changing boundary conditions (localization of railway route in a roadway cross-section, size of transported loads, additional machines and equipment present on a railway route),
- speeding up the analyses and possibility of documentation of the results,
- possibility of creation of 2D models or 3D models of any degree of complexity,
- determination of real trajectory of load during transportation of large-size materials – outline of transported load,
- determination of collision surfaces or solids,
- possibility of making the measurements of obtained collision surfaces or solids to suggest measures indispensable to eliminate the collision,
- determination of distance of transported material from the potential obstacles.

Prototypes of computer tools, which can significantly support the designers of underground transportation systems, were developed in a result of realization of the MINTOS European research project (MINTOS, 2007-2010) at KOMAG, co-financed by the Research Fund for Coal and Steel, and in a result of continuation of the statutory research work (KOMAG, 2010). They were positively assessed by the representatives of Coal Company, JSC, who took part in the MINTOS project on behalf of industry sector. Developed prototypes of computer tools are still being improved and prepared for commercialization in the selected mines.

Making the developed prototype of the system available on the internet platform should contribute to improvement of designing of the new transportation routes as well as should enable analysis of existing transportation routes as regards verification of possibility of collision occurrence and their modification for selected sections of transportation roads.

Further development of the author's programme for collision analysis by adding new functions as well as extension of data base of graphical models are planned in the future. So the following tasks should be realized:

- 2D and 3D computer models of selected large-size and long loads,
- 2D and 3D computer models of transportation and auxiliary machines, which are present on transportation routes (e.g. belt conveyor, pipelines, etc.) and which can be the obstacles during transportation of loads,
- 2D and 3D parametric generators of selected types of crossroads and forks of roadways.

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Received: 16 March 2012