CREATION OF MODEL MESHES FOR HYDROGEOLOGIC MODELING

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Abstract

A number of practical problems are solved through modeling. Examples include the water flow and transport in the rock environment. They are modeled by finite element method, the solution uses software tools for which it is always necessary to process real data of the modeled area. In mathematical modeling of processes is the construction of model meshes and their filling with data significant challenge. The existence of the model mesh with required properties is a prerequisite for specific calculations in mathematical modeling of processes investigated in the study area. Processing of real world data requires the use of GIS and geoinformatic modeling approaches.

For each modeled area is always created its own model mesh or set of model meshes with different parameters. In order to address the construction of model meshes was explored methods to create a file of model geometry based on data stored in the GIS and, consequently file of model mesh, which is filled by all the necessary data and will be used for calculations. To create a model mesh and fill it with data are used real data stored in the GIS, which serves as the basis for modeling the area of interest. The model mesh must always reflect the purpose and desired characteristics of the area and at every moment during creation of model mesh must be ensured the continuity with real data in GIS. Therefore, the methodology for data preprocessing, data storing in GIS, data processing in GIS including generalization, and for transformation to geometric model and model mesh is created. Another task is to fulfill the model mesh by data from GIS.

Abstrakt

Řada úloh z praxe je řešena pomocí modelování. Příkladem jsou úlohy proudění a transportu v horninovém prostředí. Jsou modelovány metodou konečných prvků, k řešení se používá softwarových nástrojů, pro které je vždy nutné zpracovat reálná data modelované oblasti. V rámci matematického modelování procesů je výstavba modelových sítí a jejich naplnění daty podstatným úkolem. Existence modelové sítě požadovaných vlastností je podmínkou nutnou pro konkrétní výpočty v matematickém modelování procesů, které jsou v daném modelovém území zkoumány. Zpracování reálných dat o území vyžaduje nasazení GIS a přístupů geoinformatického modelování.

Pro každé modelované území je vždy vytvářena vlastní modelová síť nebo množina modelových sítí s rozdílnými parametry. V rámci řešení výstavby modelových sítí byla hledána metodika, jak efektivně na základě dat uložených v GIS vytvořit soubor geometrie modelové sítě a následně soubor sítě, které ponesou všechna potřebná data a budou bází pro modelové výpočty. Pro tvorbu modelových sítí i jejich naplnění daty jsou využívána reálná data uložená v GIS, který slouží jako základ pro modelování dané lokality. Modelová síť musí vždy pro daný účel vystihovat požadované charakteristiky území a v každém okamžiku výstavby musí být zajištěna návaznost na reálná data v GIS. Proto je vytvářena metodika pro předzpracování dat, jejich uložení v GIS, předzpracování dat v GIS včetně generalizace a jejich transformaci do geometrického modelu a modelové sítě. Dalším úkolem je naplnění modelové sítě daty z GIS.

Keywords: geometric model, model mesh, GIS, GMSH, GEO format, MSH format

Klíčová slova: geometrický model, modelová síť, GIS, GMSH, formát GEO, formát MSH

1 INTRODUCTION

In this paper willl be explained transformation procedures of particular part of the landscape sphere (area of interest) into geometric model and model mesh, which are used in modeling of transport and flow in the rock environment, simulating the process of disseminating the risk of contamination, etc.

Area of interest is described by the geographic data. For example maps in analogue or digital form, data of watercourses, watersheds, divorces, surface relief, but also socio-economic activities that cause pollution and contamination of surface, underground geological data with rock structure, tectonic areas, physical properties of rocks, cracks in the rock properties, data describing wellsprings, wells, geological exploration (drilling), geological profiles, mine maps, hydrogeological characteristics of the territory, a number of textual and tabular data describing the area with attributes of selected objects and phenomena in the area.

Geoinformation technologies are used for processing of primary data describing the area of interest into the desired formats and geoinformatic models. For modelers – users of our geoinformatic models - a black box. From different data sources and requirements by which is final model defined, they obtain appropriate model. This model must be filled with data. Then it can be used for calculations in mathematic modeling. This is a specific set of models which are used for mathematical modeling and calculations by finite element method. Model is called model mesh. We assume models that are fully 3D, volumetric, so we work in conjunction with GIS software and software for solid modeling in which the model mesh is created.

Construction of the model mesh is not trivial, various processes and software are used. What exactly model mesh is and what is a methodology of its creation, will be explained below.

2 MODEL MESH AND ITS CREATION

2.1 Model mesh and geometric model of area

The model mesh is given by a finite number of two-dimensional and three-dimensional elements in 3D. These elements covers the area in accordance with established criteria and the spatial resolution [4].

Model mesh is model of the area in accordance with given purpose. The model of the area is the system model of the geographical area where the system elements and relationships are defined in order to carry out the analysis and calculations of data base. Conceptual model of the model mesh is created first. There are elements of the real world and their relationships defined. Both elements and relationships are essential according to the purpose of the model.

The logical model is implemented in a particular software and its file system and filled with data about a particular territory. It is appropriate to handle such models in a geographic information system (GIS) and then use GIS filled by data as the data basis for derived models creation - geometric models and model meshes.

Model mesh is essentially a model compiled from 2D and 3D elements in space. 2D elements are triangles and 3D tetrahedral elements. All surfaces and volumes in original GIS of modeled area, which is needed to be described for the mathematical model, are discretized and a finite number of triangles is created to fill the surface (eg rock interface cracks of vertical and horizontal progression, the surface relief, etc.) and a finite number of tetrahedra to fill volumes of model is created (volumes of rocks, volumes of cracks in a high-resolution, volumes of anthropogenic shapes, etc.). Exactly it is filling of areas and volumes of geometric model (will be described later). How these elements form the model is dependent on the resolution of the model and the requirements for the resulting number of elements in the model. This resolution is due to the length of the element edge and sets up the final mesh of geometric model [5].

The geometric model describes the entire modeled area from the view of geometry. This is a solid model, realistic 3D. It is composed by elements of geometric model: 0D – point, 1D - Line, 2D - plane, 3D - volume. 1D elements can be difficult - for example, splines, 2D element can also be ruled surfaces, space balls, etc. Then they have a special definition in the source code of the geometric model. The closest to this model is wireframe body, which requires CAD access to model creation (see fig. 1, 2). In GIS SW (ArcGIS, GRASS

GIS) this volumetric vector model can not be completely created. Geometric models created on the base of real-world data are usually complex.

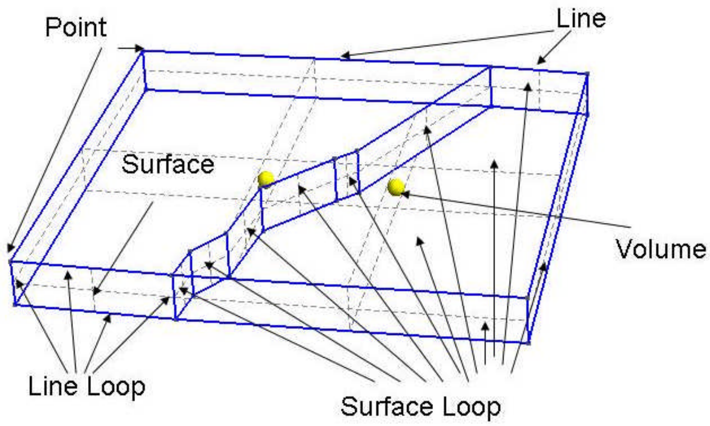

Fig. 1 Elements of geometric model

For example a block of broken rock with fissures with both vertical and horizontal direction. These fissures divide a single block of rock in many volumes. Geometry of area is affected also by many other features and phenomena - configuration of the terrain, rivers and their effect on the circulation of water, the course of the watershed, the water table and many others. Which geoobjects will be introduced into geometric model depends on purpose of the model, depends on desired resolution and accuracy of the model. The geometric model addresses not only the decomposition into sub-volumes and surfaces in space, but also defines a sets of volumes and areas according to physical properties. Then one physical volume is formed by set of all volumes with particular property, which is essential in particular physical group for the subsequent model calculations. Likewise, the areas or lines or points in the model can be a part of physical group of appropriate dimension.

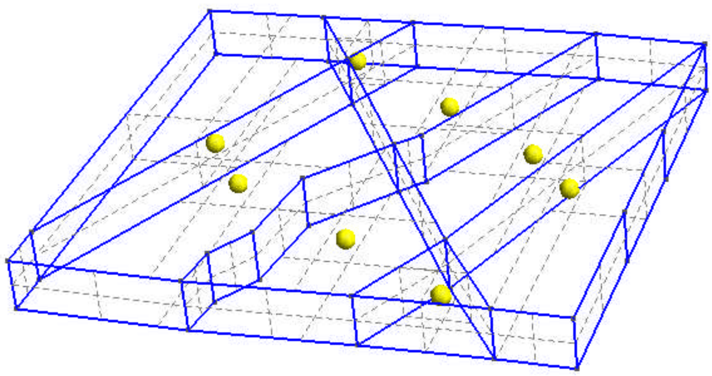

Fig. 2. Geometric model

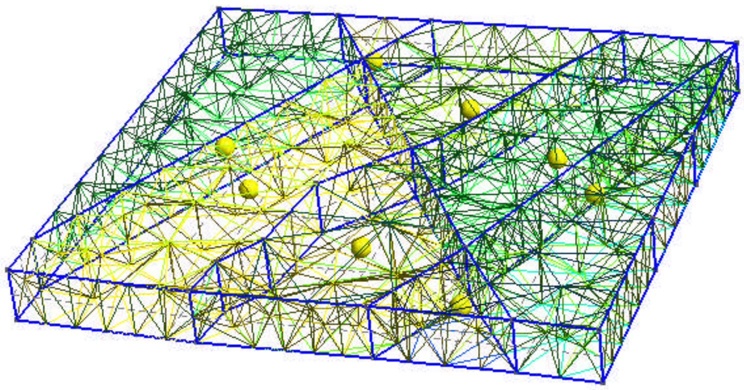

Fig. 3. Model mesh

In this paper is handled only the issue of the construction of geometric models and model meshes, solutions will be demonstrated on the model data from different areas. Creation of geoinformatic system as data base for construction of model meshes is sufficiently described for example in [3].

2.2 Model mesh construction

Construction of the model mesh (fig. 3) is in several successive steps. Asume that geographic information system of modelled locality is created [3]. Next step is to determine the requirements for model mesh. Creating a conceptual model of the mesh. Conceptual model of mesh is a description future mesh in terms of size in horizontal and vertical directions, the extent of area to be modeled, the boundaries of the model - which type of elements will define the boundary, the determination of the exact boundary shape, what will be the mesh density, constant or variable length of element edge and the resulting number of mesh elements. Selected geographic features - rivers, lakes, conduct watershed, ridges, walleys. Geological elements - rock, rock boundaries, tectonic fault lines. Hydrogeological features and phenomena - springs, wells, cracks, and their permeability and groundwater level.

These all are things that affect geometry and water flow and transport in rock environment and will be included in geometric model [3]. Their attributes will be involved. It is necessary to define context and relationships of individual phenomenon included in the geometric model and model mesh. Parameters of the future model influence generalization - selection, simplification of shapes, aggregation of object classes and attribute generalization.

The next step is geoinformation system data preprocessing to the required format of the modeling tools used in consecutive processing. This step includes preparation of geometric model and data preprocessing in GIS. It also includes generalization methods of both geometric and database. In detail, the issue is described in [1]. The resulting geometric model can be geometrically simplified, but it must be topologically correct. They must be well maintained neighborhood, including the relative distance of the elements that interact or have a common influence on the course of flow and transport. Further attributes are prepared for future model mesh data fulfillment. Attributes are usually exported from GIS database in text format file and it is joined with source code of the model mesh to combine element with its properties.

Since the geometric model is built from the points (0D elements), in the data preprocessing is first created a definition point set. All the elements entering into geometric model are replaced by point sets (see fig. 4, 6), and each point carries information about its absolute location in the model, belonging to the element or phenomenon, information about neighboring points, belonging to line and area, volume, and then carries the attributes of all phenomena in which it occurs (eg point lies on the boundary model, which is also a water course, lies on the surface at certain altitude, belongs to a certain volume of rock that has given physical properties, at the crack with certain characteristics, etc.). On the basis of these points can element of higher dimension obtain relevant information (eg cracks in the geometry model, the volume of rock, etc.). Such a way new data model is created. The result of data preprocessing for construction geometric model are files with data about points with their properties, which are the basis for geometric model creation. Each file can be converted to the GEO format, which is a format for geometry described in GMSH software (see below).

For construction of a geometry model of model mesh we use software GMSH [6]. GMSH is a 3D finite element generator of spatial meshes. This SW is also used for construction of geometric models. Purpose why this software was selected was given by requirements from mathematical modeling, which require the input mesh in the MSH format, which is being generated by GMSH. Geometry is created on the basis of pre-processed data. More about building of concrete geometries is described further in examples of model mesh ceration.

Generally, geometric model always begins with points that are then connected by lines (line segments), the surface is defined by border lines, the volume is defined by its surface - a set of surfaces that make it up. Furthermore, physical groups of surfaces and volumes are defined - by the same properties (eg cracks of the same bandwidth, equal volumes of rock).

Creation of the model mesh file is in the program GMSH based on geometric model. Areas and volumes of geometric model are filled with finite number of elements (see fig. 3). You can set the mesh density, ie, the length of edge of an element. The result is a MSH file format containing a description of all nodes of the mesh and description of all elements and their types with codes of points on element.

Last step is to create files of physical and material properties and files of initial conditions for simulation. It is done on the basis of physical groups defined in the model geometry. To these files can be attached files contains the attributes of elements, which are created in GIS from the stored attribute data (rock type, geological structure, areas of the same hydraulic conductivity).

3 GEOINFORMATIC MODELING OF GEOMETRIC MODELS

3.1 Original geoinformatic system

Creating of geoinformatic system is an important thing (meaning mainly conceptual model of data base, which specifies the individual elements of real world and their relations in accordance with the fundamental purpose of the model created). Such geoinformation system allows multiple use for derivation of various geometric models of the area, easy data update and, ultimately, feedback for creating a model meshes - their geometry and initial conditions, which, despite on the specifics of their construction must remain in line with reality.

More about the creation and processing of GIS data layers in [3]. Consequently, it is necessary to define which objects, phenomena, layers will be treated as the basis of geometry, then determine their range and resolution based on the requirements for future model geometry of the mesh [1]. This is a task of creation of a conceptual model for the model mesh. On this basis, data in GIS are preprocessed for the geometric model.

3.2 Creation of model geometry – specific types of problems

Creation of a geometrical model is not trivial. It consists of different steps, depending on the character of the area and available data. Way of creating geometric model depending on requirements to geometric model and the model mesh. Furthermore, we explore different ways of preprocessing data and creation of various types of geometric models.

3.3 Preprocessing of data in GIS and creation of volumetric geometry in GMSH

All elements (meaned geographical, hydrological and geological objects) entering the geometry or affecting the geometry of the model are converted to a point sets (fig. 4, 5), every point has coordinates given in S-JTSK (czech national geodetic coordinate system). Individual objects of real world (ie original geoinformatic system) that enter the mesh model geometry, are initially described by lines and subsequently represented by point sets. Spatial objects have their boundary line, so they workare processed the same way. When creating a set of points generalization starts with selection and simplification. Line can be simplified by generalization algorithm and then the simplified line replaced with a set of points. Or the opposite approach, where the point set is reduced. The resulting set of points represents an appropriate shape and size of the object in the original model in the desired degree of resolution. Simplification is necessary because of the quantity of processed data and also in terms of purpose and resolution of model mesh. The model mesh is not important the exact shape (eg lines, which can be very complicated in their course), but maintaining above topological adjacency relations, and including, maintaining the distance between the individual elements.

At this stage, the points are exported from GIS to CSV or is appropriately adapted attribute table of points and is used DBF format. As follows files are converted to the GEO format for GMSH, it contains information about points and their position in absolute coordinates x, y, z. File describing the points in GEO format is loaded into GMSH. Next geometric model is edited in GMSH. To ensure good orientation in the GEO file during editing source code of geometry, it is essential to choose the numbering of points, lines, areas and volumes according to a certain order.

The geometry consists of a set of points, lines, surfaces and volumes. First, they are always defined points (imported points preprocessed in GIS), then lines are created by connection of points, on the basis of lines are defined surfaces and volumes ared defined on the basis of surfaces.

This process (the creation of geometry at the basis of point GIS layers) is appropriate in two cases. For small geometric models with a simple structure (fig. 3) where the direct editing geometry in GMSH is fast. The second case is a complex geometry (fig. 5), which, however, consists of a relatively small number of elements of geometric model. In the second case it can be very difficult have algorithm for automated solutions. Such a solution can be partially automated. Then is created model mesh atomatically on the vase of geometric model in GMSH.

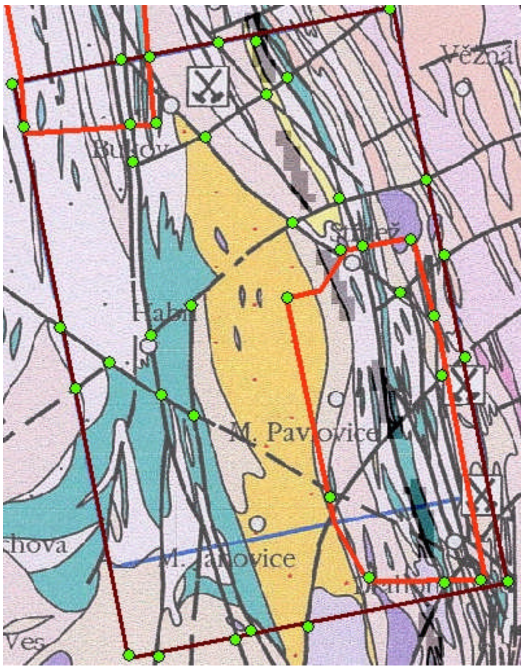

Fig. 4. Creation of part of point set in GIS – example of complex geometry

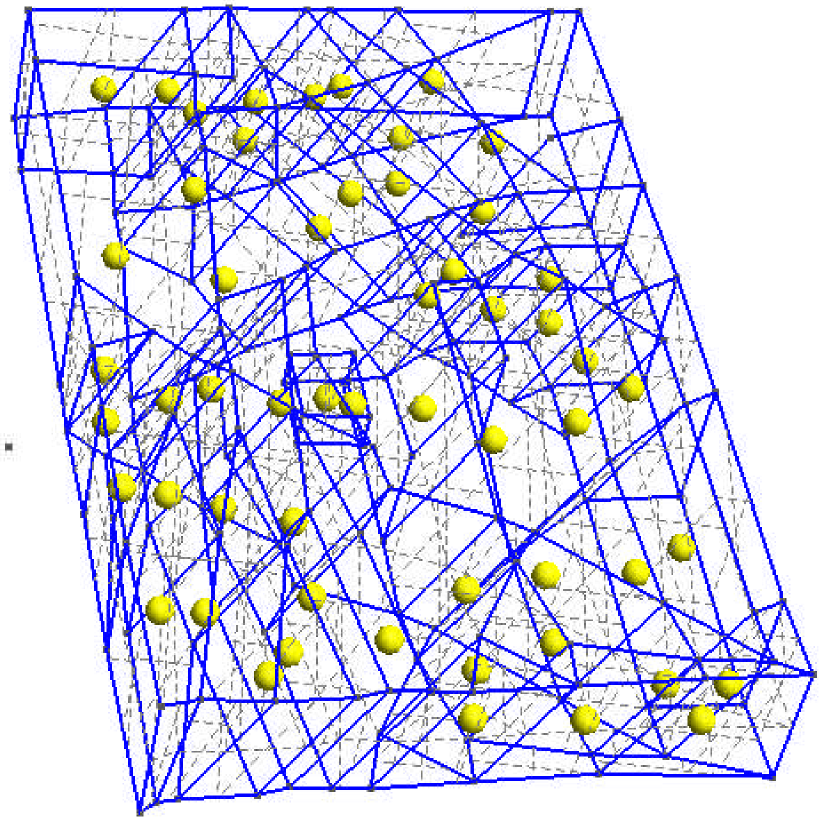

Fig. 5. Geometric model – example of geometry of locality from fig. 5

3.4 Creation of surface mesh in GIS

If working with volumes are not required, and demand is for surface model network (ie the surface in space), we use GIS tools. Preprocessing of data to generate the surface geometry in GIS means creation of a set of points representing the elements of geometry. For this purpose the line elements was replaced by points (in accordance to model resolution). See fig. 6.

Areas between lines in model are filled with regular points (see fig. 6, 7). Geometry is based on the point layer, which consists of a point field defining characteristics of modelled area. Each point has coordinates x, y.

Next is used a digital elevation model. On its basis is assigned altitude as the coordinates of Z to every point in point layer which was created. Point layer has attribute table, where they are recorded in addition to coordinates X, Y, Z, other characteristics - the belonging of point to the type of line (tectonics, rock interfaces, boundary), points inside the area carry information about the area in which belongs (thereby physical characteristics, such as type of rock). Attribute data of point are used to create a file of physicas properties of model mesh for subsequent mathematical model.

In the point layer is then formed triangulation (Delaunay) (fig. 7) and the triangles are stored as lines and surfaces. It is necessary to create topology - relationships between points from point layer, lines and surfaces from triangulation and results are recorded to the database tables.

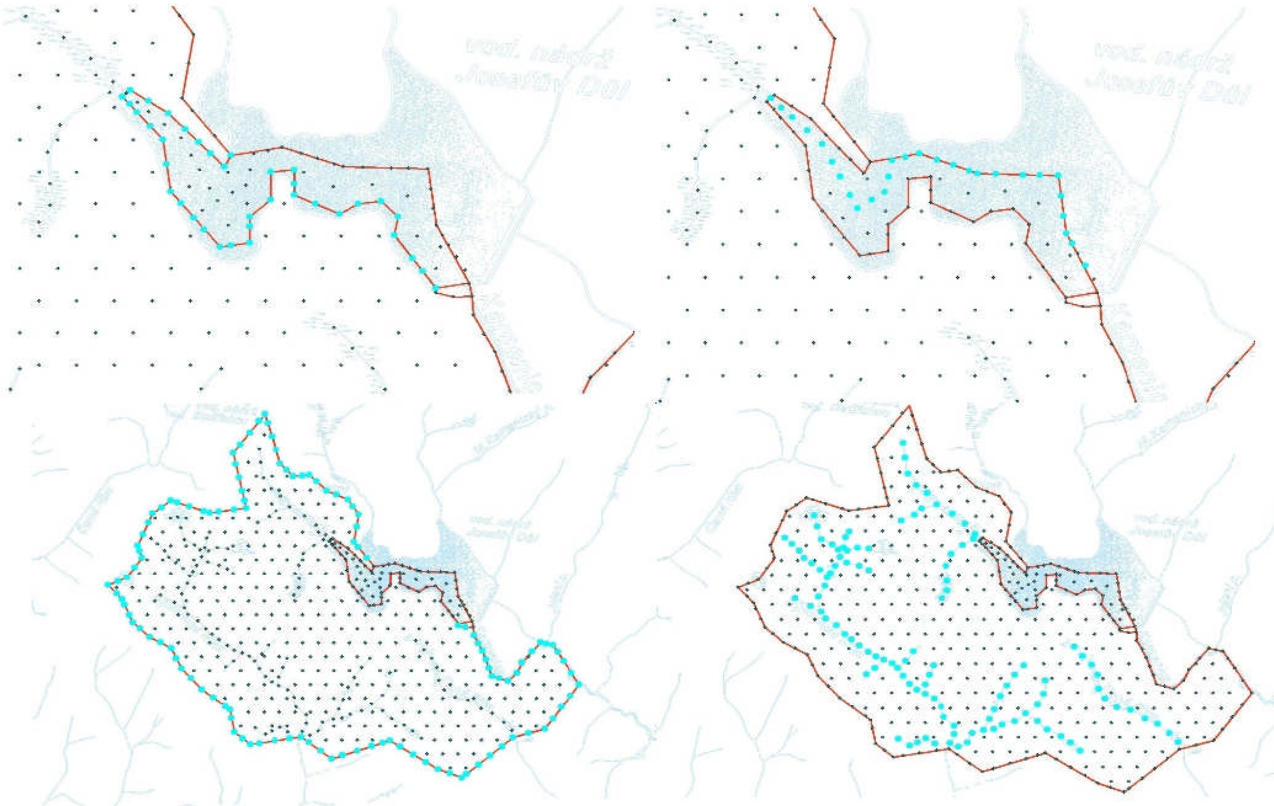

Fig. 6. Replacement a line by points and fill of resting area by regular point grid

Gradually, the information about lines is obtained (line IDs, IDs of extreme points). Then information about the area (triangular area ID, ID numbers of lines – triangle edges). Prepared table can be transformed to the format of GEO and loaded into the GMSH. Here, triangular geometry is meshed. Or directly can be created a format MSH (a mesh), where triangular elements in GIS were created diectly as elements of the model mesh. Elements (triangles) are easy assigned to the GIS features (eg. information about the type of rock, of wells, etc. associated to surface element – fig 8).

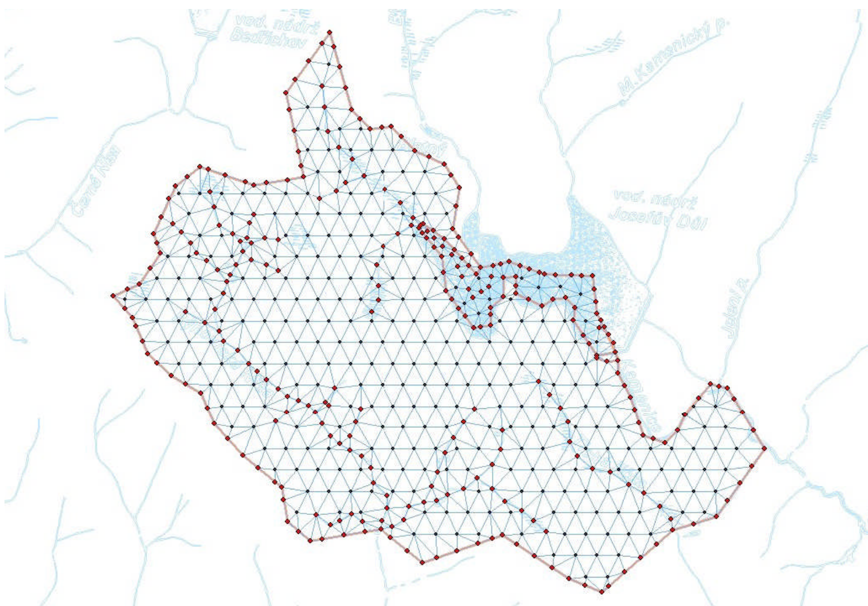

Fig. 7. Triangulation in processed point layer

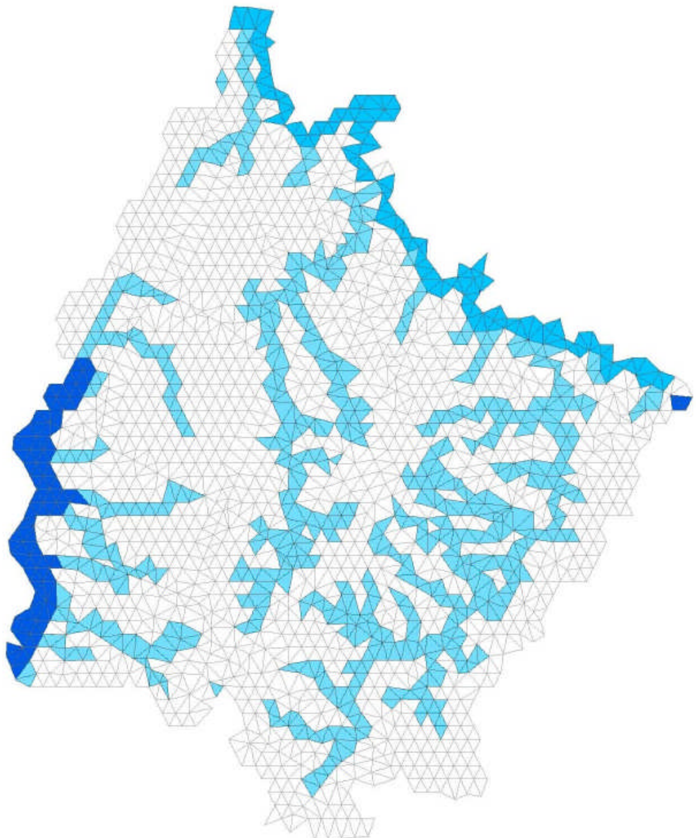

Fig. 8. Properties of surface mesh elements – elements with occurrence of water are selected

3.5 Preprocessing of data in GIS for automatic creation of geometric model

In this variant of modeling preprocessing procedure is the same as in the previous case. Triangular grid is created in GIS and relations between points, lines, areas in triangular network are described. The basis for future geometric model is formed. As follows data from GIS to dbf of desired structure are transformed. It is created a table of points (point ID, x, y, z) and table of triangular areas (area ID, ID point1, point2 ID, point3 ID). Subsequently, the dbf files are input into the application for automated processing of model geometry. For the construction of geometry, where the necessary information for the entire volume of the geometric model are contained in the surface layer, has been developed applications Convert2geo [2].

4 AUTOMATIZATION IN CREATION OF MODEL GEOMETRY

Because construction of geometric model from pre-processed data is in many cases only a matter of routine, we searched for a way to automate the construction of the geometry for such models. First, we conducted a search of available software products that are potentially capable of creating a fully automated spatial mesh. Standard GIS tools allow only so-called 2.5D interpolation (two and a half dimensional). This type of interpolation is specific in the resulting interpolated surface, which is described by a 2D matrix (grid), or possibly by using a TIN (Triangulated Irregular Network). These data types do not save the interpolated values of the two values of the same phenomena (eg height Z) to one point with coordinates [x, y]. Selected software products are fully able to interpolate the data in 3D - the ability to model overhangs, cumulus geological layers - the one where the value of the coordinates [x, y] associated with two (or more) values of Z. From the available resources was chosen three commercial products and one software distributed under the GNU Open-licensing: EVS-PRO – C-TECH company, RockWorks 2006 –RockWare company, VOXLER – Golden Software company, GRASS 6.3 – OPEN-GNU licensing.

The test results both commercial and non-commercial software products for creating a fully spatial data shows that none of these programs is able automatically create a triangulated network, which fulfill our requirements to model mesh [2]. We proceeded to design and implement an algorithm which is capable from entry points representing geographic and geologic phenomena (as described above) to generate a mesh format for GMSH program.

The application is based on generalization of the surface geometry into space. The surface geometry of triangles means the triangular prisms in space. Thanks triangles generated in the point layer (point layer formation described in chapter 3.4) we can describe the surface of terrain, the course of an interface of rocks, tectonic vertical lines etc. (as is reflected in the geological map). By creating triangular prisms (see fig. 10) we are able to describe the volumes, the vertical surfaces and another surface which is approximated by the triangles forming the bottom base of triangular prisms. If such prisms are used in multiple layers on each other, we are also able to describe the horizontal surfaces (cracks with horizontal direction, groundwater level or interface of horizontally laid geological layers). Each triangular prism is defined by points, points define a line, lines define the area: the two triangles, three rectangles (surface of prizm), areas define volumes (prisms).

To implement the algorithm we choose two solutions independent on platform. There were created two applications - one that uses XML database options and XSL programming and JAVA application CONVERT2GEO described in [2]. The data entry for application is generated by preprocessing as described in chapter 3.5.

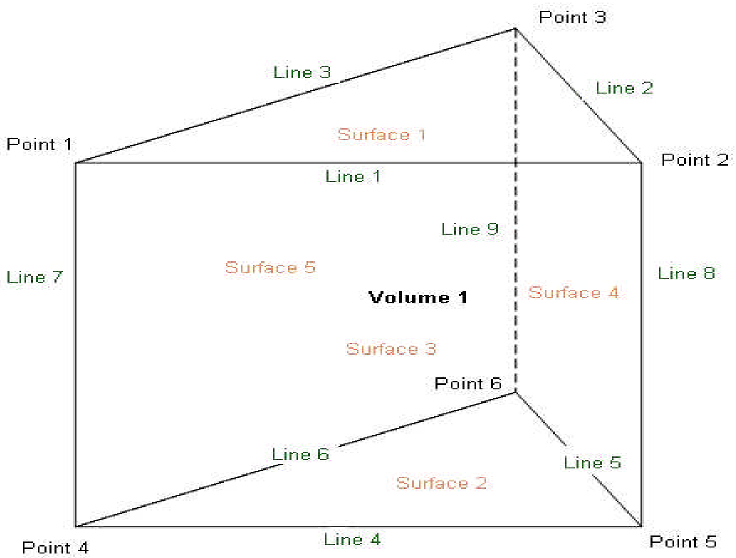

Fig. 9. Definition of triangular prism in GEO format

Data input to application issues from triangular network (fig. 11):points on each layer - contains the coordinates X, Y, Z1 and X, Y, Z 2, ..., X, Y, Zn (in the application Convert2Geo the point layers of the model levels are specified in the top bottom order) triangles - the area contains triangular identifier and references to 3 points IDs- triangle vertices [2].

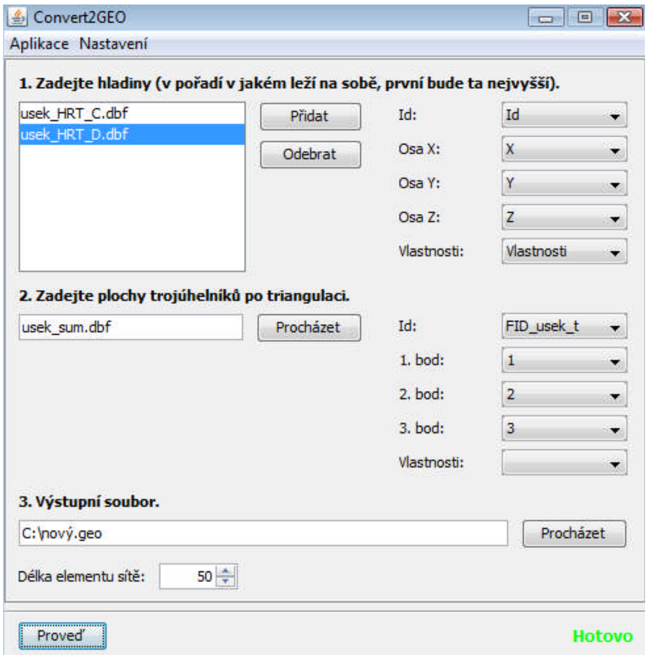

Fig. 10. Application Convert2Geo – input data dialog window

The data triangulated in GIS are next processed in GIS to gain required data format as an input to application. Data are stored in DBF tables and are read through the user interface (see Fig. 13). Algorithm for generatig a model mesh using triangular prisms assumes corresponding nodes (peaks) in all layers have identical X and Y.

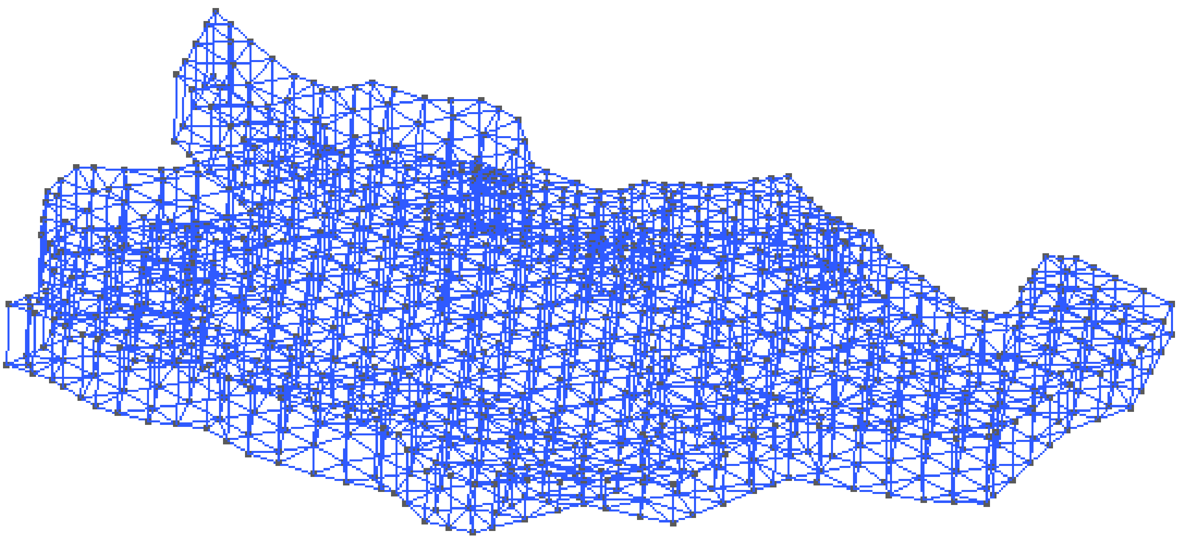

Fig. 11. Triangular prisms model geometry

This procedure allows to model complex area with number of lines projected into the surface layer in GIS. The disadvantage is that the size of triangular prisms in the model (as well as the length of triangle edge in surface geometry) must be consistent with the size of the mesh element. Model mesh is generated on the base of model geometry. The problem is for example the length of the edge of the prism 500 m and effort to generate mesh model with an element edge length of 400 m. Therefore, in data is taken into account the desired density of the model mesh.

This application now allows to create a model containing the layer between two surfaces which is filled with a single volume (fig. 12). Another type of model geometry contains only complex boundary and single volume (fig. 13).

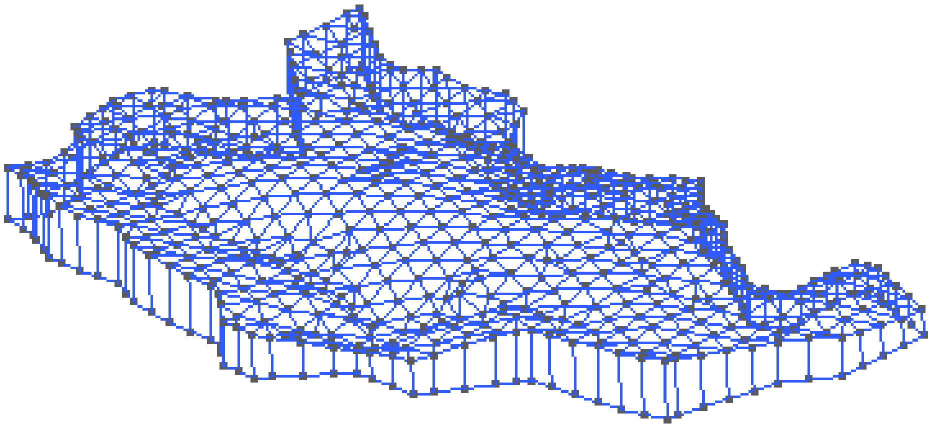

Fig. 12. Geometric model with surfaces and one volume

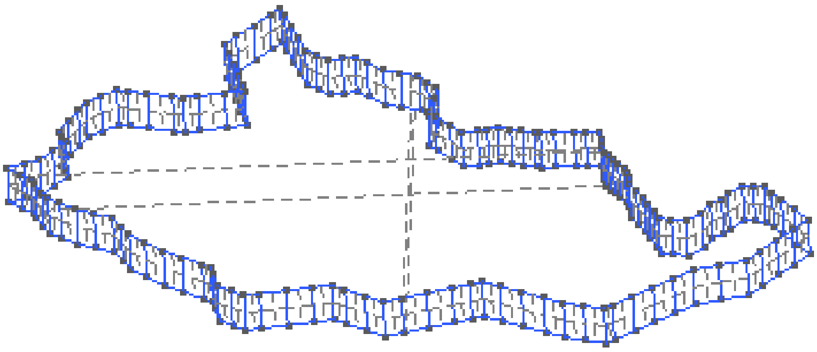

Fig. 13. Geometric model with complex boundary and one volume.

5 CONCLUSION

Creating of geometric models based on real data is a geoinformatic task which requires full 3D modeling and use both GIS and also other programming tools, which enable to create a geometric volume model based on data pre-processed in GIS.

Each modeled area has a different structure in shapes, but over time we created a methodology of preprocessing various data describing the various types of geographical and geological phenomena. We have also methodology of processing the geometric model and model mesh and its fulfill with data processed in GIS.

There are geometric models that we can create automatically, where preprocessed data in the required format are available. In this area we are working on automating the data preprocessing and automating control algorithms for each stage of preprocessing. Other types of models are not created automatically, for example, currently we have no automatic solution for modeling the vertical wavy surface and sloping surfaces. Automated processing allowes create model geometry in real time, quickly check the overall configuration of the mesh and assess its quality in terms of modeling requirements. Also is the possibility to quickly create a new (corrected) model geometry and mesh according to the requirements of network modeling. Automation of mesh construction also allows creation of multiple meshes based on different variants of input data. For an extensive models automated solutions enables introduce corrections in the input data and then quickly generate a new model.

A methodology and implemented algorithms were tested on several model areas, all designed model geometry and model meshes were used in the practice of mathematical modeling.

REFERENCES

[1] Malá, B., Pacina, J., Capeková, Z. (2009). Účelově odvozované modely v procesu předzpracování dat pro tvorbu geometrie modelových sítí. In: SiMoNA 2009 — Simulace modelování a nejrůznější aplikace Seminář výzkumného centra ARTEC. TUL Liberec.

[2] Tomčík, D., Malá, B. (2010) Automation in construction of 3D models and meshes. In: Petr Šaloun (ed.), DATAKON 2010, Mikulov, 16-19. 10. 2010, University of Ostrava, pp. 153 to 157.

[3] Maryška, J., Malá, B. (2008) Creation of model mesh and its fill with data from GIS SURAO and definition of initial conditions for variations of migration. Partial final report Research of the field of remote interaction of underground storage of spent nuclear fuel and high-level waste.Technical Univerzity of Liberec, 52 pp.

[4] Maryška, J., Královcová, J., Hokr, M., Šembera, J. (2010) Modelling of Transport Processes in Rock Environment. Technical Unversity of Liberec. 303 pp.

[5]. GMSH. http://geuz.org/gmsh/

Acknowledgment

This article was realized under the state subsidy of the Czech Republic within the research and development project "Advanced Remediation Technologies and Processes Center" 1M0554 - Programme of Reserch Centers supported by Ministry of Education.