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LOADING THE DATABASE OF TOPOGRAPHIC OBJECTS BDOT10K WITH THE DATA FROM PUBLIC REGISTERS, SUPPORTED BY DIGITAL GENERALIZATION

Key words:

database, cartographic generalization, standards of cartographic studies

Abstract

The article presents legal and technological conditions of creating and maintaining the database of topographic objects (*baza danych obiektów topograficznych* – BDOT10k). A particular attention in paid on the adjustment (harmonization) of a new base from already existing public registers. The stage of harmonization considers the selection and definition of proper operators of quantitative and qualitative generalization for individual objects and their attributes. Also technologies for the up-dating of the topographic database in the whole country was taken into account.

ZASILANIE BDOT10K DANYMI Z REJESTRÓW PUBLICZNYCH WSPOMAGANE CYFROWĄ GENERALIZACJĄ

Słowa kluczowe:

baza danych, generalizacja kartograficzna, standardy opracowań kartograficznych

Abstrakt

W artykule przedstawiono prawne i technologiczne uwarunkowania tworzenia i prowadzenia bazy danych obiektów topograficznych (BDOT10k). Szczególną uwagę zwracając na dostosowanie (harmonizację) nowej bazy z już istniejącymi rejestrami publicznymi. Etap harmonizacji uwzględnia dobór i określenie właściwych operatorów generalizacji ilościowej i jakościowej dla poszczególnych obiektów i ich atrybutów. A także technologie dla aktualizacji bazy danych topograficznej w całym kraju.

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[1] Head Office of Geodesy and Cartography

1. Legal and organizational bases of the continuous updating of the permanent and temporary database of topographic objects (BDOT10k)

Making the database of topographic objects (BDOT10k) started in Poland in 2003 and within 10 years it will cost an enormous amount of money: about 300 million złotys, including about 100 million złotys from the budget of the European Union. After establishing BDOT10k, Polish Surveying and Cartography Service awaits further very important tasks resulting from the current regulations, i.e.:

– for the area of respective provinces (voivodeships) collecting data in the teleinformation system BDOT10k, including the datasets of spatial infrastructure and spatial information, provided by the marshals of the voivodeships,
– making standard cartographic documents – topographic maps, scale 1 : 10 000 by the marshals of the voivodeships,
– making standard cartographic documents – topographic maps scales: 1 : 25 000, 1 : 50 000 and 1 : 100 000 by the Surveyor General of Poland.

One should notice that according to the Surveying and Cartographic Law, the Surveyor General of Poland coordinates actions of the public administrative organs, in particular the marshals of the voivodeships and other bodies carrying out public tasks referring to aspects like, among others – establishing and carrying out BDOT10k and making standard cartographic documentation, as well as, based on separate agreements in factual and financial aspect of their implementation.

ROZPORZĄDZENIE MINISTRA SPRAW WEWNĘTRZNYCH I ADMINISTRACJI (The Enactment of the Minister of Internal Affairs and Administration of 17th November 2011 on the database of topographic objects and database of general geographic objects as well as standard cartographic documentation, in §7, chapter 3 – organization, mode and technical standards of making BDOT10k and BDOO (database of general-geography objects), defines the data making base for the creation and updating of BDOT10k. These are the following:

1. Data gathered in the sets of data on spatial infrastructure – spatial information maintained by the Surveying and Cartography Service, defined in art. 4 passage 1a pts. 2–6 and 11 and art. 4 passage 1b of the Law, i.e.:

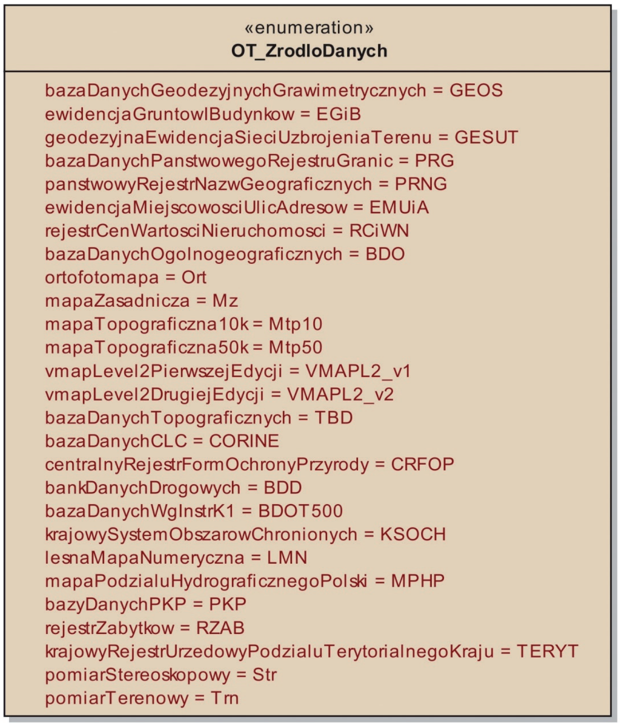
– inventory of land and buildings (real estate cadastre),
– surveying inventory of the network of the infrastructure,
– state register of the borders and areas of the territorial division units,
– state register of the toponymy,
– inventory of the localities, streets and addresses,
– air-borne and satellite images and orthophotomaps and digital model of the terrain,
– database of topographic objects of precision allowing making standard cartographic documentation in scales 1 : 500–1 : 5000, established and carried out in teleinformation system for the areas of cities and densely built up and/or designed to be built up rural areas.

2. Data contained in the registers carried out by other organs or institutions, in particular by:

– minister proper for the affairs of transport in the area of the communication network,
– minister proper for the affairs of communication in the network of infrastructure,
– minister proper for the affairs of construction in the area of buildings and facilities,
– minister proper for the affairs of: agriculture, environment and spatial management and housing in the area of complexes of land management and area cover,
– minister proper for the affairs of environment and General Director of Environmental Protection referring to the protected areas,
– minister proper for the affairs of culture and the pro tection of the national heritage in the area of historical buildings,
– the National Water Management Authority and the Institute of Meteorology and Water Management in the area of water network,
– the President of the Central Statistical Office in the field of the identifiers and names of the administrative territorial units of Poland,
– head offices of cities and communes in terms of the seats of the institutions.

Data obtained from the interview in the field.

Moreover, in the enclosure nr 3 to the enactment „Application scheme UML and GML scheme of databases BDOT10k and BDOO" the diagram is put with the list of the sources of data for the topographic objects with the stereotype of „enumeration" i.e. the list of constant values was made and the attribute can only take values from the list.



According to § 14 passage 2 of the enactment, the updating of data contained in BDOT10k should take place immediately after getting new data.

2. Expectations and needs of changes in the regulations referring to public registers to harmonize the structures of databases of public registers with the structures of BDOT10k

The necessary condition for the possibility of loading BDOT10k with the data from other registers is assuming the principle that such registers can only be registers of public character. Subsequent rule is taking into account only these registers, which can be significant in the process of filling BDOT10k, i.e., they contain data referring to the classes of objects or their attributes, and, moreover these are registers carried out in a digital form.

Apart from that, the important thing from the point of view of the purposes of system digitalization of the state is to inspire and propose the initiators the projects of legal regulations so that during the legislation work on laws and enactments of „area management character", these data to maximal extent consider the remark referring to the use of geoinformation technologies, leading to the creation of registers in the form of database. It is also very important to propose proper regulations in legal acts, during the legislation work referring to the possibility (necessity) of using BDOT10k as official, reference base available in the form of spatial data services, in particular WMS and WFS by the national portal of the infrastructure of spatial information www.geoprtal.gov.pl. There are also public registers not carried out in the form of restructured databases and they do not have the character of databases, they are only sets of information written in text editors or calculation sheets, and it does happen sometimes that they still do not have any digital form, e.g.: the address register in many communes.

The fragment of the national register of schools

	Name	Affiliation
141.	4-letnie Technikum (4 Years' Technical School)	The Complex of Schools in Bielice

Address	Organ Running the School	REGON (identification number)
Bielice, 88-330 Gębice	Powiat (District) Mogileński	09296497600000

The Fragment of the Register of Chemists

	Name	**Locality**	**Powiat (District)**
x	Panceum	**Gliwice**	**Gliwice**

Gmina (Commune)	**Postal Code**	**Street**	**House Number**
Gliwice	**44-100**	**Basztowa**	**3**

The harmonization of the database structures in public registers with the structures in BDOT10k requires the introduction of procedures and **standards** of the exchange of information and shared use of systems between the Surveying and Cartographic Service and the users of respective public registers containing information important for BDOT10k. Harmonization and adequate modernization of co-operating registers is an absolutely necessary condition of constructing proper functions automating the processes of BDOT10k updating. The degree of this harmonization will be significant in the process of automatic filling BDOT10k with the data from external sources using the constructed in GUGiK National System of Management (*Krajowy System Zarządzania* BDOT10k-KSZBDOT) in the framework of the implementation of the task of the GBDOT project. In favour of the maximization of this process are factual, organizational and first of all economic arguments.

Constructing KSZBDOT it was assumed that the system should provide service for 3 basic options of obtaining data from external registers:

1. “Zero” harmonization. In the case of external registers, with the conceptual model, structure and/or accuracy much deviating from the BDOT10k requirements, when their reasonable harmonization is not possible, KSZBDOT should allow loading these data in the source format, supplying them with adequate metadata and using these data in an extent possible for the control and updating of BDOT10k.

2. “Partial” harmonization. In the case of external registers, with the conceptual model structure and/or accuracy close to the BDOT10k requirements and when these registers offer systems providing services of spatial data, but these data can only be used as background material in the process of updating BDOT10k; KSZBDOT should allow the presentation of these registers on the screen.

3. Harmonization of “almost 100%”. Data from external registers, based on technical standards contained in executive regulations to the Geodetic and Cartographic Law, such as: BDOT500, GESUT, EGiB, EMUiA, PRNG and PRG, a large part of the data can be used in automatic updating BDOT10k. In other cases, when potential harmonization of registers with BDOT10k register is possible, this process should be carried out in agreement and co-operation with the organs keeping them, in particular regarding the implementation of INSPIRE directives.

3. Co-operation with the external bodies keeping public registers.

To make at least partial automation of the process of the updating of BDOT10k data from public registers, the users of the registers should:

- make decision and officially confirm it in the form of respective legal regulations on carrying out the register in the relation form or relation-object base data – if still do not keep them in such a form,
- lead to standardization of the collected data, in particular address data,
- take one standard of recording names of localities, streets and addresses, defined in the enactment on EMUiA, in particular: name of the locality of a town or village status and its identifier TERYT, name of the location making a part of town or village and its identifier TERYT, name of the street or square and its identifier TERYT, order number, postal code,
- carry out the process of the adjustment of the address data to the standards and introduce proper procedures of the records of address data in their databases – using PRG,
- define and implement precise and strict procedures of updating their data,
- make decision on using the services of special data WFS or in the file form (GML), to make their data available to external users, including updating databases carried out by Surveying and Cartographic Service,
- use services available in www.geoportal.gov.pl (services available in the generic interface of the Universal Map Module), owing to which they can use standardized funktion of geocoding data and have the possibility of the vizualization of their data on the background of maps made available by a national access point www.geoportal.gov.pl,
- base the construction of their own data structures on the basic model of spatial data proposed by GUGiK (BT_ModelPodstawowy.xsd),
- construct data models that could be used in geoinformatic systems,

- the constructed construct models of new databases should be based ISO standards, commonly applied at modelling data for systems of GIS class,
- not to obtain independently any reference data, such as e.g., administrative units, names of localities, addresses, land lots, buildings i.e. registers kept updated by the Geodetic and Cartographic Service,
- in branch systems identifiers of reference objects (idIIP) should be used – the invariability of identifiers and keeping historical data guarantees the possibility of automatic updating of records.

Allowing data recorded in public registers mutually available, including PZGiK data is carried out based on the availability requests, the form of which is defined in the Enactment of the Council of Ministers (Rozporządzenie Rady Ministrów) of 27th September 2005 on the procedures, scope and mode of making the data collected in the public register available. The organs of administration applying for the data are obliged to fill in the form and submit the following information:

- the name and address of the organ applying for the data,
- the name of the organ, to which the request is made,
- specifying the register, where there are data, which are to be made available,
- indicating the public task and legal bases for its implementation by the organ applying for the data,
- marking the scope of the data and the way of making them available,
- indicating the period of making the data available,
- the organ of administration applying for the data is obliged to apply them only for carrying out the public task indicated in the application and signs the statement that it fulfils the technical and organizational security requirements for the access to the data.

It seems that this formal aspect of the procedure of data exchange, including spatial data between administrative organs, has good foundations in legal terms.

4. Requirements for the operators of generalization (simplification, aggregation, merging, rectangularization) providing branch accuracy of processed data

Updating BDOT10k must have a continuous, system and complex character. The automation of the updating process of the selected objects and attributes, in other mode than so far, carrying a serious risk of losing consistency of the data, requires procedures according to the rules given below:

- strictly defined in KSZBDOT uniform procedures of updating BDOT10k for the area of the whole country,
- the implementation of the quality criteria to KSZBDOT, including **generalization parameters**, and in particular the “size” criteria of the objects, on-line controlling the quality of the data introduced to the base,
- sharing automatic information on new, up-dated records in other registers,
- on-line control of the cases of making data available to the users of the system from the defined area,
- permanent training of personnel responsible for the quality of BDOT10k in the established procedures of updating.

The obtained data from other registers in XML format should allow effective automatic updating of BDOT10k. The present model of the data defined in the enclosure to the enactment of the Minister of Internal Affairs and Administration of 17th November 2011 on databases of topographic objects and database of the general geographic objects, as well as standard cartographic documents, gives the possibility of recording only one data source for one object. Attribute x_zrodloDanychA (source of attribute data) is one-folded and disables writing many different data sources for many attributes of the same spatial object. The possibility of technical updating of data from different sources means in such cases the necessity of the participation of system administrators responsible for updating the datasets BDOT10k in this process.

Using KSZBDOT in a few years should bring to including the generalization criteria, for subsequent objects and their attributes.

5. Methods of verification of the obtained and processed data from public registers filling BDOT10k.

Considering methods of the verification of obtained and processed data from public registers, one should regard changes in the philosophy of obtaining

spatial data in the aspect of creating and future updating of BDOT10k. The following issues are important:
– accuracy of the results of measurements,
– general rules of the measurement of objects,
– rules of collecting data according to the sets of a definite geometric accuracy of the situation of objects and definite coefficient of miniaturization – the scale.

Accuracy of the results of measurements.

Every kind of field measurements, finally aimed at making a database and making a map is related to a very important question – accuracy of the measurement results. The results of surveying are always loaded with some errors, which can be caused by many factors. In traditional measurements, but not only in that case, the main source or errors can be:
– mistakes of persons carrying out the measurements,
– quality of instruments – their technical parameters,
– the applied measurement methods,
– terrain and atmospheric conditions, in which the measurements were made,
– statistical errors.

According to the required technical standards, during the measurements one should take care so that measurement errors do not exceed certain already defined limit values. For example: the Technical Instruction K-2 *Mapy Topograficzne* (Topographic Maps) for economic purposes, defined that the accuracy of presenting situation objects in rough and fair copies of topographic maps in scale 1 : 10 000 and 1 : 5 000 should meet the following conditions:

1. Mean errors of the situation of points of the horizontal surveying control line and points of the mathematic control line put on the map could not exceed ± 0.1 mm, and maximal errors ± 0.15 mm.

2. The accuracy of the situation of the details of accuracy group I, referring to the closest points of the control line could not exceed ± 0.5 mm, and in the mountain areas or the areas of dense forestation ± 0.75 mm. While establishing this accuracy one should respect the rules of generalization.

3. The accuracy of the situation of other situation points could not exceed ± 1.0 mm.

All the above mentioned required accuracies are much worse than technical possibilities provided by contemporary techniques of surveying and charting, taking into account that 0.1 mm in the map of scale 1 : 1 000 is 10 cm, and in the map scale 1 : 10 000 it is 1 metre. „In the base of the same accuracy of the data there are no limitations in the number of generalization levels from one base. This results from the fact that such a multi-representation base allows:
– creating objects of any generalization,
– presentation of objects in any (without limitation) scale of the map.” [3]

The accepted in Poland assumption on continuous updating of BDOT10k – a multi-resolution/ multi-representation database – WBDT is strictly connected with the functioning constantly updated systems: inventory of land and buildings (EGiB), basic map and geodetic map, inventory of the area infrastructure (GESUT). The models of the data of these systems were significantly modernized in the form of technical standards issued based on respective enactments, regarding, among others, harmonization with BDOT10k.

General rules of the object measurements.

During the surveying in the field, over the centuries, two basic rules have to be obeyed at any measurement:
– the rule of the measurement control,
– the “top-down” rule.

In case of making the measurement of a single object, the simplest way of the control of an individual measurement is its repetition. The comparison of two results gives premises to the assessment of correctness and accuracy of the carried out measurement. If every measurement covers certain complex of objects, one should take into account the rules of the control, as well as measure certain excess elements.

The second rule, which was necessary while making field measurements is the “top–down” rule. Having a certain area to measure, it was necessary to mark these points in the area, i.e. establish and measure the control line. After the establishing the measurement control line based on the geodetic control line, one could start the measurement of details in the area. It was not allowed to „put together” the whole image by recording details. Performed in such a way measurement would sum up all the errors.

The newest methods of the measurement, using multi-function system of precise positioning ASG-EUPOS and GPS technology, allow accuracy of measurements x,y,z reaching centimetres in a global scale. Such a high level of measurement accuracy, now allows the following:

– avoiding the artificial division of class accuracy of surveying networks during the measurements,
– using the results of measurements of high accuracy in geoinformation systems and visualization of measured objects in any scale, regarding the rules of the quantitative and qualitative generalization,
– high accuracy consistency during current updating of spatial databases,
– carried out once measurement of the object and using the results of this measurement to different purposes: cadastral, inventory, topographic and other.

Quick propagation of GPS measurement technology in Poland allows serious thinking of a general change of „the philosophy of measurements" and the implementation of the "bottom-up" rule, getting data on the area to all the geoinformation systems, first of all including the database of topographic objects.

Rules of collecting data according to the sets of definite geometric accuracy situation objects and definite miniaturization coefficient – scale.

The map made in any scale has not been able to meet the requirements of different users. The development of information techniques compromised a traditional way of collecting and visualization of geodata. Spatial data collected in the memory of a computer do not have scale. The most important data attribute on the objects is their source, and to be more specific, the accuracy of the situation of objects in the area. Objects collected in the information database can go through cartographic visualization in any scale on the screen or in print, however, under one condition – that the cartographic visualization is subdued to the generalization process, according to definite parameters accepted for a given scale of visualization and presentation during empirical studies.

The accepted in the enactment model data for creating and updating BDOT10k is based on the principle of maximal possible (from factual and technological point of view) obtaining data of different level of details, in particular registers carried out by the Geodetic and Cartographic Service, including obtained with the use of satellite techniques. It is obvious, that created and updated this way system with time will contain more and more data on the objects, geometric accuracy of situation points, measured in centimetres and decimetres. Data of such accuracy can be generally used in cartographic visualization of any scale. Every base of **multi-resolution/ multi-representation** type in this BDOT10k, in principle makes us create different level of details – LoD in geometric and attribute aspect of the objects in this base. Such a solution is particularly justified from the economic point of view – costs of making the database and the process of making topographic maps in different scales and generating BDOO and making general geographic maps in different in different scales.

General model of transfer and updating BDOT10k was defined in the enactment. Its practical implementation will take place in the moment of initiating KSZBDOT. The success of the whole, very complicated operation, not having so far any tested patterns in such a scale of the project, depends on many factors, first of all on:

the quality of the accepted model of data in the enactment and the degree of the harmonization of databases in the required scope necessary for the automatic updating certain objects – as a result of the implementation of KSZBDOT one should consider the need of updating technical standards – enactments (not only for this reason),

– quality broadly understood (up-dating, credibility, accuracy, completeness, topologic consistency, etc.) data in the registers of Surveying and Cartographic Service including the quality of already obtained data in BDOT10k,
– selection and quality of informatic tools – programming and instruments used in this process,
– knowledge and experience of teams implementing KSZBDOT on national, regional and district level,
– substantial support of scientific environment in the implementation of KSZBDOT,
– non-standard Polish organization of Surveying and Cartographic Service and the division of tasks resulting from the Surveying and Cartographic Law,
– values of financial means used in annual budgets and multi-year budgets on the level of disctricts, voivode-

ships, national level and European level for updating spatial databases including BDOT10k,

and in particular the consciousness, on the consciousness of the need of using by a large group of users (now taught within the realization of project GBDOT) from such technologically advanced databases of spatial data as BDOT10k.

6. Conclusions

Database of topographic objects is a fundamental source data to build the whole complex of databases with spatial thematic data: soil, geological, hydrographical, sozological, geo-morphological, statistic, road-network, social, demographic, economic, environmental, etc. Without a database of topographic objects BDOT10k, there will be no sustainable development of other official systems of spatial thematic data. **Making a database of topographic objects loaded with data of other public registers, supported by digital generalization is one of the ways to increase the efficiency** in: planning, economy, trade, transport, civil service, safety and in other areas of life, which, at the same time, by facilitation of processing data, enabling the improvement and acceleration of the work of public administration.

Making the official register BDOT10k efficient, in my opinion, for geodetic and cartographic environment, will mean the following:

- change of the organization in the functioning of documentation centres of geodetic and cartographic information,
- necessity of continuous and systematic process of teaching and training of the staff in such centres,
- the need of strengthening of the co-operation of administration, scientific environment and geodetic and cartographic companies,
- change of the profile of production for the commercial firms towards the part of the participation of the construction of knowledge bases,
- the need of carrying out administration-sponsored marketing and promotion actions referring to BDOT10k sets.

I understand the carrying out BDOT10k for the whole country as system-made, i.e.: integrating, updating, administrating and making available datasets, and future functioning of central, provincial (voivodeship) and district (powiat) centres of geodetic and cartographic documentation should be seen in such a role. In my opinion the future of the official databases of spatial data belongs to cadastral and topographic databases. We are slowly approaching such a moment when there would be technological possibilities of generating and passing to the users (on request, with the help of spatial data) the information on topographic objects, at any time, in any place, of definite quality, including geometric and attribute, in small portions and the amount not larger than necessary in that moment.

The "industry" of geographic information consists of quickly changing information technologies, but also institution, organization and mentality of the society, in which changes are slower than in technology. Slowly, but successfully coming to an end, implementation of almost 10 years process of making the "initial" BDOT10k, can make one of milestones in building Polish infrastructure of spatial information. Perhaps too slow speed of work was a result of many objective and subjective factors, but it should not make us regret that we spent a considerable amount of money for making in Poland one of the most modern databases of this type in Europe, and possibly in the world.

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THE USE OF MERGING AND AGGREGATION OPERATORS FOR MRDB DATA FEEDING

Key words:

cartographic generalization, databases – MRDB, geoinformatics

Abstract

This paper presents the application of two generalization operators – merging and displacement - in the process of automatic data feeding in a multiresolution data base of topographic objects from large-scale data-bases (1 : 500–1 : 5000). An ordered collection of objects makes a layer of development that in the process of generalization is subjected to the processes of merging and displacement in order to maintain recognizability in the reduced scale of the map. The solution to the above problem is the algorithms described in the work; these algorithms use the standard recognition of drawings (Chrobak 2010), independent of the user. A digital cartographic generalization process is a set of consecutive operators where merging and aggregation play a key role. The proper operation has a significant impact on the qualitative assessment of data generalization.

WYKORZYSTANIE OPERATORÓW ŁĄCZENIA I AGREGACJI DO ZASILANIA WBD

Słowa kluczowe:

norma rozpoznawalności mapy, cyfrowa generalizacja kartograficzna

Abstrakt

Artykuł przedstawia zastosowanie dwóch operatorów generalizacji – łączenia oraz przesuwania w procesie automatycznego zasilania danych w wielorozdzielczej bazie obiektów topograficznych na podstawie danych baz wielkoskalowych (1 : 500–1 : 5 000). Uporządkowany zbiór obiektów stanowi warstwę zabudowy, która w procesie generalizacji, zostaje poddana procesom łączenia, jak i przesuwania, aby zachować rozpoznawalność w zmniejszonej skali mapy. Rozwiązaniem powyższego problemu są opisane w pracy algorytmy, które wykorzystują normę rozpoznawalności rysunku (Chrobak 2010), niezależną od użytkownika. A proces cyfrowej generalizacji kartograficznej to zbiór następujących po sobie operatorów, w którym łączenie i agregacja pełnią kluczową rolę. Ich poprawne ~~ość~~ działania mają znaczący wpływ na ocenę jakościową uogólnienia danych.

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1. Introduction

Building structures together with roads, railways, rivers and topographic profile make the reference content of a topographic map (Chrobak & Koziol 2009). In addition, elements of building layers and communication networks in Poland often change. Therefore, much attention has been given to the issue of the road network generalization (Regnauld & McMaster 2007). At the same time the development of multiresolution database systems (MRDB) enforces the need for research on automating the processes of generalization, without which there can be no functioning of MRDB in real time (Hampe et al. in 2003).

As far as the generalization of building structure is concerned, there are many different algorithms, but the complexity and the problem of the representation of building structures at different scales makes the issue of the generalization of building structures still current. Building development, depending on the level of generalization (scale), is represented as: single surface structures (buildings), single symbols (a chapel marked with a cartographic sign), integrated surface structures (number of dwelling-houses) or as a filling (dense area). In the case of large-scales (from 1 : 500 to 1 : 10 000) when single buildings are the objects of the map, the main problem is the geometric representation after the simplification process is carried out by deleting unnecessary details of the building (Sester 2000, Haunert & Wolf 2008, Fan and Meng 2010, Kozioł 2012). While reducing the scale it is necessary to group the buildings in building development (clustering) (Sester & Brenner 2000). Changing the scale of the buildings grouped together makes their removal, displacement and aggregation (Regnauld 2003, Li et al. 2004) or typification necessary, which reduces the number of objects while maintaining the spatial distribution (Regnauld 2001, Burghardt & Cecconi 2003).

2. Merging objects

The change of the shape and location of the buildings in the process of generalization can be performed only by preserving their geometry and topology. As a consequence, the number of possible solutions in the process of cartographic generalization is much reduced (Chrobak, Kozioł, Krawczyk, Lupa 2012). Because the building layer of topographic maps is the dominant part and the one of fastest dispersible changes, the preparation of appropriate tools to increase the automation of the process of generalization is an open task for new solutions.

The merging operator requires that the building facilities have been subjected to pre-classification process, which means unequivocal ordering. In addition, the uniqueness in the process of merging objects layer building is fulfilled (Chrobak, Koziol 2009), if:

- geometric data of buildings retain visibility conditions of the map drawing,
- buffers (equidistants) of merged buildings have a common part, specified by the condition:

$$2bf \leq d < \varepsilon_{03} \wedge bf \leq \frac{1}{2}\varepsilon_{03} \qquad (1)$$

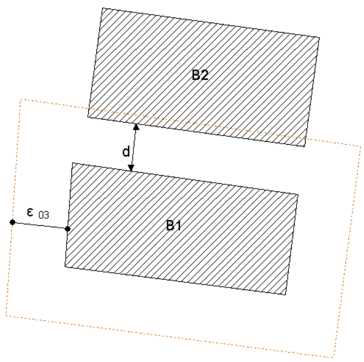
where:

d – the shortest actual (field) distance between buildings,

ε_{03} = 0,4 M [mm] – standards for man-made (anthropo genic) objects (Chrobak 2010),

bf – actual length of the buffer, measured from the contour line of the building.

The process of merging buildings is a shift of a single edge, which is the wall of the building or of the entire facility classified as less important, in relation to the object of the upper class. Therefore, in order to make the automation of this process it is necessary to precede this operation with a properly realized classification. Chrobak (2010) presented a division of merging operations of linear objects into classes C^1 and C^2. In this paper these concepts were developed and modified, respectively, in order to increase the efficiency of the algorithm for merging. As far as linear merging is concerned, two variants of merging were distinguished: parallel linear and non-parallel linear. Parallel linear merging of buildings (Fig. 1a) occurs when the slope of a straight line for the standard recognition is consistent for both directions of the walls of buildings. Non-parallel linear merging (Fig. 2b) occurs when slopes of straight lines of both walls of the buildings are different for a given standard of recognition, and at least one edge of a)



b)

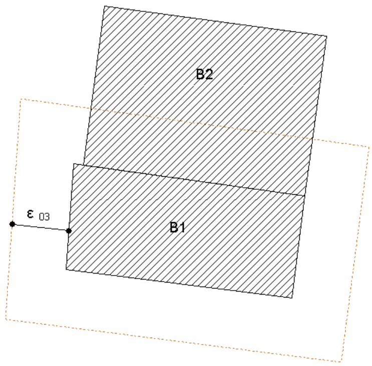
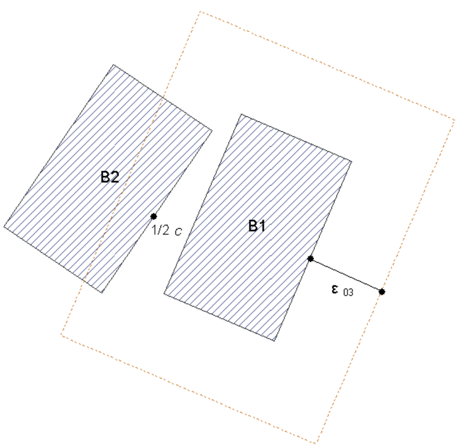


Fig. 1. a) Schematic diagram of the parallel linear merging of neighboring buildings b) Schematic diagram showing the result of the parallel linear merging operator application

Rys. 1. a) Schemat przedstawiający łączenie liniowe równoległe budynków sąsiadujących b) Schemat przedstawiający wynik działania operatora łączenia liniowego równoległego

a)



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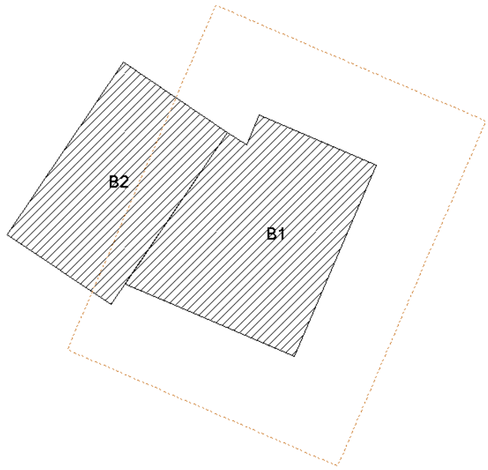

Fig. 2. a) Schematic diagram of the non-parallel linear merging of neighboring buildings b) Schematic diagram showing the result of the non-parallel linear merging operator application

Rys. 2. a) Schemat przedstawiający łączenie liniowe nierównoległe budynków sąsiadujących b) Schemat przedstawiający wynik działania operatora łączenia liniowego nierównoległego

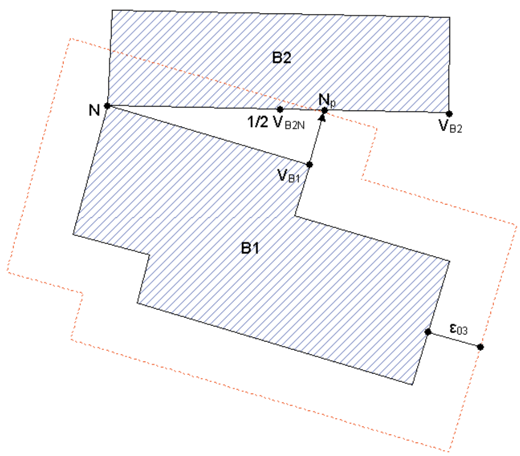

Fig. 3. Schematic diagram showing pointwise merging of adjacent buildings

Rys. 3. Schemat przedstawiający łączenie punktowe budynków sąsiadujących

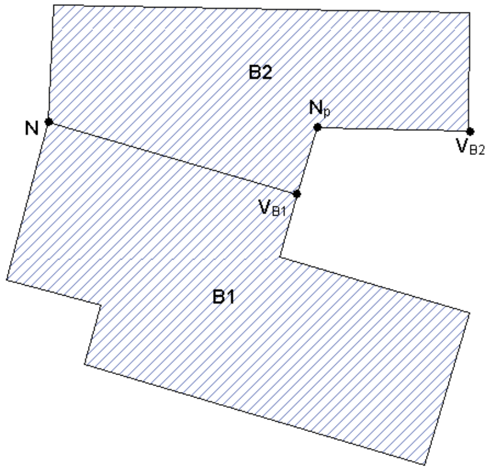

Fig. 4. Adjacent buildings obtained as a result of pointwise merging operator application
Rys. 4. Budynki sąsiadujące otrzymane w wyniku działania operatora łączenia punktowego

the object is classified as less important and satisfies the following condition:

$$\frac{1}{2}c \in bf \quad (2)$$

where:
bf – actual length of the buffer, measured from the contour line of the building,
c – length of the edge of the building at a lower grade, which has a common buffer *bf*

If the edges of the buildings have one vertex in common, that is they are pointwise tangential (Fig. 3) and the condition (2) is fulfilled, the merging operation is performed based on the point variant. Vertex V_{B1} of building B_1 (Fig. 3) of the upper class, is projected perpendicularly onto the edge of building B_2 (point N_p). In this way, the resulting vector NN_p is then projected onto the vector NV_{B1} of building B_1, and point V_{B1} becomes a node connecting buildings $B_1$and B_2, (Fig. 4).

3. Procedures for the algorithm for merging

Concepts presented in the previous chapter are the essence of the algorithm, on which the building merging operator is based. In addition, building development is a layer of a very large variety, and therefore design tools that take into account and identify the vast majority of the existing relations between the neighboring buildings is a non-trivial task. The further section of this chapter presents the procedures for the algorithm for merging adjacent buildings.

The following description distinguishes the steps that should be made to receive properly merged buildings in the process of parallel linear merging:

Input: Building objects layer, part of BDOT

Step 0:
Verify that the building has neighbors at a distance of more than ε_{03}.
If so – select a building and go to step 1, if not – quit.

Step 1:
Verify that the selected building is classified higher than its neighbors.
If yes – go to step 2 if not – quit.

Step 2:
Find the closest edge of the adjacent building.

Step 3:
From the edge of the adjacent building found in step 2, create temporary buffer tbf 1 of a size of ε_{03}.

Step 4:
Check if buffer tbf1 contains any edge of the selected input building. If yes – go to step 5, if not – go to step 8

Step 5:
Based on the edge of the adjacent building found in step 2, create temporary buffer tbf 2 of a size of ε_{03}.

Step 6:
Determine common part tibf12, for temporary buffers tbf1 and tbf2.

Step 7:
Merge and aggregate the adjacent building and the common part of buffers tib12. Then quit.

Step 8:
Verify that the buffer tbf1 intersects any edge of the selected input building. If yes – go to step 9, if not – quit.

Step 9:
Find the intersected edges and the find the nearest edge.

Step 10:
Based on the edge of the adjacent building found in step 9, create temporary buffer tbf 2 of a size of ε_{03}.

Step 11:
Determine common part tibf12 of temporary buffers tbf1 and tbf2.

Step 12:
Merge and aggregate the adjacent building and the common part of buffers tib12. Then quit.

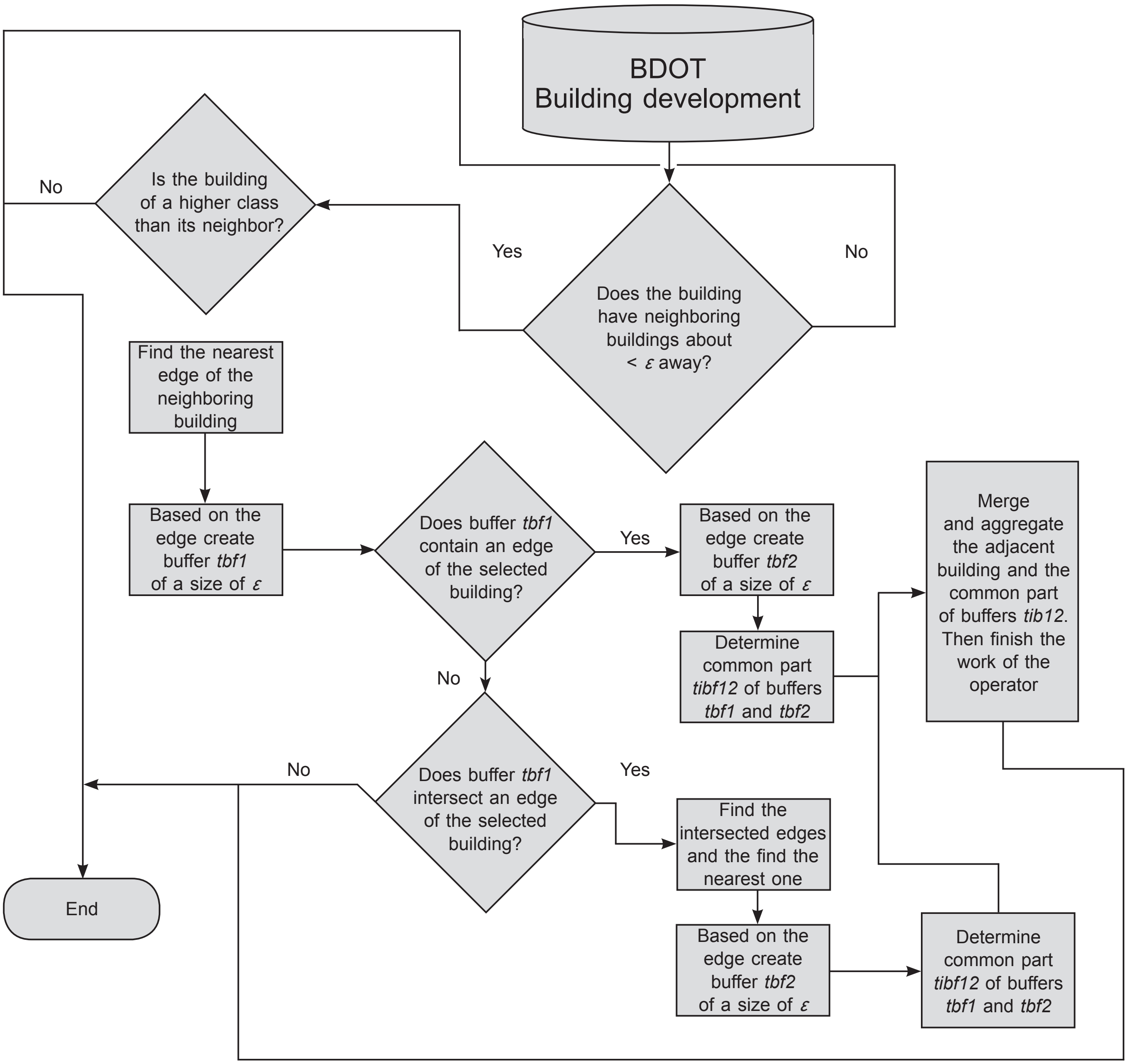

Fig. 5. The block diagram of the algorithm for merging
Rys. 5. Schemat blokowy algorytmu łączenia

Sample results of the application of merging operator for neighboring buildings are presented in the figures below. (Figure 6, Figure 7)

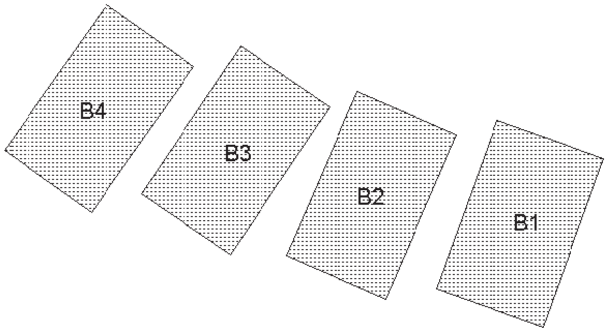

Fig. 6. Building development layer – input buildings before the application of merging operator
Rys. 6. Warstwa zabudowy – budynki wejściowe przed działaniem operatora łączenia

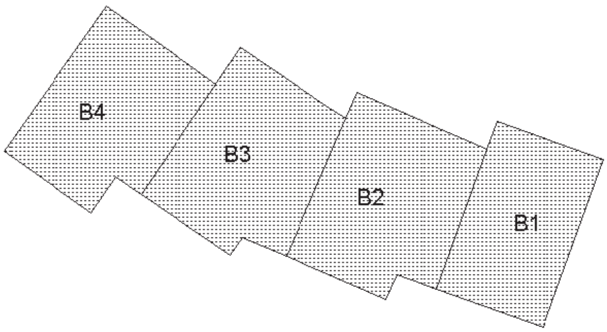

Fig. 7. Building development layer – buildings obtained as a result of the merging operator application
Rys. 7. Warstwa zabudowy – budynki otrzymane w wyniku działania operatora łączenia

4. Aggregation of buildings

Aggregation operator allows you to aggregate neighboring polygons into one, in the case where their edges are tangential within a section of not less than the norm for man-made (anthropogenic) objects. The resulting building has the attributes of a component object, which has been classified as the most important.

Sample results of the application of aggregation operator are presented in Figures 8 and 9.

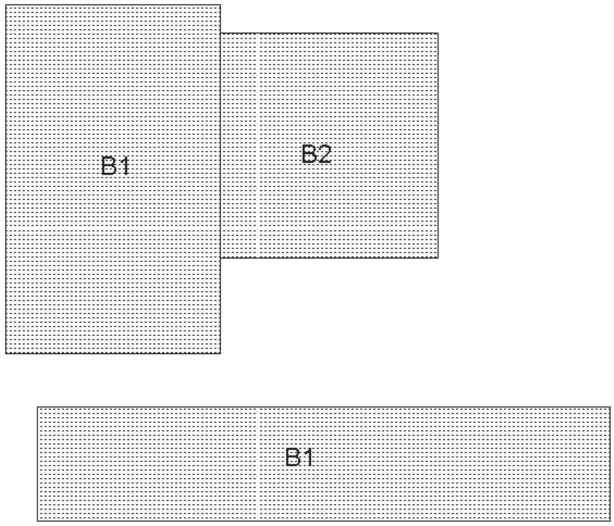

Fig. 8. Building development objects before the process of aggregation
Rys. 8. Obiekty zabudowy przed procesem agregacji

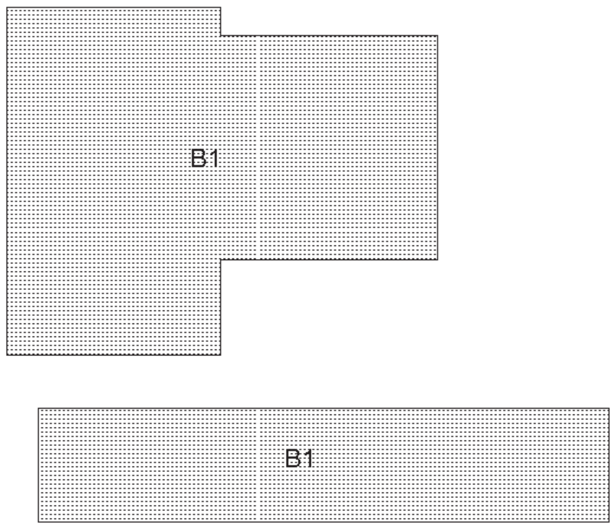

Fig. 9. Building development object resulting from the application of aggregation operator
Rys. 9. Obiekty zabudowy będące wynikiem działania operatora agregacji

Buildings created as a result of aggregation, which satisfy the neighborhood condition, are subject to the application of merging operator, which is described in the previous section.

Conclusions

The use of the recognisability standard (Chrobak 2010) increases the degree of automation of building facilities generalization by:

- ordering source data (input data), i.e.:
  – maintaining the topology of objects,
  – classification of objects,
  – objects' vertexes hierarchy,
- verifying the process results in relation to the drawing recognizability data arrangement.

The standard applies to individual generalization operators for building development, including merging operator, and is used to assess their performance. Automation of the merging operator is possible if:

- standard is applied,
- data are ordered,
- the result verification can be performed.

The standard used in the merging and aggregation operators for building development objects can increase the degree of automation in the process of data generalization within the databases of topographic objects.

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TRANSFORMATION OF AREAL OBJECTS INTO LINEAR OBJECTS, REGARDING THE MAP SCALE

Key words:

digital cartographic generalization, geomatics, databases, Medial Axis Transform

Abstract

The Digital Landscape Model is characterized by preserving strict georeference of the content and the included classes of the objects on a definite level of datail. In the process of digital cartographic generalization, it is often necessary to change the objects into the ones of a lower level of datail than the source level, preserving their strict georeference. One of the generalization operations is a partial or total change of areal objects into linear objects (collapse). This transformation is used in the mentioned above model, for the Digital Cartographic Model.

In the solution proposed by the Author, the change of the dimension of the areal objects (of natural origin) into linear objects is carried out by the constructions called *Medial Axis Transform* (*MAT*) and the elementary disc. The idea of the elementary disc is based on the Perkal's method and the standard based on the Chrobak's elementary triangle. Owing to the combination of these elements the operator of digital cartographic generalization was obtained, making an unambiguous result (independent from the operator).

In the process of automatic cartographic generalization, the presented method allows the transformation of the areal object into a linear object in any scale (dependant on the drawing recognizability norm), in an unambiguous way, as well as regarding the detection and solution of graphical conflicts arising during the collapse.

PRZEKSZTAŁCANIE OBIEKTÓW POWIERZCHNIOWYCH W LINIOWE ZALEŻNIE OD SKALI MAPY

Słowa kluczowe:

cyfrowa generalizacja kartograficzna, geomatyka, bazy danych, Medial Axis Transform

Abstrakt

Cyfrowy Model Krajobrazu charakteryzuje się zachowaniem ścisłej georeferencji treści, a zapisane w nim klasy obiektów o określonym poziomie szczegółowości. W procesie cyfrowej generalizacji kartograficznej często konieczna jest zamiana obiektów na niższy od źródłowego poziom szczegółowości przy zachowaniu ich ścisłej georeferencji. Jedną z operacji generalizacji jest częściowa lub całkowita zamiana obiektów powierzchniowych na liniowe (ang. *collapse* – zapadanie). To przekształcenie jest wykonywane w ww. modelu, na potrzeby Cyfrowego Modelu Kartograficznego.

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W rozwiązaniu zaproponowanym przez Autora zmiana wymiaru obiektów powierzchniowych (pochodzenia naturalnego) w liniowe jest realizowana poprzez konstrukcje *Medial Axis Transform* (*MAT*) oraz koło elementarne. Idea koła elementarnego oparta jest na metodzie Perkala oraz normie opartej na trójkącie elementarnym Chrobaka. Dzięki połączeniu tych elementów otrzymano operator cyfrowej generalizacji kartograficznej zapewniający wynik jednoznaczny (niezależny od operatora).

W procesie automatycznej generalizacji kartograficznej prezentowana metoda pozwala przekształcić obiekt powierzchniowy jednoznacznie na liniowy w dowolnym zakresie skal, a także uwzględnia wykrycie i rozwiązanie konfliktów graficznych powstających podczas zapadania.

1. Introduction

Transformation of areal objects into the linear ones, called collapse, belongs to the processes of digital cartographic generalization (Chrobak, Keller, Kozioł, Szostak & Żukowska 2007; McMaster & Shea 1992). This process can be divided into two components: generalization of the shape and symbolization (Grünreich, 1995, Li & Openshaw 1993, Sarjakoski 2007). In digital cartography two models of geographic reality are applied: Digital Cartography Model (DCM) and Digital Landscape Model (DLM) (Głażewski 2006). The model applied in the generalization of the shape is DLM (Chrobak 2010). The method presented in this article is designed for the transformations of areal objects written in DLM. The obtained result in DLM is used in making DCM, i.e. the map.

2. Transformation of areal objects into linear objects

2.1. The nature of collapse

Several kinds of geometric operations of digital cartographic generalization are defined as the operator of collapse (Li 2007a). In this article, collapse will be understood as partial or total transformation of areal objects into linear objects. The presented procedures are appropriate for the 2D representation of natural objects connected with the hydrographical network i.e. rivers, lakes etc. The decision about carrying out the collapse of the whole object or its part in the given scale, should depend on the width of the stream/lake (J. Choi & Hwang 2009, Gotlib 2005).

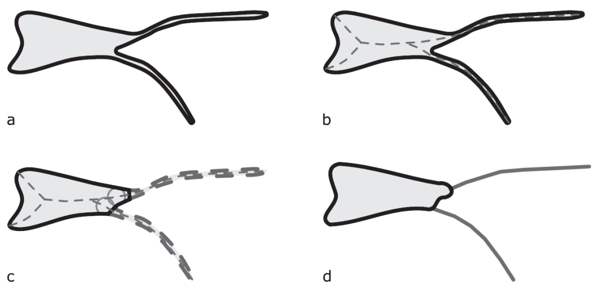

Fig. 1. The scheme of the work of the collapse operator: a – the object in the scale of $1:M_0$, b – determination of the sketon of the object, c – finding unrecognisable parts of the object in the scale of $1:M_i$, d – the object in the scale of $1:M_i$ withpartially changed geometric representation

Rys. 1. Schemat działania operatora zapadania: a – obiekt w skali $1:M_0$, b – wyznaczenie szkieletu obiektu, c – znalezienie nierozpoznawalnych części obiektu w skali $1:M_i$, d – obiekt w skali $1:M_i$ z częściowo zamienioną reprezentacją geometryczną

The collapse of the object in the scale of $1:M_0$ (Fig. 1a) to the scale $1:M_i$ is done in the following way:

1. Determination of the skeleton of the object (Fig. 1b).

2. Checking the recognisability of the object in the scale of $1:M_i$ or comparing the width with the decided value (Fig. 1c).

3. Changing the part or the whole areal object in the scale of $1:M_i$ into the linear one with the application of its skeleton (Fig. 1d).

Determination of the skeleton of the object can be carried out using different geometric constructions (Fig. 2):

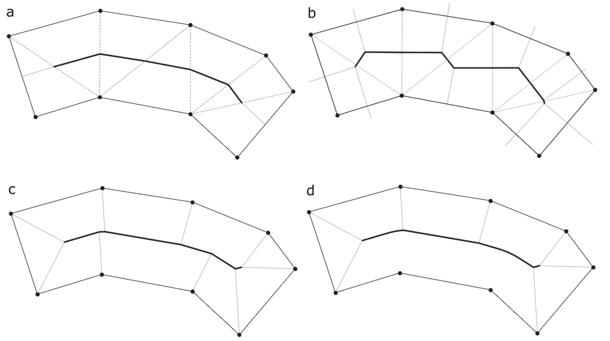

Fig. 2. Geometric constructions applied in determining the mean axis – a Constrained Delaunay Triangulation, b – edges of Voronoi diagrams, c – Straight Skeleton, d – Medial Axis Transform

Rys. 2. Konstrukcje geometryczne wykorzystywane do wyznaczenia osi średniej – a Constrained Delaunay Trangulation, b – krawędzie diagramów Voronoia, c – Straight Skeleton, d – Medial Axis Transform

Constrained Delaunay Triangulation (Jones, Bundy & Ware 1999), edges of Voronoi's diagrams (Gold & Snoeyink 2001) (Voronoi's diagrams can be made denser to obtain better visual effect), Straight Skeletons (Haunert & Sester 2007), Medial Axis Transform (Christensen 1999, 2000, Szombara 2012).

For the raster data to determine the skeletons of areal objects Morphologic Models are applied (Su Li, & Lodwick 1998).

The second step is determining the parts of the objects, which should collapse, because they cannot be recognised. The first way of the carrying out this step is the measurement of the width of the object and its comparison with the presumed value (J. Choi & Hwang 2009, Haunert & Sester 2007) for scale $1:M_i$. The second is using the norm connected with the recognisability of the drawing in the map (Su et al. 1998; Szombara 2012). In the further part of the article the application of the elementary triangle in the collapse operator will be presented in detail.

The norm given by Su and co-authors (1998) is based on earlier studies on "natural principles" in generalization (Li & Openshaw 1992, 1993). The real value K of the smallest recognizable object in the map is calculated by the formula: $K = k \times S_T \times \left(1 - \frac{S_S}{S_T}\right)$,

where:

S_T – denominator of the target scale,
S_S – denominator of the source scale,
k – experimentally found value of the smallest recognisable object in the map.

The authors recommend the acceptation of this value from the range (0.5 mm; 0.7 mm). For the collapse, the authors presume 0.7 mm. For the raster data processed with the use of Morphological Models, the critical value is calculated: $S_2 = \frac{S_S}{S_T} \times 0{,}7$ mm defined as threshold of collapse (value 0.7 mm refers to the research quoted earlier).

The third step of the collapse process is the change of the areal representation into the linear one for the whole object or its part, with the application of its skeleton. The important factor that has to be taken into account at this step is preserving the topology of the objects in the map (Kang, Kim & Li 2004). If before the collapse the objects were in the relation of the neighbourhood with the areal object, this relationship must be preserved.

2.2. Other definitions of collapse

Transformation of areal objects into linear objects, in the framework of digital cartographic generalization was called by different authors in different ways. In the literature written in English, the word "collapse" is predominant (Christensen 2003, Kieler, Huang, Haunert & Jiang 2009, Li 2007b, McMaster & Shea 1992, Meijers 2011, Ruas & Lagrange 1995). In Poland, Iwaniak, Paluszyński and Żyszkowska (1998) call this process "dimension reduction" (*redukcja wymiaru*), i.e. the change of areal objects into linear ones. Olszewski (2006) describes "collapse" as the change of geometric representation. It seems reasonable to use the expression "collapse", which shows the idea of the process correctly (Małyszko 2009, Szombara 2012).

3. Scale-depending collapse

In the method of collapse proposed by the author, the geometric representation of the skeleton of the object is Medial Maxis Transform (MAT). The first definition of Medial Axis was based on the concept of Grassfire Transform (Blum 1967). MAT can be defined in many ways (Okabe, Boots, Sugihara & Chiu 2000), in this article the definition based on "maximal disc" was chosen (H.I. Choi, Choi & Moon 1997). Such a definition allows conceptual combination of MAT with Perkal's *ε-generalization* (Perkal 1966).

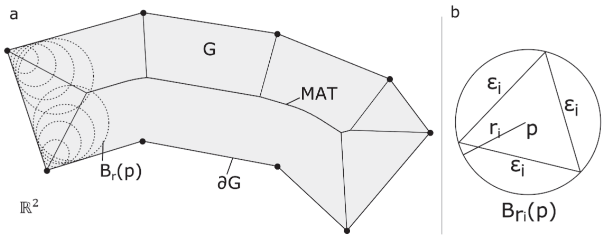

Fig. 3. Medial Axis Transform (a) and elementary disc (b). In the background of the areal object *G* the dotted line presents a few examples of discs $B_r(p)$ belonging to the object core *R(G)*

Rys. 3. Medial Axis Transform (a) i koło elemenarne (b). Na tle obiektu powierzchniowego G zaznaczono przerywaną linią kilka przykładowych kół $B_r(p)$ należących do rdzenia obiektu *R*(*G*)

Let *G* mean the areal object limited by the closed polyline (its boundary) ∂G in 2D R^2 (Fig. 3a). $B_r(p)$ will mean the enclosed disc – of radius *r* and the centre in point *p*. Let us define set *D*(*G*) as:

$$D(G)=\{B_r(p):B_r(p)\subset G\}. \tag{1}$$

D(*G*) is the area of inclusion with all the complete discs fully contained in *G*. For the areal object *G*, the core *R*(*G*) is defined as the area of all the maximal elements of set *D*(*G*), that is:

$$R(G)=\{B_r(p)\in D(G):\neg\exists B_{r'}(p')\in D(G)\ni B_r(p)\subset \subset B_{r'}(p')\}. \tag{2}$$

Thus the core of the object *R*(*G*) is constituted by the discs $B_r(p)$ belonging to *D*(*G*), i.e. there is no disc $B_{r'}(p')$ belonging to *D*(*G*) and containing complete $B_r(p)$. Accepting the definition of the core of the object as the area of the discs completely included in this area, we can define Medial Axis (*MA*) of object *G* as the set of points making the centres of the discs belonging to the core of the object *R*(*G*), that is:

$$MA(G)=\{p\in G:B_r(p)\in R(G)\}; \tag{3}$$

and *MAT* – as the set containing the pairs of the centres and radii of discs belonging to the core of the object *G*, that is:

$$MAT(G)=\{(p,r)\in G:B_r(p)\in R(G)\} \tag{4}$$

MAT defined in such a way allows the use of collapse areas for the definition. The author uses *MAT* to define which parts of areal object in the scale of $1{:}M_i$ should be subdued to collapse, and which can still be presented as areal objects.

Further speculations apply minimal size of areal objects defined by Salishchev (1998). Chrobak (2010) applied these dimensions in digital generalization to the process of simplification with the application of elementary triangle and to define standard verifying the result of the process. In the process of collapse, to examine the recognisable parts of the object, the author proposes the application of the norm based on the elementary triangle (equilateral) inscribed in the disc. The norm depending on the scale for the side of the elementary triangle is defined by the relationship:

$$\varepsilon_i = 0,5 \cdot M_i \ \text{[mm]} \tag{5}$$

where:

ε_i – minimal side of the elementary triangle for the given scale,

M_i – denominator of the scale of the elaborated map.

The elementary triangle (equilateral) inscribed into the Perkal's disc, takes the radius determined by the formula:

$$r_i=\frac{\varepsilon_i\cdot\sqrt{3}}{3}. \tag{6}$$

The radius of the equation (6) determines the disc, which will be called elementary (recognisability) and marked $B_{r_i}(p)$ (Fig. 3b). Elementary disc at the same time allows unambiguous establishment of the recognisability of the studied object in any scale *i*, regardless the editor of the map.

Based on the properties: objective Perkal's generalization, elementary disc of the areal object and properties MAT, we can state:

- supplementation *G'* of the object in Perkal's *ε-generalization* is a part of the object, which collapses in the generalization process;
- discs of any degree of generalization (change of scale) touching the boundaries of a areal object will always have centres belonging to MAT (Christensen 1999);
- not-fully determined level of generalization is defined by the elementary disc that is the measure of the recognisability of the object in the generalisation process.

The following definition of the part of the areal object that will be recognisable and will not collapse in the scale of $1{:}M_i$ is proposed: in DLM the recognizable part $nC_i(G)$ of the areal object G generalized to scale $1{:}M_i$ is defined as the area of discs $B_r(p)$ belonging do $R(G)$ such as radii r are bigger or equal to the radius of the elementary disc r_i , which is presented by the relationship:

$$nC_i(G) = \{B_r(p) \in R(G) : r \geq r_i\}. \qquad (7)$$

Thus the area, which should collapse $C_i(G)$ will be the supplementation of object G:

$$C_i(G) = G \setminus nC_i \Leftrightarrow \{B_r(p) \in R(G) : r < r_i\} \setminus \{B_r(p) \in \in R(G) : r = r_i\}. \qquad (8)$$

Consequently, object G is the sum of the recognisable and unrecognisable areas, subdued and not subdued to the collapse for any scale:

$$G = C_i(G) \cup nC_i(G). \qquad (9)$$

Figure 4 presents the result being the area that in the elaborated scale will not be subdued to the collapse (thick black line). This is the sum of the surface of all discs belonging to the core of the radius bigger or equal to the radius of the elementary disc (light grey). The area not subdued to collapse is marked by discs (dotted line) of the radius equal radius elementary disc and centres (grey crosses) belonging to MAT. The area subdued to collapse (dark grey) makes the rest of the areal object.

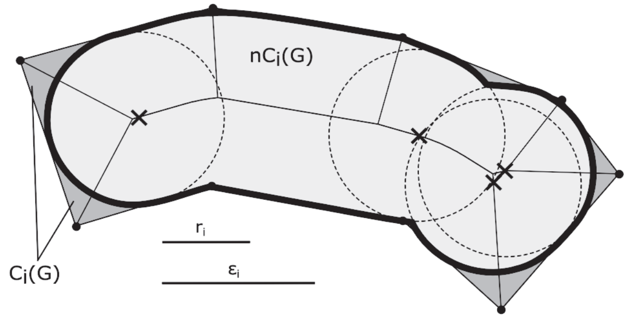

Fig. 4. The example of collapse. Explanations in the text

Rys. 4. Przykład zapadania. Oznaczenia w tekście

4. Internal graphic conflicts

In surface objects representing real natural objects one can make classification of vertices of begin and end MAT edges. Figure 5 presents the distinct types of MAT vertices. Vertices of type "0" are vertices on the boundary of the object. Vertices of type "1" are divided into 2 subtypes: "1a" is a vertex, approached by 2 edges MAT and left by 1 edge (the direction is considered the direction of the increase of the radius r of disc $B_r(p)$), "1b" is the

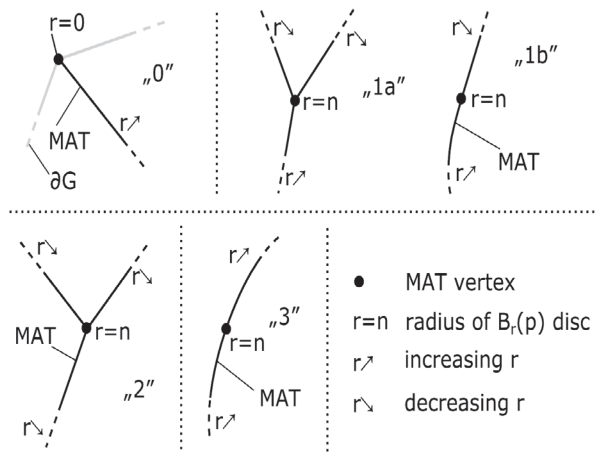

Fig. 5. Types of MAT vertices. 4 types and 2 subtypes of type "1" are presented

Fig. 5. Typy wierzchołków MAT. Wyróżniono 4 typy i 2 podtypy typu „1".

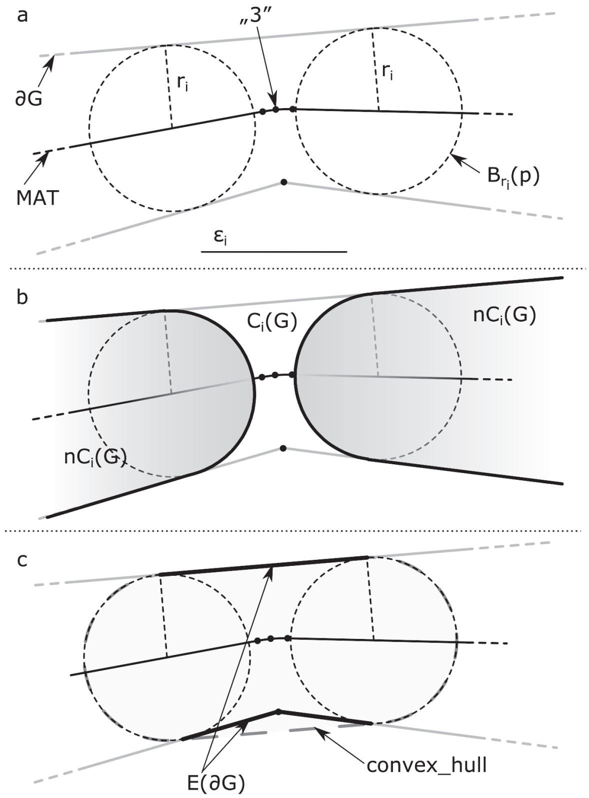

Fig. 6. Solving internal graphical conflicts after the collapse. a – the elementary disc, the closest to the local minimum, b – the areas of areal object not subdued to collapse (grey fill), c – fragments of the object boundary (thick black line) marked by intersect with the convex hull (dotted grey line)

Rys. 6. Rozwiązanie wewnętrznych konfliktów graficznych po zapadaniu. a – koła rozpoznawalności najbliższe lokalnemu minimum, b – obszary obiektu powierzchniowego nie ulegające zapadaniu (wypełnienie szare), c – fragmenty granicy obiektu (czarna gruba linia) wyznaczone przez przecięcie z otoczką wypukłą (sza ra przerywana linia)

vertex related to the segment of the character of parabola, 1 segment is approaching and 1 segment is leaving it. Vertices type "2" can be called local maximum, 3 segments are converging there (in degenerated cases more than 3). This vertex will make a local centre, to which a areal object will collapse. Finally, type "3" of vertices is the most important due to the recognisability of areal objects. From this vertex 2 vertices are leaving it (including, at least 1 of the character of parabola), which allows calling it local minimum.

Areal character of the object at vertices of type "3" makes the situation that if it is presented in the map only applying the formulae (7) and (8) then the object (Fig. 6) can locally cause graphic conflicts. These conflicts should be solved if the following condition is fulfilled:

$$d(p_j, p_k) < (2r_i) + \varepsilon_i \qquad (10)$$

where:

$d(p_j,\ p_k)$ – distance between the centres of the discs $B_r(p)$ of radius $r = r_i$ the closest to MAT vertex of type "3".

Solving the conflicts can be carried out in two ways:

1. Detecting the parts of the object boundary, which must be increased in DCM model, marked as $E(\partial G)$ (Fig. 6c).
2. Including to $nC_i(G)$ the area of graphical conflicts and its increasing.

In both cases the "filled in" convex hull is calculated for the recognizable discs the closest to the local minimum. Then the hull is intersect by from the boundary of the object or the area $C_i(G)$, which contains MAT vertex type "3", which can be presented as follows:

1.
$$E(\partial G) = convex\_hull\big((B_{r=r_i}(p_j) \cup (B_{r=r_i}(p_k)\big) \cap \partial G \qquad (11)$$

2.
$$E(G) = convex\_hull\big((B_{r=r_i}(p_j) \cup (B_{r=r_i}(p_k)\big) \cap G \qquad (12)$$

5. The example of applying the method

The proposed formulae were tested in several examples. One of them was presented below. The tested object "Mały Staw" (Little Pond) presents a pond of this name in the region of Sanok (Fig. 7). The representation of the shape of the tested object comes from vector files written in format ESRI Shapefile and made available

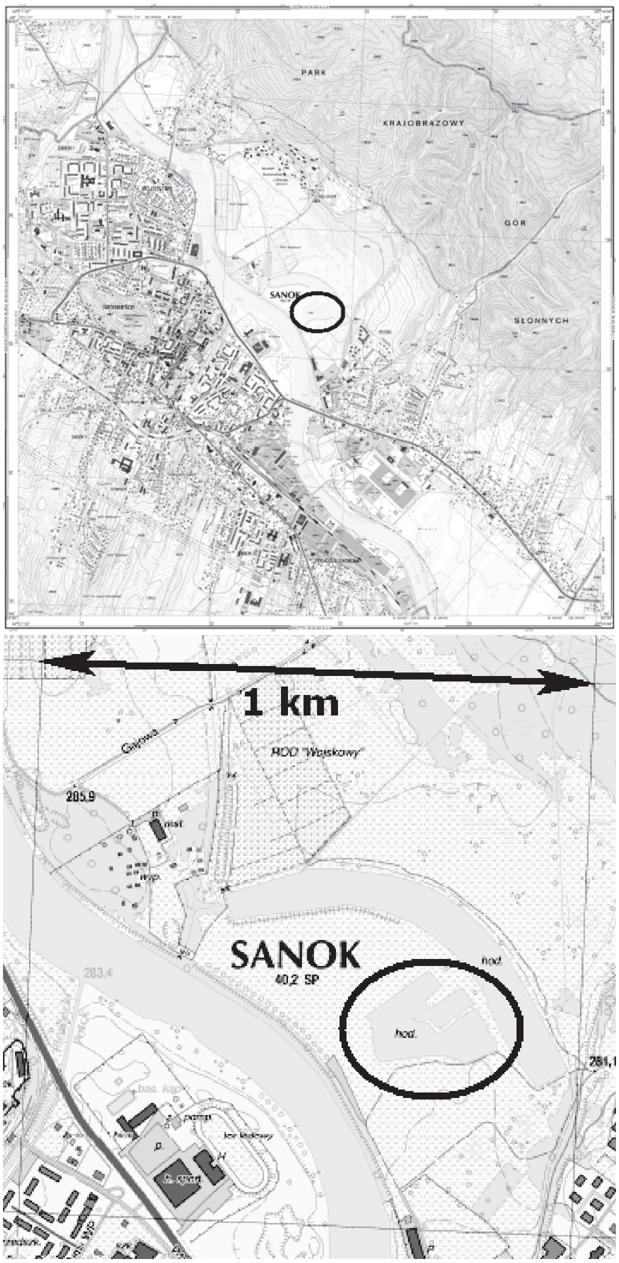

Fig. 7. Test object "Mały Staw" in the topographic map 1 : 10 000 ("Mapa topograficzna w standardzie TBD," 2009)

Rys. 7. Obiekt testowy „Mały staw" na mapie topograficznej 1 : 10 000 („Mapa topograficzna w standardzie TBD," 2009)

by the Head Office of Land Surveying and Cartography (*Główny Urząd Geodezji i Kartografii*). It is a part of the sheet of the Topographic Database in the reference scale of 1 : 10 000. The pond area is 2.38 ha.

The collapse was carried out for five scales: 1 : 25 000, 1 : 50 000, 1 : 75 000, 1 : 100 000 and 1 : 125 000, the results were presented in figure 8. Figure 9 shows generalization of the test object "Mały Staw" with the solution of its internal graphical conflicts, according to the formula (12).

Fig. 8. Object "Mały Staw" generalized to 5 final scales. Presentations in all the scales are preserving the proportions

Rys. 8. Obiekt „Mały staw" uogólniony do 5 skal docelowych. Prezentacje we wszystkich skalach przedstawione są z zachowaniem proporcji

Fig. 9. Object "Mały Staw" generalised to 4 scales with the detection and solving internal conflicts. The presentations in all the scales are preserving the proportions

Fig. 9. Obiekt „Mały staw" uogólniony do 4 skal z wykryciem i naprawą konfliktów wewnętrznych. Prezentacje we wszystkich skalach przedstawione są z zachowaniem proporcji

The presentation of the losses of the area of the object in subsequent scales is presented in table 1. The proposed solution for the collapse of the object "Mały Staw" justifies the proposed formulae. The analysis of fig. 8 and 9 shows that solving graphical conflicts proves that the solution is reasonable already at the stage of the collapse.

Table 1. The area of the generalised object "Mały Staw" in subsequent scales
Tab. 1. Powierzchnia uogólnionego obiektu „Mały staw" w poszczególnych skalach opracowania

Scale	Collapse without conflict solving		Collapse with conflict solving	
	Area [ha]	Area loss [%]	Area [ha]	Area loss [%]
1 : 25 000	2.37	0.2	2.37	0.2
1 : 50 000	2.34	1.5	2.35	1.2
1 : 75 000	1.89	20.4	1.89	20.3
1 : 100 000	1.62	31.9	1.69	28.9
1: 125 000	1.30	45.1	1.62	31.9

6. Conclusions

Presented in the article solution for the transformation of areal objects into linear ones for DLM, allows the following conclusions:
- the presented method is determinist, independent from the editor, only depends on the scale of the map;
- owing to the use of MAT in the construction of the skeleton of the object, it would be easy to combine the operator of the collapse with other operators i.e. simplification, exaggeration, and this is characteristic to interoperability in the understanding of the Law on Infrastructure and Spatial Information;
- the application of the proposed method increases the automation of the process of the generalization of DLM.

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DETERMINATION OF THE CRITICAL NET OF DIGITAL TERRAIN MODELS DEPENDING ON THE TOPOGRAPHIC MAP SCALE

Key words:

digital terrain model generalization, norm of recognition, critical net

Abstract

The article presents the designation of critical net of digital terrain model with regard to the recognition of objects on the map in the selected scale. Digital Terrain Model (DTM) based on spot heights (TIN model, laser scanning) generate the need for the classification of the data, hierarchy of components and identification of the areas in which morphologically homogeneous generalization can be carried out. These areas limited by the local minima and maxima and the hinge points (the points units) form a critical net. Within each field of the net the elevation points are divided into the areas within which you can independently make a generalization of the elevation model.

WYZNACZANIE SIECI KRYTYCZNEJ NUMERYCZNEGO MODELU TERENU W ZALEŻNOŚCI OD SKALI MAP TOPOGRAFICZNYCH

Słowa kluczowe:

generalizacja numerycznego modelu terenu, norma rozpoznawalności, sieć krytyczna

Abstrakt

W artykule przedstawiono wyznaczenie sieci krytycznej numerycznego modelu terenu z uwzględnieniem rozpoznawalności obiektów na mapie w wybranej skali. Numeryczny Model Terenu (NMT) tworzony na podstawie punktów wysokościowych (model TIN, skaning laserowy) wymusza na użytkowniku potrzebę uporządkowania danych, hierarchizację elementów składowych oraz określenie obszarów morfologicznie jednorodnych w których można przeprowadzić generalizację rzeźby terenu. Obszary te, ograniczone przez minima i maksima lokalne oraz punkty przegięć (tzw. punkty siodłowe) tworzą sieć krytyczną. W obrębie każdego pola wyznaczonej sieci punkty wysokościowe są podzielone na obszary, wewnątrz których można niezależnie dokonać procesu generalizacji modelu wysokościowego.

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1. Introduction

In the topographic maps, one of the ways of presenting the relief can be contour line drawing and putting characteristic elements such as points, discontinuity lines and skeleton lines. To properly present the relief in a selected scale one should apply an adequate source digital model of terrain. A simplified model should contain elements characteristic of the area for a given scale such as: local extremer, hinge points, saddle ridge lines, the lines of steepest descent, etc. The definition of these elements is possible if the identification, classification and prioritization of the individual objects in the digital model of terrain is correct. To do this it was decided to apply automatic decomposition of the height model, depending on the scale of the final map. Decomposition divides numeric terrain model into morphologically uniform areas determined by local extremes of the model and skeleton lines joining the extremes. Source elements to make decomposition are elevation points originating from photogrammetric studies or the cloud of points from laser scanning and determined based on them triangles from Delaunay's triangulation. As a result of decomposition the critical net is made, determining the skeleton lines of the model. In their definition there is a condition of the ability to recognize the drawing in the map (which depends on the scale of the final map). The existing skeleton lines made while the generation of the primary digital model of terrain are not taken into account at the decomposition, because they are not sufficient in the total division of the model into the regions and marking the critical net covering the study area.

With the growth of the increase of denominator of the final map scale, the number of local extremes and number of skeleton lines determined in the model. Formed as a result of the division critical net divides the model into regions, within which the simplification can be made, at the same time indicating which elements of this model (determined extremes and detected saddle points) should be presented in the map as points characteristic to the model (mounds, pits, elevation points). Due to defining the parameter of recognition, characteristic elements, important from the point of view of the relief visualization in the map, are recognized in a scale.

2. Legal and theoretical foundations

According to the Enactment of the Minister of Internal Affairs and Administration (Rozporządzenie MSWiA of 17th November 2011), there are cartographic symbols placed on maps, representing the relief generated from the digital model of terrain (NMT). Although the numeric model of terrain is not a part of the Database of the Topographic Objects (BDOT), this makes an important element of the presentation of elevation data on a topographic map.

Before presenting a relief on a topographic map or general geographic map one should first prepare digital data of the terrain model subduing it to the process of generalization. Suitably simplified model regarding characteristic elements identifiable in a selected scale of the final map could be only presented in an established form in the map. This will provide the presentation in the map only those forms and objects, which are recognizable in the map. Generalization of the digital terrain model should first of all provide the preservation of characteristic elements, such as ridge lines, bottoms of river valleys, summits and saddle points of the model recognizable in a provided scale of the map. One of the forms of the presentation of the relief in the map is the contour model with characteristic points. Depending on the scale of the final map the number of characteristic objects will change. The decision which points will be identifiable as characteristic points is possible after prior taking into account the standard of the recognition of objects in the map (Chrobak 1999).

To avoid ambiguous removal digital elements of the terrain model and preserve the mentioned above elements one should divide the whole model into morphologically homogenous areas and only then, in these areas make simplification of the model. Such a division of the model makes a so-called critical net, being a result of the decomposition of the digital terrain model. The decomposition of the digital terrain model was, among others, studied in the papers by Bajaj (1998) and Danovaro et. al. (2003).

In this paper the determination of a critical net digital terrain model according to Danovaro (2003), regarding the recognition parameter for the objects in the map.

2.1. Recognition of local extremes

Minimal size for the objects in the map were defined by Salishchev (Saliszczew 1998) and based on them Chrobak (2010) made a recognition standard for the objects, depending on the scale of the edited map. The recognition standard defines the minimal distance between objects, to make them one visible in the edited map. In creating critical nets local extremes were applied. The point defines the local maximum (minimum), when the following conditions are fulfilled:

- In its vicinity there are no points of greater/smaller elevation than this point,
- distance between the neighbouring local extremes will be higher than the condition of recognition.

Defining the condition of recognition is crucial do state, if the point is taken or not taken into account in decomposition as local extreme. Points that are characteristic in a decided scale should be presented in the map. Their visualization and identification is possible if two neighbouring extreme points of maximum are separated by the point of extreme minimum. To fulfil this condition it is necessary to modify the recognition standard into the form:

$$\varepsilon_{3D} = 2\,\varepsilon_f M \text{ [mm]}, \quad (1)$$

where:
ε_{3D} – recognition drawing,
$2\,\varepsilon_f$ – two minimal distances (ε_f) between the neighbour ing extreme points,
$\varepsilon_f = 0.5$ M [mm],
M – denominator of the scale of the processed map

Points fulfilling the above conditions are defined as local extremes of the model in a given scale and based on them critical net of the model is determined.

2.2. Decomposition – marking the critical net NMT

Marking the critical net according to Danavaro (Danavaro et. al. 2003) is based on the extended Morse-Smale distribution (1960), which in the model is made independently for the minimal points (stable distribution) and maximal points (unstable distribution). Overlapping of both areas marks extended Morse-Smale distribution (Fig. 1). It makes the set of lines and the points characteristic to a model in a selected scale of the final map. These lines in the field represent ridges (drainage divides) and bottoms of river valleys. Characteristic points are identified in the formed net. These are mainly saddle points. Their behaviour in the model is also important due to the correct presentation of the relief in the map. Moreover – the marked characteristic lines cross the previously defined points of local extremes.

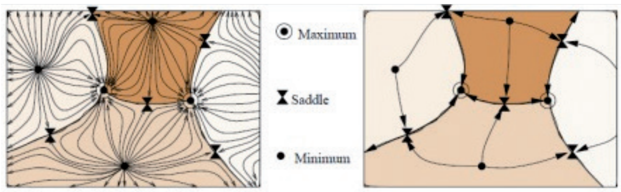

Fig. 1. Extended Morse-Smale distribution with the marked characteristic points (Danavaro et. al. 2003)

Rys. 1. Rozszerzony rozkład Morse'a-Smale'a wraz z zaznaczonymi punktami charakterystycznymi (Danavaro et. al. 2003)

The process of marking the critical net begins from the definition of the gradients of triangles (Fig. 2) making a numeric terrain model. Analysing the inclination of each triangle and the angle made with the normal of each side of this triangle, it is defined, which edges of this triangle are "entrances" and which ones are "exits" (Fig. 3). Flat triangles are excluded from the whole analysis due to their zero inclination. Every triangle of the model shall receive information saying which of its edges are "entrances" and which are „exits". Data prepared in such a way (identification of local extremes in the model and the definition of the edges entrance/exit for triangles) allow carrying out the extended Morse-Smale distribution.

As a result of the analysis independent two divisions of the same model shall be made, dividing the numeric terrain model into zones belonging to the defined local extremes. Crossing these areas one with another will mark critical net of the digital terrain model. The

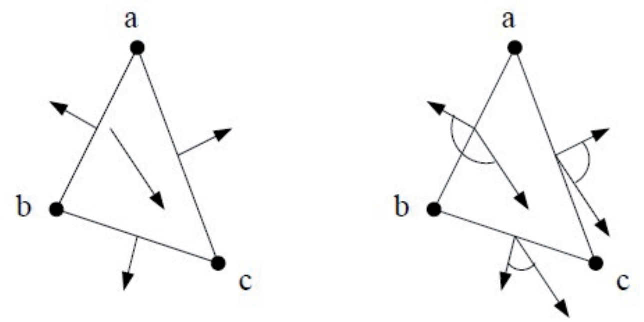

Fig. 2. Triangle abc with its gradient and normals for each of its edges. Side a–b makes the entrance edge, while sides b–c and a–c make exit edges (Danavaro et. al. 2003)

Rys. 2. Trójkąt abc wraz z jego gradientem oraz normalnymi do każdego z boków trójkąta. Bok a-b jest krawędzią wejścia, natomiast boki b-c oraz a-c są krawędziami wyjścia (Danavaro et. al. 2003)

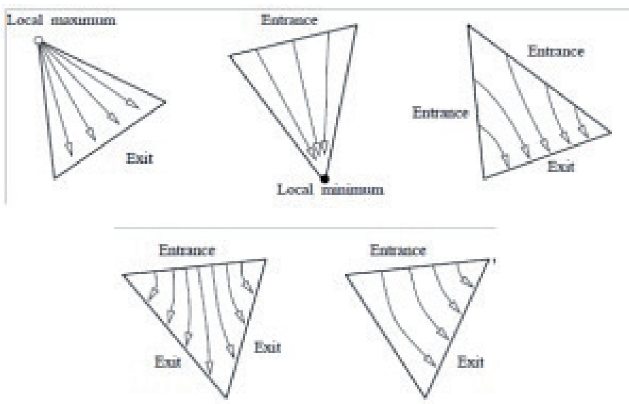

Fig. 3. Defining the entrance and exit edges of triangles (Danavaro et. al. 2003)

Rys. 3. Określenie krawędzi wejścia i wyjścia trójkątów (Danavaro et. al. 2003)

points of crossing these zones define the situation of the saddle points in the model.

3. The work carried out so far and the applied software

Marking critical net of the digital terrain model depending on the scale of the edited map was carried out for the test area covering the fragment of TIN (Triangle Irregular Net) model from the region of Beskid Sądecki in the vicinity of Krynica Zdrój. The test area of 630 × 480m was within the sheet of the topographic map M-34-90-D-b-4, while the height amplitude was 116 m. There were 1008 triangles in the area, 1562 edges and 554 vertices (Fig. 4).

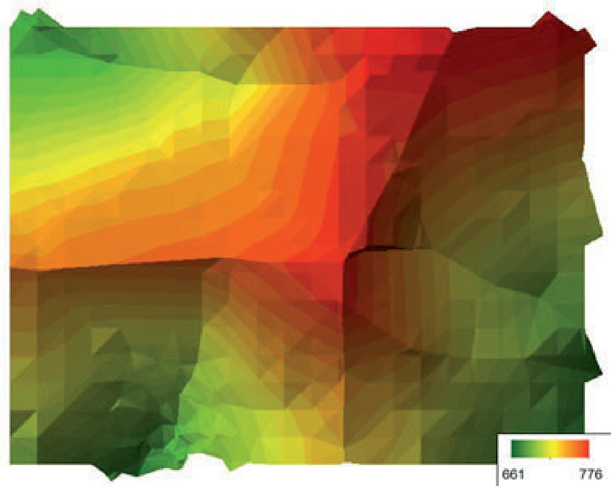

Fig. 4. The test area in the Beskid Sądecki, consisting of 1008 triangles, 1562 edges and 554 vertices

Rys. 4. Obszar testowy w Beskidzie Sądeckim składający się z 1008 trójkątów, 1562 krawędzi oraz 554 wierzchołków

All the procedures were carried out in the environment Python, with the application of the tools of ArcGIS. After defining appropriate parameters, all of this was imported as script into ArcToolbox. The input (entrance) data in the script is the vector layer with triangles and the denominator of the map scale, in which the elevation model will be presented. The output (exit) element of the script is the database, where the triangle model after decomposition shall be recorded.

4. Marking critical net for different scales of the final map

The created script consists of 5 basic elements (Fig. 5):

- obtaining information on the triangles of the model and its characteristics (inclination, coordinates of the points, edges),

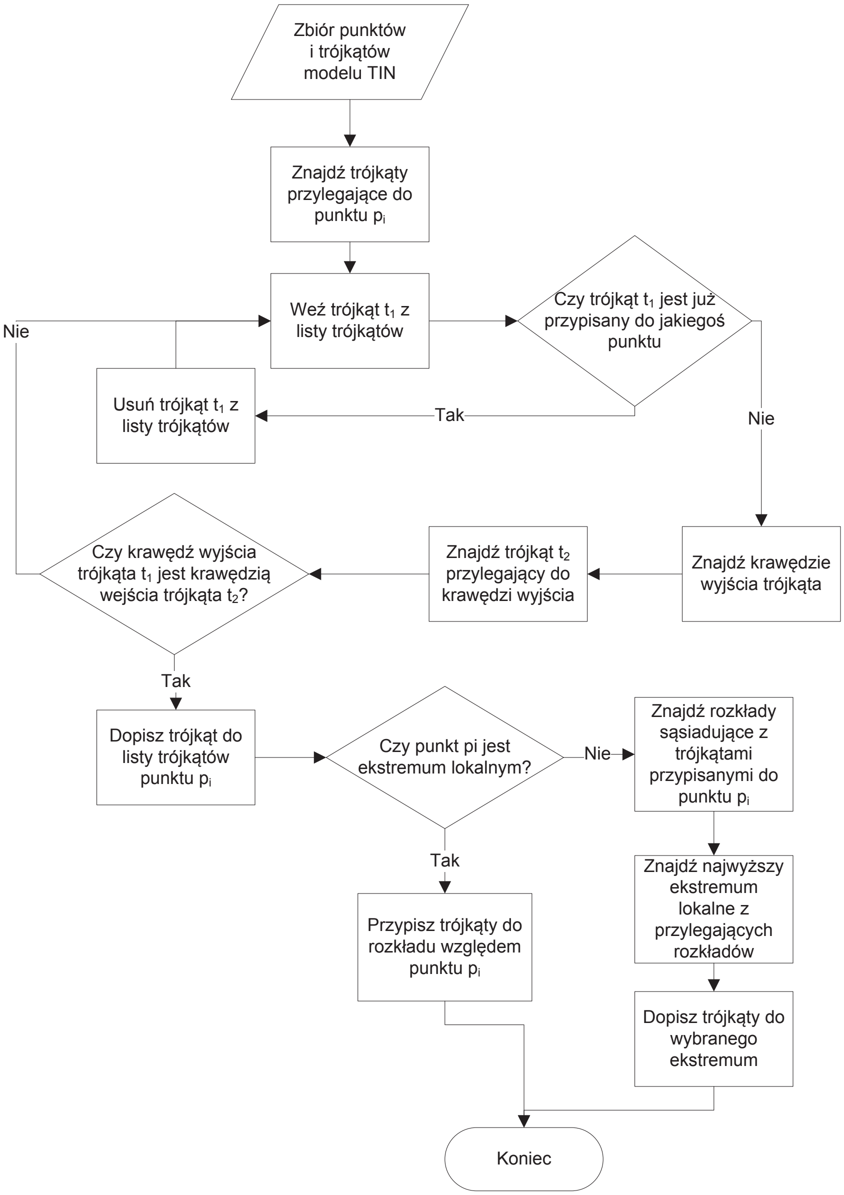

Fig. 5. The scheme of the algorithm

Set of points and triangles of TIN model; Find triangles adjacent to point p_i; Take triangle t_1 from the list of triangles; Is triangle t_1 already attributed to any point?; Yes – remove the triangle t_1 from the list of triangles, No – Find the exit edges of the triangle; Find triangle t_2 adjacent to the exit edge; Is the exit edge of t_1 the entrance edge of t_2?; Add the triangle to the list of triangles of point p_i; Is point p_i a local extreme?; Attribute triangles to the distribution regarding point p_i; Find distributions neighbouring to the triangles attributed to point p_i; Find the highest local extreme of the adjacent distributions; Add the triangles to the selected extreme; End

Rys. 5. Schemat działania algorytmu

- marking entrance and exit edges for every triangle,
- defining local extremes, depending on the value of the denominator of the map scale,
- making stable and unstable distribution – attributing every triangle to the points of local minimum and maximum,
- making critical net for triangles and marking lines and characteristic tangent points of the model.

In the first stage from the vector layer containing triangles, the following information was obtained: triangle identifier, inclination, slope and coordinates XYZ of its vertices. Based on this also the edges of individual triangles was determined, together with its direction. The last action of this stage was making lists containing data put properly in order: the list of points with the coordinates, the list of edges with the direction and identifiers of the initial and final point, as well as the list of triangles containing the information on inclination, slope and identifiers of the vertices and edges of the triangle.

The following stage was defining the entrance and exit of edges for each triangle. Analysing the angle between the inclination of the triangle and the direction of each edge, in each triangle it was identified which edge was the entrance edge and which the exit edge (Fig. 2). Based on this attribution the data was prepared to mark the critical net of the model. Flat triangles were removed from the analysis due to their zero inclination and the lack of the possibility to define entrance and exit edges.

To define local extremes at the given scale the norm of recognition of the object in the map was applied. To detect if a given point is defined as local maximum the elevation points and edges around the studied point were analysed in the distance defined by the recognition standard of the objects. If any of the points or edges was situated higher than the analyzed point, than this point was not classified as local maximum. When all the points and edges had elevation values smaller than the analyzed point, this point was defined as local maximum. This analysis was carried out for the whole set of points until all the points that could be identified at this scale of the map were verifiable as local maxima. In the same way the points of local minima were found.

After determining local extremes as well as defining entrance and exit edges for each triangle, the determination of critical net of the model was carried out. It consists of overlapping two Morse-Smale distributions: stable and unstable. The process of marking these distributions was described using an example of unstable distribution. Its creation started from segregating all the points in the lowering order regarding their height. The first point of the pile defined global maximum of the model, the subsequent points had respectively smaller values of height. The point was taken from the pile. For the selected point all the adjacent triangles were found. If the triangle had not been earlier attributed to any point, it was added to the list of triangles of this point. For each triangle from the list the entrance edges were identified and it was checked if the triangle adjacent respectively to that edge had that edge defined as entrance edge. If so, the subsequent triangle was added to the list of triangles. The analysis of entrance/exit edges was carried out for all the triangles found on the list belonging to a given point. If the point was defined as local extreme, all the triangles were added to this point, if the point did not belong to local extremes, the tangents to the adjacent area were looked for, the areas already defined and the analyzed area were added to the distribution, the extreme point of which contained larger elevation. After attributing triangles to a definite area, a subsequent point from the pile was taken. The whole procedure of marking unstable distribution lasted till the moment of attributing to all the triangles in the model, the point, towards which it was attributed to a definite area.

The stable distribution was made in the same way in terms of the points put in order from the lowest point to the highest one and finding the edges of the entrance triangle and checking if the adjacent to this edge triangle has analyzed edge marked as exit edge.

The last stage of the described procedure was getting the critical net for the elevation model. Overlapping the areas marked as a result of stable and unstable distribution a critical net was obtained for the model. The net depended on the value of the final scale (Fig. 6).

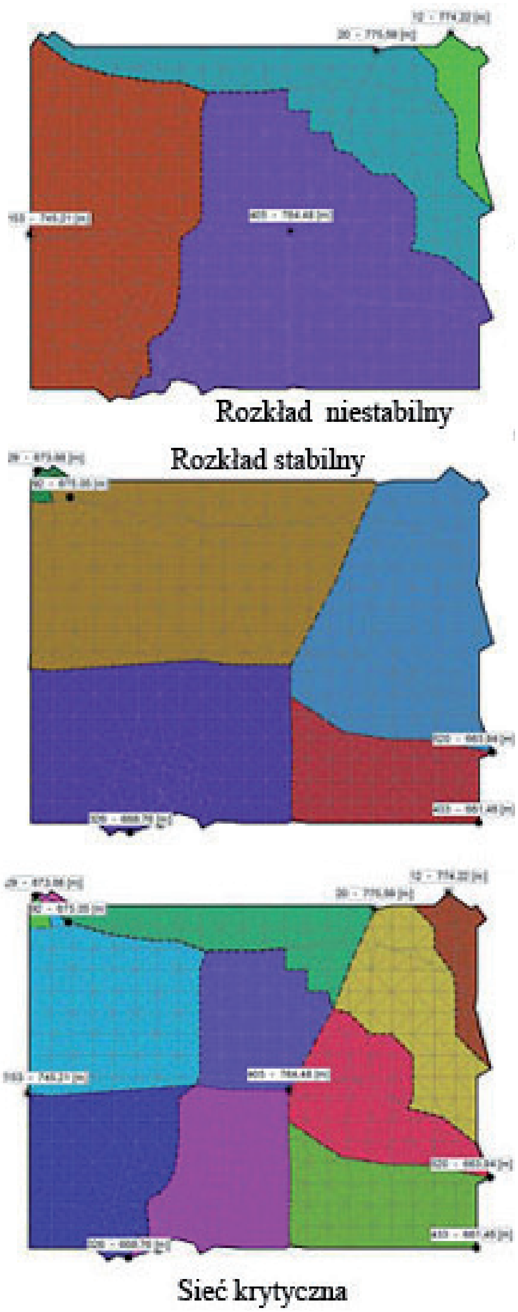

Fig. 6. Unstable and stable distribution of the digital terrain model for scale 1 : 10 000 and the critical net based on them

Rys. 6. Rozkład niestabilny i stabilny numerycznego modelu terenu dla skali 1 : 10 000 oraz wyznaczona na ich podstawie sieć krytyczna

5. Results and final remarks

Depending on the change of the edited scale value a different number of local minima and maxima. The combination of the detected local extremes was presented in Table 1. As a result of crossing the areas belonging to proper local extremes the critical net for the test area was obtained on different levels of details (Fig. 7). The final scale for which one local maximum and one local minimum were identified was 1 : 200 000. As a result of crossing stable and unstable distribution one area of critical net was obtained. Other results for the selected scales were put in Table 1.

Table 1. The presentation of the marked minima, maxima and areas of critical net for selected scales

Tab. 1. Zestawienie wyznaczonych minimów, maksimów i obszarów sieci krytycznej dla wybranych skal

Scale Denominator	Number of Local Minima	Number of Local Maxima	Number of Critical Net Areas
10 000	5	4	12
15 000	5	4	12
20 000	5	4	12
25 000	5	4	12
30 000	5	4	12
40 000	4	4	9
50 000	4	4	9
75 000	4	2	6
100 000	1	2	2
150 000	1	2	2
200 000	1	1	1

In further works the determined critical net of the digital terrain model will be applied in the generalization of the model as well as marking other lines of the model discontinuity and its verification with the existing skeleton lines.

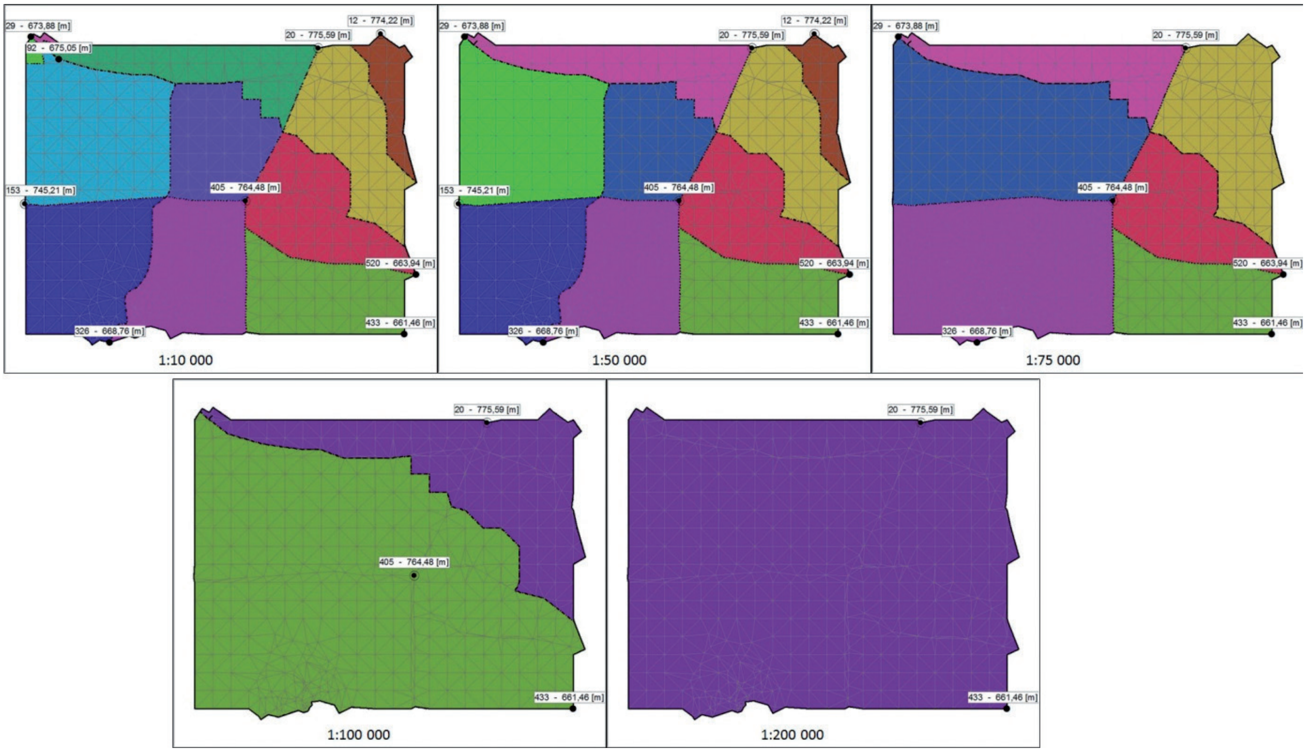

Fig. 7. Critical net determined for different scale intervals (1 : 10 000, 1 : 50 000, 1 : 75 000, 1 : 100 000 and 1 : 200 000) with the recognizable local extremes

Rys. 7. Sieć krytyczna wyznaczona dla różnych przedziałów skal (1 : 10 000, 1 : 50 000, 1 : 75 000, 1 : 100 000 oraz 1 : 200 000) wraz z rozpoznawalnymi ekstremami lokalnymi

6. Conclusions

Due to the application of the condition of recognition depending on the map scale, different number of local extremes and areas of critical net is obtained. The critical net allows the division of the digital terrain model into the surface, regarding their morphological structure. The lack of ambiguity in their definition is provided by local extremes and the recognition standard depends on the scale of the processed map.

The segmentation of digital terrain model into morphologically homogenous elements allows the automation of the generalization process of the elevation in the subsequent areas. Moreover, segmentation provides the adequate behaviour of characteristic elements of the model, such as: characteristic elevation points and main skeleton lines of the model.

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Rozporządzenie MSWiA z dnia 17 listopada 2011 *w sprawie bazy danych obiektów topograficznych oraz bazy danych obiektów ogólnogeograficznych, a także standardowych opracowań kartograficznych*, Dz.U., no. 279, position 1642

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Summary

According to the Enactment, on topographic maps cartographic symbols representing the terrain generated from a digital terrain model (DTM) are placed. Digital terrain model is not a part of the Topographic Objects Database (BDOT), however, represents an important element in the presentation of elevation data on a map.

The topographic maps are presented as the contour model with distinctive features such as elevation points, mounds, pits and slopes. The proper presentation of the terrain in the selected scale uses the appropriate simplified source terrain model. The simplified model should incorporate specific elements of the site for the scale such as local extreme, points of saddle ridge lines, the lines of steepest descent, etc. The determination of these elements is possible with proper identification, classification and prioritization of component objects of the digital terrain model. The author in this paper proposes to use for this purpose automatic decomposition of the model-dependent elevation map scale decomposition. The source elements, which perform the decomposition, are elevation points from photogrammetric studies or point clouds from laser scanning and triangles determined based of them, as a result of Delaunay triangulation. As a result of decomposition a critical net is created and this net defines a skeletal lines. The condition of recognition depended on the scale map has a big influence to determine them. Existing hard lines, created during the generation of the original DTM are not taken into account in the decomposition, because they are not sufficient to completely split the model into regions and designation of critical net in the whole area.

With the increase in the denominator of the target map scale, the number of local extremes and the number of skeletal lines decrease. As the result of this division the critical net is made diving the model into regions within which you can make a simplification and indicate which parts of the model (designated extremes and the detection point unit) should be shown on the map as characteristic points of the model (mounds, pits, elevation points). The parameter of recognition determines the characteristic features of the scale, relevant to the visualization of the terrain on the map.

Streszczenie

Zgodnie z Rozporządzeniem na mapach topograficznych umieszcza się symbole kartograficzne reprezentujące rzeźbę terenu wygenerowane z numerycznego modelu terenu (NMT). Numeryczny model terenu nie jest częścią składową Bazy Danych Obiektów Topograficznych (BDOT), jednakże stanowi on istotny element w trakcie prezentacji danych wysokościowych na mapie.

Na mapach topograficznych rzeźbę terenu przedstawia się w postaci modelu warstwicowego wraz z elementami charakterystycznymi tj. punkty wysokościowe, kopce, doły oraz skarpy. Do prawidłowego przedstawienia rzeźby terenu w wybranej skali należy skorzystać z odpowiednio uproszczonego źródłowego numerycznego modelu terenu. Uproszczony model powinien zawierać w sobie elementy charakterystyczne terenu dla danej skali takie jak: ekstrema lokalne, punkty siodłowe, linie grzbietowe, linie największego spadku itp. Określenie tych elementów jest możliwe przy prawidłowej identyfikacji, klasyfikacji i hierarchizacji obiektów składowych numerycznego modelu terenu. Autorka w swoim referacie proponuje wykorzystanie w tym celu automatycznej dekompozycji modelu wysokościowego uzależnionej od wartości mianownika skali mapy. Elementami źródłowymi do wykonania dekompozycji

są punkty wysokościowe pochodzące z opracowań fotogrametrycznych lub chmury punktów ze skaningu laserowego oraz wyznaczone na ich podstawie trójkąty powstałe w wyniku triangulacji Delaunay'a. W wyniku dekompozycji powstaje sieć krytyczna, która wyznacza linie szkieletowe modelu. W ich określaniu uczestniczy warunek rozpoznawalności rysunku na mapie, zależny od skali mapy docelowej. Istniejące linie szkieletowe tworzone w trakcie generowania pierwotnego NMT nie są brane pod uwagę przy dekompozycji, ponieważ nie są one wystarczające do całkowitego podziału modelu na regiony i wyznaczenia sieci krytycznej obejmującej rozpatrywany obszar.

Wraz ze wzrostem mianownika skali mapy docelowej maleje liczba ekstremów lokalnych oraz liczba linii szkieletowych wyznaczonych na modelu. Powstała w wyniku podziału sieć krytyczna dzieli model na regiony wewnątrz których można dokonać uproszczenia jednocześnie wskazując, które elementy tego modelu (wyznaczone ekstrema oraz wykryte punkty siodłowe) powinny być przedstawione na mapie jako punkty charakterystyczne modelu (kopce, doły, punkty wysokościowe). Dzięki zdefiniowaniu parametru rozpoznawalności określne zostają elementy charakterystyczne w danej skali, istotne z punktu widzenia wizualizacji rzeźby terenu na mapie.

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DATABASE OF TOPOGRAPHICAL OBJECTS AS A GROUND FOR CREATION THE SPATIAL DEVELOPMENT STUDY IN POLISH COMMUNES

Key words:

BDOT, cartographic visualization, cartographic generalisation

Abstract

In connection with the duty of municipalities to create land use plans, the present article has presented opportunities for adapting BDOT. According to the proposed assumptions and methods of procedure, the author has shown the structure of the base STUDIUM_BDOT, which following the necessary operations on the attributes and geometries of objects, has become the basis for cartographic visualisation.

BAZA DANYCH OBIEKTÓW TOPOGRAFICZNYCH PODSTAWĄ DO OPRACOWANIA STUDIUM ZAGOSPODAROWANIA PRZESTRZENNEGO W POLSKICH GMINACH

Słowa kluczowe:

BDOT, wizualizacja kartograficzna, generalizacja kartograficzna

Abstrakt

Ze względu na obowiązek gmin do tworzenia studium uwarunkowań i kierunków zagospodarowania przestrzennego w tym artykule zostały przedstawione możliwości adaptacji BDOT. Według zaproponowanych założeń i sposobu postępowania wskazano konstrukcję bazy STUDIUM_BDOT, która po niezbędnych operacjach na atrybutach i geometrii obiektów stała się podstawą do wizualizacji kartograficznej.

1. Introduction

The state of geodetic and cartographic resource steadily continues to accept new Database of Topographical Objects (BDOT) sheets for districts throughout the country under the project entitled "Georeference Database of Topographical Objects" (GBDOT). According to the Management System of the Database of Topographical Objects (SZBDOT) at regional level, data from the BDOT resource is compiled with other data, e.g. with the Register of Lands and Buildings, which is of considerable significance in the daily operations of municipal

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offices (Gąsiorowski 2011, Wytyczne TBD wersja 1 uzupełniona 2008 rok).

Currently, the primary owner and user of the spatial database is the public administration. However, to perform the tasks faced by the public administration, it is recommended to utilise the smallest quantity of spatial data and the simplest tools that can ensure the requisite quality of the final product (Białousz 2011).

Pursuant to the provisions of the Spatial Planning and Management Act of 27th March 2003, one of the most important duties of municipalities is to elaborate the land use plan. In accordance with the Regulation of the Minister of Infrastructure, dated 28th April 2004, such a plan is made on a topographical map from the state of geodetic and cartographic resource, or on a copy of a military topographical map drawn up on a scale ranging from 01:05000 to 01:25000. At present, each municipality prepares the land use plan usually in a graphic form, solely for the purpose of printing, without creating a layered structure based on the vector model.

The main objective of the present deliberations is the possibility of using the Database of Topographical Objects to create a base of land use plans for the municipality and to present methods of cartographic visualisation. In the research, the first of all digital method of cartographic generalisation was applied (Chrobak et al. 2007). Data was generalised by means of geometric operations (MacMaster, Shea 1992, Medyńska-Gulij 2012, Kaczmarek 2010) and operations on attributes (Kaczmarek 2010). The processed data were recorded in the spatial data database in the standard SHP format (Goodchild at al. 2006, Bielecka 2006). The visualisation of spatial qualitative information was achieved by the method of signatures and the method of ranges (Medyńska-Gulij 2012, Ratajski 1989, Saliszczew 1998).

Using the municipality of Śrem as an example of data, the author proposed a procedure for transforming BDOT into the base of the spatial planning framework, and subsequently presented variants of cartographic visualisation. From the four components of BDOT, the TOPO component was selected for the study; this contains information about spatial objects recorded in the form of a vector model, with the location of each object given in a coordinate system (1992).

2. Transformation of BDOT into the base of the spatial planning framework

The proposed method of transforming BDOT into the base of the spatial planning framework includes the performance of the following actions, which makes a universal procedure for each municipality that has the TOPO component. The end-product of the created STUDIUM_BDOT base is a cartographic visualisation, while its specific result is the publication of topical maps in the form of printout or a PDF file with low interactivity. The basic assumptions for transformation were included in the following points:
- division into layers with topical content, in accordance with the scope required for the spatial planning framework, and into the necessary reference sublayers;
- assigning the geometric form of objects: points, lines and surfaces;
- vector recording in SHP format;
- accuracy of the geometric position in accordance with coordinates (1992) and a scale of 1 : 10 000;
- level of detail and recording of object attributes in accordance with BDOT guidelines.

Figure 1 presents the structure of the base of the land use plan following transformation from BDOT, which has been named *Baza_STUDIUM_BDOT.* The base is made up of two types of sublayers: TIFF raster and SHP vector, and SHP topical layers. Inclusion in the base of two raster sublayers with an ortophotomap and a PUWG topograhical map (1992) is very useful for comparing the vision of arable land contained in the plan with the current state of the municipality's topography. In turn, buildings from BDOT in SHP format are recorded as the functions of buildings, and this may be of significance when interpreting arable land in the study. For managing the municipality, it is important to make a reference to the division into registered plots, and for this reason a register map has also been included in the base. The topical range includes 65 layers in SHP format, in accordance with separations for the plan, of which 9 have been presented in Figure 1. Additionally, the base contains a dictionary for reading the abbreviated names of 65 separations.

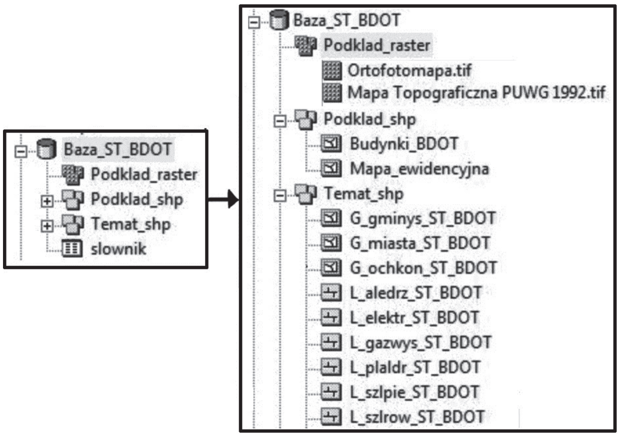

Fig. 1. Structure of the base of the land use plan following transformation from BDOT

Rys. 1. Struktura Bazy ST_BDOT według grupy warstw zawartości podkładowej i grupy warstw tematycznych

The land use plan does not represent the factual spatial situation, but it shows a future vision of the development of the land. For this reason, the geometries of objects of the actual situation in BDOT rarely coincide with separated complexes of land development in the plan. On the basis of visual analysis of geometries for the municipality of Śrem concerning objects in BDOT, with arable land drawn in the municipal plan on the scanned traditional topographical map in the 1992 arrangement, the author created the base_ST_BDOT.

Data from BDOT has been classified under individual land separations present in the map of directions of the municipal plan. Table 1 contains successive separations in accordance with the order of signs given in the key in Figure 2. The columns contain the names of arable land from the plan, and these are followed by the pertinent layer names from BDOT and geometry types. The third and fourth columns present operations on the geometries of objects and operations on attributes, which were necessary to supplement the base ST_BDOT with new layers, shown in the fifth column of the table. The final column contains the TERYT number, which will make it possible to streamline objects according to this unique identifier for municipalities. In the future, the TERYT recording will allow comparisons with plans made in neighbouring and other municipalities. Unfortunately, at present each municipality has a plan in the form of a separate graphical document, which cannot be combined in a single joint file for comparison in the GIS software. Table 1 shows first and foremost examples for area layers, since these predominate in the plan. An example of the transferral of objects directly from BDOT to ST_BDOT is the ADM_A layer, i.e. without interfering with geometry, the border of the municipality has received a new name: G_gminy_ST_BDOT. In turn, operations on attributes included the following: generating new attributes, that is supplementing a new table with qualitative information and numerical values, for example the area calculated on the basis of object geometry. Another example is the creation of a new layer in consequence of vectorisation for area objects (planned protection zone), linear objects (pedestrian tourist routes) or point objects (archaeological stands). In order to separate "areas of developed greens", operations on geometry were used: the selection and joining of objects from two BDOT layers, and of operations on attributes: the classification of objects and the generation of attributes.

For the municipality of Śrem used in the present example, transformation covered 65 separations, of which 6 were adapted from BDOT without the need to interfere with the geometry of objects. 22 items of arable land were created thanks to the appropriate operations on the geometry of objects from BDOT layers, while for the remaining 36, the vectorisation of objects was applied, however adapted to the geometry of existing BDOT elements. Geographical names were created on the map as graphics.

The names of layers were coded in the column heading, and for this reason it was necessary to include a dictionary table in the base STUDIUM_BDOT. Hereunder we have presented a fragment of the dictionary table for reading the meanings of headings by the user. Table 2 contains the successive designation number from the plan's key, and then the name of the item of arable land, with the layer name in the plan base being given in the final column. The first capital letter stands for: G – granice (borders), T – tereny (lands), L – linie (lines), P – punkty (points); this is followed by 6 small letters of the abbreviation of the full name of the separation, and the suffix _ST_BDOT.

Table 1. Fragment of table: Transformation of BDOT into the base of the spatial planning framework STUDIUM-BDOT
Tab. 1. Tabela transformacji użytków w tradycyjnym studium do bazy STUDIUM-BDOT

Number in the STUDIUM	STUDIUM (Name of arable land)	BDOT (Name of layer)	Geometry	Operations on geometries	Operations on attributes	STUDIUM/BDOT (Name of layer)	TERYT
1	Granica gminy	ADM_A	area	transferral directly	generating new attributes, supple-menting a new table with qualitative information and numerical values	G_gminy_ST_BDOT	3026045
4	Planowana strefa ochronna lub docelowe tereny zamknięte	—	area	creation of new objects	generating new attributes, supple-menting a new table with qualitative information and numerical values	T_plasto_ST_BDOT	3026044 3026045
8	Tereny łąk i pastwisk	PKTR_A	area	– selection and joining of objects – creation of new objects	– classificayion of objects; – generating new attributes, supple-menting a new table with qualitative information and numerical values	T_lakipa_ST_BDOT	3026044 3026045
17	Tereny zieleni urządzonej	KUAA_A PKUT_A	area	– selection and joining of objects – creation of new objects	– classificayion of objects; – generating new attributes, supple-menting a new table with qualitative information and numerical values	T_zieurz_ST_BDOT	3026044 3026045
24	Turystyczne szlaki piesze	—	line	creation of new objects	generating new attributes, supple-menting a new table with qualitative information and numerical values	L_szlpie_ST_BDOT	3026044 3026045
49	Stanowiska archeologiczne	—	point	creation of new objects	generating new attributes, supple-menting a new table with qualitative information and numerical values	P_starch_ST-BDOT	3026044 3026045

Table 2. Fragment of the dictionary table STUDIUM_BDOT
Tab. 2. Fragment tabeli słownikowej bazy STUDIUM_BDOT

Lp.	Studium – nazwa użytku	Nazwa warstwy w bazie studium
1	Granica gminy Śrem	G_miny_ST_BDOT
2	Granica miasta Śrem	G_miasta_ST_BDOT
3	Tereny zamknięte	T_zamkni_ST_BDOT
4	Planowana strefa ochronna lub docelowe tereny zamknięte	T_plast_ST_BDOT
5	Tereny wód powierzchniowych	T_wodpow_ST_BDOT
6	Tereny lasów	T_lasow_ST_BDOT
7	Tereny dolesień	T_dolesi_ST_BDOT
8	Tereny łąk i pastwisk	T_lakipa_ST_BDOT
9	Tereny rolnicze	T_rolnic_ST_BDOT
10	Tereny zabudowy mieszkaniowej wielorodzinnej	T_zabnwi_ST_BDOT
11	Tereny zabudowy mieszkaniowej jednorodzinnej	T_zabmje_ST_BDOT
12	Tereny wielofunkcyjnej zabudowy wiejskiej w obszarze zwartej	T_wzwwob_ST_BDOT
13	Tereny wielofunkcyjnej zabudowy wiejskiej poza obszarem	T_wzwpoz_ST_BDOT
14	Tereny zabudowy letniskowej	T_zablet_ST_BDOT
15	Tereny zabudowy usługowej	T_zabusl_ST_BDOT
16	Tereny zabudowy techniczno-produkcyjnej	T_zabtpr_ST_BDOT
17	Tereny zieleni urządzonej	T_zieurz_ST_BDOT
18	Tereny górnicze	T_gornic_ST_BDOT
19	Tereny infrastruktury technicznej	T_inftec_ST_BDOT

3. Cartographic visualisation

Directly from the base STUDIUM_BDOT, we receive a topographical model, i.e. the digital record of the geometry and characteristic features of objects, without a fixed method of graphical presentation of these objects on a printout or monitor (Bielecka 2006). The digital topographical model is the basis for elaborating a digital cartographic model, in which there are graphical parameters concerning symbolisation already recorded (Medyńska-Gulij 2010). The cartographic model, in turn, constitutes the basis for generating the cartographic content of the map. Following the addition of the necessary elements to the map, such as the title, key, scale, information about sources of data, about the system of coordinates, etc., the map project can be recorded as a PDF document and printed in the form of a properly edited map.

Relatively simple symbols on the map of directions of the land use plan may be easily selected from the library of any geoinformation programme. Figure 2 shows a key with signs for which the appropriate graphical variables have been selected, presenting qualitative information about objects. The study map is a signature

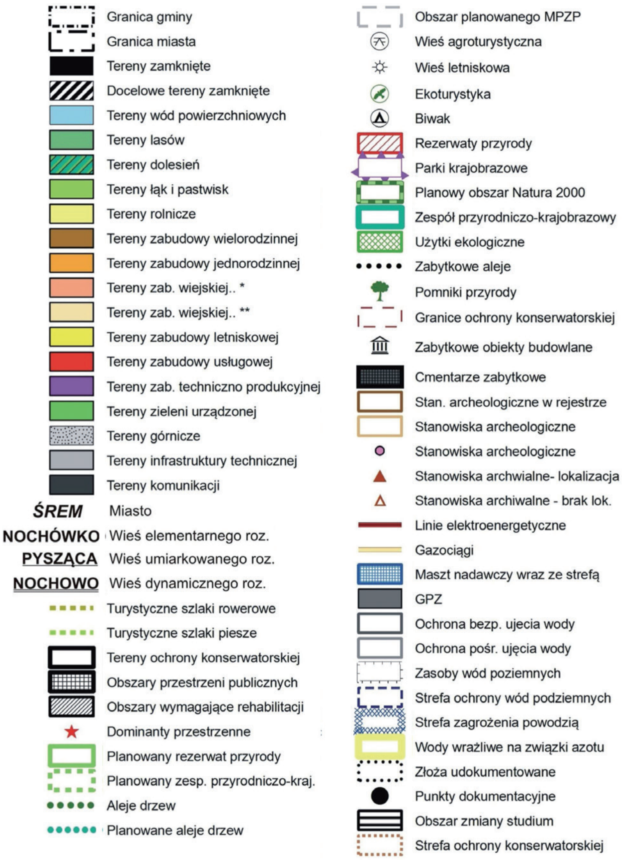

Fig. 2. Symbols in the legend
Rys. 2. Znaki w legendzie

Fig. 3. Three variants of visualisation of the base STUDIUM_BDOT
Rys. 3. Trzy sposoby wizualizacji kartograficznej bazy STUDIUM_BDOT

map, although ranges play an important role, and these may be considered as a specific form of the surface signatures method (Ratajski 1989).

A considerable advantage of the creation of a cartographic model on the basis of the base STUDIUM_BDOT is the choice of numerous visualisation variants, which in the proposed solution means the three instances included in Figure 3. The first fragment elaborated for the municipality of Śrem contains signs from the plan's key without sublayer content. The central visualisation uses a transparency of 50% for plan's layers due to the included layer of the topographical map 01 : 10 000. The third visualisation of topical content, in turn, has been placed on the ortophotomap, which is the most up-to-date image of the municipality's geographical space. In the event of using transparency, it becomes difficult to read the meaning of signs, for the key explains full-colour – i.e. non-transparent – signs.

Usage of the BDOT layer with buildings functions (Fig. 4) may turn out to be important in managing the municipality's space. The geometry of buildings from BDOT is well suited to the topographical sublayer 1 : 10 000, and thus the reader may observe the dependence between the function of a building and designated areas of arable land. When viewing Figure 4, it is worth noting that the location of buildings with educational and cultural functions on land earmarked for services. The method of publishing the map of the plan from the base STUDIUM_BDOT is in the form of a JPG or PDF file, which is

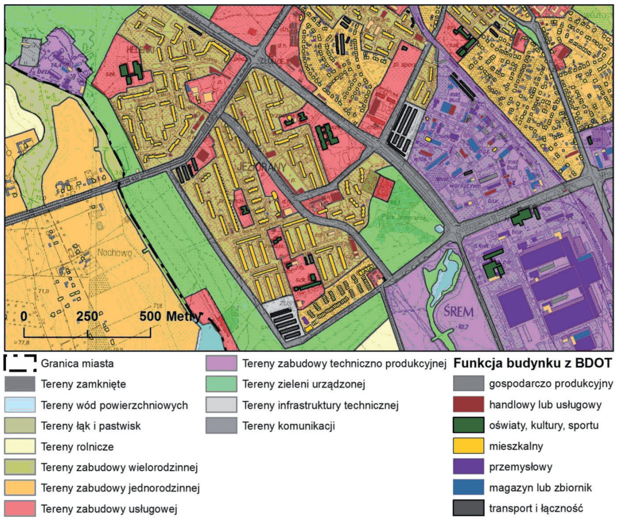

Fig. 4. Usage of the BDOT layer with buildings functions

Rys. 4. Wykorzystanie warstwy BDOT z funkcjami budynków

interactive: it enables the inclusion and exclusion of topical layers. Such an user-friendly file with limited interactivity may be made available to the residents as a download from the website of the municipal office.

4. Conclusions

In connection with the duty of municipalities to create land use plans, the present article has presented opportunities for adapting BDOT. According to the proposed assumptions and method of procedure, the author has shown the structure of the base STUDIUM_BDOT, which following the necessary operations on the attributes and geometries of objects has become the basis for cartographic visualisation. The main advantage of BDOT is the possibility of its universal application for each municipality, which may lead to the creation of a single model of the plan, enabling comparisons with plans elaborated in neighbouring municipalities. Another advantage is the utilisation of various cartographic sublayers, e.g. an ortophotomap or a traditional topographical map. Difficulties with the process of adapting BDOT concern first and foremost the necessity of performing operations in geoinformation software on geometries and attributes of objects of individual groups. Manual vectorisation is, unfortunately, a laborious process, for it is based on the traditional visual analysis (Saliszczew 2003). The possibility of using computer editing supported by automatic generalisation (Chrobak 2005) is still open to discussion. On the basis of the results presented herein, it may be stated that BDOT is a universal and fundamental source of information for elaborating the obligatory land use plan by each and every municipality.

At this point the author would like to thank Mr Mateusz Kołtoniak, who performed the research that was used in the present article as part of his Master's thesis, written under the scientific direction of the author of the present.

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Streszczenie

W związku z oddaniem do użytkowania Bazy Danych Obiektów Topograficznych dla wielu już gmin zaistniały podstawy do wykorzystania tego źródła danych przestrzennych w zakresie tematycznych opracowań obligatoryjnych dla urzędów w całym kraju. Ze względu na obowiązek gmin do tworzenia studium uwarunkowań i kierunków zagospodarowania przestrzennego w tym artykule zostały przedstawione możliwości adaptacji BDOT. Według zaproponowanych założeń i sposobu postępowania wskazano konstrukcję bazy STUDIUM_BDOT, która po niezbędnych operacjach na atrybutach i geometrii obiektów stała się podstawą wizualizacji kartograficznej. Głównym atutem BDOT jest możliwość jej uniwersalnego wykorzystania dla każdej gminy co może spowodować zaistnienia jednego wzoru opracowania studium pozwalającego na porównywanie studiów sąsiadujących gmin. Kolejną zaletą wskazaną w artykule jest wykorzystanie różnych podkładów kartograficznych dla referencji np. ortofotomapy lub tradycyjnej mapy topograficznej. Natomiast trudności w procesie adaptacji BDOT dotyczą przede wszystkim konieczności wykonania operacji w oprogramowaniu geoinformacyjnym na geometrii i na atrybutach obiektów z poszczególnych grup. W artykule przedstawiono konkretne działania tworzenia i wizualizacji kartograficznej na przykładzie fragmentu gminy Śrem.

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CONSTRUCTION OF FUZZY INTERFERENCE SYSTEM FOR GENERALIZATION OF GEOGRAPHIC INFORMATION – SELECTION OF ROAD SEGMENTS

Key words:

generalization, fuzzy logic, selection, knowledge base, selection

Abstract

Automation of generalization of geographic information is known as one of the biggest challenges facing modern cartography. Realization of such a process demands knowledge base which will help to decide which algorithms in which sequence should be used and how to parameterize them. Author proposes the knowledge base based on non-classical logics: rough and fuzzy. This article presents results of first trials on the fuzzy rules for realization of selection operator. Usage of fuzzy rules and linguistic variables allows better mimic the subjective character of generalization process. Test were established on the data about roads segments coming from Topographical Database (TBD) two test areas. Conducted experiment proved the possibility of utilization of fuzzy rules in the generalization of geographic information. It may be very valuable to use the idea of rough sets and reducts for selection of the attributes which are the most significant in terms of the made decision. This will be the subject of author's further research. Presented research are the initial step for creation of knowledgebase based on non-classical logic (fuzzy and rough).

SYSTEM WNIOSKOWANIA ROZMYTEGO DLA GENERALIZACJI INFORMACJI GEOGRAFICZNEJ – SELEKCJA ODCINKÓW DRÓG

Słowa kluczowe:

generalizacja, logika rozmyta, baza wiedzy, selekcja

Abstrakt

Problem wykorzystania algorytmów inteligencji obliczeniowej do tworzenia baz wiedzy systemów generalizacji informacji geograficznej jest w ostatniej dekadzie niezwykle często poruszany w kontekście prac koncepcyjnych i badawczych. Autorka referatu podjęła jednak próbę opracowania także prototypu narzędzia informacyjnego automatyzu-

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jącego proces selekcji wielocechowych obiektów przestrzennych jako źródła danych dla tworzenia map topograficznych w różnych skalach. Opracowany system, wykorzystujący jako silnik obliczeniowy proces wnioskowania rozmytego, jest niezwykle efektywny obliczeniowo, pozwalając zarazem na pełną parametryzowalność systemu generalizacji.

1. Introduction

Automation of generalization of geographic information is known as one of the biggest challenges facing modern cartography. Through the ages cartographers generalized geographic information available on maps using traditional technologies. This manual work demanded knowledge and experience as well as a specific artistic sense, allowing maintaining not only beauty, but also (even more important) usefulness of the maps created in smaller scale.

Today, when popularity of digital modeling of geographic information increases, and spatial databases become more and more common, there is a need for the automation of generalization process. There is also a high demand for the reuse of already acquired, detailed data to produce information at the higher level of detail (LoD) by judicious and possibly automate generalization (i.e. Inspire Directive). Fulfilling those demands a number of algorithms was created, corresponding with the generalization operators (Shea, McMaster 1989) as selection, simplification, exaggeration, etc. However, newly developed algorithms are not able to holistically realize the process of generalization of geographic information. To do it knowledge base is required, to specify which algorithms, in which sentence and parameters should be applied.

Currently used knowledge is based on classical, binary logic and does not seem to reflect the subjective and contextual character of generalization. Author proposes the knowledge base based on non-classical logics: rough and fuzzy. The paper presents results of first tries with the fuzzy rules (within fuzzy interference system – FIS) for selection operators.

2. Fuzzy logic

Fuzzy logic, in contrast to the classical one, allows the stages between two values as yes/no, 0/0, belongs/not-belongs. In this case belonging to the certain set is not defined binary but using the continuous membership function by which the linguistic variables are defined. For example according to the binary logic the road can be either narrow or wide. If those categories are established, it is required stiff determination of the boundary between those two sets (i.e. the road is wide if it has more than 10 m width, if it has less it is narrow). This kind of classification (into crisp sets) makes similar objects to be in different groups (i.e. the road which is 10 m width is "narrow", the one which is 10,1 m is "wide", while they are both more similar than the roads which are 10.1 m and 30 m width and both are "wide"). The mathematical tool which allows better reflection of these intuitively sensed relations includes fuzzy sets. They allow us to say not only that the road is "wide" (in default "wide" = 1, "narrow" = 0), but also reflect commonly used expressions as "quite wide" (i.e. "wide" = 0.4). What is more it does not mean that the same road cannot be (to some degree) the narrow road (i.e. "narrow" = 0.2) undermining the law of excluded middle formulated by Aristotle in the classical approach (Fig. 1).

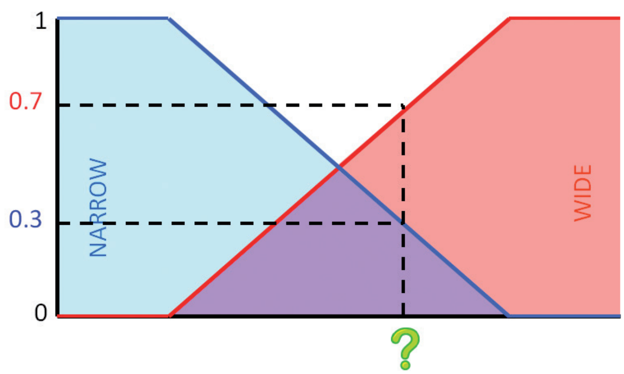

Fig. 1. Definition of linguistic variables in fuzzy logic by membership functions

Rys. 1. Definiowanie zmiennej lingwistycznej poprzez funkcję przynależności

Membership function, which assigns the values for the linguistic variables, is defined subjectively. It can take different shapes (triangular, trapezoid, Gaussian curve etc.) and various parameters. Subjective character of membership function is one of the reasons why the usage of fuzzy logic for generalization of geographic information (which is also subjective by its nature [Olszewski 2009]) seems reasonable.

The fuzzy allows not only definition of assignment to the sets in the non-classical way, but also definition of fuzzy rules and construction of interference system using linguistic variables with the usage of specific mathematical tool. There is a few ways of interpreting logical operators as "and" or "or" in fuzzy logic. In this paper the most commonly known was used and its idea is presented in Fig. 2.

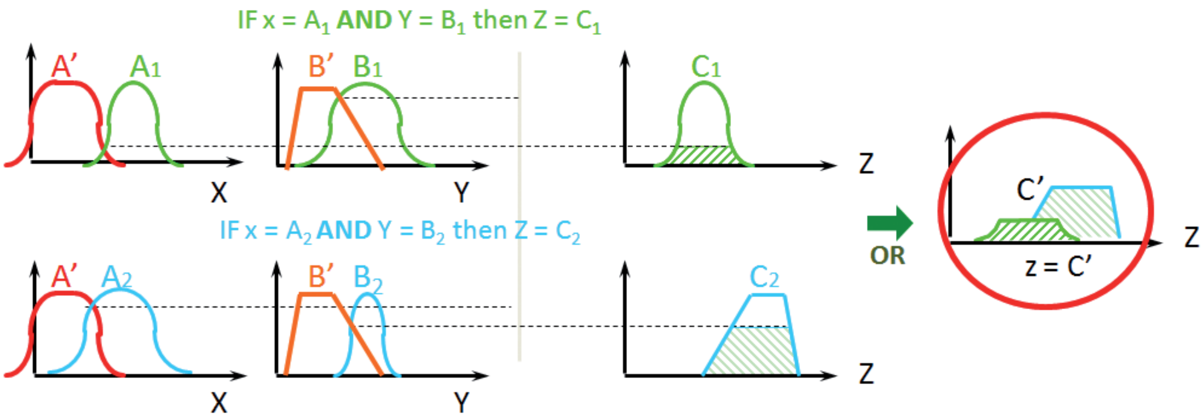

Fig. 2 Logical operators "and" and "or" in fuzzy logic. [source: http://www.cs.nthu.edu.tw/~jang]
Rys. 2 Operatory logiczne „i" oraz „lub" w logice rozmytej. [źródło: http://www.cs.nthu.edu.tw/~jang]

3. The experiment proposed

3.1. General idea

Conducted experiment was one of the first trials designed to check the usefulness off fuzzy logic for formulation of generalization rules. It was limited to one class of linear objects (road segments) and one generalization operator (selection). Proposed rules were supposed to give an answer to the question if certain object should be represented in a specified scale.

3.2. Source data and test area

The source data came from BDOT10k (Database of Topographic Data) which is the basic reference database in Poland, at the level of data 1 : 10 000. The main data source was the class SKJZ containing information about road segments. Both descriptive attributes from database as well as the geometry of generalized object were utilized. Also information about other objects classes (as settlements areas or buildings) were used to indirectly reflect the spatial context of road segments location and character.

Analyzed test area is located in south Poland and covers rural areas of Low Beskid Mountains. The main place located in the analyzed 100 km^2 was a small town of Dukla.

3.3. Data preparation

Only some of the data delivered from BDOT10k could be directly utilized in fuzzy interference system (FIS). That is because FIS demands attributes in an interval scale for fuzzification, while most of the attributes were in ordinal scale. Those attributes were firstly prepared by artificial transformation into interval scale. Besides attributes from the databases table the attributes coming from spatial analysis were used as an input to FIS.

The number of attributes for road segments in BDOT10k is in ordinal scale. That means that before they are used in FIS, it is necessary to transform them into interval scale. This change has artificial and subjective character while in the original – ordinal sequence is known, the distances between classes are not defined. Therefore several trials were done, using diverse approaches:

- distance between classes = 1,
- equal distances between classes, range normalized to 100,
- increasing distances between classes,
- decreasing distances between classes.

The example of such a reclassification for one of the attributes road class is shown in Table 1.

The other type of attributes used in the created fuzzy interference system are attributes computed by spatial analysis of the data. In this case not only data about the generalized class were exploited, but also data about other objects which location in the relation with the road segments may influence the generalization process. To include also this kind of spatial relationships the number of analysis were established, and their results became new attributes used for creation of rules for generalization process. The example of such an analyze calculating the area of created regions attributable to 1 m of road in a buffer of 100 m is presented as a model in ArcGIS ModelBuilder in Figure 3. Attributes calculated in this way were also often (depending on the version of the experiment) normalized.

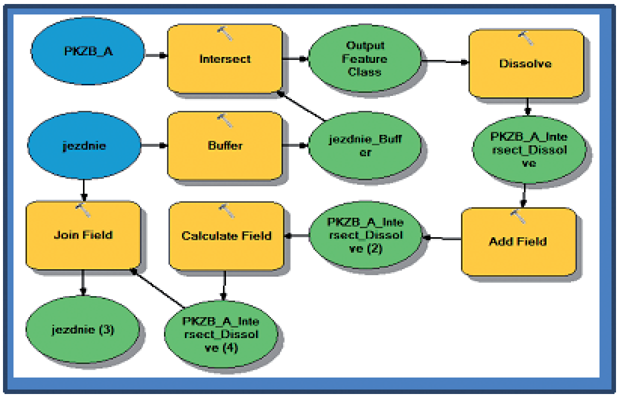

Fig. 3. ArcGIS ModelBuilder for calculation of one of the attribute based on geometry and topology of objects – built-up regions attributable to 1 m of road in a buffer of 100 m

Rys. 3. Wykorzystanie ArcGIS ModelBuilder do obliczenia jednego z atrybutów w oparciu o geometrię i topologię obiektów – obszary zabudowane przypadające na 1 m drogi w buforze 100 m

Table 1. The example of reclassification road class (source: Fiedukowicz 2013)
Tab. 1. Przykład reklasyfikacji klas dróg (źródło: Fiedukowicz 2013])

Original attribute	Attribute in interval scale			
	step = 1	normalized, equal steps	normalized, rising steps	normalized, decreasing steps
Interior	1	1	1	1
Other	2	20	5	45
Municipal	3	40	15	70
District	4	60	30	85
Provincial	5	80	55	95
State	6	100	100	100

3.4. Definition of membership functions and fuzzy rules

The main part of the experiment was designing base of fuzzy rules based on previously defined linguistic variables. It demanded definition of both: linguistic variables described in chapter 3.3 as well as decisive attribute (including the linguistic variables describing it).

Definition of linguistic variables is done by assigning them membership function which specifies the range and degree of affiliation to each category (according to the rules of fuzzy logic described in chapter 2). Membership functions can have various character (shape and parameters), which can differ not only between attributes but also between linguistic variables defined for the same attribute (the example of such a situation was presented in Fig. 4), however in the conducted experiment this possibility have not been used. The number of linguistic variables for each of the attributes can also vary. In case of this experiment mostly three fuzzy classes were used while this number of classes is easy to manage and it is relatively easy to create rules based on smaller number of linguistic variables (thanks to this FIS stays more legible).

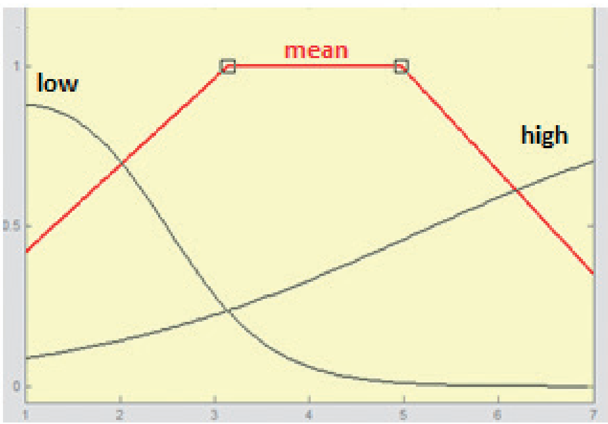

Fig. 4. Different types of membership functions describing three linguistic variables of the same attribute
Rys. 4. Różne rodzaje funkcji przynależności opisujące trzy zmienne lingwistyczne dla tego samego atrybutu

The decisive attribute for the fuzzy reasoning also was also defined at this step. The natural answer, when considering selection operator seems to be yes/no – so the object is or is not selected for current LoD. This approach however has the major disadvantage namely this kind of definition limits the applicability of such a FIS to only one, particular scale/LoD for which the rules are created. Therefore it was decided to use target scale denominator as decisive attribute. Above this scale denominator considered object is not chosen (Fig. 5).

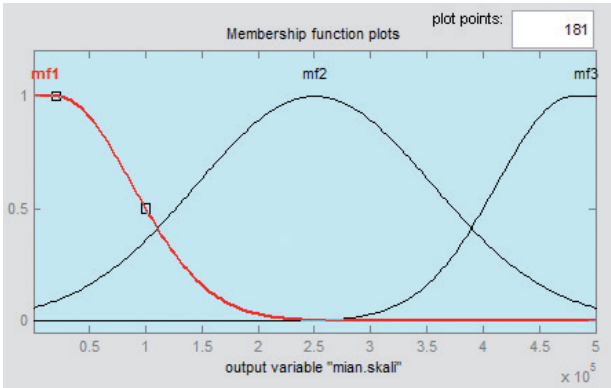

Fig. 5. Decisive attribute in the form of scale denominator above which the object is not selected
Rys. 5. Atrybut decyzyjny w postaci mianownika skali powyżej którego obiekt nie jest wybierany

The output of fuzzy reasoning process has also fuzzy character (it is defined by membership function). As such it demands defuzzification – coming back to the crisp, numeric value (in this case it is the scale denominator). Number of defuzzification methods exist but in this case centroid method was chosen. However it cannot be forgotten that defuzzification method influences the reasoning process (Fig. 6).

3.5. Tests in another area

As the final part of the experiment the rules designed for specific test are were used on another dataset to check results comparability. This step was established to check whether the rules have universal character or

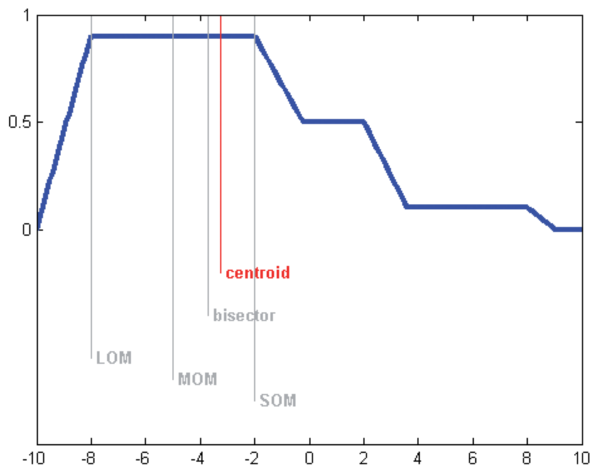

Fig. 6. Various defuzzification strategies and their influence on reasoning process. Red – centroid method used in this research. (source: http://www.mathworks.de/)

Rys. 6. Różne strategie defuzyfikacji i ich wpływ na wynik wnioskowania. Kolor czerwony – metoda centroidu wykorzystania w niniejszym badaniu. (źródło: http://www.mathworks.de/)

need to be adjusted to the character of dataset and terrain for which generalization is done. Originally the rules were created for the mountainous area around Dukla (south-east Poland). The comparison was done for the area around Brzeg Dolny in Lower Silesia region (both are rural areas).

4. Results

FIS'es proposed previously for Dukla region (Fiedukowicz 2013) was now tested also for the other set of data (Brzeg Dolny). For each of the following figures (7–9) A-C is "Dukla" test area, while D–F is "Brzeg Dolny". Comparing the original data (Fig. 7A and D) we can see that the road density in Dukla is higher than in Brzeg Dolny. The roads are also placed more unevenly in this case. However what is not visible here (as only geometry of roads is visualized) there are also differences in road character (i.e. there is no country road in Brzeg Dolny). With the increasing scale denominator less objects are selected within the same fuzzy system (Fig. 7B vs. C and E vs. F). However the results for the new test area seems to be not so promising as for the area for which the rules were design (see especially Fig. 7C and F where for in the second case only short, single road segments left).

Fig. 8 shows how the attributes of the transformation step influence the results of generalization process. All of the cases in figure 8 are presented for the LoD of 1 : 100 000. The only difference is the way of transformation from ordinal into interval scale. Based on this figure one can conclude that the general trend is the same for both test areas: for increasing intervals the number of selected futures is lower than for equal intervals. The higher number of futures is selected when the attributes in interval scale have decreasing intervals. However it has to be highlighted that for all of those attributes higher means better/more important road segment. Situation could be different if some of the high attributes meant lower importance of the road segment. Because of high influence of attributes transformation for generalization results this step should be always considered as one which can help in scalability of the system.

As it is visible in Fig. 9 using only attributes coming from spatial analyses we got either too few (A, D) or too many (B, E) road segments. Much better results were achieved for Dukla test area using FIS which combines these two types of attributes (Fig. 9C). However for the other test area the result is not so good. It does not impair the idea of combining attributes of those two types, it rather shows that different area may demand different parameterization of the process. What is important in case of fuzzy logic it does not have to mean changing all of the rules. Changes in linguistic variables definition may be sufficient in this case.

5. Remarks and future challenges

5.1. Process subjectivity

During the proposed generalization process there is a number of step which allow including the originally subjective character of generalization process.

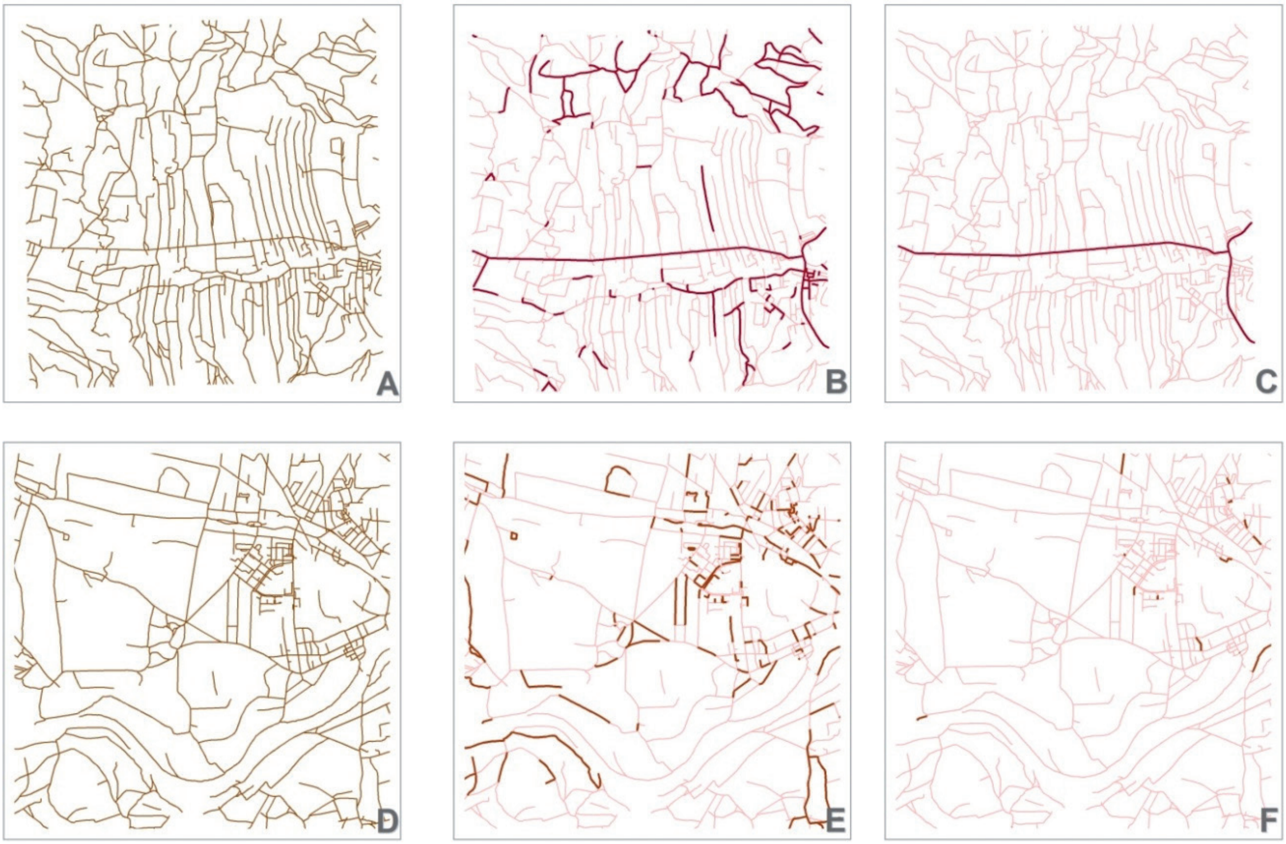

Fig. 7. Test areas: A–C: Dukla, D–F: Brzeg Dolny. A and D are original data, the others are results of FIS selection based only on attributes directly from the database (TBD): B&E – 1 : 100 000 scale, C&F – 1 : 250 000

Rys. 7. Obszary testowe: A–C: Dukla, D–F: Brzeg Dolny. A i D – dane oryginalne, pozostałe – wynik selekcji opartej o wnioskowanie rozmyte bazującej wyłącznie na atrybutach pochodzących z bazy danych (TBD): B&E – skala 1 : 100 000, C&F – 1 : 250 000

Among which we can point:

- attributes transposition from ordinal into interval scale,
- choosing attributes which are calculated out from the spatial analysis,
- choosing the set of attributes used in the rules,
- linguistic variable definition,
- creation of fuzzy rules,
- generalization process evaluation.

Those steps allow better reflection of subjective character of generalization process. They allow process adjustment to the specific condition. It is possible that for different areas not whole the interference system has to be changed but for example only the linguistic variables definitions. The strong point in using fuzzy logic is the mathematical formalism behind it. However so many subjective steps within the process make it difficult to manage and scale. Therefore it may appear that instead of scale denominator some other (more sophisticated) decisive attribute can be used.

5.2. Support in FIS designing

Due to the subjective character of the generalization process the number of decision has to be taken while designing fuzzy interference system (as it was described

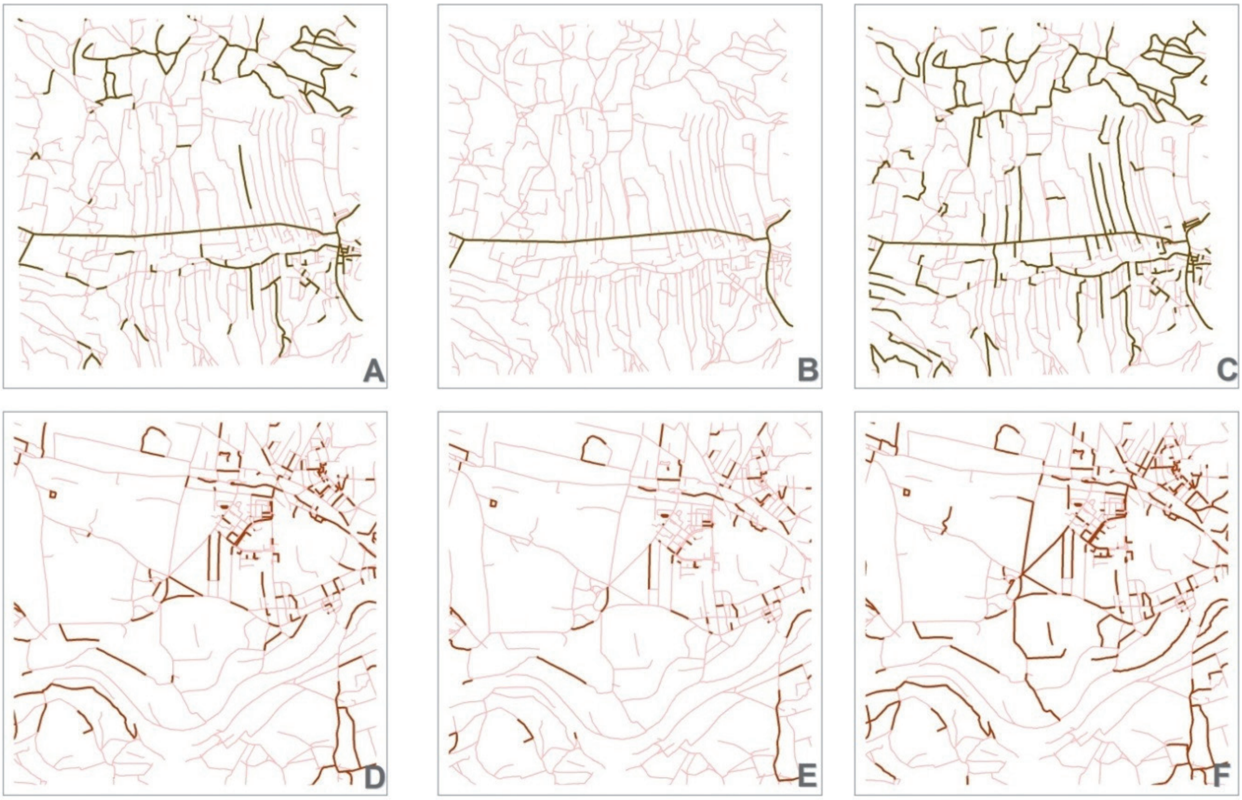

Fig. 8. Test areas: A–C: Dukla, D–F: Brzeg Dolny. All of the results are based on the same FIS as in figure 7, all are at the LoD 1 : 100 000. They differ by attributes reclassification: A&D – equal intervals between attributes values, B&E – increasing intervals, C&F – decreasing intervals

Rys. 8. Obszary testowe: A–C: Dukla, D–F: Brzeg Dolny. Wszystkie wyniki oparte o ten sam FIS co na ryc. 7, wszystkie na poziomie szczegółowości 1 : 100 000. Różnią się tylko sposobem reklasyfikacji: A&D – równe interwały między wartościami atrybutów, B&E – rosnące interwały, C&F – malejące interwały

above – 5.1). Some of those decisions may be difficult to take even by an expert. Therefore it may be desirable for the system's designer to have a support at some steps.

One of such a examples is selection of attributes which act in the FIS. Among many attributes both from databases as well as from the spatial analysis it is difficult to choose (only using expert knowledge) few that have significant impact into generalization process. Therefore the rough sets theory may be utilized by looking for reductions, leaving only attributes significant for the final decision. This approach can be realized using free software like RSES [http://logic.mimuw.edu.pl/~rses/] and will be tested in author's further research and published in individual article.

The other possibility is to use data mining (DM) techniques to support fuzzy rule designing. However DM software looks for the crisp rules from the data, such information may become a tip for designing fuzzy rules. This assumption also needs further test which will be conducted using free software like Weka.

5.3. Keeping roads connectivity

One of the most important challenges during roads generalization is to keep the connectivity between road segments. In case of this research this step was neglected as the research was concentrated mainly on creation of

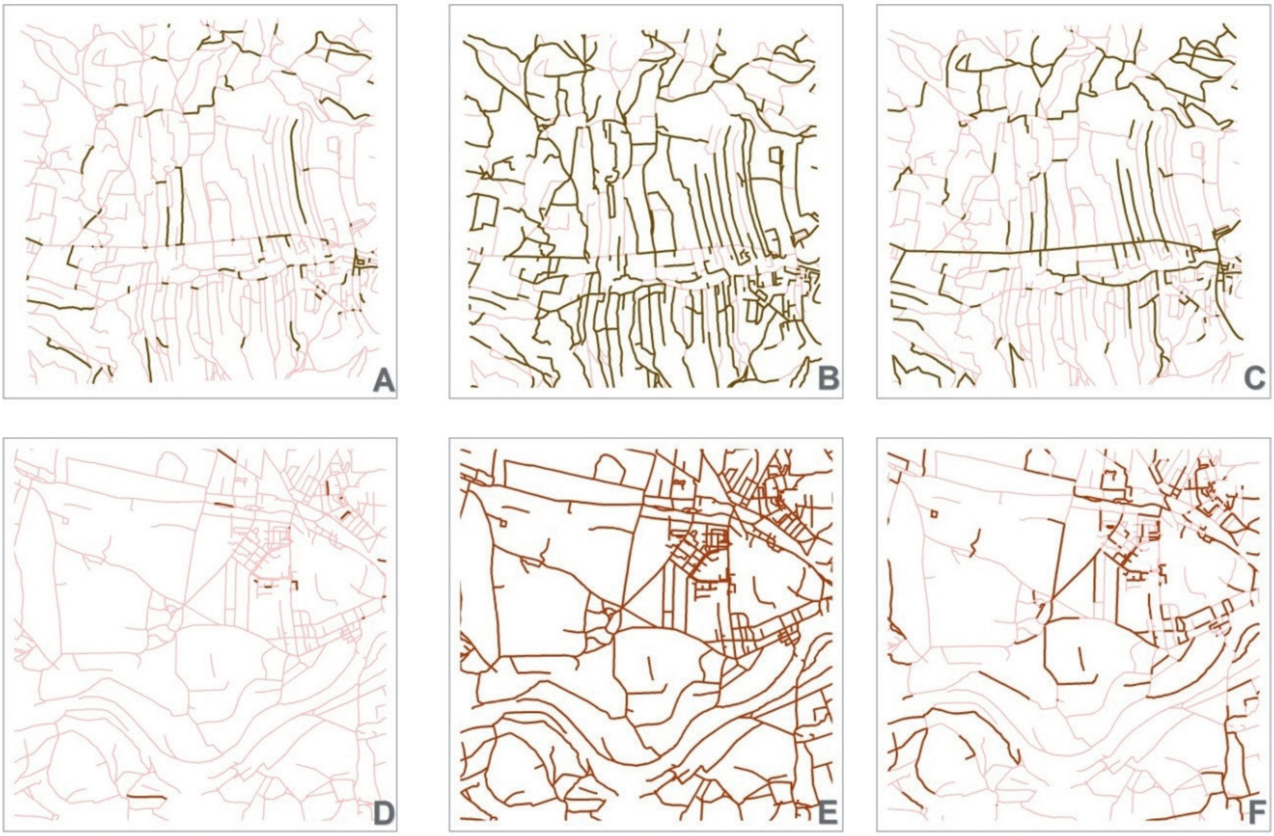

Fig. 9. Test areas: A–C: Dukla, D–F: Brzeg Dolny. A&D, B&E – results for FISes based only on geometric information, C&F – FIS based on both types of attributes: coming from database and from spatial analysis

Rys. 9. Test areas: A–C: Dukla, D–F: Brzeg Dolny. A&D, B&E – results for FISes based only on geometric information, C&F – FIS based on both types of attributes: coming from database and from spatial analysis

fuzzy interference system. However within further research this problem needs to be solved. It can be done for example by the application of approach presented by Chaudhry and Mackaness (2005) which allows preserving connectivity. Undoubtedly the first step for keeping connectivity between road segments is their junction into roads which can be generalized as a whole. Such an approach is closer to the Weibel's idea of generalization which establishes thinking about the real world object behind the geometrical representation, which is to be generalized. In this context the road segments which make artificial formations coming out of the database structure, does not respond the real world objects and should not be directly generalized.

5.4. Adjustment to different region

As it was shown during the experiment, the results were coming from FIS for another test area then the one for each it was designed are not as good as the previous ones. It can be the result of different character of data (i.e. there is no country road in Brzeg Dolny test area) but its origin can be also more technical. As the FIS was designed for the specific set of data with known range of attributes the linguistic variables were defined basing on that information. When FIS was applied to the new set of data with different attributes range the problem could appear when the new range of attributes was wider than the original one. This could influence the generalization results. To check this assumption linguistic variables should be defined once more for the new test area (while fuzzy rules may stay the same). The following research will be obtained by author to solve the problem described above.

5.5. Results evaluation

The evaluation of the results was done only by visual rating. This kind of evaluation is very useful in the initial step of the research – it allows seeing general trends. However the further research will need more objective methods to judge their usefulness. Those can be for example comparison with the maps and databases of lower LoD, graph analysis, consultation with the expert in certain area (like the road experts) as well as some statistical tools. The evaluation of generalization process however stays still unsolved problem and it is very difficult to find the judgment methods which is objective (numeric) and, at the same time, includes the spatial aspect of generalized data (Mackannes, Ruas 2007, Olszewski, Fiedukowicz 2011).

6. Conclusions

The research shows that the non-classical (in this case fuzzy) logics are useful for geographic information generalization and mimic the original subjectivity of generalization process. However the methodology presented above needs some methodological improvements (as described in section 5), it may be developed and utilized in spatial data generalization.

Because of the initial step of the research some part of work was done manually however this methodology can be easily upgraded by proper programming which will provide automation of the linkages between different software used within the process.

At current stage there is a high potential for additional research in this field covering especially the possibility of usage of rough sets (and reduce concept) in attribute selection as well as the problem of attribute transformation. Minor problems like missing values are not very often in the test data however it should be also considered for the future.

The obtained research makes one of the initial steps in designing the knowledge base for generalization of geographic information based on non-classical (fuzzy and rough) logic. The following steps will include other types of spatial objects as well as test areas of various character. The final goal is to provide the base of knowledge by which one can manage the subsequent steps of generalization process.

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PUBLIC GEOSPATIAL DATA SOURCES

Key words:

geographical data, cartography, GIS

Abstract

In recent years there has been tremendous progress in the field of software for managing geographic information (GIS – Geographic Information System). Data processing capabilities expand with every new version of GIS applications. Similarly, the processing power of computers to process and manage geographic data. Once we have got such a powerful tool, the question arises: where to get the relevant data from? There are many sources of data (public, paid for), but after closer examination it turns out that they are mostly processed data from other sources. In this article I will present the primary source of data that can be used to suit one's needs. All of these data are publicly available.

OGÓLNODOSTĘPNE ŹRÓDŁA DANYCH GEOGRAFICZNYCH

Słowa kluczowe:

dane geograficzne, kartografia, GIS

Abstrakt

W ostatnich latach w dziedzinie programów do zarządzania informacjami geograficznymi (GIS – Geographic Information System) dokonał się olbrzymi postęp. Możliwości przetwarzania danych poszerzają się z każdą nową wersją aplikacji GIS. Podobnie z mocą obliczeniową komputerów, które przetwarzają i zarządzają danymi geograficznymi. Gdy już mamy do dyspozycji tak potężne narzędzia, nasuwa się pytanie: skąd wziąć odpowiednie dane? Istnieje wiele źródeł danych (ogólnodostępnych, płatnych), jednak po głębszej analizie okazuje się, że są to głównie dane przetworzone z innych źródeł. W niniejszym artykule przedstawione zostaną pierwotne źródła danych, które można wykorzystać do własnych potrzeb. Wszystkie opisane dane są ogólnie dostępne.

1. Introduction

Recently, the access to digital geographic data has improved. Different types of geographic data are available on the Internet. For the most part the data are made available free of charge. Unfortunately, there are many available geographic data, sometimes they come from a single source.

This paper will present several types of data, indicating the source. Having data source it is possible to use

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them for making maps. Unfortunately, so far there has been no single consistent format for digital geographic data. Therefore, to allow the processing and the presentation of data it is necessary to know the tools for this purpose. This paper will also describe selected computer programs for processing and presentation of digital geographic data.

At the end of this paper, the comparison of the accuracy and relevance of geographic data from public and free sources will be presented.

2. GIS Applications

Geographic Information Systems (GIS) developed as a tool for quick access to maps and their easy creation, processing and presentation [27]. Currently on the market of geographic information management (GIS) software, there are many items, both commercial (paid) and Open Source solutions. Most programs give the possibility of processing, analysis, presentation and creation of geographic data sets on various subjects. The most popular and most common among users is the ArcGIS system provided by ESRI. This system consists of a set of programs to work with geographic data. It is a commercial solution, and the only free application is ArcReader, which allows only the presentation of maps created with the ArcGIS system.

Another popular GIS is GRASS (Geographic Resources Analysis Support System) [3]. This solution is free of open source character licensed under the GPL (General Public License). The unquestionable advantage of the system (apart from the lack of charges for its use) is a full view of the application source code and documentation [17]. In conjunction with the modularity of software you can create new modules of processing, presentation and data creation. Following changes in the number of modules in GRASS, we can observe more and more perfect solutions for use in almost every field of geoinformatics broadly defined [15].

GRASS is a very complex system, and also requires a broad knowledge of computer science. A simpler application – also free – is QuantumGIS [6]. The main difference between them is that QuantumGIS is not modular. It allows you to present and manipulate geographic data. But it does not have such a comprehensive set of tools as GRASS. However, there is the possibility of combining the QuantumGIS application interface with GRASS modules.

These systems are not unique; there are many applications for managing geographic data. However, special attention should be paid to the format of geographic data processing. GRASS, QuantumGIS and ArcGIS (version from 9.2) use a consistent library called GDAL (Geospatial Data Abstraction Library) [4] used for reading and writing geospatial data. This library supports approximately 130 data formats in a form of raster and about 70 data formats in a form of vector. It should be noted that originally the GDAL library supported only raster formats. Currently GDAL contains also OGR library (OpenGIS Simple Features Reference Implementation) and they are jointly designated as the GDAL / OGR set of libraries. Formally, however, OGR libraries are not compatible with the OpenGIS standard – yet the name has remained. Overall, the GDAL / OGR library uses about 80 programs for the management of geographic information (GIS). The GDAL / OGR library is available under an Open Source license.

These GIS systems can process a variety of data, but do not have a coherent geographical database. However, there are programs with their own geographical databases. One of them is free DIVA-GIS [2]. On the website of the DIVA-GIS project the following information is provided:

For the individual countries of the world:

- the administrative division,
- inland waters,
- the network of roads,
- the railway network,
- the elevation map,
- a map of land cover,
- the demographic map;

Global data:

- the administrative map of the world,
- climate data from the years 1950-2000 (among others. temperature, precipitation)
- the data on the occurrence of animal species,
- the data on the distribution of agricultural crops,
- the elevation data (90m resolution),
- Landsat satellite images from the years 1990 to 2000.

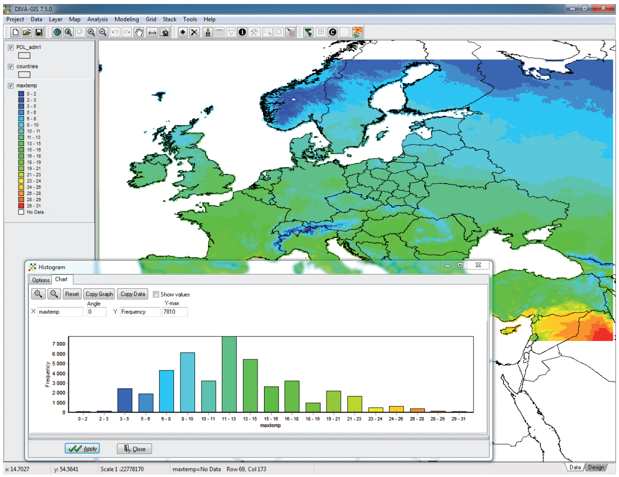

Fig. 1. Presentation of maximum annual average temperatures in the Diva-GIS program
Rys. 1. Prezentacja w programie Diva-GIS maksymalnych średniorocznych temperatur

Data from the DIVA-GIS can be used for any purpose. In addition, the DIVA-GIS data format is compatible with GDAL / OGR libraries. The accuracy of geographic data from a global or even national perspective is sufficient for the presentation of maps at the macro level (including the selected country).

Apart from global GIS systems, there are also regional solutions. For example, in Poland there are specialized systems, such as MICARIS (Cartography Mine Information System) for mining mapping [13], allowing you to easily search for archival maps for mining, or IKAR (Geoportal National Geographic Institute) [13].

3. Geographical data

3.1. Global data

Geographical information has been available on the Internet for each user recently. Initially, they were simple satellite images and road maps. For some time, however, we have got access to a range of thematic geographic data of varying accuracy. The most recent, and also the most comprehensive global data set is EarthExplorer system [25]. It was developed by the USGS (United States Geological Survey).

Among others, the following data are available through the EarthExplorer system:

- aerial photographs (some areas),
- radiation images of the Earth taken from space by AVHRR (Advanced Very High Resolution Radiometer) instruments,
- elevation data, including ASTER [21], SRTM [20], GTOPO30 and GMTED2010,
- images from satellite EO-1 (Earth Observing 1 launched in 2000):
  – by ALI – Advanced Land Imager – multispectral image,
  – by Hyperion – images of radiation in the range of 0.357 to 2.576 microns,
- Landsat satellite images:
  – the Landsat 1–5 since 1972 (for selected areas)
  – the Landsat 7 ETM + (Enhanced Thematic Mapper Plus) – from 1999 to the present day (planned launch of the next Landsat 8 satellite in 2013),
- LIDAR (Light Detection and Ranging) data showing the state of the atmosphere – the data available mainly for areas of the U.S.,
- images from the MODIS sensor (Moderate Resolution Imaging Spectroradiometer) operating in the wavelength range from 0.46 to 14.39 microns placed on the Terra and Aqua satellites,
- images with a resolution of 1 meter from the OrbView-3 satellite launched in 2003 by GeoEye.

These data sets are available through the EarthExplorer website. Most of the data is also available for the Polish territory. The data available in the EarthExplorer system are treated as source data.

The EarthExplorer system interface is based on the backing map made available by Google. It is based on the so-called Google API (Application Programming Interface). Interestingly, Google maps use the parts of the data obtained by OrbView-3. Describing the areas of geographic data sources, the popular Google Earth application should be mentioned. [10] This program provides a map of the road network and aerial / satellite all over the world, as well as SRTM elevation data. Map browsing is possible via two interfaces: the web-browser interface (known as Google Maps) and a separate program called Google Earth. The data in these applications

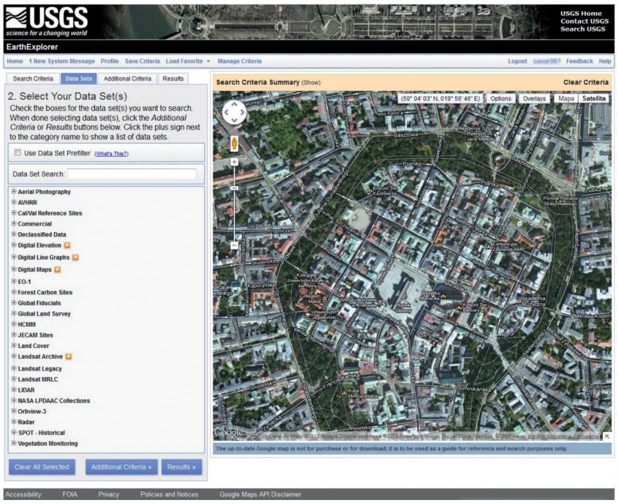

Fig. 2. USGS EarthExplorer system
Rys. 2. System USGS EarthExplorer

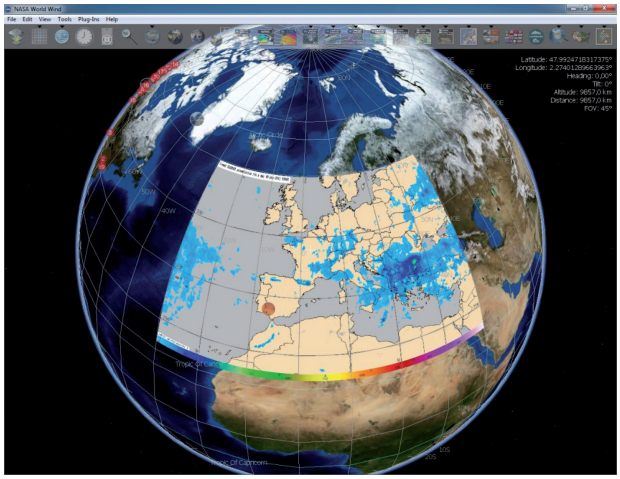

Fig. 3. The WorldWind program interface with the presentation of precipitation data
Rys. 3. Interfejs programu WorldWind z prezentacją danych opadowych

are the same – they differ as to their functionality. For example, the Google Earth application allows for the presentation of geographical data in a three-dimensional view and the StreetView service presents environment pictures from ground level. Google Earth is based on the 3D EarthViewer program created by Keyhole, Inc. The company was taken over by Google in 2004, and in 2005 the first version of the program for viewing geographic data came out.

It should be noted that the Google data are for information only, as any commercial use is not permitted. It is made possible, however, by using the paid version of the program called Google Earth Pro.

Another non-commercial application for geographic data presentation is WorldWind developed by NASA (National Aeronautics and Space Administration) [22]. WorldWind presents not only the geographical data in the form of satellite and aerial imagery in the band of visible light. Data available by this application include also pictures from Landsat 7, global weather data, data on natural phenomena (earthquakes, volcanic eruptions), images from the MODIS sensor, and SRTM elevation data for topographic maps of selected areas (mainly the U.S.). The resolution of basic data (pictures of the land) is approximately 15 m. As to the use of data from the WorldWind application, there is no limit to modify and use even for commercial purposes.

Apart from the data sources in the form of satellite imagery and simple road maps there are also topographically accurate maps available on the Internet. An example of a global topographic map available free of charge is OpenStreetMap [5]. This application has the ability to view maps and export selected areas. The OpenStreetMap data are in the form of vectors that can be saved in XML (Extensible Markup Language). Maps in this application are created and verified by the users of the system. Accuracy coverage dependence area ranges from 60% to 89% [12]. The data in OpenStreetMap are licensed through the Open Database License. It truth be told, this is not a legal form of data sharing, but in the description of its creators there are statements regarding the possibility of any modification or duplication of data from the sources indicated.

The above-mentioned data sources are not the only ones available on the Internet. There are many others, but their usefulness may be limited. Most sources have no possibility to save data, and there are restrictions on their use in accordance with law. An example of this may be solutions from Yahoo (Yahoo Maps site designer [28]) and Microsoft (Bing Maps service [19]). These applications allow you only to view the data, yet they have the basic qualities of maps – cognitive values, which, as

Fig. 4. Planty (Krakow green belt around the Old City Center) by OpenStreetMap
Rys. 4. Planty według OpenStreetMap

noted by [9] constitute the priority value in the entire development of cartography.

For other services, such as Wikimapia [8], the access to data is unlimited. But the service is based on Google's backing data to the map and there is no option to export data. You can view and edit, as this service is available under Open Source.

3.2. Data for the Polish national coverage

The majority of data sources Indicated in the previous section also provide geographical data for the Polish territory. This does not mean, however, that there are no data sources exclusively for the area of our country. Well, there are geographic data on various topics related only to Polish territory available on the Internet. However, as stated in [24] many spatial databases were created ad hoc to meet current needs. The solution to this problem is to implement the provisions of the EU INSPIRE Directive and the Polish Law on spatial information infrastructure.

The most powerful web portal presenting free geographic data is Geoportal [11]. It has its counterparts in other European countries, but a cursory analysis shows that in Poland the database is the most comprehensive. The data provided in the Geoportal are as follows:

- data from the National Institute of Gegraphical Names (cities, towns, rivers, etc.)
- data from the National Register of Borders (range of provinces, counties, municipalities, along with the names)
- cadastral data on the numbers of plots and houses together with the cadastral,
- digital terrain model,
- vector topographic map form General Geographic Database,
- vector topographic map VMap L2,
- data from the Database of Topographic Objects,
- satellite and aerial orthophotomaps,
- raster topographic maps as scanned paper maps.

Geoportal web pages, through the Documentation Centre of Geodesy and Cartography, provide also indexes of maps available in digital form. They are not available on the Internet.

Free use of Geoportal data is limited only to viewing the data. You cannot export data or process them, or use for any purpose other than demonstration.

Fig. 5. Orthophotomap together with the data from the Database of Topographic Objects displayed on the Geoportal web page
Rys. 5. Ortofotomapa wraz z danymi z Bazy Danych Obiektów Topograficznych prezentowane w serwisie Geoportal

Geoportal is a nationwide service which displays data for the whole country. However, individual regions and even cities (eg, Krakow, Katowice) have their own Geographical Information Systems. This article will present the data available on the website of the Lesser Poland Spatial Data Infrastructure (Małopolska Infrastruktura Informacji Przestrzennej) [26]. The service user can view the following data:

- topographic in vector form,
- topographic in raster form,
- as an orthophotomap raster (picture date is given for the year 2009, with the ability to browse older maps),
- the terrain profile,
- boundaries of buildings in vector form,
- environmental air conditions (Air Protection Program)
- relating to a property belonging to the province (voivodeship),
- buildings and monuments
- Special Economic Zones,
- sources of electromagnetic radiation (mainly mobile phone base stations),
- thematic routes,
- the location of hospitals,
- waste management,
- bike trails,
- form the Database of Topographic Objects,
- Nature of Landscape Parks Complex base of the Lesser Poland (Małopolska) Region,
- the emission of pollutants,
- acoustic for provincial roads,
- sozological (Raster, 1 : 50 000),
- hydrographic (Raster, 1 : 50 000).

In addition the following data are available for the city of Krakow:

- in the form of vector geodesic maps of the City Council of Krakow,
- the structure of land ownership.

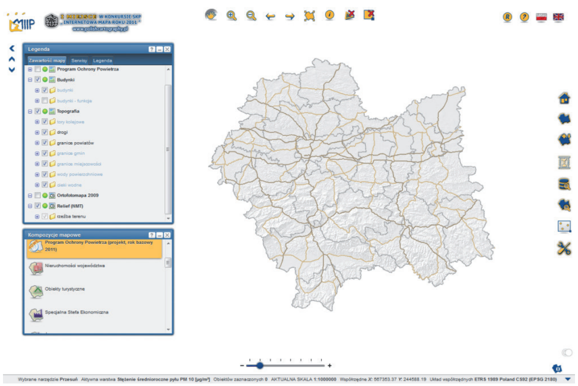

Fig. 6. Lesser Poland Spatial Data Infrastructure
Rys. 6. Małopolska Infrastruktura Informacji Przestrzennej

Similarly to Geoportal, the application for the presentation of geographical data does not have the possibility to save the selected data. Also, it is impossible to reproduce, modify and publish the data. In summary, these applications are designed just to show a number of geographic data.

However, there are data sources that can be freely used. The Polish source of vector geographic data primarily related to the communication network is the UMP pcPL project (Supplementary Polish Map – almost all of Poland) [7]. Originally this project was to create vector maps for Garmin GPS receivers. Currently, they operate on most commercially available GPS receivers. Moreover, you can freely modify the maps and their further dissemination and use is allowed. It should be noted that the accuracy of the maps – especially in urban areas – is not worse, and sometimes even better than in the solutions of OpenStreetMap. Maps of the UMP website are made available under the Creative Commons license.

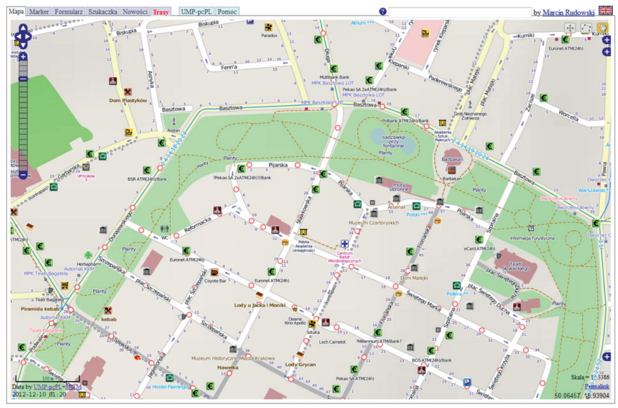

Fig. 7. Krakow Main Market Square area presented using a UMP map
Rys. 7. Okolice krakowskiego Rynku Głównego przedstawione przy użyciu map UMP

The last notable source of free geographic data is historical maps of the Military Geographical Institute (Wojskowy Instytut Geograficzny). [1] There are topographical maps in raster form scanned from the original paper maps. Maps were released in the 1920's and 1930's. The collection includes maps of the area of II. Republic of Poland at scales from 1 : 750 000 even to 1 : 5 000 Most available are maps at the scales of

1 : 25 000, 1 : 100 000 and 1 : 300 000. Most of the maps are available at resolutions of 400 dpi and 600 dpi. Unfortunately, they do not have a have a raster reference system. However, they are available for free and can be modified, and shared with the source of origin provided. The maps are intended solely for non-commercial use.

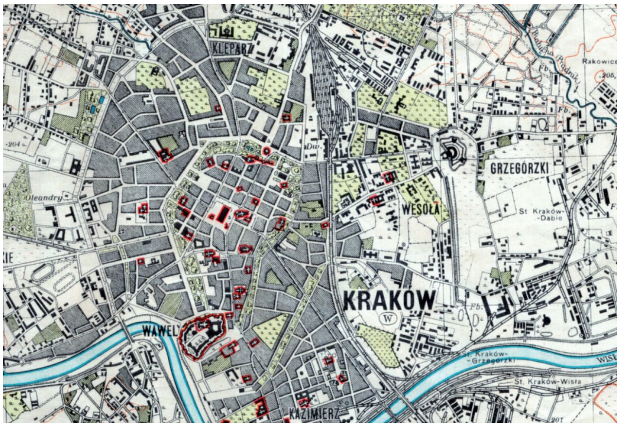

Fig. 8. Fragment of a WIG map of the city and area of Krakow in 1936

Rys. 8. Fragment Mapy WIG Krakowa i okolic z roku 1936

4. Comparison and use of data

4.1. Comparison of data

Due to the wide use of free geographic data, their accuracy is an important matter. This paper compares the vector data of communication network and elevation data of various models.

In order to compare of the vector data, three sources were selected: data on topography of the Lesser Poland Infrastructure for Spatial Information site, data from OpenStreetMap and a UMP map. The comparison was made in two areas with different degrees of density of the communication network: the city center and around the locality of Lubień in the district of Myślenice.

Comparing the data for urban areas on the example of Krakow (Fig. 9) in the QuantumGIS program one can observe a roughly good coverage of the network. As for the accuracy of the placement of the communication network junctions there is no difference greater than a few feet (8 m) shift in relation to the topographic map. The shift is calculated from the center of the communication route of the reference map. The topographic map is treated as reference data. All figures are in the same frame of reference, namely the WGS84.

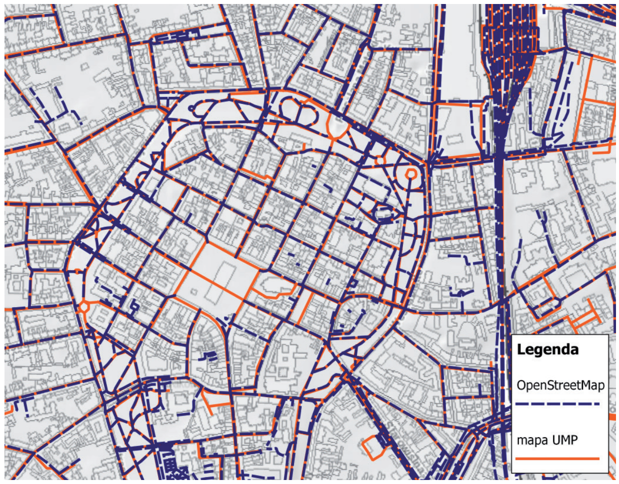

Fig. 9. Comparison of OpenStreetMap and UMP data on a base topographic map MIIP of the Kraków Main Market Square area.

Rys. 9. Porównanie danych OpenStreetMap oraz UMP na podkładzie mapy topograficznej MIIP okolic Rynku Głównego w Krakowie

Larger differences can be observed in less populated areas, such as the locality of Lubień (Figure 10). Here OpenStreetMap project falls slightly better compared to the UMP. However, both the first and the second sets of data show some shifts of up 20 m. It may be due to inaccurate positioning of commercially available GPS receivers. Both OpenStreetMap and UMP mapmakers use the traces recorded with such receivers. It should be noted that the main routes (such as S7 road functioning as a bypass of Lubień) are marked in an accurate way (local shift around 4 to 5 m).

Generally, it can be said that the public (and usable) data in vector format are reliable and accurate particularly in urban areas. This is confirmed by the author's experience in this matter.

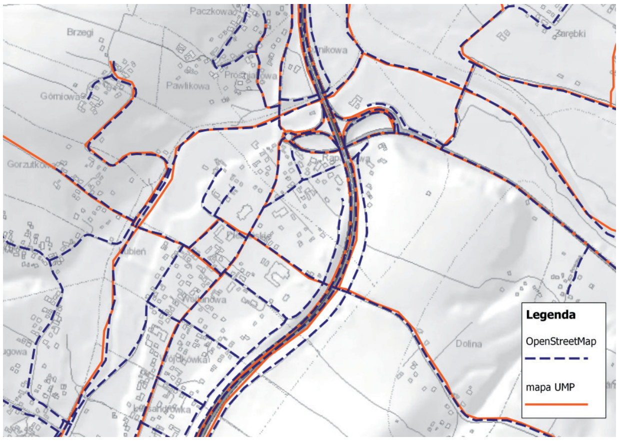

Fig. 10. Comparison of OpenStreetMap and UMP data on a base topographic map MIIP of the area Lubień

Rys. 10. Porównanie danych OpenStreetMap oraz UMP na podkładzie mapy topograficznej MIIP okolic miejscowości Lubień

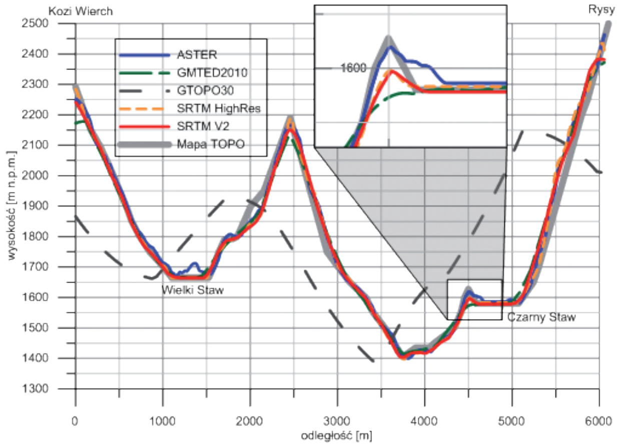

Fig. 11. Comparison of elevation profiles from different data sources

Rys. 11. Porównanie profili wysokościowych z różnych źródeł danych

To compare raster data, or more precisely elevation data, five different sources were carefully selected. The comparison was made on the example of the extended elevation profile between Kozi Wierch and Rysy in the Tatra Mountains. An elevation profile based on topographic map available on the Lesser Poland Infrastructure for Spatial Information site was treated as reference data. Data from elevation models ASTER, SRTM, GTOPO30 and GMTED2010 were compared. These data were obtained by the EarthExplorer application. As indicated in the elevation profile (Fig. 11), GTOPO30 topographic data model most visibly departs from the reference. It was developed before 1996, and the data resolution is about 1 km. Therefore, the difference between the elevation points not necessarily arises from errors of the model itself, but also because of the resolution. GTOPO30 model was developed based on existing elevation models, where the land surface mapping was not always accurate.

Other data better describe the elevation profile. It is worth noting that there are several versions of SRTM model. The first is no longer published, and the other was revised on the basis of the existing elevation data. Therefore, in areas where there are reservoirs (Wieli Staw and Czarny Staw) a flat water surface is observed. The third version of the SRTM data has an increased resolution (3-arc second to one) based on the map data of specific areas of interest. As can be seen, there is no significant difference between the SRTM V2 (Version 2) data and SRTM HighRes (version 3) data. ASTER data, which is a formal successor to the SRTM, are more accurate, due to the use of improved methods of data acquisition. Besides, ASTER data are collected continuously, in contrast to SRTM data, which were collected during one space shuttle mission in 2000. ASTER has been collecting data from 2000 to the present day, and the first version of the data was made available after the processing in 2009. Currently available data are the second version. Recent data source is GMTED2010 (Global Multi-resolution Terrain Elevation Data 2010) published in 2011. They are available in three resolutions: 30, 15 and 7.5 arc seconds. The comparison uses the highest resolution.

4.2. Use of data

Free public data may be used for different purposes, provided that they are not limited to the conditions contained in the license. Most of the data presented in this article can be used for private purposes and research, and can be exported to any digital format.

Publicly available geographic data are used, among others, in hydrology, where the catchment area of the stream can be determined with just a digital terrain model (DEM) [16]. In addition, these data serve as a parameter of hydrological input models based on physical phenomena [18]. Another input parameter is e.g. land cover data derived from images taken using Landsat. In [18] only data available from public sources were used. The results were comparable with commercial solutions designed exclusively for hydrological purposes.

Another use of the data from the sources described is for creating map bases for thematic maps. In particular, the popular elevation data are used for example in car navigation programs. Also OpenStreetMap map and UMP is used to develop navigation systems [14].

Also, data of a limited access (viewing only) are used for instance by surveyors – mainly for map surveying (e.g. geodetic map of the City Council of Krakow) and geodetic, gravimetric and magnetic matrices from the Center for Documentation of Geodesy and Cartography.

In addition, there are many other applications strictly dependent on research conducted on maps, or for the presentation of results of studies.

References

On the Internet there are many sources of geographic data. Some of them duplicate the others, but knowing the direct source of data one can create a large database of free data. Depending on the research we obtain different data. Maps based on them are more accurate, since most of the sources are reliable. As pointed out in the article [23], important information about the accuracy of the map is mostly its author. Therefore, any geographic information should be documented as to its origin.

This paper presents only a fragment of the whole area of free geographic data on public-access. As has been shown, the data are reliable and have high accuracy. Yet, using free data one should be careful. Some of them may be credible, some not. Sometimes it is worth investing some money in verified maps. It is recommended to make sure if the data are free by definition, and if they come from reliable sources.

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INFLUENCE OF SEISMIC WAVE FREQUENCY ON THE QUALITY OF THE LANDSLIDE SURFACE EXPLORATION IN THE LIGHT OF NUMERICAL MODELING

Key words:

numerical modeling, seismic refraction, frequency of seismic wave, resolution of seismic recognition, landslide surface, Carpathian flysch

Abstract

The paper summarizes results of numerical analysis of source frequency influence on the quality of seismic recognition of the landslide failure surface. Numerical simulation was carried out for the seismic refraction method in two-dimensional model of landslide. The analyzed model was constructed on the basis of geological engineering model of typical landslide conditions in the Carpathian flysch located in the Mucharz village area.

Numerical analysis allowed us to obtain the optimal frequency for recognition of surface failure location. It was shown that frequency above 50 Hz is the most promising in measurements conditions. It was proved that seismic measurements allowed us to get more adequate results in detecting discontinuity borders in comparison with theoretical resolution. Numerical computations were realized by finite difference method using FLAC 5.0 software and their interpretations using Plotrefa software.

WPŁYW CZĘSTOTLIWOŚCI FALI SEJSMICZNEJ NA JAKOŚĆ ROZPOZNANIA POWIERZCHNI POŚLIZGU OSUWISKA W ŚWIETLE SYMULACJI NUMERYCZNEJ

Słowa kluczowe:

obliczenia numeryczne, fala refrakcyjna, częstotliwość fali sejsmicznej, powierzchnia poślizgu osuwiska, flisz karpacki

Abstrakt

W artykule przedstawiono wyniki numerycznej analizy wpływu częstotliwości fali sejsmicznej na dokładność sejsmicznego rozpoznania powierzchni poślizgu osuwiska. W tym celu opracowano metodykę numerycznej symulacji sejsmicznych pomiarów refrakcyjnych. Metodykę tą zweryfikowano dla budowy i właściwości osuwiska w miejscowości Mucharz w Karpatach fliszowych. Analiza numeryczna pozwoliła na ustalenie optymalnej częstotliwości dla uzyskania możliwie dobrego rozpoznania położenia powierzchni poślizgu osuwiska w przyjętych warunkach geologiczno-inżynier-

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skich. Wykazano, że najkorzystniejsze są częstotliwości powyżej 50 Hz w analizowanym zakresie do 120 Hz. Pokazano, że pomiary sejsmiczne pozwalają na dokładniejsze wyznaczenie granic nieciągłości, niż to wynika z teoretycznej rozdzielczości. Obliczenia numeryczne sejsmogramów wykonano programem FLAC w wersji 5.0 (prod. Itasca, USA), a ich interpretację programem Plotrefa (prod. Geometrix, USA).

1. Introduction

The seismic method is often used in the course of identifying landslide surface discontinuities (Bestyński and Trojan 1975, Ślusarczyk 2001, Dziewański and Pilecki Z. 2002, Kirsch 2006, Marcak and Pilecki, Z. 2003, Popiołek et al. 2008). Depending on the measurement conditions, the usefulness of this method is varied. In general, for Carpathian flysch, which is predisposed to the occurrence of landslides, the refraction profiling technique is applied.

In the Carpathian flysch formations there are specific conditions for the formation of landslides associated with the construction and properties of the layers, often involving water. Discontinuity planes are formed and the medium layers are moved along these planes. Frequently, the planes separate the medium layers of clearly different elastic properties, such as watered eluvia from less weathered bedrock. Such planes can be determined by the seismic method. Figure 1 shows a general scheme of how to recognize the limits of discontinuity in a landslide in flysch formations using the seismic refraction method.

An important element of the quality of the recognition is the frequency of seismic waves. The higher this frequency, the greater is the resolution of the recognition. The resolution in terms of the calculations carried out under this work should be understood as the accuracy of the recognition of the landslide surface position in the seismic profile. In general, the resolution of the seismic waves means the ability of a seismic wave to recognize the position of the borders of a layer of a particular thickness (Kirsch 2006). If the thickness is less than ¼ the length of the wave, then such a layer is "invisible" to this wave.

An interesting tool that can analyze such issues is the numerical modeling. The paper presents an example of numerical simulation of seismic refraction measurements for typical landslides in flysch formations located

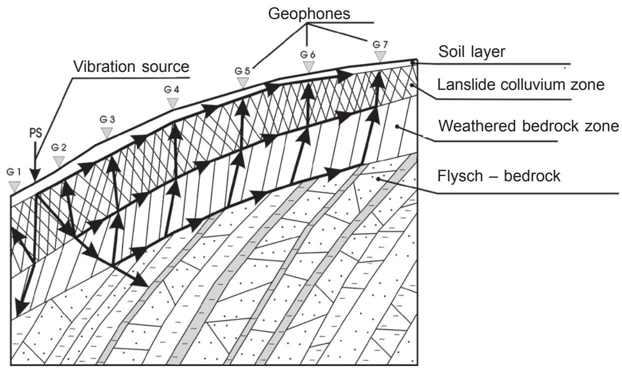

Fig. 1. General pattern for the recognition of the slip surface with the use of the refraction method (Marcak and Pilecki 2003)

Rys. 1. Ogólny schemat rozpoznania powierzchni poślizgu metodą refrakcyjną (Marcak i Pilecki 2003)

in Mucharz near Wadowice. Numerical simulation was performed using FLAC 2D ver. 5.0 (Flac 2007) based on the method of finite differences. The interpretation of the seismograms in simulated geophone points were carried out with the application of Plotrefa, the software produced by Geometrix, USA. The paper is a part of a broader study carried out by the author in the diploma thesis (Pilecki R. 2008).

2. Selected theoretical issues related to the impact of refractive seismic wave frequency on the resolution of landslide surface recognition

The frequency of seismic waves is an important part in the recognition of borders of discontinuities in seismic examinations. As a result of the application of a particular wave frequency, a particular resolution of seismic borders recognition is obtained. The issue of the resolution of the recognition of the medium structure using wave methods was addressed in the work by Sheriff and Geldart (1995), Hagedoorn and Diephuis (2001), Kirsch (2006) and Popiołek et al. (2008).

The wave recorded at the receiver in the refraction profiling scheme is the result of the transition, not only along the radius from the source wave, but also from the medium directly immediately surrounding this radius (Fig. 2.1a). This results from the Huygens principle concerning wave propagation in an inhomogeneous medium. The medium subject to wave propagation from the source to the receiver is called Fresnel zone (Figure 2.1b).

It is assumed that the surface of the Fresnel zone is the envelope of all possible radii of wave propagation between the source and the receiver, along which the wave transit time is delayed by no more than half the period of the fastest wave. The radius of the Fresnel zone as a measure of the resolution of seismic borders recognition has a practical significance. Signals coming from such borders located at a distance less than the radius of Fresnel zone interfere with each other, thus they cannot be distinguished. Formulating this problem in other words – signals from neighboring borders can be distinguished if the minimum distance between these borders is greater than the radius of the Fresnel zone (Hagedoorn and Diephuis 2001).

In the case of refraction profiling method, you can define the horizontal and vertical resolution. It is assumed that the two borders in the geological medium are recognized in the vertical direction, if the distance between them is greater than one fourth the length of the seismic method (Figure 2.2). In practice, the dominant frequency is assumed to calculate the wavelength. Rafaelsen (2006) reports that the actual resolution may be more favorable and may even be $\lambda/32$.

In the case of refraction wave propagating along the border between the layers in a two-layer medium, Fresnel zone radius r_F^{refr} is (Kirsch 2006):

$$r_F^{refr} = \frac{[v_1 \cdot T \cdot z_1 + (v_1 \cdot 0{,}5T)^2]^{0,5}}{1 - \frac{v_1^2}{v_2^2}} \approx (v_1 \cdot T \cdot z_1)^{0,5} \quad (2.1)$$

where:
T – period of the signal,
z_1 – the thickness of the first layer, subsurface,
v_1 – the speed of the signal in the first surface layer,
v_2 – speed of the signal in the second layer.
t – transition time from the source to the receiver.

According to Rafaelsen (2006), the issue of horizontal resolution can be simplified in a homogeneous and isotropic medium. Then the radius of the central Fresnel zone is determining. Objects, whose horizontal dimension is greater than the maximum radius of the

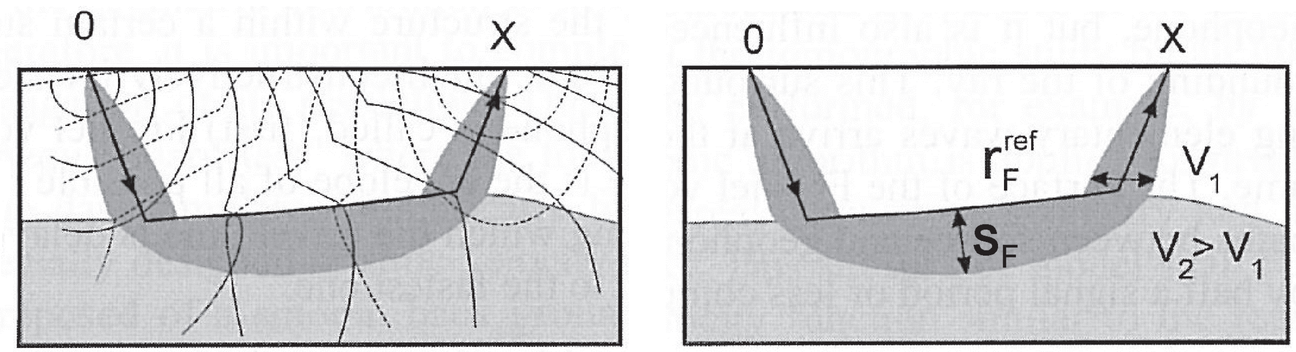

Fig. 2.1. Fresnel zone between the source 0 and the receiver X for refraction wave (a) and its radius r_F^{refr} and width s_F in the lower layer of the medium, where v_1 and v_2 are the refraction wave velocities at the upper and lower layer respectively (b) (Kirsch 2006 after Hagedoorn and Diephuis 2001)

Rys. 2.1. Strefa Fresnela między źródłem O i odbiornikiem X dla fali refrakcyjnej (a) oraz jej promień r_F^{refr} i szerokość s_F w dolnej warstwie ośrodka, gdzie v_1 i v_2 są prędkościami fali refrakcyjnej odpowiednio w górnej i dolnej warstwie (b) (Kirsch 2006 za Hagedoornem i Diephuisem 2001)

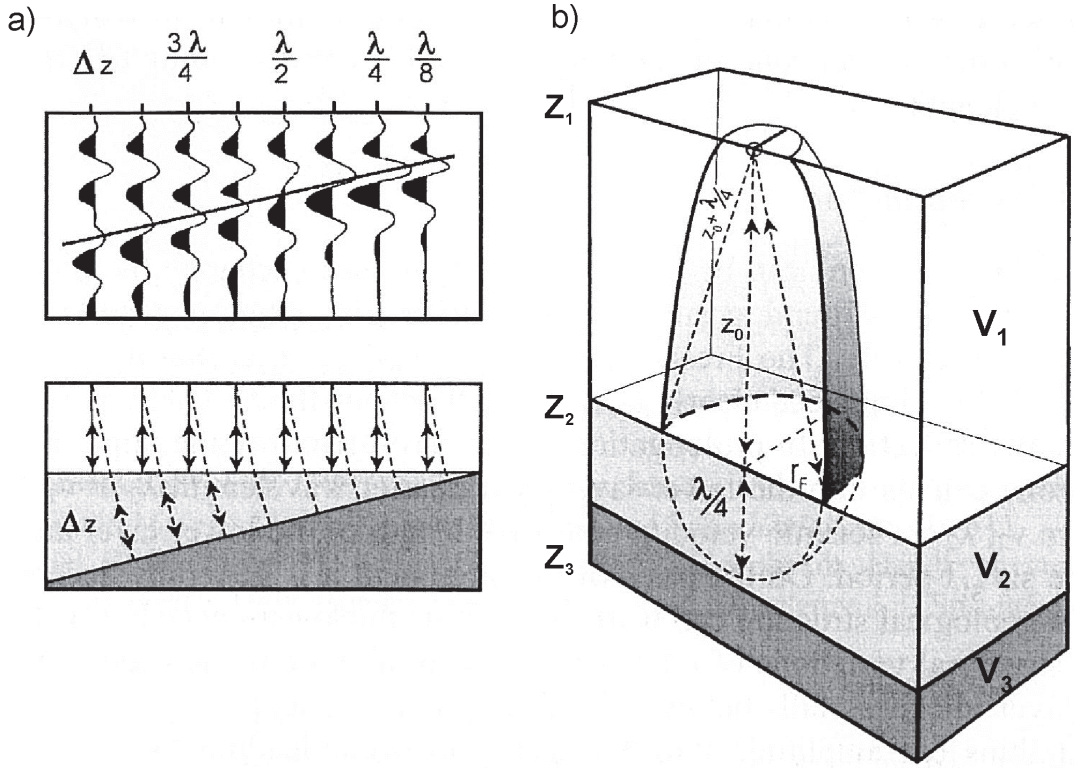

Fig. 2.2. **Vertical resolution of wave reflected from the border located at varying distances Δz (forming of a wedge-shaped layer) (a) horizontal resolution, depending on the radius of the Fresnel zone r_F (b) (Kirsch, 2006) λ – wavelength, z_1, z_2, z_3 – thickness of 1, 2 and 3 layers, v_1, v_2, v_3 – wave velocity in the first, second and third layer respectively**

Rys. 2.2. **Rozdzielczość pionowa fali odbitej od granic położonych w zmiennej odległości Δz (wyklinowująca się warstwa) (a); rozdzielczość pozioma w zależności od promienia strefy Fresnela r_F (b) (Kirsch 2006) λ – długość fali; z_1, z_2, z_3 – grubość odpowiednio 1, 2 i 3 warstwy; v_1, v_2, v_3 – prędkość fali odpowiednio w 1, 2 i 3 warstwie**

central Fresnel zone, are discerned by the seismic wave for small depths (in engineering recognition) according to the general formula:

$$F = \frac{v}{4f} \tag{2.2}$$

where:
v – velocity of seismic wave,
f – frequency of the seismic wave.

For example, a seismic wave with a frequency of f = 70 Hz and a velocity of v = 600 m/s, the resolution is 2.1 m.

3. Numerical calculations of the impact of seismic wave frequency on the recognition of the landslide surface

3.1. Methodological assumptions

Numerical modeling requires a detailed analysis of the problem of the physical and mechanical processes, a proper selection of the method of calculation and the relevant structure of the numerical model. It should also take into account the limitations that result from the choice of initial and boundary conditions, and the need for a number of simplifications and methodological limitations.

The primary objective of numerical calculations was to analyze the impact of seismic wave frequency on the accuracy of the position of discontinuity borders in the landslide in Mucharz. Seismic measurements were simulated for different frequencies from 30 to 120 Hz. The resulting synthetic seismograms for each considered frequency were used to assess the accuracy of the determination of the landslide slip surface.

3.2. The structure of geometry of the numerical model with the calculation of material constants

Based on geological and engineering survey of the landslide located in Mucharz in the formation of the Carpathian flysch, the geometry of the numerical model was developed. First, the three-dimensional geological-engineering model of the landslide was developed based on data from test holes. Based on the results of geological, engineering, geotechnical and geophysical data (documents of 2005) three basic layers that form the putative borders of the slip surfaces were distinguished in the medium. Figure 3.1 presents models of the surface, indicating boreholes.

The three-layer geological-engineering model can be described as follows:

- The first layer of a thickness of up to 8.2 m – Quaternary formations of a type of landslide colluvia consisting mainly of cohesive soils with fragments of rock with a predominance of cohesive clays and silts,
- The second layer of a thickness of 3.8 to 8.0 m – highly weathered bedrock (breccia) made up of shales with veined sandstones with clayey material fillings,
- Third layer – less weathered bedrock with predominant shale clay and sandstone, and mudstone deposits compacted or semi-compacted, probably intact landslide processes.

A graphic interpretation of the three-layer geological-engineering model is shown in Figure 3.2. Subsequently, a sectional view taken along the axis of the landslide was developed, as it was the most characteristic to assess the position of the slip surface (Fig. 3.3).

The material constants of the model layer adopted to simulate the seismic data are summarized in Table 3.1.

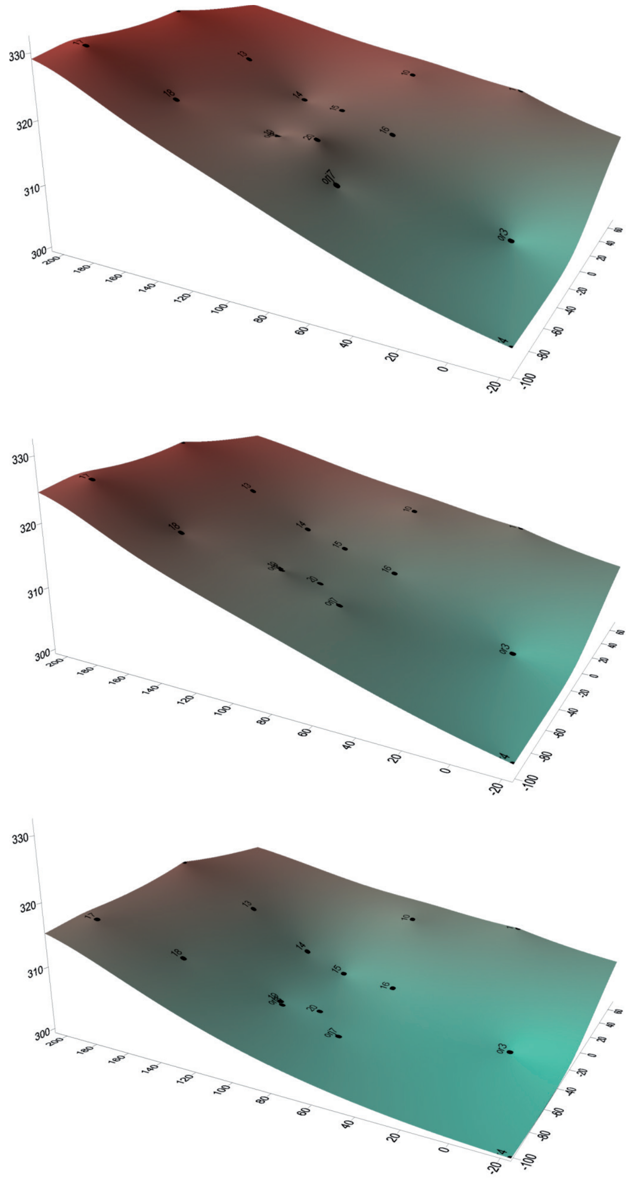

Fig. 3.1. 3D models of the land surface a) slip surface between the first and the second layer b) slip surface between the second and the third layer c) points on the surfaces mark the executed test holes

Rys. 3.1. Modele 3D powierzchni terenu a) powierzchni poślizgu między 1 i 2 warstwą b) powierzchni poślizgu miedzy 2 i 3 warstwą c) Punkty na powierzchniach oznaczają wykonane otwory badawcze

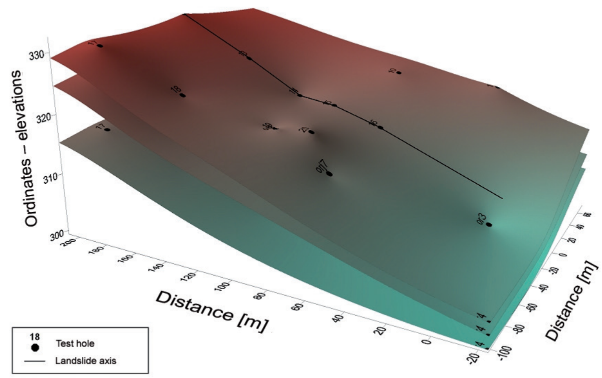

Fig. 3.2. Geological-engineering three-layer model of the landslide with the longitudinal axis of the landslides marked with a line

Rys. 3.2. Geologiczno-inżynierski model trójwarstwowy osuwiska z zaznaczoną linią osi podłużnej osuwiska

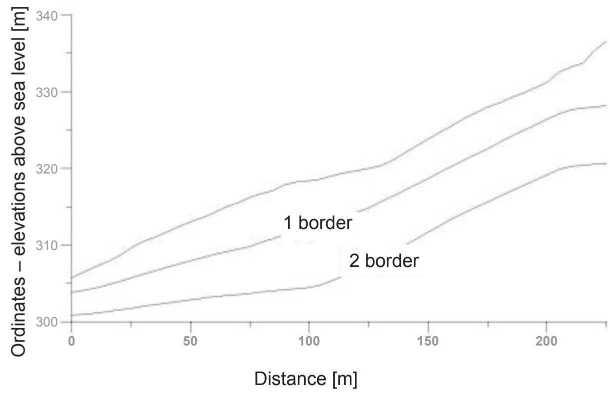

Fig. 3.3. Two-dimensional model of the course of borders along the landslide axis

Rys. 3.3. Dwuwymiarowy model przebiegu granic wzdłuż osi osuwiska

Table 3.1. Material constants of geological layers in 2D model

Tab. 3.1. Stałe materiałowe warstw geologicznych modelu 2D

Layer kind	Bulk density [kg/m³]	Bulk elasticity module [Pa]	Shape elasticity module [Pa]	Internal friction angle [degree]	Cohesion [Pa]
Layer 1	1970	6,20E+07	1,26E+07	14,00	13,6E+03
Layer 2	2050	1,46E+09	2,96E+08	15,95	12E+03
Layer 3	2415	1,04E+10	2,61E+09	21,70	11,2E+04

These constants are based on the speed of seismic waves P and S measured at the stage of developing geological-engineering technical documents (Documentacja 2005a).

3.3. Development of computational model

Numerical calculations were carried out in plane strain, in elasto-plastic medium with Coulomb – Mohr failure criterion and observing the associated flow rule.

The computational model had dimensions of 250 meters long and 6 meters high from the left frame and 36 meters high from the right frame (Figure 3.4). The computational grid was adopted in such a way that the mesh had a maximum dimension of not greater than 20 cm. The choice of the mesh size allowed for the propagation of dynamic disorder, up to a maximum of 120 Hz (Flac 2007).

Boundary and initial conditions were adopted in accordance with the classical principles applied by the numerical analysis of the stability of the landslide (Stopkiewicz and Cała 2004). Primary stress increased linearly with increasing depth, and ties on the vertical frame of the model allowed for vertical displacement and blocked horizontal displacement.

Ricker signal with an amplitude of 10 m/s and frequencies of 30, 50, 75 and 120 Hz was used in the simulation of seismic wave source. The wave source was placed in five points marked PS between geophones marked with filled triangles on the terrain surface in

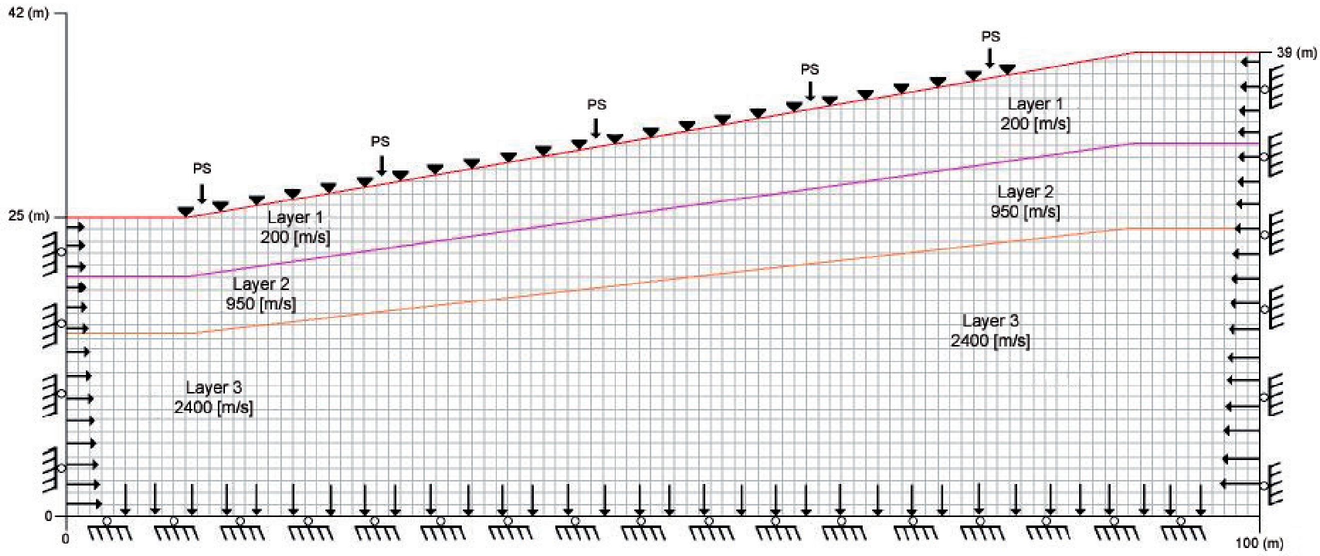

Fig. 3.4. Computational model of the landslide
Rys. 3.4. Model obliczeniowy osuwiska

Figure 3.4. Seismic waves recording was done using 24 geophones monitoring changes in velocity of the medium vibrations. Internal damping of the model due to the mechanical properties of the medium (natural damping) was used. The calibration of the model showed that the damping factor in the substrates was acceptable and amounted to about 1%. Rayleigh silencers were used in the frames of the model (Flac 2007).

3.4. Results and analysis of numerical calculations

As a result of vertical loading of the model by using Ricker signal of a specific frequency in 5 points PS (Figure 3.4), the model's response was recorded in 24 points – receivers. Horizontal velocities were recorded for a clearer separation of refraction P-wave. An example of such a recording for PS located at the beginning of the profile in a 200 ms time window with the amplitude spectrum for the frequency of 75 Hz for Ricker signal is shown in Figure 3.5.

The seismograms for the considered higher-frequency wave source show clearly the entrance of the refraction wave for the first and second landslide slip surface. The second, deeper border is harder to observe for the source frequency of 30 Hz, but still possible to determine. Waveforms of scaled amplitude spectrum show that with the increasing distance from the source, the main frequency band decreases its value. Consequently, the seismic image resolution decreases.

Based on the average velocities on hodographs, seismic models of basic discontinuity borders of the landslide were developed, which is presented in Figure 3.6. In calculations for each model, as intended, the same velocities were assumed in each layer: I – 200 m/s, II – 950 m/s and III – 2400 m/s.

The cross-sections show that the position of borders varies depending on the frequency of the seismic wave. Generally, it was noted that with increasing frequency the arrangement of borders was close to their arrangement in the base model. Simultaneously, the thickness of layers I and II varies for different frequencies. This effect is the result of less favorable resolution achieved for the lower frequency wave. Table 3.2 summarizes depths of the location of the interpreted two borders of the model averaging from three points in comparison with the average depth of the base model.

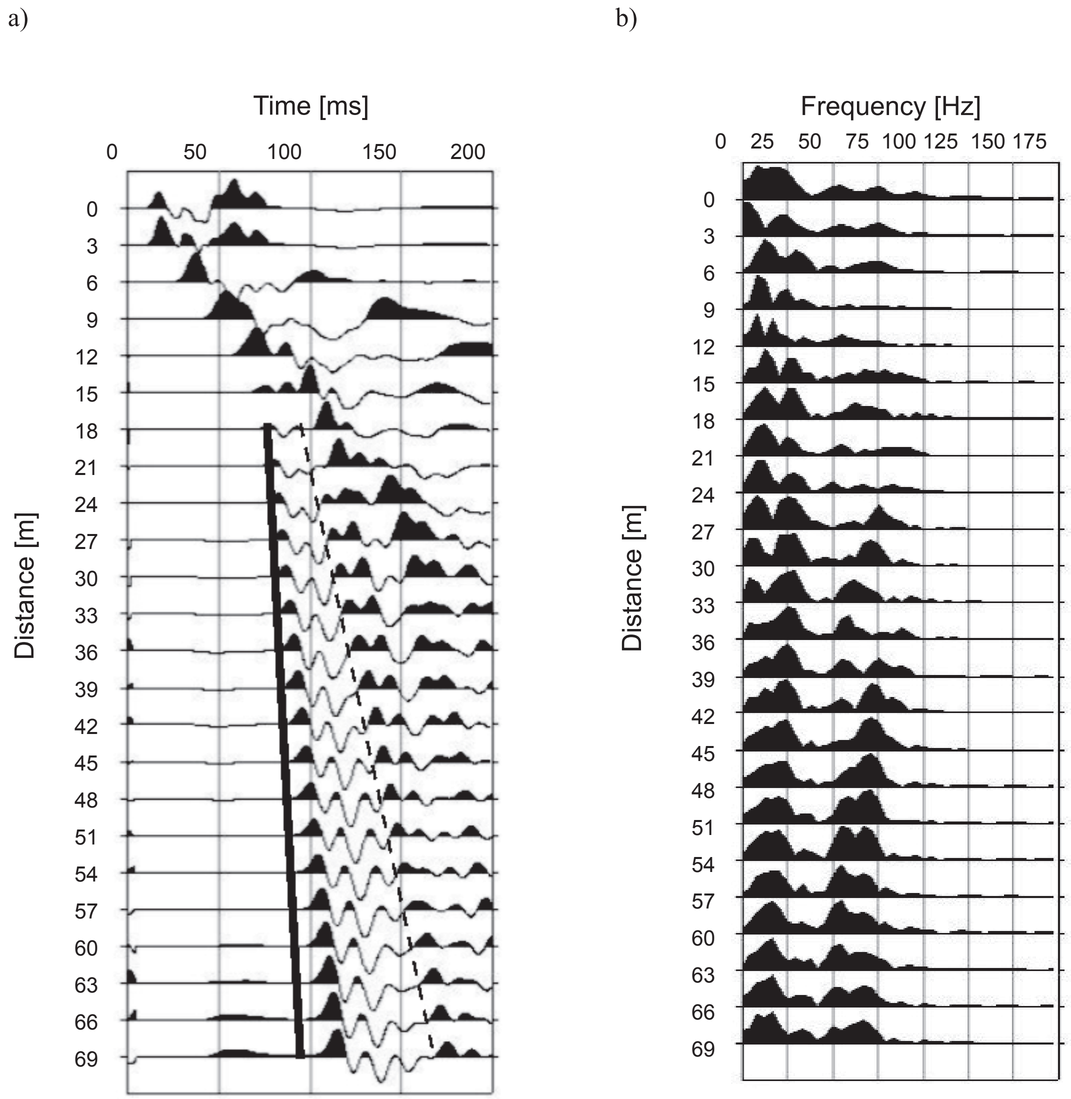

Fig. 3.5. Example of a scaled synthetic seismogram of horizontal velocity (a) and the scaled amplitude spectrum (b) for the source waveform of a frequency of 75 Hz calculated by FLAC program, a solid line indicates the entrance of a refraction P-wave for border 1 and the broken line the entrance of a P-wave for border 2

Rys. 3.5. Przykład skalowanego syntetycznego sejsmogramu poziomej prędkości (a) oraz skalowanego widma amplitudowego (b) dla źródła fali o częstotliwości 75 Hz obliczonego programem FLAC; ciągłą linią oznaczono wejście fali refrakcyjnej typu P dla 1 granicy, a linią przerywaną wejście fali P dla 2 granicy

a)
b)
c)

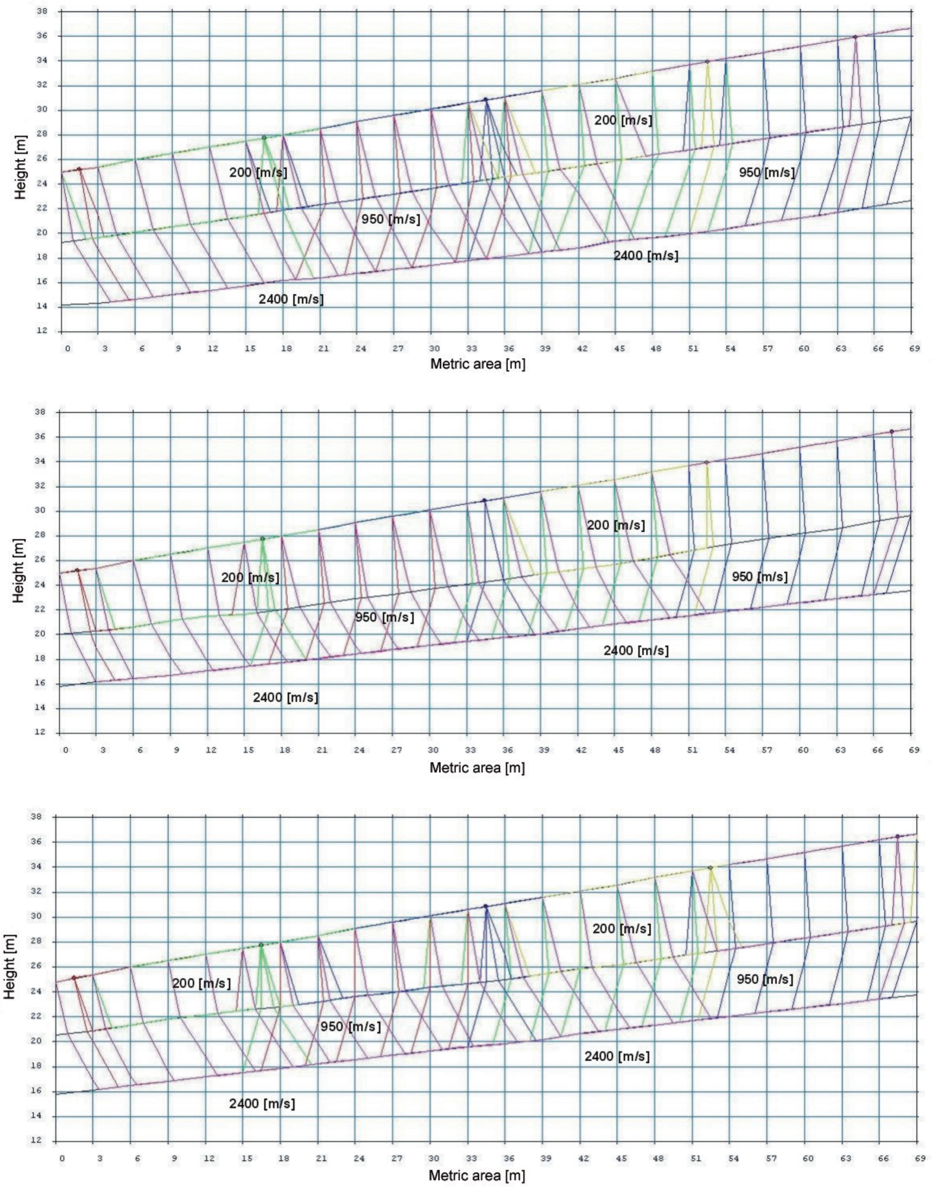

Fig. 3.6. Seismic-cross section along the axis of the landslide including the interpreted course of seismic rays for the wave source of a frequecy of 30 Hz) b 50 Hz) and 120 Hz c), the colors are used to mark rays coming from a particular PS

Rys. 3.6. Przekrój sejsmiczny wzdłuż osi osuwiska wraz z wyinterpretowanym przebiegiem promieni sejsmicznych dla źródła fali o częstotliwości 30 Hz a) 50 Hz b) i 120 Hz c); kolorami zaznaczono promienie pochodzące od konkretnego PS

Table 3.2. Calculated position of the landslide slip borders for the frequency of seismic source of 120, 75, 50 and 30 Hz
Tab. 3.2. Położenie obliczonych granic poślizgu osuwiska dla częstotliwości źródła sejsmicznego 120, 75, 50 i 30 Hz

Model type	* Depth of the border between the 1st and 2nd layer [m]	* Depth of the border between the 2nd layer and the 3rd layer [m]
Base model	6	11,6
30 Hz source model	6,53 (+ 0,53)	12,75 (+ 1,15)
50 Hz source model	6,48 (+ 0,48)	11,14 (- 0,46)
75 Hz source model	6,07 (+ 0,07)	11,20 (- 0,4)
120 Hz source model	5,88 (- 0,12)	10,99 (- 0,61)

* differences of the borders' location as compared to the basic model are given in parentheses

The highest deviations from the values of the border depth in comparison with the position of the borders in the basic model were found in the 30 Hz source model. The position of the second border in this model differs from that of the second border of the basic model by 1.15 m. In the case of the other models with a source of higher frequency (50, 75, 120 Hz), these differences are in the range from 0.07 to 0, 48 m for the first border, and from 0.4 to 0.61 m for the second border. This means that for the source frequencies above 50 Hz the resolution of the discontinuity border recognition in the landslide model has a smaller deviation not exceeding 0.61 m. Probably, the efficiency of exploration is also possible for a source frequency slightly lower than 50 Hz because of the lack of calculation data in the range 30–50 Hz.

Table 3.3 summarizes the theoretical value of the vertical and horizontal resolution of discontinuity border recognition in the landslide calculated according to the formula 2.1 and 2.2, for the assumed frequency of the seismic source. These data show that for the analyzed frequencies, the error in border recognition can be significantly large. In fact, as well as in numerical simulation, the results indicate much lower error in the position of borders. Assuming that for frequencies from 50 to 120 Hz the recognition error is 0.61m, we obtain for a velocity of 2400 m/s (second border) vertical resolution of detection equal from 1/79 to 1/33 wavelength, respectively. However, for a velocity of 950 m/s (the first border), vertical resolution of recongition equals from 1/40 to 1/17 wavelength, respectively.

4. Summary

The calculations prove the impact of the seismic wave frequency on the quality of the recognition of the landslide slip surface. It is shown that for a low-frequen-

Table 3.3. Theoretical values of the resolution of discontinuity border recognition in the landslide for the frequency of seismic source of 120, 75, 50 and 30 Hz
Tab. 3.3. Teoretyczne wartości rozdzielczości rozpoznania granic nieciągłości osuwiska dla częstotliwości źródła sejsmicznego 120, 75, 50 i 30 Hz

Border location	Velocity of refraction P-wave [m/s]	Vertical/horizontal resolution [m]			
		f = 120 Hz	f = 75 Hz	f = 50 Hz	f = 30 Hz
1 – 2 layer	950	1,98/3,41	3,17/4,34	4,75/5,29	7,91/7,45
2 – 3 layer	2400	5,00/9,19	8,00/12,50	12,00/16,63	20,00/24,54

cy seismic wave the divergences in identifying the position of the border are higher than for higher frequencies. Numerical analysis allowed us to determine the frequency of achieving the recognition of the discontinuity borders position in the landslide in Mucharz in flysch formation conditions. Favorable results for discontinuity borders position, almost identical with the position of the borders in the geological-engineering model, were obtained for wave source frequencies above 50 Hz at frequencies up to 120 Hz. Presumably a similar efficiency of recognition can be achieved for frequencies slightly less than 50 Hz. For frequencies lower than 30 Hz the divergences are too high from the engineering point of view (more than 1 m). An attempt was made to carry out calculations for the source frequency equal to 10 Hz. The wave image obtained in the model for this frequency was strongly distorted, making it impossible to determine the proper course of a refraction P-wave.

The calculation results also show that the practical ability to recognize the borders of the medium discontinuity in seismic refractive profiling is greater than the theoretical value. For the main frequency between 50 to 120 Hz the recognition resolution for a velocity of 2400 m/s corresponds to 1/79 to 1/33 wavelength. However, for a velocity of 950 m/s the recognition resolution is in the range from 1/40 to 1/17 wavelength. This observation is consistent with the practice and is probably related to the phenomenon of wave dispersion to a greater extent than the ones theoretically predicted from the radius of the Fresnel zone.

The presented example of numerical modeling carried out for the landslide in the Carpathian flysch can be used for this kind of calculations in other engineering-geological conditions.

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