THE ACCURACY OF DIGITAL MODELS FOR ROAD DESIGN

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ABSTRACT

The paper presents majority of current methods for digital terrain models (DTM) measuring and basic requirements of traffic engineers on accuracy in the process of road design and construction. Conventional geodetic surveying methods are described as well as modern non-contact methods of the ground surface measurement, e.g. the laser scanning measurements from cars. When designing new road infrastructure, all the requirements of the environmental impact assessment imposed by the European Union must be taken into account. In connection with the application of Directive 2011 /92/ EU of the European Parliament saying that all newly constructed multi-lane roads must go through an intense impact on the environment (EIA analysis) and it also includes repairs of existing roads of more than 10 km length. Shortest roads may not require an EIA, but still must be built according to geometrical design standards. Calculations of the horizontal and vertical road centreline determine the three-dimensional physical location of a road considering operational, economic and environmental requirements. The density and accuracy of the DTM determine the final quality and efficiency as the design work, the quality of the geometric structure of the building. The quality and accuracy of the DTM especially determine the financial performance of the road construction. All alternative solutions are then assessed simultaneously with all the environmental and economic criteria. During reviews variants, for a first approximation with the situation, can be used DTM with less accuracy approximately 15 cm. For the design selected variant is required the accuracy of DTM around 2-3 cm. Only high quality DTM will allow us to rightly and accurately calculate the cost of road construction, to determine the exact volume of material moved and make any necessary animations and simulations. Then all simulations of transport capacity, fuel consumption and emissions will be of high quality. Only on the basis of high quality three-dimensional data it is possible to determine the horizontal and vertical axis of communication and to optimize the location of the axis, and consider operational, economic and environmental performance.

Key Words: EIA, DTM accuracy, methods of DTM measuring

INTRODUCTION

Construction of roads is a very complicated process – spatially, financially and organizationally. Preparation, realization and the construction itself will change the neighbouring terrain and the environment related to the construction for a long time. The basic source materials for road preparation, planning and construction are the surveying data obtained by various surveying methods. The geodetic, photogrammetric and laser scanning methods belong to them. Outputs of these methods provide the basic information for all stages of the road construction, from study of the road run up to the construction implementation.

DATA AND SURVEYING METHODS USED DURING THE ROAD PLANNING

Data sources must be provided for preparation stage as well as the implementation itself. Majority of the data should be in 3D form. The topicality, accuracy, correctness and suitability of the sources for the planning and implementation itself must be considered. Within preparation of the source materials, data and maps, it is necessary to concentrate on early obtained documents made by state administration bodies, which should be verified for topicality and accuracy. If they do not comply with the required accuracy or topicality, new data must be obtained.

When determining the area for motorways and first class roads in the Czech Republic, the 1:200 000 regional schematic road maps are used. Another map source is usually the Czech Republic (CR) 1:50 000 road map depicting the motorways, roads, grade separations, nodal points of the localization system of the road databank, bridges, underpasses, railway-crossings, tunnels, ferries, curves, risings, passes, etc. Also cadastral maps, which contain points of the point field, planimetry, all real estates, parcel indexes and relevant cadastral territory, are used for designing works. From the Partial Territorial Decision level, the designer requires current cadastral maps in vector form, i.e. the digital cadastral map or digitized cadastral maps.

Geodetic data forms the basis of the special-purpose materials that practically enables to incorporate the construction into the area of interest. The detailed point field serves to that purpose. In the CR, the digital terrain model is used for the study level in form of 3D contour lines as a part of the Fundamental Base of Geographic Data of the Czech Republic (ZABAGED). Furthermore, the Digital Relief Model (DMR) can be used in DMR1 to DMR5 versions. The latest versions feature utilization of aerial laser scanning. By 2016, a model with regular 5m grid will be available in the whole CR territory. However the accuracy, because of the RMSE h=0.18 m [1] will only be suitable for study of the road run and its variants. For subsequent designing works more precise elevation data must be obtained.

The entire documentation of all stages of the road construction is elaborated in the Baltic system after adjustment and in the national S-JTSK datum. The geodetic, photogrammetric and laser scanning serve for obtaining quality input data for designing documentation elaboration. The data enable to incorporate the construction variants into the territory of interest. Required accuracy and size of the territory of interest are the decisive factors for selecting a suitable method for the material elaboration. One of the most important source data, on which quality depends majority of control surveying during the designing works and during the construction itself, are the elevation data in the future construction area as well as in the area of future borrow-pits and other construction manipulation areas. If the natural terrain is not surveyed precisely, the assessment of suggested road variants is very uncertain and simulation of vehicle movement on thus variants is not sufficiently evidential. All subsequent calculations will be uncertain since there would not be a first-quality origin, from which the drawn/thrown up material could be calculated and which would enable to compare the current state with the designed one [2]. Following methods seem to be suitable for sufficiently precise digital terrain model:

a) Methods of aerial photogrammetry and stereoscopic mapping of aerial photographs. The resulting material for the road variant study as well as for subsequent designing works is a set of digital planimetry and altimetry files of a special-purpose map. The RMSE accuracy of the altimetry derived by photogrammetry-stereoscopic method is h=0.045 m for the ground sample distance of the aerial photographs equal 0.035 m, see e.g. [3].

b) Methods of aerial laser scanning for creating a digital model needed for designing activity (after selecting and approving the appropriate variant) enable to obtain (after the flight and primary data processing) very dense and precise digital terrain model. The laser scanning apparatus usually emits one light beam and receives it back (after its reflection from the terrain) divided up to eight so called echoes. Information recorded for the first and last reflection of the beam is used for evaluation of planimetry and altimetry information on the terrain. Such determined Digital Surface Model contains all terrain obstacles. The model is further adjusted with special algorithms and calibrated onto map control points surveyed in the terrain. After subsequent result adjustment and necessary filtrations of the terrain objects, the DTM of the particular area is obtained with density up to 12 points per m2 (in open terrain) with RMSE h=0.03 m.

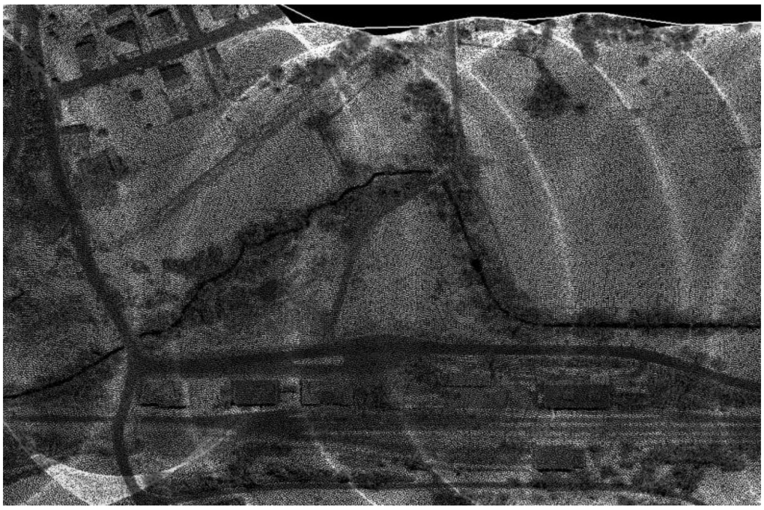

Fig.1. Data sample of the aerial laser scanning – source material for re-laying the R55 road (*Courtesy of GEODIS BRNO Ltd*.)

c) Methods of terrestrial mobile laser scanning for production of precise 3D digital terrain model utilized during designing works are based on an apparatus usually consisting of two integrated units: scanning and navigational. Due to high density, speed and above all the spatial accuracy of obtained point clouds, the method represents one of the most effective methods of obtaining spatial information for precise designing works. By selecting a suitable measurement method, using appropriate vehicles (eventually utilizing terrain three-wheelers or manual walk-survey under hard inaccessible terrain conditions with an apparatus in bag) and subsequent elaboration we can reach results, which we could not reach by other methods. During post-processing, we can use additional information received during scanning each point, especially the sequence of reflections and reflective intensity. The cleared data can serve for generating detailed digital models, depicting cross and longitudinal sections in any position and make other elevation analysis. Such data with RMSW h=0.015 m – see [4], represent the most accurate source material for designing works. Currently there are various SW platforms, which are ready to work with these data and also enable the 3D designing. In comparison with conventional methods, this one brings relatively high time savings during the designing works and above all the savings during the construction itself.

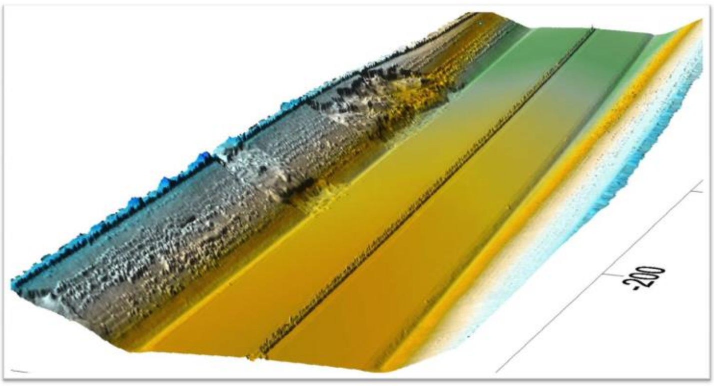

Fig.2. Sample of detailed 3D digital model of a current road *(Courtesy GEOVAP Pardubice Ltd.)*

d) Methods of terrestrial static laser scanning represent suitable methods for operative and precise surveying of partial source materials for designing activities of selected transportation objects (e.g. probably crossing of designed construction with existing bridges, tunnels, supporting walls, noise protection barriers). In connection with the aerial and terrestrial mobile laser scanning, the methods enable complex surveying of existing transportation facilities, which are supposed to influence the future construction or to utilize it. The RMSE elevation of these methods is e.g. at the bridge surveying utilizing phase laser scanners with range of 20 to 50 m 0.005 m – see [5].

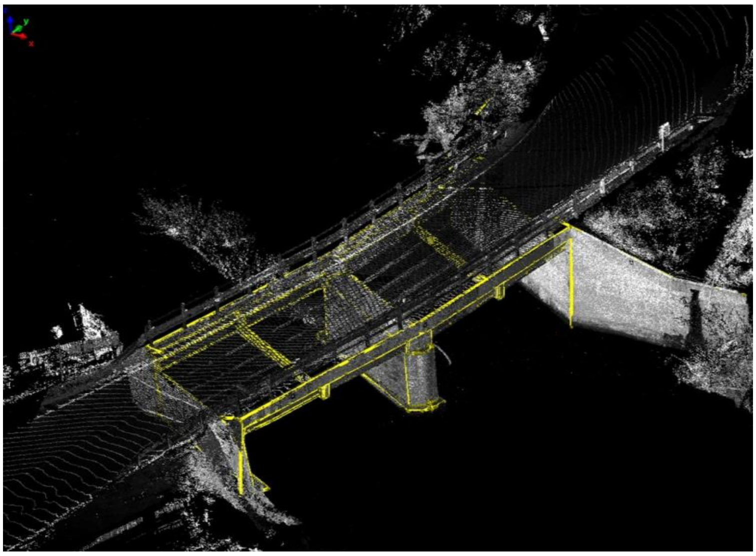

Fig.3 – Sample of a road bridge surveying *(Courtesy GEOVAP Pardubice Ltd.)*

RESULTS AND DISCUSSIONS

Point clouds received by both correlation methods from stereoscopic photographs (or by direct stereoscopic measuring by an operator) and laser scanning methods (mainly by mobile terrestrial laser scanning) can also be utilized in connection with an orthophotomap with ground sample distance of 2.5 cm for creating various types of visualizations and animations above a real landscape. The data can be used for simulations of various vehicle movements. Such a view and simulation can reveal potential future danger sections and suggest and design with utilizing real data a safe, economically optimal and ecologically acceptable road and thus exploit all features of the digital terrain models, which can currently be utilized by above mentioned methods.

Table 1. Financial, time and accuracy characteristics of surveying methods used on 10km section elaborated in three variants *(Parameters of test area - 3 strips (variants) , long 10km (each), 0,5km (width) = 500ha, 70% open area, 30% covered (forest))*:

Description of method:	Vertical accuracy (RMSE) in [cm]:	Approximate price for the area 500 ha in Euros:	Approximate time of delivery in days:
Data DMR 5	18	125	3
Aerial photogrammetry and stereoscopic mapping	4,5	8 800	30
Aerial laser scanning	3,5	11 200	30
Terrestrial mobile laser scanning	1,5	25 600	60
Terrestrial static laser scanning	0,5	58 000	100

CONCLUSIONS

New requirements on always more superior altimetry map sources for needs of road designing call (within more effective collection of altimetry data and their subsequent elaboration) for suitable selection of the acquisition method. Using above stated methods for acquisition of source materials for designing works and above all their accuracy, 3D character and optimization of the designing works will enable to suggest and create a real work, which will be both economical and ecological one.

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