

Analysis of Road Repairs in Undermined Areas

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Abstract—The article presents analysis results of maps of expected subsidence in undermined areas for road repair management. The analysis was done in the area of Karvina district in the Czech Republic, including undermined areas with ongoing deep mining activities or finished deep mining in years 2003 - 2009. The article discusses the possibilities of local road maintenance authorities to determine areas that will need most repairs in the future with limited data available. Using the expected subsidence maps new map of surface curvature was calculated. Combined with road maps and historical data about repairs the result came for five main categories of undermined areas, proving very simple tool for management.

Keywords—GIS, Map of Subsidence, Road, Undermined Area

I. INTRODUCTION

EVERY year the road administration authority in the Moravian-Silesian region, district Karvina (SSMSK) deals with repair of roads damaged by results of deep mining. The costs are very high but they are paid mostly by mining corporations. But there is an issue of limited manpower that should also be considered. When the regular road repairs are in progress there is not enough resources (human, machines) for high-quality repairs of damage caused by mining. This may cause delays in repair schedule and threaten safety of drivers on the affected roads. If the local road maintenance authorities knew where the next major road repairs would be needed they could schedule the work on repairs accordingly. The article tries to determine if the maps of expected subsidence are valid source of information for the road repair authority for analyses of future impact of the subsidence on road repairs.

The Czech Republic roads density is above-average of European countries. Road network density is about 0.7 km/km² and if we include the urban roads the value is approaching 1.5 km/km² [1]. The density of the entire road network is one of the highest in Europe. It can be assumed that the need for new roads constructions and especially constructions in risk areas should be minimal. This includes undermined areas.

II. UNDERMINED AREAS

Constructions are affected by non-standard moves of surface in areas affected by deep mining activities. There is a heterogeneous deformation of the surface and this phenomenon has a significant influence on structures with

linear character such as roads, railways, and other similar constructions.

The centers of such areas in the Czech Republic can be found in the central Bohemian region, South Bohemia region, North Bohemia region and Moravia-Silesia region.

The issue of mining impacts is very extensive. In principle influences can be divided into two main areas, which is a continuous deformation of the surface and a discontinuous deformation. Continuous deformations are characteristic for deep mining in higher depths. Effect of this is large-scale subsidence trough. The most dangerous part is the border of the subsidence area. Surface transformation alongside the subsidence can be described with the following characteristics [2]. Surface inclination i [rad] is used as a basic characteristic.

$$i(x) = \frac{ds(x)}{dx} \quad (1)$$

The next characteristic is surface curvature η where a positive value describes the curvature with the curvature circle centre under the ground and negative values describes radius of curvature above the ground.

$$\eta(x) = \frac{d^2s(x)}{dx^2} = \frac{1}{R(x)} \quad (2)$$

Horizontal shift v

$$v(x) = \frac{r}{\sqrt{2\pi}} \frac{ds(x)}{dx} \cong 0,4 \cdot r \frac{ds(x)}{dx} = 0,4 \cdot i(x) \quad (3)$$

is used with horizontal relative ε deformation, which is a derivation of the horizontal shift. Positive values indicate surface stretching and negative values indicate surface compression.

$$\varepsilon(x) = \frac{dv(x)}{dx} = 0,4 \frac{d^2s(x)}{dx^2} \quad (4)$$

Variables used in (1), (2), (3), (4) are as follow:

- i surface inclination,
- η surface curvature,
- v horizontal shift,
- ε horizontal relative deformation,
- r full effective area radius,
- R curvature radius,
- s line of subsidence.

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The second type of surface deformation, discontinuous deformation, is more dangerous because it occurs suddenly and more quickly. It is always an accompanying phenomenon of continuous deformation and it is a result of deep mining at shallow depth. Basic types of expressions are diagonal or vertical landscape levels, landscape waves, cracks and depressions.

III. BUILDING REGULATIONS IN UNDERMINED AREAS

Different countries have different approaches to which area is still safe for building structures and where should some construction measures be applied. Examples of differences in the Czech Republic, Poland and United Kingdom are shown in Table I. All three countries have similar system of categorization of undermined areas although designations of categories might differ. In the Table I the categories are united under the Czech Technical Standard– category I to V from severe to slight damage. In the comparison, the system in the U.K. is the strictest in contrast of the most benevolent in the Czech Republic.

In the Czech Republic regulations and standards for constructions in undermined areas are regulated by ČSN 73 0039 Designing buildings on undermined territory. The choice of ensuring of the construction against undermining influences is always based on several factors [3]:

- type and size of continuous or discontinuous surface deformation,
- period during which the object is exposed to undermining affects,
- meaning and supposed lifetime of the construction,
- construction solution of the object,
- demands based on function of technological equipment.

The expected deep mining influences are set by so called mining conditions which are mandatory for securing the constructions against the effects of mining activities. Sites can

be divided according terrain deformation parameters into the five categories. The construction site “V” is supposed as safe and can be used with no special modifications. Construction sites “IV – III” are sites requiring treatment. It is not allowed to build on sites “II – I”; only the necessary communication for mining companies are allowed [3].

Design of repair or a new construction building should reflect expected time factor of supposed terrain deformations. Based on the previous statement the quality of used materials should be chosen. For example when the horizon of surface deformation is short it is senseless to use expensive materials. New design linear constructions should be situated along the subsidence contours to ensure steady subsidence. Or if the supposed subsidence is too big, it is possible to design higher fill and thereby mitigate the impact of future subsidence.

Some basic demands for designing new constructions, reconstruction or repairs can be briefly set. In the case of roads the ideal choice of material for pavement and other constructions sheets is supple material, which is able to transform together with terrain deformations.

Bridges must be secured in terms altitude and directional arrangement as part of the adjacent roads or railroads. Construction of the bridge must be designed for the worst possible effects of mining.

Surface monitoring should continue until the subsidence stops. Terrain can drop by several meters and significantly change water flow conditions. This fact may lead to malfunction of drainage facilities, or worse, flooding the construction, as described in [4].

IV. METHODS AND TOOLS

Each year mining companies create so called map of expected subsidence. The maps contain subsidence contours in defined time period. The whole area of subsidence is always bounded by so called zero line which shows the border of influenced area. The maps of expected subsidence are one of

TABLE I
CATEGORIES OF DAMAGE IN UNDERMINED AREAS

Category of damage	Czech Republic [2]	United Kingdom [5]	Poland [6]
I - very severe	$R \leq 3 \cdot 10^3 \text{ m}$ $i > 10 \cdot 10^{-3} \text{ rad}$ $\varepsilon > 7 \cdot 10^{-3}$	$\Delta l > 0.2 \text{ m} / 60 \text{ m}$ $\varepsilon > 3 \text{ mm/m}$	$\eta > 120 \cdot 10^{-6} / \text{m}$
II	$R \leq 7 \cdot 10^3 \text{ m}$ $i > 8 \cdot 10^{-3} \text{ rad}$ $\varepsilon > 5 \cdot 10^{-3}$	$\Delta l > 0.12-0.2 \text{ m} / 60 \text{ m}$ $\varepsilon > 2-3 \text{ mm/m}$	$T < 15 \text{ mm} / \text{m}$ $\eta < 120 \cdot 10^{-6} / \text{m}$ $\varepsilon > 9 \text{ mm/m}$
III	$R \leq 12 \cdot 10^3 \text{ m}$ $i > 5 \cdot 10^{-3} \text{ rad}$ $\varepsilon > 3 \cdot 10^{-3}$	$\Delta l > 0.06-0.12 \text{ m} / 60 \text{ m}$ $\varepsilon > 1-2 \text{ mm/m}$	$T < 10 \text{ mm} / \text{m}$ $\eta < 90 \cdot 10^{-6} / \text{m}$ $\varepsilon > 6 \text{ mm/m}$
IV	$R \leq 20 \cdot 10^3 \text{ m}$ $i > 2 \cdot 10^{-3} \text{ rad}$ $\varepsilon > 1 \cdot 10^{-3}$	$\Delta l > 0.03-0.06 \text{ m} / 60 \text{ m}$ $\varepsilon > 0.5-1 \text{ mm/m}$	$T < 5 \text{ mm} / \text{m}$ $\eta < 50 \cdot 10^{-6} / \text{m}$ $\varepsilon > 3 \text{ mm/m}$
V – very slight	$R > 20 \cdot 10^3 \text{ m}$ $i \leq 1 \cdot 10^{-3} \text{ rad}$ $\varepsilon \leq 2 \cdot 10^{-3}$	$\Delta l > 0.03 \text{ m} / 60 \text{ m}$ $\varepsilon > 0.5 \text{ mm/m}$	$T < 2.5 \text{ mm} / \text{m}$ $\eta < 20 \cdot 10^{-6} / \text{m}$ $\varepsilon > 1.5 \text{ mm/m}$

R – curvature radius, ε - horizontal relative deformation, i – surface inclination, Δl - change in slope, T - change in slope, η - ground curvature
 $R = 1/\eta$

the key documents in the construction or reconstruction of a new building in affected area [3]. The simplest way, how to determine if the road is in the undermined area, is to use Geographic Information System (GIS) software and compare a road net layer and a layer of map of expected subsidence.

Local road maintenance authority SSMSK has data about roads in vector form but a list of repairs is in a spreadsheet only. SSMSK also obtains expected subsidence maps in printed form only. The data have to be joined using GIS, database tools, and spreadsheet application.

All data used for analysis has been obtain from SSMSK or from Reditelstvi silnic a dalnic (road administrator in the Czech Republic)

V. ANALYSIS OF ROAD REPAIRS

Given only scanned maps of subsidence, the preparations for the analysis had to start with georeferencing of the scanned maps in GIS. Next step was to vectorize the contours of subsidence. Using 3D analysis SW tools the digital terrain model was interpolated from the contours. Several interpolation methods were examined (kriging, IDW, spline, etc.), before choosing the Natural neighbor method, which created the smoothest terrain model, converging to the real world as much as possible. The preceding mentioned procedures have tremendous impact on the precision of the whole analysis and have to be done very dutifully. Even then the results are affected by double interpolation (real data – contours; contours – digital terrain model). Also the subsidence contours units from the maps have to be converted from centimeters to meters otherwise the next steps of the analysis would bring wrong results. A digital terrain model was used to create data layers with slope of terrain and curvature of the surface. These outcomes had to be converted to be compatible with layers of the roads and without data loss at the same time. Road data layer on the other hand was in the vector form and features were well described by unique identification, road number and stationing. Roads were divided into segments (features) according road junctions (nodes). The historical data about road repairs stored in the spreadsheet were identified by road number and stationing. Road repairs often affected more segments of a particular road and so a simple algorithm was developed to identify these segments. With duplicated road data layer the repaired road segments were split and identified and afterwards merge together using identification. This allowed creating continuous segments of road repairs even when the road repair crossed more than on road segment. The spatial join was performed between road repair layer and layers of digital terrain model, slopes, and surface curvature for each year.

VI. RESULTS

Outcomes of the analysis were processed and the surface curvature was found to be the most characteristic result. In Table II there are frequencies of road repairs based on the category of the undermined area (see Table I) and according to

TABLE II
ROAD REPAIRS BASED ON CATEGORY OF AREA AND YEAR OF REPAIR

Category of the area in the year ^a	Frequency of repairs			
	2003	2004	2005	2006
I	37	23	25	
II	20	8	15	
III	8	2	2	
IV	1	0	0	
V	18	14	4	
2004	2004	2005	2006	
I	17	22	15	
II	4	7	2	
III	6	3	1	
IV	1	2	0	
V	4	2	4	
2005	2005	2006	2007	
I	24	18	11	
II	8	4	4	
III	0	5	0	
IV	0	0	0	
V	0	1	0	
2006	2006	2007	2008	
I	19	28	31	
II	8	8	10	
III	1	2	4	
IV	2	4	9	
V	9	9	13	
2007	2007	2008	2009	
I	31	53	34	
II	6	7	6	
III	7	8	8	
IV	4	5	0	
V	3	3	0	

^a categories based on surface curvature according to [4]

the year when this category was set. The frequencies are shown for the year the categories are determined and the next two years. This is because of a delay between damage to road and an actual repair. The results in categories might be affected by change of category during the time period of deep mining effects. This might be also an answer for many repairs in category V, because they did not have to be in this category before. It is apparent the highest number of repairs is in the categories I and II. Even structures designed for undermined areas have limits to what they can withstand and need repairs from time to time.

VII. CONCLUSION

The road repair authority can use the maps of expected subsidence for analyses. This will help to prepare the maintenance schedule of the repairs allowing better decision making, faster repairs and also safer roads and economic effectiveness. It would also be beneficial to study history of each road segment during longer period of time to precisely determine delays between damage and repair.

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