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Variations in the building site categories in the underground mining region of Doubrava (Czech Republic) for land use planning

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ABSTRACT

In terms of demands and needs of ground investigation and foundation engineering, the engineering-geological conditions in the underground mining territories represent anthropogenically influenced areas in the most complicated manner, since they suffer the impacts from the underground mining of mineral resources. The subjects of observation are the so-called building site categories, which represent a certain risk factor that must be taken into consideration during foundation engineering and engineering-geological studies in the undermined territories. It is necessary to realise that underground mining is an anthropogenic geodynamic process which significantly varies over time due to mining change, and consequently with variations in the position, shape and size of subsidence in a subsidence basin. All the above mentioned variations should be mandatory knowledge for land use planners, engineering geologists, geotechnicians, foundation engineers and designers because of the evident logicality of these needs. This work presents a case study (Ostrava-Karvina Coal District in the north-east of the Czech Republic) of variations in the building site categories over time, and the results show that the chronology of the changes has a very significant influence in this area of interest. The results of the building site category evaluation imply that the majority of the interest area falls within relatively good conditions for founding all kinds of structures. However, it was then necessary to consider variations over time in the surface area of less suitable building site categories. A trend certainly confirmed the existence of the previously presumed mutual relationship between building site categories and subsidence size distribution. It is apparent from the analytic results of the relationship between building site categories and planned development that the negative impacts of mining have been only partly considered, or completely disregarded, in the development planning process. Consequently, future land use planners should carefully consider these particular building site categories as the most important and significant factors in the undermining of a region. In this manner, development can be successfully planned for present and future safety.

1. Introduction

Presentation of engineering geological data in the form of a hazard/risk map is a useful tool in urban planning. In order to avoid the problems related to the subsurface and thus save property and money, detailed geo-scientific data should be collected and used in urban development plans. The main topic providing the integrated information for urban development is engineering geology. Engineering geological maps contain information mainly on the physical — mechanical properties of soils, shallow groundwater levels, potential hazardous processes, etc. In order to implement a control scheme for avoidance from severe collapse and destruction of properties and infrastructures, relating engineering geological map should be prepared by means of land use planning (Yilmaz and Yavuzer, 2005; Yilmaz and Bagci, 2006; Yilmaz, 2008; Yilmaz, 2009).

Ground subsidence induced by underground mining activities is one of the serious geological hazards because it can effect slopes, damage engineering structures, settlement areas, natural lakes, and allow infiltration of contaminant into the groundwater. Subsidence, slope deformation, etc. as consequences of underground mining activities are very important problems in most countries and these types of impacts are very well known in coal, metal and other types of mining (Altun et al., 2010).

Undermined territories are anthropogenically influenced areas within deep mining impact. This case study deals with deep black coal mining in the Ostrava-Karvina Coal District, and from an engineering-geological and technical perspective such impacted territories cause a whole range of complications. These are reflected in the foundation

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engineering conditions or they are manifested in the form of impacts on already existing development. Underground mining results in changes in the state of stress within the rock massif and in the formation of free space which consequently collapses and causes deformation at the ground surface. Such deformations are also transferred onto all engineering structures present. Some of the most prominent impacts are noted on spatially larger structures or on line structures such as roads, power-supplies and other underground services.

If the uneven deformation or subsidence (i.e. differential subsidence on the top of the mined-out area) cannot be effectively controlled then it will cause damage and even a disaster, such as deformation or even cracking of buildings, particularly tall buildings. This means that the failure of a building is to a great extent controlled by the presence of differential subsidence rather than the absolute magnitude of subsidence (Li et al., 2006).

In the past, such territories used to be considered totally unsuitable for new development. However, with time, the need to build over such areas is being seriously considered. In general, this is connected with higher building density and the required protection of agricultural land and landscape which is significant from an environmental point of view. This trend will certainly continue in the future due to the expected rise in population and the automatic need to build on land previously considered unsuitable for construction. Naturally, an inseparable part of this development must be an increased awareness of the mechanisms of deep mining effects on the ground surface. There is improved foundation engineering technology for new development and for the current built-up area there has been special development in remediation technology. In order to control the process of undermined territory utilisation in a practical manner, this must be incorporated in land use planning.

However, it is necessary to find an instrument that permits the quantification of underground mining impact on the built-up area. This can be achieved by its projection in map applications via geographic information systems, without which land use planning processes cannot currently be implemented. Two fundamental options exist. The first is land risk assessment according to existing and estimated subsidence values represented in GIS layers as isocatabases which depict lines with identical subsidence values. However, these have the disadvantage of ignoring relationships with structural sites. Therefore, they may only provide information of a reference value.

The second and more recommended option is characterised by the employment of the so-called building site categories on undermined territories through the ČSN 730039 (1989) Standard on Design of premises on undermined land. This standard was prepared especially for point-wise problem solving during the investigation and design of specific structural sites on undermined land. Nevertheless, building site categories may also be applied in 2D maps by means of information obtainable from mining companies, as from OKD (Ostrava Karvina Mines Company in Czech Republic) in this case. This study utilises such information in the preparation of improved land use plans. We propose to overlay isolines which consider the specific building site categories together with the sites of future and current development. Building site categories represent a risk index of new development which takes into consideration the underground mining impact on structural sites.

The area of study is situated in the cadastral districts of the municipalities of Rychvald, Orlova, Detmarovice, Doubrava, Karvina and Petrovice u Karvine in the Moravian-Silesian Region, in the north-east of the Czech Republic near the Polish border (Figure 1). It covers an area on map sheet 15-44-03 (Czech reference number of topographic map sheet) in a 1:10000 scale. Deep mining of black coal is carried out in the allotments of Karvina-Doly I, Karvina-Doly II and Doubrava by the Karvina Mine (CSA and Lazy Plants) and the Darkov Mine.

Fig. 1. Location of the study area.

This study evaluates the undermined territory conditions, in terms of the distribution of building site categories that describe; a. the state of risk in the territories affected by mining and b. the needs of foundation engineering. This means that given categories recommend the steps necessary to ensure that future structures will not be damaged in such an influenced territory, and, moreover, whether constructions should be carried out on such territory at all. On the other hand positive cases are recommended in areas of low influence with minor modifications. Normally, during assessment of an individual structure within engineering-geological studies, we evaluate only one specific site affected by undermining, however, this study examines the distribution of characteristics throughout the entire interest area over time. It also aims to incorporate findings in land use plans.

Building site categories were evaluated within the overall territory according to the ground deformation parameters. Overlay analyses of the building site categories were carried out and evaluated in relation to the current built-up area, the land use plan and the engineering-geological zoning.

As a main aim of the study, five possible building site categories were evaluated in the four time periods of 1983–1990, 1983–1995, 1983–2000, and 1983–2005. This was done to establish the chronological variations in the building site categories and to provide an educational demonstration of such case study in understanding the importance of time variability in the critical characteristics of undermined regions.

Overlay analysis in GIS was then carried out using individual data layers of vectorized subsidence maps (OKD), which depict the building site categories in the stated time periods with the vectorized built-up area in accordance with the land use plan and the current built-up area.

However surface impact from underground mining activity is very well known and reasonably well understood, as a result of the effect of underground mining activities; many hazards, undesired structural and environmental problems on the surface are being addressed in many countries. That's why; the main aim of this article is to provide a case study of environmental impacts related to underground mining, to discuss significant impacts on the environment and landuse during and/or after underground mining projects. This article will also be important in order to better understand the nature and magnitude of displacements that can affect surface infrastructure.

2. Geological framework

In terms of geo-morphologic classification, the study area forms part of the Ostrava Coal Basin complex, and it is in the Ostrava Bottomland, Karvina, Havirov and Orlova Plateau district (Demek et al., 1987). From a regional geological perspective, the pre-Quaternary basement (in the deepest section at 1000–4000 m below ground level) is composed of different migmatitized biotite paragneiss and metamorphic massifs of plutonites (Brunovistulicum). The Palaeozoic demonstrably overstepped into Middle Devonian clastics, while compared to an analogy with Polish territory, local occurrences of erosional residues of the Lower Cambrian cannot be excluded. The Devonian sedimentation of a dolomitized limestone complex of variable intensity lasted until the Uppermost Devonian, so that after sedimentation discontinuance, basal clastics of the Lower Carboniferous became overlaid with discordance. As a result of subsequent gradual sea shallowing, there was a rise in sandstone with the highest member of the Lower Carboniferous being Spirifer sandstone. This was equivalent to the group of Stur faunistic horizons. This group gradually passed into cyclic coal-bearing sedimentation of the Upper Carboniferous, which in the Upper Silesian Coal Basin stratigraphically divides into the Ostrava (paralic coal-bearing mollase) and later into the Karvina Formation (continental coal-bearing mollase). The Ostrava Formation of the Namurian age divides into the Petrkovice, Hrusov, Jaklovec and Poruba Members, and all of these are characterised by a completely uneven alternation of siltites and sandstones with coal seams. The Karvina Formation (Namurian B to Westphalian A) forms Saddle, Sucha and Doubrava Members. The Saddle Member is characterised by the predominance of sandstone with inter-stratified beds of conglomerates while the Sucha Member is characterised of dominant siltite over sandstone in the lower section and a predominance of sandstone over siltite in the upper section. The lower section of the Doubrava Member predominantly comprises sandstone of fluvial origin with the upper one becoming typical alternating aleuropelites and sandstone.

Following a stratigraphic break, the articulated Carboniferous paleorelief was covered by up to hundreds of metres thick of Miocene sediments of the Carpathian front foredeep. Below this, there exists only local Lower Jurassic or Lower Cretaceous landwaste of the so-called recycling beds or else brown Lower Miocene landwaste. In terms of lithology, the Miocene sediments (Moravian, Carpathian, and Eggenburg in the axial part of the Detmarovice gully) are mainly clays and claystones with an abundant proportion of silty and sandy constituents. The deposits of the Carpathian front foredeep are covered with superincumbent Quaternary formations with the lithologically varied complex character of genetically variable glacial, fluvial, proluvial, lacustrine, eolian and slope sediments (Čurda et al., 1998).

3. Underground mining and building site categories

There are five categories of building site categories, which are defined below. Before defining them, the basic boundary conditions affecting the transformation of the surface must be defined. This is connected with the gradual "mining-out" and "caving-in" of the underground space and the formation of a subsidence basin with a characteristic dish or funnel shape. Generalisation concerning ground surface deformation is quite complicated as it depends on a number of factors.

The first of these is the limit angle (μ) of mining influence (Figure 2), which is the angle formed by the horizontal planar line of the face margin of the mined-out space and the subsidence basin edge. In the studied Ostrava-Karvina Coal District, according to Dopita et al. (1997) its value is 50–55° for Tertiary rocks and 70–80° for Carboniferous rocks. The value difference between these geological environments is caused by the different geotechnical characteristics of each environment, and in this case Carboniferous rocks are more rigid than Tertiary ones. The second condition is ground surface subsidence which gradually increases and reaches a maximum value S_{max}. It reaches 80–95% of the mined-out seam thickness (h).

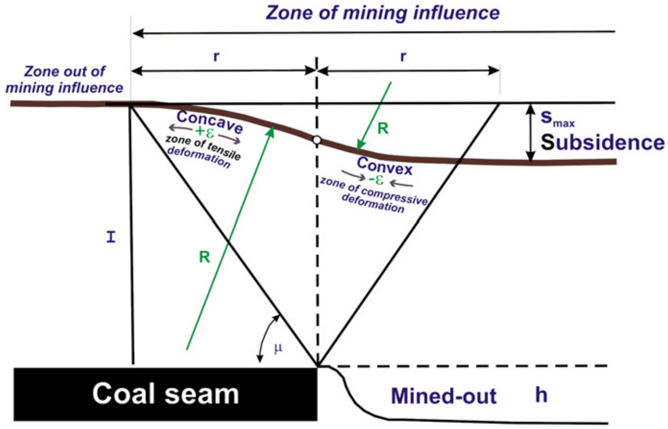

Fig. 2. Basic characteristics of the subsidence basin with the characteristics important in determining the building site category in green (after Marschalko and Treslin, 2009).

According to Standard (ČSN 730039, 1989), building site risk categories on undermined territories, are defined on the grounds of three characteristics (Table 1). These characteristics are included with other information provided by mining companies in their mining conditions.

The first is horizontal unit deformation (ε) given by the proportional length variation in a subsidence basin section in the horizontal direction (Its units are in millimetres per metre). A positive change in the value is caused by tensile changes in the ground, while a negative value is influenced by compression. The second characteristic is the radius of ground curvature (R — in kilometres) representing the radius of an oscillating circle of the ground surface curvature in the subsidence basin. When the curvature centre is below the ground surface it is a convex curvature and a concave curvature is above the ground surface. The third parameter is ground declination (i — mm/m), which is characterised by the difference in the distance ratio between two subsidence points in the subsidence basin.

Structures situated on building site category V do not need protection against the effects of underground mining, except the structures sensitive to certain ground deformation parameters subject to mining conditions (e.g. an underground structure wider than 6 m, pressure piping, large reservoirs, etc.). However, evaluation of the effects of an elevated ground water level by an expected value of ground subsidence is always necessary. Although building sites in groups III and IV can usually be safeguarded against the effects of underground mining in an economically acceptable manner, the utilisation of all building sites in group I and II must be justified, except structures necessary to ensure mining company operations. These must be constructionally simple structures resistant to the effects of underground mining. Only special-purpose structures of wide public importance, such as railway structures, can be situated there. Group one also covers building sites where an occurrence of discontinuous ground deformation is expected. When the ground shoulders and land waves are smaller than 100 mm and the crack

Table 1
Building site groups on land affected by underground mining (ČSN 730039, 1989).

Building site group	ε ($mm.m^{-1}$)	R (km)	i ($mm.m^{-1}$)
I	>7	<3	>10
II	5–7	3–7	8–10
III	3–5	7–12	5–8
IV	1–3	12–20	2–5
V	≤1	≥20	≤2

ε: horizontal unit deformation, R: radius of ground curvature, i: ground declination.

width is less than 100 mm, the site and structures situated there fall within building site category II (ČSN 730039, 1989).

4. Methodology

In order to evaluate the building site categories within the overall study area due to the so-called ground deformation parameters, overlay analyses of the building site categories were carried out. The results of these analyses were evaluated in relation to the current built-up area, the land use plan and the engineering-geological zoning. Engineering geological zoning map can be seen in Fig. 3. Overlay analysis using the maps of building site categories in various time periods, mining subsidence, engineering-geological zones, currently built-up area, future development built-up area–land use plan and topographic map was carried out in GIS (Geographical Information Systems) environ using ArcGIS 9.1 (2005) software. For this analysis, individual data layers of vectorized subsidence maps (OKD) were first prepared. These vectorized data layers of subsidence maps depict the building site categories in the stated time periods with the vectorized built-up area in accordance with the land use plan and the current built-up area.

In order to establish the chronological variations in the ground surface in the building site categories, five possible building site categories were evaluated for 4 time periods of 1983–1990, 1983–1995, 1983–2000, and 1983–2005 in the analyses. The map of distribution of the building site categories in the study area in the time period 2003–2010 was then constructed for land use planning for future development.

The basic characteristic of ground subsidence is determined in two ways. The first method uses repeated measuring of exact levelling on selected polygons. The remaining network of points is interpolated on the grounds of the relevant subsidence basin shape. The second method is the so-called forecast, expected or projected. This was defined on the basis of special software used in OKD mining company. In the Development and Working Face Advance Plan (DWAP), i.e. expected subsidence isolines were determined prior to the exploitation of a particular coal face or face group. The determination was grounded in the selection of a point network on the surface and subsidence was calculated for each of them. These calculations considered the coordinates of marginal points of the planned area to be mined, its thickness, the thickness of the Carboniferous roof and the thickness of Miocene superincumbent formations. Next, empirical limit angles of mining influence of 65° for the Carboniferous and 55° for the Miocene were used.

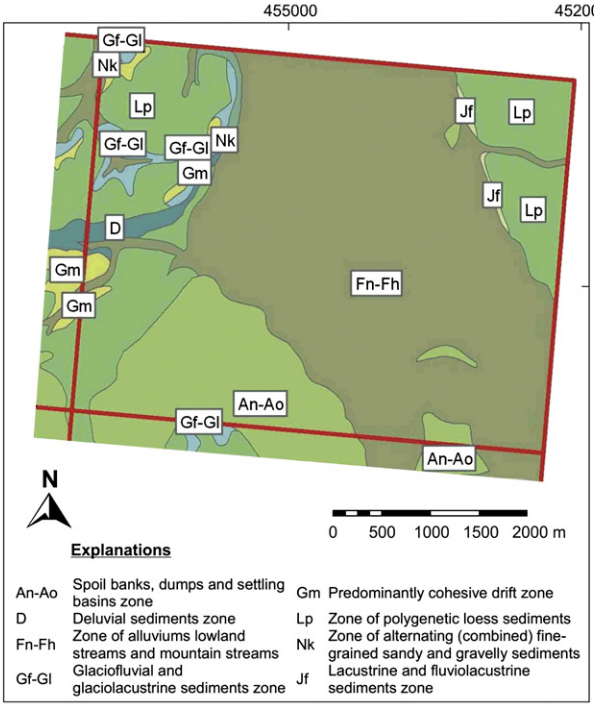

Fig. 3. Engineering geological zoning map.

5. Overall evaluation of building site categories in the undermined territory

The first step involved evaluation of the distribution of the building site categories in relation to the overall study area (Figures 4, 5), while the individual groups were evaluated from the most favourable (Category V) to the least favourable groups which exhibited the most prominent impacts (Category I). Structures constructed on site group V do not require any measures against the effects of underground mining, except for particularly sensitive structures, which require the setting of ground deformation parameters according to mining conditions (e.g. underground structures wider than 6 m., power pipes, extensive reservoirs, etc.), while constructional requirements must comply with Standard (ČSN 73 0039). However, it is always important to consider the effects of an elevated ground water level on the expected ground subsidence value. Building site category V represents a territory where stress from undermining has a value lower than the 30% stress caused by other effects, and the majority of the interest area falls within this category. Over the course of the studied time period (Figure 5) the surface area decreased from an initial 82.5% (15.06 km^2) to 57.9% (10.58 km^2). This means that during the course of the observed time periods, there was an actual reduction in this more suitable building site category due to the spreading impacts of underground mining. As a rule, all kinds of structures may be safeguarded against the effects of underground mining on land in building site categories III and IV in an economically acceptable manner provided that the recommended constructional principles of Standard (ČSN 73 0039) are adhered to during foundation engineering.

The second most spread interval is in category IV wherein an opposite trend to the previous category is noted. An increase in this category's surface area can be observed over time, and this is a consequence of a reduction in the area of building site category V. The increase starts at the value of 13.4% (2.46 km^2), continues via 15.3% (2.8 km^2) and 23.2% (423 km^2), which represents the highest achieved value of the set. This is followed by a decrease to 20.4% (3.73 km^2). The distribution of the building site in category III continues in the established trend with one difference. Here, each of the subsequent values is higher than the previous one (2.9%—0.53 km^2, 6.3%—114 km^2, 7.7%—1.4 km^2 and 11.3%—2.07 km^2).

The utilisation of building site categories I and II must be carefully considered and justified. Engineering structures are not recommended there, except those which are absolutely necessary to ensure the mining company's operation in accordance with Standards (CSN 73 0039). Other exceptions are simple structures resistant to undermining effects, which have special purpose and are of public importance. An example is railway structures, which cannot be moved or relocated beyond the reach of undermining impacts. In other cases, potential building sites in areas with the expected occurrence of ground subsidence cannot be used for building. The previously mentioned trends in building site category values continue in the last two categories. In building site category II, there was a rise in the surface area from 0.7% (0.13 km^2) to 6% (1.1 km^2). In the least suitable building of site category I, the values are slightly lower than in the previous set (0.5%—0.09 km^2, 13%—0.23 km^2, 2.2%—0.41 km^2 and 4.3%—078 km^2), but the overall difference between the first and last

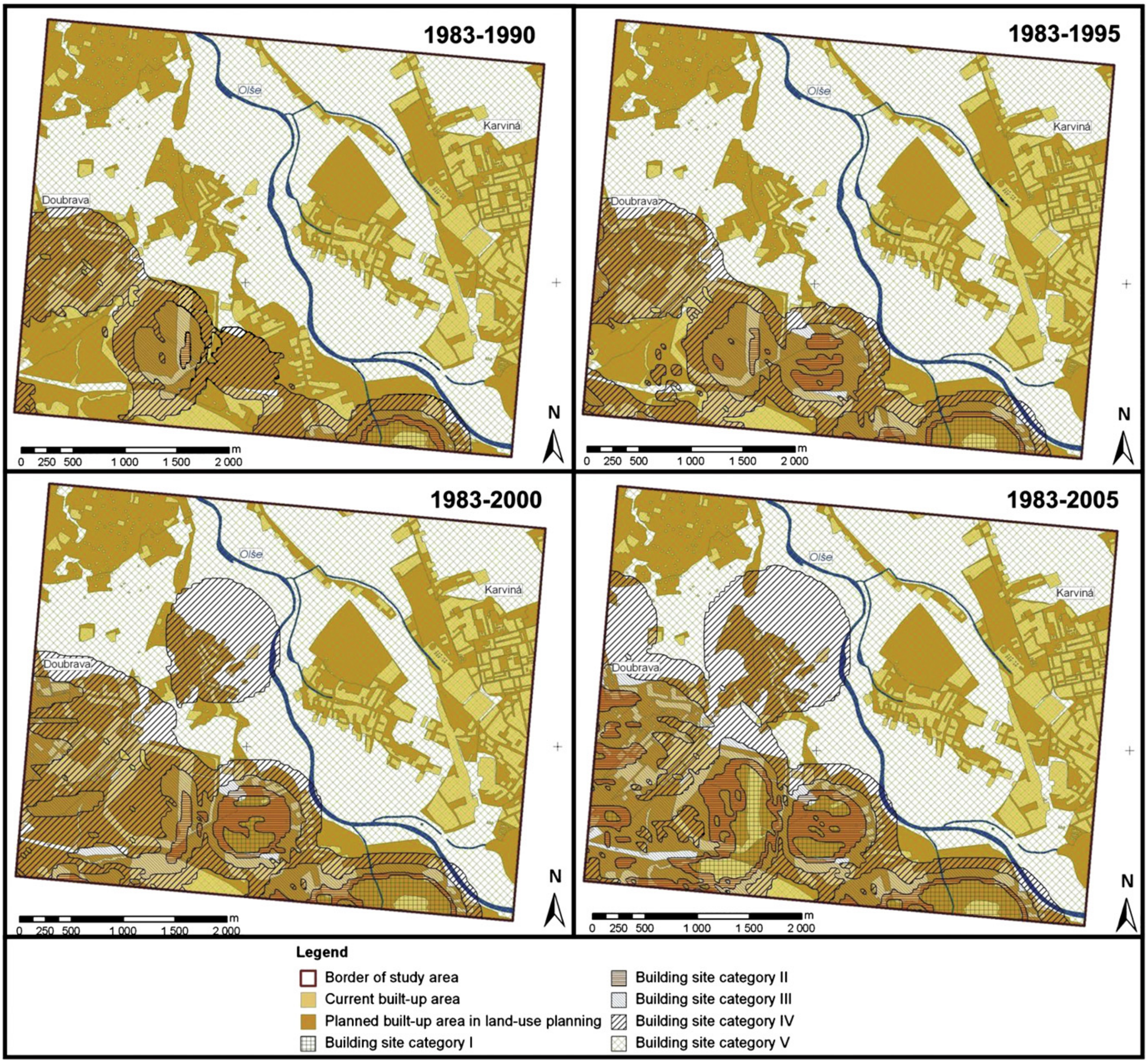

Fig. 4. The maps showing chronological changes in the building site categories.

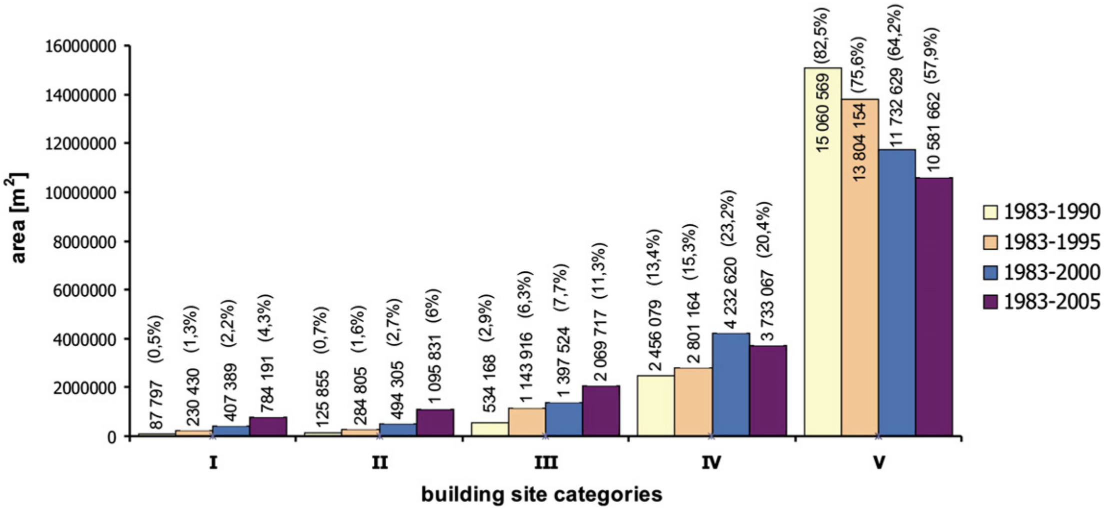

Fig. 5. Spatial distribution of the individual building site categories in the overall study area.

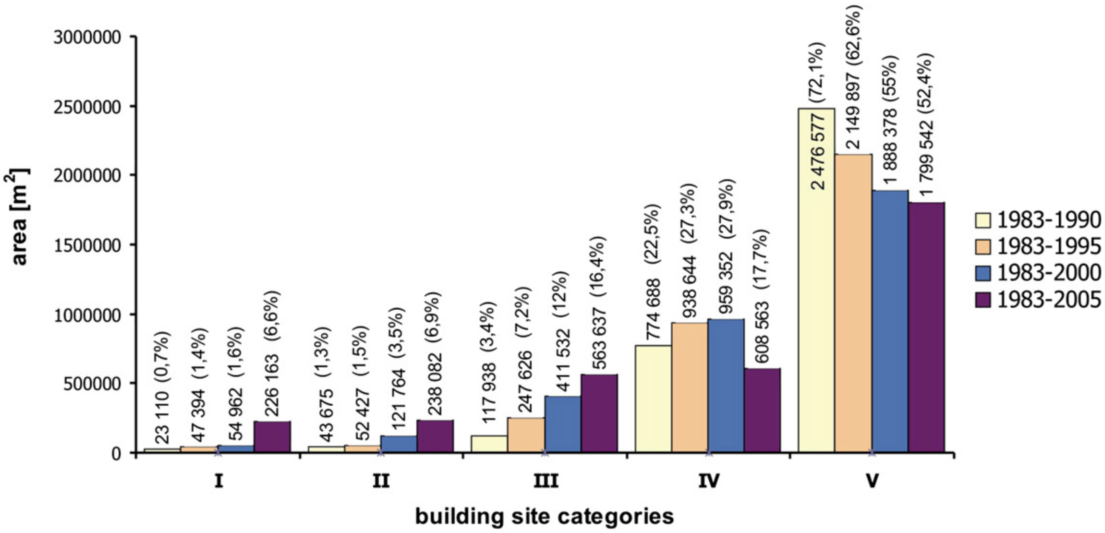

Fig. 6. Spatial distribution of the individual building site categories on the currently built-up study area in the observed time periods.

time intervals is extremely striking, showing the remarkable increase of 860%.

6. Evaluation of building site categories in relation to the current built-up area

This section evaluates the distribution of the building site categories in relation to the current built-up area (Figure 6). This constitutes an important index which exhibits a much more prominent influence on buildings than other landscape elements in the studied area. Structures already exist which are affected by underground mining, and in certain cases, it is important to reinforce them or to perform constructional corrections. Important factors which must be considered include their foundation technology, the quality of the building materials used, the shape and area of the foundations, the characteristics of the load of structure transfer, and the existent and newly formed ground morphology caused by underground mining.

The built-up area constructed on building site category V is represented by an area which decreased over the course of the four time periods from an initial value of 72.1% (2.48 km^2) to 52.4% (1.8 km^2). This decrease of almost 20% in the surface area can be explained by the change in classification of the development from the original category V into other categories. The built-up area constructed on building site category IV constitutes the second largest group and the almost ranged from 22.5% (0.77 km^2) to 17.7% (0.61 km^2) over the time periods. A trend of increasing values over time begins to be noted in building site category III. The built-up area there grew from an initial 4% (0.12 km2) to 16.4% (0.56 km^2). The surface area of development constructed on building site category II changes from 1.3% (0.04 km^2) to 6.9% (0.24 km^2). This trend is apparent in the least suitable building site of category I, where there is a significant increase between the 3rd and 4th time intervals, from 1.6% (0.06 km^2) to 6.6% (0.23 km^2), thus representing an increase of more than 400% in the built-up area in this unsuitable building site category.

7. Evaluation of building site categories in relation to land use plans

This chapter evaluates the distribution of the building site categories in relation to the planned development based on the land use plan (Figure 7). The data layer for the land use plan analysis was produced

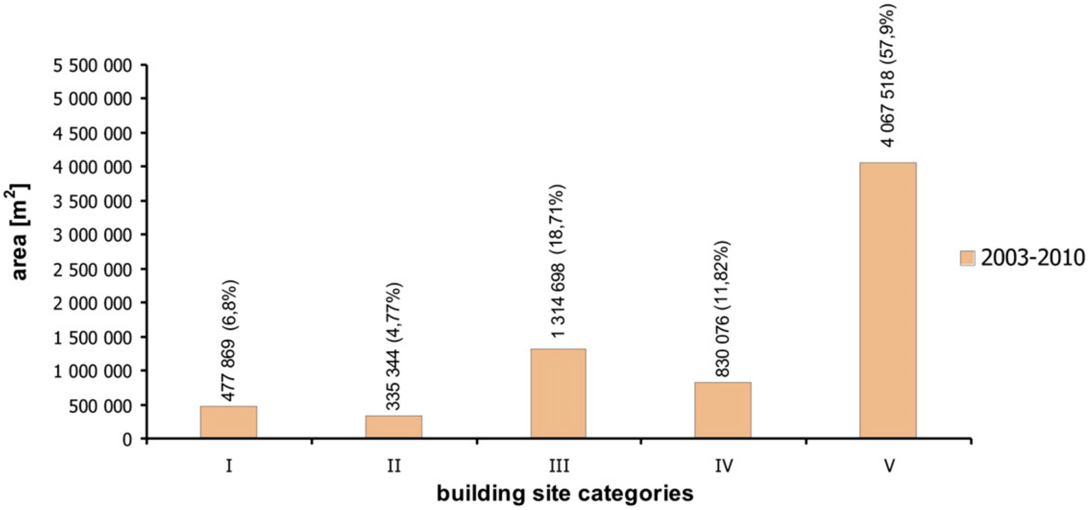

Fig. 7. Distribution of the building site categories in the study area in the time period 2003–2010 related to future development on the land use plan.

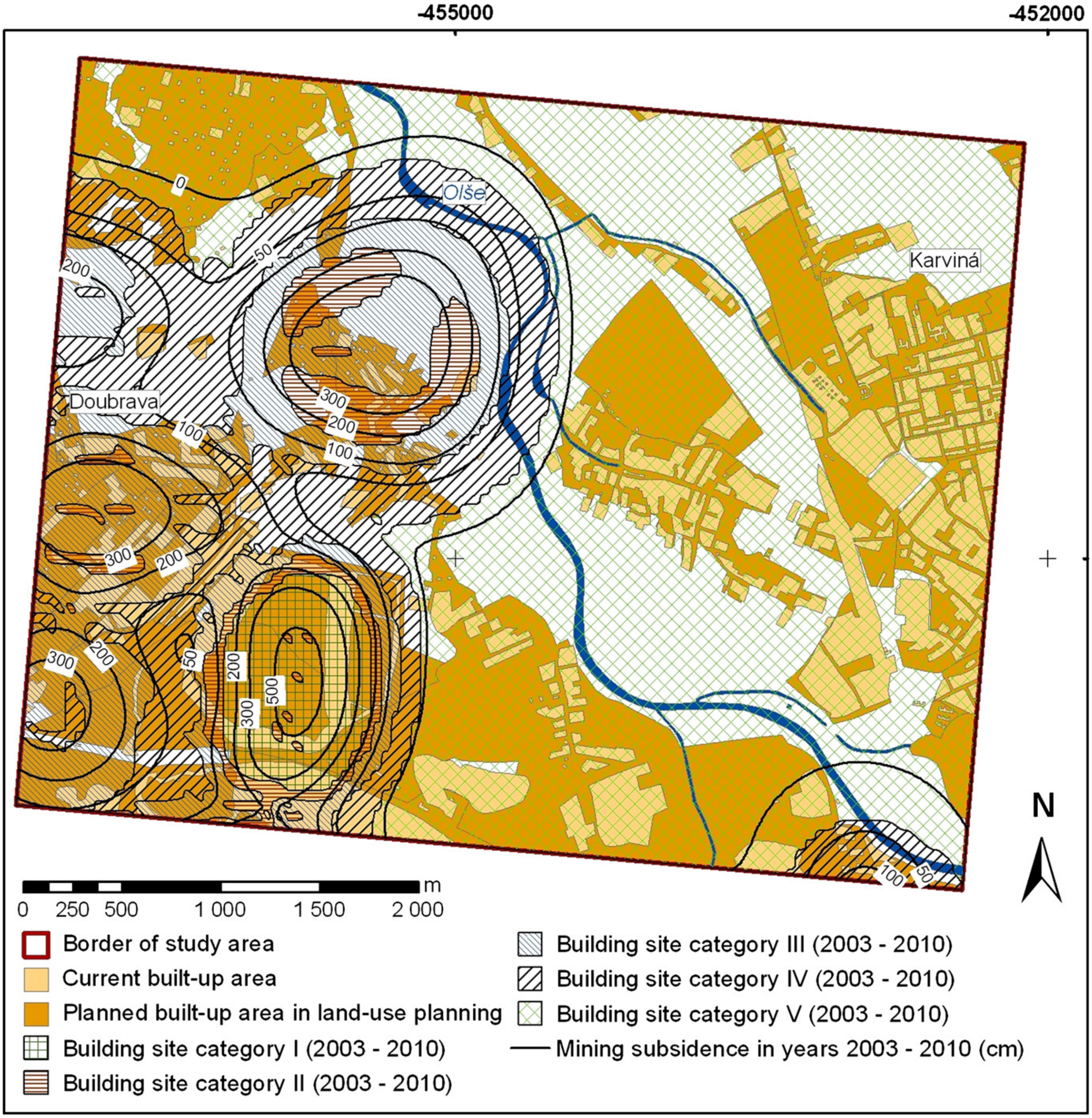

Fig. 8. Distribution of the building site categories in the study area in the time period 2003–2010 related to future development on the land use plan (subsidence data by OKD).

through vectorization of land use plan raster maps from the individual municipalities. These highlighted an extended scope of activities and their consequent complex unification in the ArcGIS 9.1 (2005) software applications. Land use planning is a sophisticated tool which permits incorporation of various marginal conditions for the benefit of rational landscape development. Undoubtedly, various geo-factors must be included in this process, as discussed by James et al. (1997), Kleb (1997), McCall (1998), Hrasna (1998), Pacheco and Oliveira (1998), Kiersch (2001), Mason and Rosenbaum (2002), Forster et al. (2004), Andrea and Allan (2007), Marschalko et al. (2008a,b), Marschalko and Treslin (2009), Gruzie and Pendergrass (2009), Bower (2010), Cui et al. (2010), etc. This study also participates in such efforts through identification of the relationship between underground mining impacts and development according to the land use plans.

It is apparent from the results of the overlay analysis that more than half (57.9%—4.07 km^2) of the planned development will be constructed on building site category V, which is the most suitable one for construction in terms of underground mining affected land (Figure 8). More than one tenth (11.8%—0.83 km^2) of the development will be built on category IV according to the land use plan. The second largest percentage is connected with the development on building site category III, with a value of 18.7% (1.31 km^2). The lowest surface area of planned development (4.8%— 0.34 km^2) will be on building site category II. However, future planned built-up area on the least suitable building site category I has a higher value at 6.8%—0.48 km^2. According to the table of Land Use Plan Categorization (Table 2), development planned on the building site category I is in the U_V_0 category of unspecified production zone and this is totally unacceptable. The other

Table 2
The land use plan categorization.

Functional zones	Codes
Zone for land reclamation	U_F
Zone of individual residences	
Zone of continuous individual housing	U_BI_1
Zone of scattered individual residences	U_BI_2
Zone of mixed individual housing	U_BI_4
Zone of family houses	U_BI_6
Zone of unspecified individual housing	U_BI_0
Mine's interest area	U_DL_2
Production zone	
Small-scale production zone	U_V_1
Unspecified production zone	U_V_0
Mixed production zone	U_V_5
Industrial production zone	U_V_3
Zone of heavy industry	U_TP
Zone of technical facilities	U_T
Zone of sports and recreation	U_SR
Central zone	U_C
Zone of collective housing	U_BH
Zone of gardening allotments	U_ZO
Zone of public grounds	U_VP
Zone of civic amenities	U_O

categories consist of U_DL_2 for mining interest area and U_F for land reclamation.

8. Evaluation of building site categories in relation to engineering-geological zones

Engineering-geological zones are important representatives of the geological environment for the sphere of foundation engineering because they generalise the geological structure into particular territorial units with analogous engineering-geological characteristics. Their significance was reported by Samalikova (1990), Vanschalkwyk and Price (1990), Demulder and Hillen (1990), Bochkarev (1994), Tosun and Ulusay (1997), Marinos et al. (2001), Delgado et al. (2003), Forster et al. (2004), Zuquette et al. (2004), Jelinek and Wagner (2007), Rasouli (2009), and Bednarik et al. (2010). The characteristics of these geological structures, especially the Quaternary one, play an important role in the impacts of undermining in the affected areas. There is a general rule that a geological structure with less suitable physical–mechanical characteristics in relation to bearing capacity and settlement facilitates a more prominent action of undermining impacts compared to those with more suitable conditions.

When examining the most prominent impact on the geological environment from an underground mining viewpoint, it is necessary to consider the spread of building site category I. It is initially important to thoroughly understand the character of its geological structure. As apparent in Figure 8, there is a dominant zone of spoil banks, dumps and settling basins (An-Ao) covering 99.5% and also the zone of alluviums lowland streams and mountain streams (Fn-Fh) at 0.5%.

In these zones, it is necessary to take into account the most negative variations in the physical–mechanical characteristics. These particularly include changes in porosity, rock volumetric weight, bulking and relative density. Subsequently, these variations influence the mechanical properties of shear strength, and deformation modules which then affect the calculation of bearing capacity and settlement in connection with future foundation engineering. The effects of such variations cannot be quantified unambiguously, but they engender differing consequences to various geological environments, especially in relation to the mineralogical composition and the granulometric character of foundation soils. In contrast, the least influence can be expected in building site category V and on land completely lacking such impacts. It is important to realise that on land with minimum subsidence and relatively suitable building site categories, situations may occur when no changes to the bearing capacity and settlement of the structure, but there may be variations in horizontal stress leading to the changes in slope stability or slope movement. This was notably demonstrated by experience gained in the research of slope movements affected by undermining carried out on the slope deformations of Doubrava Vrchovec (Marschalko et al., 2008c), Oplizi, Ujala (Marschalko et al., 2008d; Marschalko and Treslin, 2009), Staric (Marschalko et al., 2008e). This was also evident at Repiste and Orlova Lazy in the Ostrava-Karvina Coal District, where the slope stability was influenced even on the quite favourable building sites in categories IV and V.

9. Results and conclusions

The results of the building site category evaluation in this undermined territory (Figure 5) imply that the majority of the interest area (57.9%) falls within building site category V, and that this category has relatively good conditions for founding all kinds of structures. However, it was then necessary to consider variations over time in the surface area of less suitable building site categories. A trend certainly confirmed the existence of the previously presumed mutual relationship between building site categories and subsidence size distribution.

The resultant research information on building site category evaluation in relation to the current built-up area showed that as much as 6.6% of the current built-up area has been constructed on the least suitable building site in category I. In contrast, more than half of the development (52.4%) is situated on the more suitable building site category V, and consequently this presents lower future risks in this development (Figure 6).

It is apparent from the analytic results of the relationship between building site categories and planned development that the majority of the map sheet area (5.9%) falls within building site category V and therefore it has relatively good conditions for all kinds of structures (Figure 5). According to the table of Land Use Plan Categorization, the 6.8% development planned on building site category I is located in the category U_F of land for reclamation, in U_V_0 for the unspecified production zone and in U_DL_2 of the mining study area. This implies that the negative impacts of mining have been only partly considered, or completely disregarded, in the development planning process. Consequently, future land use planners should carefully consider these particular building site categories as the most important and significant factors in the undermining of a region. In this manner, development can be successfully planned for present and future safety.

The final analysis in the map sheet entailed an assessment of the merging of building site category with engineering-geological zones (Figure 9). The overall research results, confirmed that building site category I contained land with the least suitable conditions for foundation engineering. In this area, the dominant zone is the zone of spoil banks, dumps and settling basins (An-Ao) with 99.5%. This certainly manifests the intensive anthropogenic activities connected with deep mining in this locality, and furthermore it clearly illustrates the characteristics of foundation soils on which it is possible to found future engineering structures.

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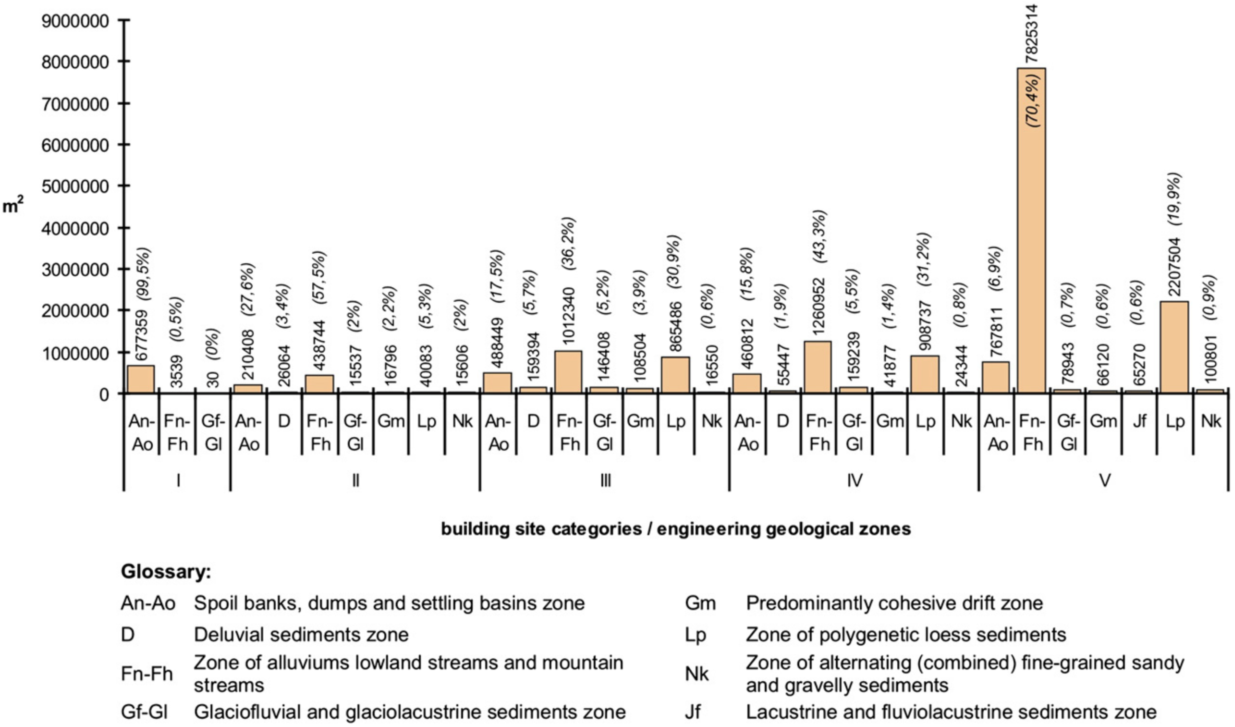

Fig. 9. Dependence of dominant engineering-geological zone distribution on the estimated subsidence value intervals in 2003–2010.

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