Multiplication Analysis of the Cause, Form and Extent of Damage to Buildings in Areas with Mining Impact

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Abstract. This publication is a summary of all tasks carried out in recent years of research, calculations, simulations and analyses related to the performed research on parameter analysis that affect the form, scope and cost of removing damage in buildings and structures in areas with mining impact. The analysed problem is interdisciplinary and contains legal, geotechnical, engineering - mining, construction, material and economic analysis. The ground reaction forces were analysed for buildings and structures in the mining area. Coordinating activities of the land model, foundations and construction of buildings and structures in the mining area were adopted and the distribution rights and changes in additional reaction forces of the structure in the mining area were analysed and various factors which affect the construction damage were indicated. Problems were also identified in the mining impact forecasts that affect the design scope of new engineering structures and the impact of existing buildings and structures. The influence of various factors was analysed and additional dependency formulas were proposed, which are needed for current calculations and analyses of the scope and costs of strengthening the structure or its modernization. Based on the output data and the analysis of the results of the empirical examination of selected buildings, the determination of all factors affecting the technical condition of the building erected in the areas with the impact of mining operations. Classification according to currently used guidelines and clarification of new attributes affecting the technical condition of buildings and structures (typical and modern geometry of the building's structure, type of foundation, type of construction protection, type and stiffness of the structure). Backward analysis of damages (their temporary changes) identified as factor affecting the current state of engineering objects.

1. Introduction
The motivation to take up the subject was a result of my technical, economic and scientific career path, filled with research on specific issues regarding legal, engineering, geotechnical, mining and economic issues of the subject in question. Confirmation of the validity of the problem is proved by the results of tests and analyses and scope of designing new buildings and removing damage in existing ones in performed, which specify the relevant engineering and economic parameters, affecting the methods and technologies of removing damages to buildings in mine areas.

Particular parts of the original series of publications [1-12] describe the research, calculations and analyses carried out over the last years under the research project "Mining Damages in Building 2013-
"2019" as part of own research at the Cracow University of Technology and at the University of Bielsko-Biała. These publications contain descriptions and analyses of the conducted research on the problem of analysis of dependent and independent attributes from the considered interdisciplinary data set containing design, construction, engineering, geotechnical, financial, economic and legal parameters which have a significant impact on the methodology areas with mining operations impact. This series of publications is a description of all-important research tasks within the cause and effect of the Ishikawa diagrams analyses carried out. The analysis of the output data for the problem of repair of engineering structures on the land of mining exploration is very important, because different initial assumptions result in different solutions to the same problem and this is the main reason for discrepancies in opinions and expert reports - in particular the ones ordered by courts. From the scientific viewpoint, various solutions provide the basis for problem analysis and the search for optimal solutions for appropriately formulated initial assumptions. My master's studies knowledge gave me the basis for theoretical analysis of the phenomena that take place in engineering structures. Developed doctoral thesis [13] knowledge gives the opportunity to model, calculate and analyse the appropriate substrate model with appropriate, additional static and dynamic impact on the engineering structures built. In addition, my continuing professional development described in item. The time devoted to acquiring empirical knowledge during the implementation of outsourced problems for various types of engineering, geotechnical, economic or legal solutions creates an appropriate research field for parameters directly and indirectly affecting the system of the structure-substrate interactions impacted by the mine exploration.

2. The scientific objective
The scientific objective is to estimate the significance of variables defined for particular functions, describing the nature, scope and type of impacts on buildings located in areas with mining exploitation due to the technical condition and costs of possible protection and repair or modernization. Specified and diagnosed variables were analysed within selected aspects, with particular emphasis on the limit state of load bearing capacity and serviceability of the structure. Forecast knowledge of the process of securing or repairing buildings on active subsoil in the assumed time interval of their use and the pre-determined mining impacts is irreplaceable when analysing the activities and costs of building interaction with the subsoil on mining areas throughout the life cycle of the building.

The initial assumptions and the appropriately specified scope of studies in the form of scope and programs for strengthening and / or repair or modernization require a diagnosis of interactions of particular variables of the functions under consideration.

The subject matter is interdisciplinary, covering both subjects in the field of construction, geotechnics and mining, as well as stochastic processes, econometrics and reliability of output data predicting the operational impact of mines in urban areas. The methodology of analysis and diagnosis presented by the author for a given group of buildings may be the basis for specifying strategic decisions in determining their use in local development plans together with appropriate guidelines which need to be met before receiving a building permit and when forecasting mining impacts on given urban areas.

3. Description of multiplication analysis – the first stage
I began to analyse this issue from studying the current legal and methodological guidelines, both national and international. Concerning the problems touched upon in court opinions and expert studies for legal and natural persons, regarding the analyses of engineering structure-subsoil interactions on mining impact areas, I analysed current publications of mentors for these issues, starting from the creative theories (Knothe 1953, 1984, 1993; Salomon 1989; Reddish 1989), where operating rims of load troughs are analysed and forecasts of terrain deformations are formulated, through to further analyses using increasingly better computational capabilities for required parameters and dependencies (Keatzsch 2008; Hu Lian 2015; Zhang 2016; etc.). The publications of Polish scientists (Białek 2003, 2011;
Federowicz 2000, 2006, 2008, 2014; Filcek et al. 1994; Gromysz, Hejmanowski, Kawulok 2010; Kowalski 2013, 2015, 2017; Kwinta, Mičiūnas 2008; Mrozek 2010; Niemiec; Tajduš et al. 2012; Wesołowski 2013, 2016) give a picture of the current situation of this problem and show the directions it follows: rock mass modelling and engineering structures located on the surface with additional mining impact and forecasting the time and size of deformations for the assumed models of the impact of underground exploitation, as well as the analysis of the form of interactions on the structure and behaviour of building materials incorporated [14-32]. A number of scientific as well as engineering and design publications have been analysed, which studied the impacts of mining operations, the speed and magnitude of ground deformation, works on the analysis of individual engineering stages interactions with mining impact as well as repair and modernization of structures, e.g. by building rectification or contact injection pushing away the ground substrate elements [12]. Data from the research, conducted within the research projects, created various groups of initial parameters for the analyses, for selected econometric models, depending on the initial coherent analysis criterion.

Data on the physical and strength parameters of the ground on which the analysed building structures are built also determine the appropriate calculation models of the building interaction with the subsoil for the assumed initial assumptions as to the representative physical and strength parameters and the selected impact model. In addition, mining data on the forecast of mining exploitation impacts impose further significant variables on the calculation model.

In the first variant, it was assumed that calculations and analyses in the scope of defining the method for protection, repair or modernization in terms of time and cost of repairing damage to specific groups of real estate were conducted to define the initial restoration of all design construction assumptions of buildings or structures. In the second study option, the main objective was to adjust the subsoil to the standard requirements and to adequately protect it from the investment in mining areas in terms of determining the costs of such an approach.

Proper assessment of the variability of the scope of impacts in the aspect of the analysed variables is a key task of clearly defining the rules, determining the scope and costs of mining impacts on the urbanized surface above ground. The solution of various problems related to the variability of dependent task variables enables a uniform analysis of interactions and proper diagnosis of reactions to emerging changes, which ensures balanced development of the discipline.

In the publication [1], I presented the conclusions from the analysed impact of mining exploitation on properties with significant engineering structures according to the guidelines of the local spatial development plans. The article [2] presents the results of the study and analysis of discrepancies in the forecasts of mining exploitation impacts on specific areas and the final results of the active mining impact on land properties with components in the form of buildings with different functions. In publication [3], on the other hand, the analysed application of the principle of the mine operation activities impact on buildings and people with an original proposal of new coefficients for the analysed group of buildings commissioned for use in this century was presented. The [5] publication, on the other hand, presents a residual method analysis, estimating the market value of real estate in mining exploitation areas, while [7] presents the results of economic and geotechnical analysis of variables affecting the way the buildings are used in areas with mining impact. In monograph [12], the results of analyses and calculations of specific model variables of the considered problem are described, with specific weights of individual task attributes assigned. Data analyses were performed irrespective of the function and manner of land development, as well as of the values of individual model variables that had different ranges of end values. The analysis covered the group of buildings from 2000-2015.

Then the analysis of protection against mining impact was carried out with division into undeveloped and built-up properties. In the latter group, it was limited only to properties developed with residential
and commercial buildings. For the analysis of the first variant (undeveloped property), the number of variables for this group is limited. It is due to the fact that such analyses take into account many factors related to the designed or existing building, such as the design analysis itself, methods and form of works, materials used for construction, and in the case of existing buildings, additionally the scope of technical wear and the forms of repair or rectification. In the present case, the main objective of the analysis is carried out by preventing the adverse effects of the subsoil on which the construction project is planned to be implemented. Identification of factors influencing the elimination of unfavourable mining impacts was carried out. As part of the implementation of the topic, assumptions were also made to improve the market value analysis of design and construction of buildings and structures in areas affected by mining exploitation - in the form of an intelligent system for determining methods and costs of strengthening the subsoil that is being adapted to the new BIM (Building Information Modelling) approach [9].

The publication [12] presents national and European construction problems in the areas with mine operation impact and diagnosed parameters affecting the type, structure, form and scope of building construction effects on static and dynamic operational impacts of mines. On the basis of the analysed sets of output data and for selected calculation models, various values were obtained, which confirmed the high impact of certain variables on other variables in the analysed cases. Based on the analysis, it was found that for areas designated for development in local development plans in mining areas, the costs of strengthening the structure and the subsoil, ensuring the assumed time of use, doubles the replacement value for medium-class buildings. For buildings with unusual shapes or structures and for a standard of building finish that is higher than average, the costs of protection and repair or modernization are growing, and growing in the exponential function trend.

4. Description of multiplication analysis – the second stage
In the second stage, built-up developed land was analysed. In the case of existing buildings, the subject of the analysis should include damage occurring in the form of cracks or scratches of various structural and non-structural parts, and, in addition, displacements or tilts of the entire building structure for which adverse mining impacts were determined. A big problem is the separation of variables responsible strictly for the effects of mining interactions, from design, execution variables and variables defining the finish class, and technical wear of the structure based on the analysed damage impact function. Therefore, after the initial analysis, appropriate initial assumptions for the specified variables were adopted in the tests and calculations. These variables are certainly interdependent; however, the general analyses allow to obtain results for which values are in large ranges. For selected subgroups, analyses for zero-one-time values and for the failure intensity function \( \lambda(t) \), defined as the quotient of the density of the random variable determined by the Laplace density transform and the reliability function determining the probability, were adopted. In addition, it was assumed that the time of object damage exceeding limit states is greater than 1 for the analysed exponential distribution. The analysis of failure characteristics \( N_0(t) \) and structural renewals is determined by the appropriate value of cumulative distribution function and density function. Assuming \( \eta = 1/\lambda \), the Weibull distribution follows, where the probability of an event in the time known from the mining forecasts \( \Delta t \) is approximately equal to \( \lambda_{i} \cdot \Delta t \). Which is the average of the events detected in a given unit of time. These values depend on the time and number of intervals. As a result of the analysis using the Weibull distribution, information on the expected value, variance of the distribution and the coefficient of variation for the analysed building structures were obtained. This approach does not refer to the structure itself, i.e. it was taken for all elements that meet the initial assumptions of the study. The assumptions were as follows: buildings with a maximum age of 16 years and the compliance of building design guidelines with entries in construction logs - in terms of quality, quantity and type of construction materials and technologies used. These variables become constants for such assumptions. In addition, the maintenance of facilities is assumed to be at least at the medium level, i.e. with a maximum technical wear not exceeding \( S_t = 10.00\% \). Other assumptions were made for further calculations of the value of renovations or upgrades, which are
estimated after determining the scope of damage in the given buildings, to the extent that was recognized in legal terms as mining damage.

The publication [12] presents the results of the statistical analysis carried out by the author, based on the econometric model of the influence of the coefficients of individual methods and approaches to the analysis of the value of adverse mining impact forecasts for areas to be developed in accordance with the local development plan. The coefficients selected by the author are the dispersion factor, random factors, the adopted calculation model, the mining gangway and the exploitation coefficient as well as the rim parameters and the coefficient of expert values allowed according to the EC standard guidelines. Also described here is the method of reinforcing the substrate in the form of injection into the established contact zone of the designed engineering structure with the substrate, i.e. in the future area of the greatest loads and additional stresses. The analysed method consists in the contact injection pushing out the elements of the subsoil. Changing the technology of this method and initial assumptions may improve the method with a new variant of creating a "mining disadvantage zone." The analysed method consists in pumping a stable and suitably modified filling material into the subsoil that leads to compression of non-cohesive soils. The degree of soil compression (ID) increases with this method, and in the option of modernizing the cohesive substrate, the primary and secondary compressibility modulus (M), (M0) are increased and the parameters of cohesion and effective cohesion of the soil (c0) and (c’0) change. The ability to properly select all process parameters, in particular the composition, amount and manner of the filler application, is of great importance for the process and effectiveness of this type of injection. In addition, thorough observations of the substrate displacements and interactive design are necessary. Preferred methods of injection are substantively regulated in European standards, e.g. EN 12 715.

Analysing the random variable, which is mining impact greater than assumed and impacting building structures for much longer than expected, the description of the ground soil characteristics and its response to the impacts of individual limit states comes into play. For the analysed cases, a normal distribution was obtained with the expected value ($\mu$) and variance ($\sigma^2$), which determine the subsoil parameters and the manner of response to the interactions. These results are very similar to the actual strength characteristics with known or assumed level of reliability. The analysed methods are feasible in virtually all soil conditions, and their scope can be planned for multiple different mining impacts. From the environmental point of view, it is a very friendly technology for the modernization of the subsoil due to the use of harmless ingredients as the injection materials. Time and size of deformation forced by exploitation, as well as the size and stiffness of the building structure and parameters of the modernized subsoil, especially the level of pre-consolidation of the soil and soil stratification, are the main elements important in designing the reinforcement and choosing the type of foundations. Publication [7] and [12] presents the results of statistical analysis of prices for works related to the modernization of the subsoil. The analysis was based on the econometric model of the impact of ground surface modernization methods on the analysed market attributes [33-35], affecting the value and time of investment to prevent the formation of adverse mining impacts on areas designated for development. Both in these results, as in the histogram and the distribution function of the Monte Carlo simulation for the analysed 120 cases of designed and executed modernizations and the strengthening of the subsoil intended for development, aspects of the market value of such modified land property fall within a very large price range.

In the publication [3], the input data is data from vibration analyses, i.e. information on the vibrations of subsoil and structures on the surface of the studied area in the function of time. The macro-seismic and macro-geotechnical measurement scales in the interpretative process determine the appropriate parameters characterizing the description of the subsoil and building structures interactions, considering all types of static and dynamic interactions and their combinations, as well as all known cases of interactions of selected types of subsoil with pre-determined maximum loads of buildings and structures specified at the beginning, with the adopted maximum cubature of buildings and in the assumed time.
interval, resulting from mining forecasts. All analysed, confirmed and adequately qualified data were compiled into appropriate data groups, where the quality and quantity of descriptive variables, as well as the possibility of grouping and unifying them with appropriate coefficients is assessed. In the carried out and described analyses the author stated that the analysis of other dynamic impacts on buildings such as wind, transport vibrations or dynamic phenomena of geotechnical works on neighbouring properties are ignored. Therefore, in case of finding any dynamic interactions other than strictly mining-related, a given building has not been qualified to the representative data set for the analysis of a given extent of mining impacts. The reason for the rejection was the fact that at the time of the calculations the selected calculation and estimation scheme prevents correct and indisputable estimation of the parameter separating the dynamic effects of the selected source from other diagnosed sources. In addition, the described analysis did not take into account properties with calculated technical wear with the assumed value of less than 10%, for properties classified as well-managed in terms of maintenance management.

The subject of the analysis was to determine the degrees of harmfulness of rock mass tremors for objects from the separated groups D and E. However, the results presented, according to the author, are only a proposal due to the number of cases analysed in the data sets. The parameters of shocks necessary to assess the degree of vibration intensity on the surface for the GSID scale is the duration of the horizontal velocity component and the maximum amplitude of the horizontal vibrations’ velocity, determined as the resultant of the horizontal maximum of the vector length. Receivers of horizontal vibrations: $x$ and $y$ are in one plane and are mutually perpendicular. Such a calculation procedure allows to become independent of the direction of assembly of vibration receivers. Analysis of the type of damage to structures in the area of mining impacts and vibration parameters measured in selected representative monitoring locations allow for continuous verification and modification of the current limits of intensity for individual scales. All analysed scales are open scales and are intended to be the basis for determining an approximate preliminary assessment of the impact of mining shocks on buildings - starting from harmless vibrations ranges, through to vibrations causing damage in structural elements or finishing. Both in terms of the strength of these vibrations as well as on their frequency and the dynamic and static impact on building structures and subsoil, the scales are created to assess the level of impact of vibrations on limit states of bearing capacity and usability of building structures and the perception of this phenomenon by people. Publications [1] and [2] summarize the scientific achievement by systematising the analysis of the impact of mining forecast values on entries in local development plans, on designing structural reinforcements for building structures located in areas affected by mining impact, as well as on repair models and estimates, and modernization of the structure, based on the output data from forecasts and real data at the time of conducting the analyses. The theory of S. Knothe and W. Budryk (K-B) is commonly used to predict mining impact. The theory of forecasting these mining interactions must meet the postulates of the mathematical centre model, i.e. fulfil individual postulates, such as the postulate of transitivity, which determines the properties of the function of the variation of the radius range for main impacts in the analysed area.

The analysis shows that despite many scientific studies and ongoing work to improve the correlation, there are still differences between the parameters calculated and measured in the mining exploitation forecasts. In search of an answer to the reason for the discrepancy, the author made analyses using her own studies. As a result, she found that an important starting information is the description of the type and time of mining operations in the analysed area, and therefore the history of mining-origin loads. The parameter of the total thickness of the exploited area together with the dates of exploitation and the dates of measurements is also important. She also stated that the history of the analysed area is crucial, due to the inelastic behaviour of the soil and the so-called soil memory, which should be included in the description of soil behaviour with appropriate constitutive compounds in the computational model developed for the purpose of these analyses. Bearing in mind the multiplicity of mining exploitation and the total surface subsidence measured, the independent calibration of the parameters of the K-B theory
was carried out, according to the generally available knowledge about the surface deformation impact on the maximum subsidence. Thickness of the bed (layer), or so-called mining gangway (g), and the exploitation factor significantly affect the shape of surface deformation. Errors in the analysed computational models result from the inadequacy of the prognostic model against the reality. Therefore, according to the author, random factors resulting from the scattering of deformation rates around the average forecast value should be included in the procedures for forecasting the impact of mining operations on building structures [36-40]. The conducted own research show that deviations of forecast parameters in relation to values measured later can be exceeded by the value of a single standard deviation with the probability of 70%.

5. Results and discussions

In its scope, the analysed scientific achievement refers to two research areas, the first of which is the development area in the mining impact zones, and the second is the analysis of the scope and form of unfavourable structural effects in reaction to the active mining subsoil. The first analysed area covers issues related to physical and mechanical parameters of the subsoil resulting from loads transferred from the newly-constructed building to the subsoil and due to loads generated by the impact of underground mines. The second analysed area refers to the study of the impact of mining methods used to predict adverse effects of terrain deformation and the associated adverse impact on building structures, determined during the analysis of individual cases. This is related to the analysis of the impact of the location of the property in relation to the mining operations and the history of mining operations in a given area, with particular emphasis on those carried out under a given property or in its immediate vicinity. What follows is an analysis of the impact of identified factors on the market value of land properties. The scope of scientific activities is implied directly from property valuation, appraisal of the property, construction and mining damage to entities that perform public tasks as well as natural and legal persons. The research covered a total of about 100 land properties and based on their analysis, final conclusions were drawn as described in detail in the publication. The reasons for the analysed discrepancy between the forecast and subsequent measurements of terrain deformation result, among others, from: not adhering to the exploitation project assumptions, incorrectly assumed thickness of the analysed bed, incorrectly assumed exploitation time, the shape of the exploitation field other than assumed, the method of liquidation of the after-operation space other than assumed and from disregarding the history of the land surface.

Based on the comparative analyses, the shape and size of the field of exploitation is the same in the exploitation design and on many bed maps of the completed exploitation inventory, which is highly unlikely. The analysed walls are exploited with a mining lining, at the assumed height of the gangway with a ceiling caving. The operating coefficient assumed in the forecast is in line with the knowledge of deformation according to the assumed theory, but it is not compatible with the analysis of the deformation of the whole area with several beds previously exploited multiple times. Based on the research conducted in the analysed studies, the parameters of the mining forecast are burdened with an error from 38.07% to 64.85% in comparison with the actual data analysed.

The proposed changes and additional guidelines for the parameters used in the assessment of limit states and repair costs, taking into account the longer time function when forecasting mining impacts, is an original method of establishing adverse changes in buildings in areas with mining impact. The predictive analysis and time diagnosis of structural changes to buildings presented in monograph [12] and in articles [1], [2], [3] and [5], [7] is a new method, taking into account all studied variables. Modification by enlarging over 40% of the curvature radii of the terrain forming the area of mining impacts and doubling the duration of mining impact (in particular in the case of analysis of areas covered by another mining exploitation), allows obtaining results consistent with empirical data for residential buildings.
The models of mining impacts on buildings for typical traditional guidelines were analysed, taking into account the exponential distribution of Weibull reliability during use, i.e., after elimination of any damage to the structures related to design, material or executive errors and during forecasted mining interactions when technical wear is constantly modernized. The principles used in econometrics were used to analyse the impact of individual variables. Determining changes in serviceability limit states of the analysed buildings in accordance with the standard recommendations requires permanent monitoring of the structure and terrain when approaching critical values, according to the forecasted and confirmed starting conditions. The nonlinear methods of interaction processes of the active subsoil and the engineering structure are analysed taking into account the role and weight of the individual components of the considered problem.

6. Conclusions

The analysis of output data, the choice of calculation models for different groups of variables and the determination of appropriate assumptions of the initial analysis of the building’s interaction with the ground subject to mining operations is a contribution that may help in unification of the guidelines in all analysed aspects of the mining impact. Systematisation of the output data defining: the values of forecasted mining impacts, technical requirements of buildings affected by mining impact, substrate models and mining impacts as well as legal guidelines and specific methods of valuation for costs of repairs and modernization of the damage, would result in a reduction in counter-opinions or expert reports for the same case [41-45]. The very specification, at the outset of the opinion, of the initial conditions defined to be adopted, clarifies the final results of the analyses and calculations, and thus results in solving multiple problems occurring in practice. The presented approach is an attempt to combine various aspects of the necessary analyses into one coherent interdisciplinary study concerning the design of new or repair of old buildings erected in the area of mining impact.

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