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ACCURACY ESTIMATION OF THE APPROXIMATED METHODS USED FOR ASSESSING RISK OF BUILDINGS DAMAGE UNDER THE INFLUENCE OF UNDERGROUND EXPLOITATION IN THE LIGHT OF WORLD'S AND POLISH EXPERIENCE – PART 2

ANALIZA DOKŁADNOŚCI PRZYBLIŻONYCH METOD OCENY ZAGROŻENIA BUDYNKÓW WPŁYWAMI PODZIEMNEJ EKSPLOATACJI STOSOWANYCH W ŚWIECIE I POLSKIEJ METODY PUNKTOWEJ – CZĘŚĆ 2

This paper is a continuation of theoretical analyses of World's methods used for assessing damage risk to buildings with continuous strains, which were presented in Part 1. The authors focus only on those methods in which the scale of damage to buildings can be approximated. Selected methods were tested on 100 random objects sited in hard coal excavation-induced areas. The efficiency and effectiveness of those methods was evaluated. The damage risk was also verified with the use of a method currently used in Poland. The efficiency results obtained for World's methods and the one used in Poland turned out to be comparable. Practical studies were made to evaluate the adaptability of those methods in the underground exploitation-induced conditions in Poland.

Keywords: mining damage, mining, continuous deformation, risk, building vulnerability assessment

Artykuł stanowi kontynuację badań teoretycznych zaprezentowanych w części pierwszej, dotyczących oceny możliwości wykorzystania metod stosowanych na świecie do oceny zagrożenia budynków deformacjami ciągłymi. Skoncentrowano się jedynie na metodach pozwalających na przybliżoną ocenę stopnia uszkodzenia obiektów. Wybrane metody przetestowano na 100 losowo wybranych obiektach z terenu poddanego wpływom eksploatacji węgla kamiennego. Przyjęty tok postępowania pozwolił na ocenę efektywności oraz skuteczności tych metod. Ocenę zagrożenia budynków przeprowadzono również przy wykorzystaniu metody stosowanej obecnie w Polsce. Wyniki ewaluacji zagrożenia metodami światowymi można było porównać z efektywnością Polskiej metody. Badania praktyczne pozwoliły na ocenę możliwości adaptacji tych metod w warunkach eksploatacji podziemnej w Polsce.

Słowa kluczowe: szkoda górnicza, eksploatacja, deformacje ciągłe, ryzyko, ocena odporności budynków

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1. Introduction

Mass evaluation of building damage risk due to horizontal strains of ground is a very important problem in many countries. In Poland it is mainly encountered in areas staying under the influence of hard coal and copper ore excavation. The mining entrepreneur is obliged to evaluate the risk of objects sited in the mining area, use prevention measures and fix up the damage if it occurs. Mining areas in Poland are very intensely managed, therefore the problem of correct evaluation of the risk of damage to buildings has a broad range. The method used in Poland is based on point approximation of building strength followed by comparison with the predicted continuous strains (maximum strains and tilts). This method is fast but its accuracy is relatively low (Wodyński, 2012). The criteria assumed as boundary for a given terrain category and building strength category are universal for all types of underground excavations in Poland. In other countries the damage risk is assessed with a number of methods based on the assumption that damage degree can be fast evaluated for a large population of buildings. Attempts were made in the paper to evaluate the damage risk to buildings in a mining area on the basis of selected methods used over the World (Boscarding & Cording, 1989; Burland, 1997; Mine Subsidence Engineering Consultants, 2007; National Coal Board, 1975; Wagner & Schumann, 1991; Yu et al., 1988) and the Polish point method (Przybyła & Świądrowski, 1968; Instrukcja 12, 2000). The evaluation was made for a group of buildings which were damaged under the influence of on-going excavation works. Thus it was possible to compare the predicted damage degree with the actual damage to the buildings. The analyses were conducted with the use of GIS and forecasting software MODEZ which considerably enhanced the computation process and classification of the damage degree (Hejmanowski & Kwinta, 2010). The obtained results could be used for evaluating the efficiency of tested methods in the light of actual damage. By using some methods for assessing damage risk to buildings in the excavation-induced conditions in Poland it was possible to explain the causes of the discrepancy between predictions and the actual state. With the practical approach it was also possible to reveal the shortcomings of those methods and determine which of them are most effective and fit for the Polish conditions.

2. Characteristic of the study area

Empirical data were collected in a coal mine area (Upper Silesia region). A group of buildings sited over an active excavation which has never induced them before, were preselected. These were detached, low houses (one – 35%, or two-floor 65%), typical of industrial-agricultural centers. About 80% of all objects were estate houses made of brick, mostly with cellar, the remaining ones were farm or commodity buildings. About 80% of the buildings were elevated before 1985.

The study area was so selected as to make the ground continuous strains the main factor determining the damage degree. The spatial distribution of ground strains could not be determined on the basis of measurements in the given area. The strains were monitored with too low frequency and the density of observation points insufficient to determine the spatial distribution of extreme indices of strain. Ground strains were estimated with the use of the software Modez. The buildings were so distributed that they covered the area of continuous strains of low and high values (horizontal strains up to 8 mm/m). All data referring to the design and strength characteristic of buildings, measured surface damage were integrated by GIS.

3. Research methods

The research methodics assumes acquiring information about the strength of the buildings to continuous strains, determining excavation-induced deformations under buildings, and recording real damage to the buildings. The technical state and strength were assessed on the basis of a construction inventory made before the exploitation started. The technical state of most of the buildings was mediocre. The buildings had the strength category 1 (32%), 2 (65%) and 3 (3%). No buildings of 0 or 4 strength category were found in the analyzed group. There were also acquired data about damage to buildings caused by the negative influence of underground exploitation. Those data were obtained on the basis of claims and protocols of damage made since the moment the excavation impact has manifested itself on the surface. Thus defined group of buildings were analyzed for damage risk with the use of selected methods. Damage predicted with chosen methods could be compared with the real ones which actually occurred in the buildings.

3.1. Results of risk of building damage evaluation

The buildings were assessed for the risk of their damage on the basis of data about the design and geometry of buildings, as well as the predicted strains underneath. The results of evaluation of building's damage risk with six methods are listed below. For simplicity's sake, the following abbreviations were introduced: NCB (National Coal Board method), W&S (Wagner and Schumann method), MSEC (Mine Subsidence Engineering Consultant method), Bur. (Burland method), B&C (Boscardin'a and Cording method), Yu (Yu method), Pol. (Polish method based on point evaluation of objects and ground classification).

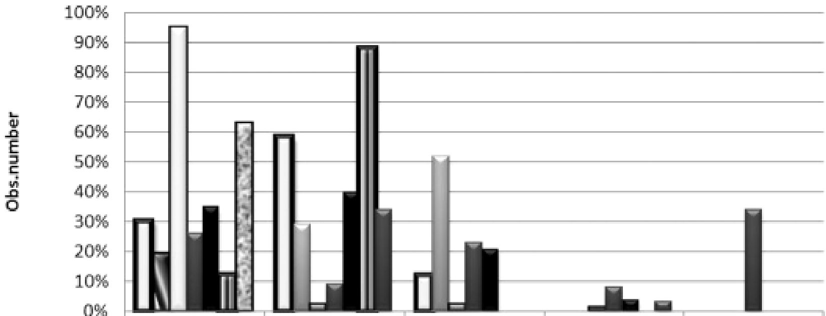
3.1.1. National Coal Board method (NCB)

In risk evaluation with the NCB method most of the buildings were classified as very low risk (30%) or low risk (58%); mediocre risk was observed only in 12 buildings (Table 1, Fig. 2a). The damage risk due to the length of the building is very low in buildings in Poland. It was assumed in this method that the damage risk can be evaluated for long buildings, therefore it has low sensitivity to small-size buildings. In the analyzed case, the influence of horizontal strains on the damage degree is smaller than the influence of the building's length. Establishing the significance of the building's length predicator is 100, whereas for extreme strains is 75.

TABLE 1

List of correct classifications

Damage category	NBC	WS	MSEC	B&C	Bur	Pol	Yu
C0	12	11	3	9	14	2	
C1	33	16	0	6	21	6	
C2	4	13	1	4	6	0	
C3	0	0	0	1	1	1	
C4	0	0	0	0	0	0	
A							36
U							0
Correct (%)	49	40	4	20	42	9	36

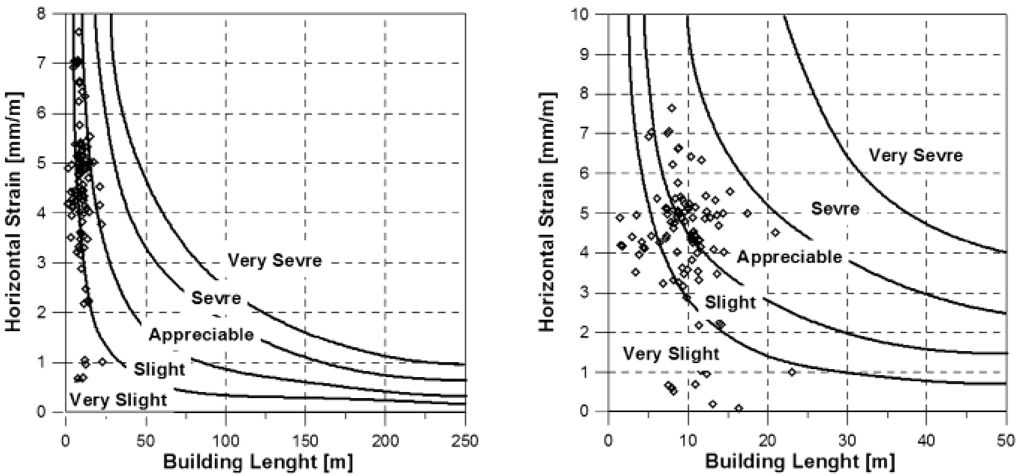


	C0	C1	C2	C3	C4
NCB Pred.	30%	58%	12%	0%	0%
W&S Pred.	19%	29%	52%	0%	0%
MSEC Pred.	95%	2%	2%	1%	0%
B&C Pred.	26%	9%	23%	8%	34%
Bur. Pred.	35%	40%	21%	4%	0%
Yu Pred.	12%	88%	0%	0%	0%
Pol. Pred.	63%	34%	0%	3%	0%

Fig. 1. Damage degree predicted for a given class

3.1.2. Wagner and Schumann method (W&S)

In the W&S method the values of predicted horizontal strains and building's length were assumed to be close to those observed in underground excavation-induced areas in Poland (Table 1, Fig. 2b). It follows from the risk assessment that 52% of buildings will undergo severe damage, 29% of buildings will undergo small damage and 19% very small damage. The significance of both variables ranking the risk degree is evaluated as very high (close to 100).



a) b)

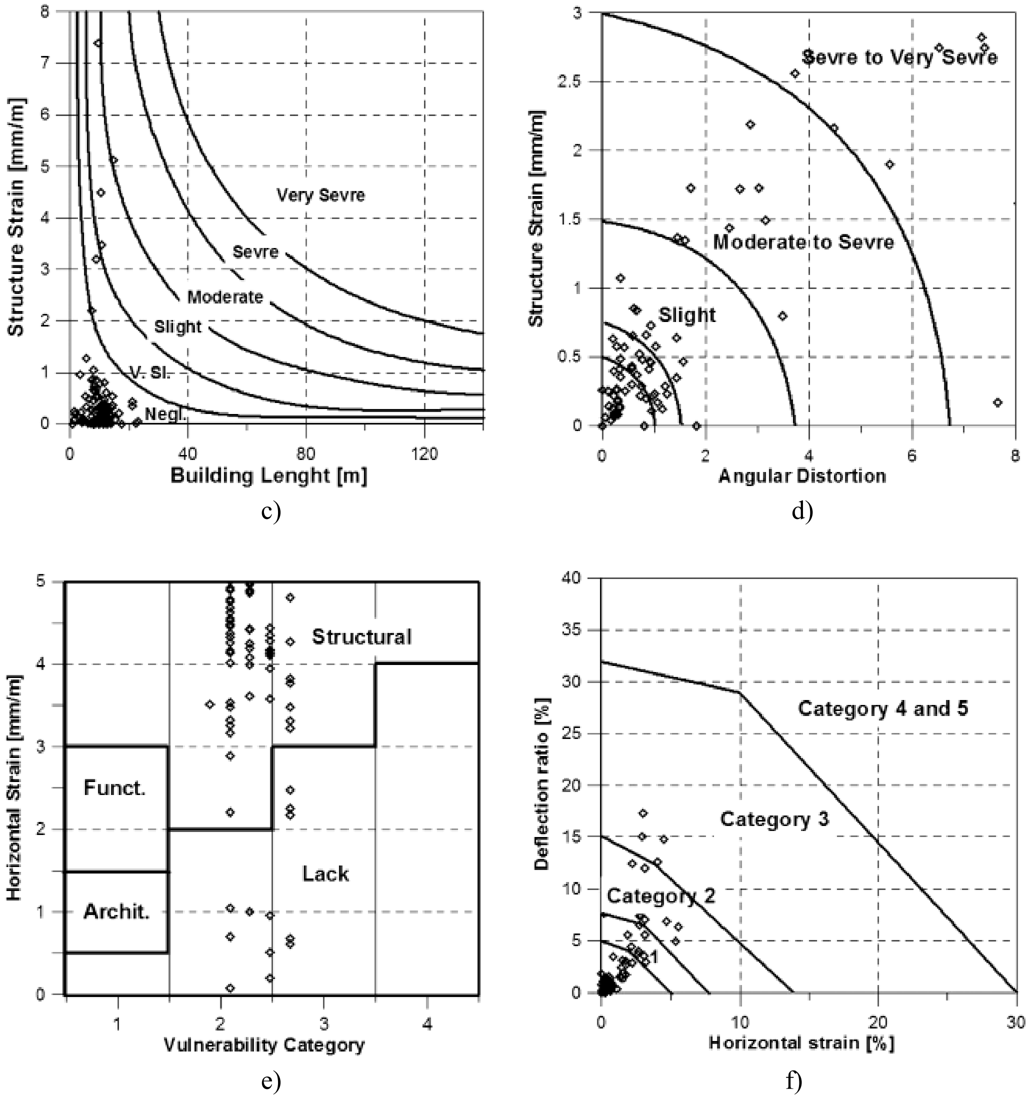


Fig. 2. Results of damage risk evaluation with selected methods a) NCB, b) W&S, c) MSEC, d) B&C, e) Bur., f) Yu

3.1.3. Mine Subsidence Engineering Consultant classification (MSEC)

The MSEC method can be used for assessing the risk of damage to buildings having elongated shape, up to 140 meters of length. This method is insensitive to small-size buildings. Most of the buildings (95%) were classified as the lowest class of damage risk. The remaining 5% of objects could undergo damage of low or mediocre degree (Table 1, Fig. 2c). The degree of building damage is differentiated only by the horizontal strain value for the analyzed group. The significance of the building's horizontal strain predicator is 100, and for building's length is only 36.

3.1.4. Boscardin and Cording (B&C)

Here the risk evaluation is based on assessing the predicted angular strain and horizontal strain of the building. The angular strains are determined on the basis of a relation of maximum and minimum subsidence of building versus its length. The horizontal strain is determined from horizontal deformation under the building and its length.

The direct transmission of ground strain on the building was assumed in this method. Accordingly, the predicted horizontal and vertical strain are associated with the ones to appear in the building. This is a far-fetched generalization which may considerably affect the accuracy of this method. Here all analyzed buildings were ascribed all damage classes. Even very light and light damage was predicted for 35% of population, mediocre for 23%, and severe ones for 42 objects (Table 1, Fig. 2d). The analysis of significance of predicators of the analyzed group revealed a significance of horizontal strain on a level of 0.64, angular strain about 1.00.

3.1.5. Burland method (Bur.)

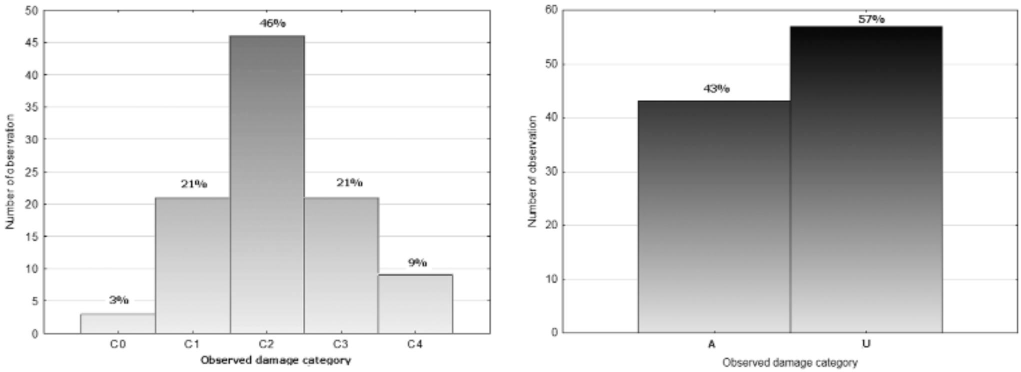
A method developed by Burland is based on similar assumptions as the B&C method. Angular strains and horizontal strains of a building are variables, on the basis of which the degree of damage to the building is evaluated. The basic difference between these two methods lies in a different scaling of the damage degree dependence. In this method high risk factor values were assumed. The result of evaluation of damage risk analysis with this method brought about good results. The evaluation of the risk degree revealed that 35% of buildings may undergo very light damage and 40% of objects light damage. In 21% of buildings the predicted risk of damage was mediocre and in 4% the risk was classified as 3 category(Table 1, Fig. 2e).

3.1.6. Yu method (Yu)

This method considerably differs from the above methods with the generalization of the damage degree. There was introduced a threefold classification of the damage degree: Architectural, Usefulness, Structural. The purpose of this classification was to simplify the evaluation of the scope of repairs to be done in the damaged object. The class of the building strength was evaluated on the basis of information about the foundation type, design, height and length of the building and also radius of curvature under the object. In the analyzed group of buildings, 78% of them were classified as 2 strength category, and 22% as 3 category (Table 1, Fig. 2f). In those two classes the damage risk was either Architectonic or none. Most of the buildings were classified as Architectonic (88%). No potential damage was attributed to the remaining 22% of buildings. In this method the damage degree mainly depends on the horizontal strain predicator. The rank for this variable is 100. The rank for building sensitivity predicator is only 14.

3.2. Results of predictions vs. real damage

The results of risk of damage to buildings were compared with the actual damage to the objects. Prior to this the real damage was classified according to the criteria assumed for the method. The classification of the damage degree was unified for the presented methods by introducing 5 categories of damage degree: C0, C1, C2, C3 and C4. For the NCB, Wagner&Schumann, Burland& Boscardin methods the damage degree precisely corresponded to the unified categorization. For the MSEC method the Severe and Very Severe categories were combined into one C4 category. In the analyzed group mediocre damage prevailed (46%), then very light and light ones 24%, severe 21% and very severe 9% (Fig. 3a). The Yu method imposed a division of observed damage into architectonic, usefulness and structural ones. The classification within this methods remained unchanged. There were only introduced letter denotation of the classes: A – architectonic, U – usefulness, S – structural. The classification of the registered damage for the Yu method assumes that the damage is divided only into architectonic (43%) and usefulness (57%) ones (Fig. 3b).

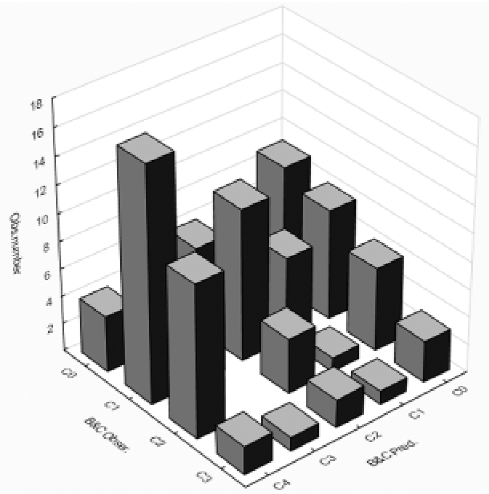


a) b)

Fig. 3. Division of registered damage into damage categories a) NCB, W&S, MSEC, B&C, Bur. b) Yu

The degree of correct classifications for the presented methods was evaluated by comparing the category of registered damage with the actual one in each of the methods. Moreover, the predicted degree of building damage was classified following the point method (commonly applied in Poland). Assumption was made that if the strength category is equal to the ground category, then very light damage may be done to the object (C0). If the ground category is bigger that the strength category by: one – light damage can be predicted (C1), two – mediocre damage (C2), three severe damage may take place (C3). The results of damage degree evaluation with specific methods and their congruence with the actually registered damage to the objects have been listed below.

The highest accuracy of estimation of real damage can be attributed to NCB method (49% of congruent predictions), Burland method (42% of congruent predictions) and W&S method (40% of congruent predictions) (Table 1). The scaling of the NCB method had a considerable influence on its high accuracy in the prediction o very light damage. This method, however, fails to accurately predict severe damage. This results from the small size of the analyzed objects. Severe damage is predicted for objects bigger than 50 m, for horizontal strains exceeding 3.0 mm/m (Table 1, Fig. 4a). The WS method is also very accurate, though it is definitely much more reliable in mediocre damage evaluation (Table 1, Fig. 4b). The MSEC method gave unsatisfactory results. This method is inefficient for small objects (below 50 m) (Table 1, Fig. 4c). This results from the assumed shape of curves classifying to risk categories and assumed values for risk variables. The B&C method enables obtaining ca. 20% accuracy (Table 1, Fig. 4d). Taking into account the complexity of the risk estimation process, this method looms as having relatively high accuracy. The scheme worked out by Burland assumes the influence of bigger ground deformations on buildings. For the analyzed data the congruence of risk evaluation and the actually observed damage to building was very high, i.e. 42% (Table 1, Fig. 4e). Attention should be also paid to the fact that high congruence was also obtained for objects with severe damage prediction. The method proposed by Yu offers even higher accuracy of evaluation of



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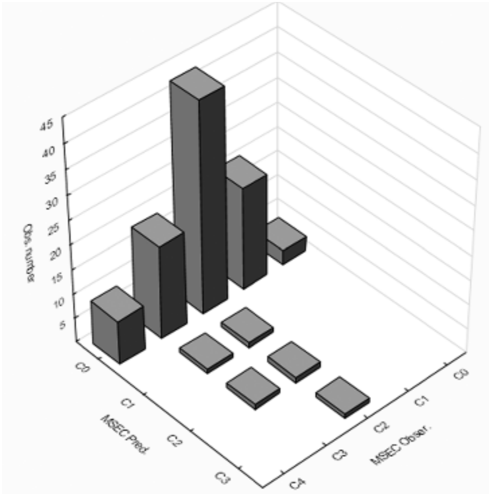

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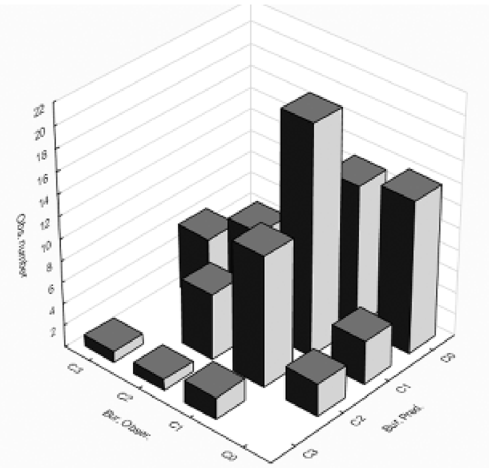

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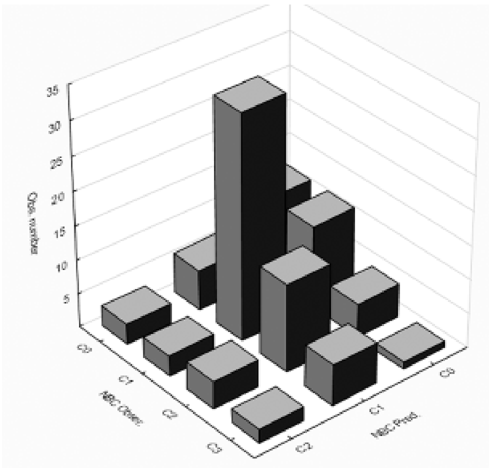

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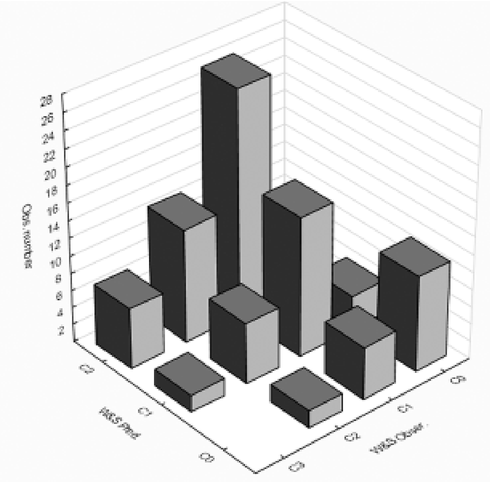

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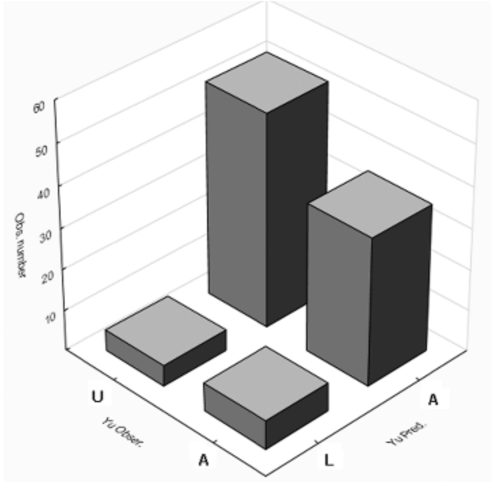

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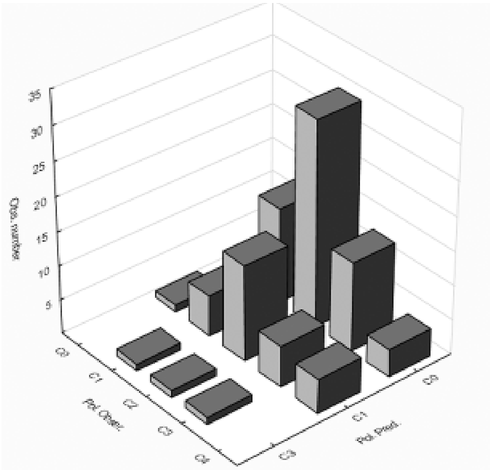

g)

Fig. 4. Comparison of predicted and observed damage after a) NCB, b) WS, c) MSEC, d) B&C, e) Bur. , f) Yu. g) Pol.

damage degree (Table 1, Fig. 4f). It should be noted that the damage degree is very generalized, which may considerably influence the congruence of this estimation with real damage. The results for the Polish method in the analyzed group of objects were poor. The congruence of the damage degree was obtained only for nine buildings. It should be emphasized that unlike other presented methods, no categorization of damage degree exists in the point method. Therefore, introducing an arbitrary classification, being a result of a difference between the mining ground category and strength category, could have influence on the low accuracy of this method.

The last stage of the study was an evaluation of significance of predicators for the observed damage. The length of the building and horizontal strains turned to have definitely the biggest influence on the damage degree.

TABLE 2

Significance of predicators for dependent variable – observed damage degree

Variable	Rank of variable	Significance of variable
Building's length	100	1.00
Predicted maximum horizontal strain	83	0.82
Difference of predicted maximum horizontal deformation under the building	82	0.82
Predicted curvature of terrain		0.79
Difference of predicted maximum vertical deformation under the building	70	0.70
Building's height	55	0.55
Foundation type	0	0.00
Type of walls	0	0.00

4. Conclusions

The results of evaluation of the risk of damage to buildings in excavation-induced areas with the use of World's methods have been presented in the paper. The study was aimed at assessing the applicability of those methods in the Polish conditions. The accuracy of those methods was estimated for the feasibility and reliability of estimation of risk factors and also reliability of the final output. The comparison of the predicted degree of damage with the actually observed one in buildings makes the evaluation of actual accuracy of those methods possible. The highest accuracy was observed for the NCB, W&S, Burland methods (congruence of predictions for 49%, 40% and 42% cases, respectively). The efficiency, high accuracy of determining risk factors (building's length, predicted horizontal strain) are considerable in the case of NCB and W&S methods. A 20% congruence was obtained for the B&C method. A very high congruence of 42% was obtained for the Burland method. Unfortunately in both those methods the way in which the risk factor was estimated is dubious and burdened with considerable uncertainty. The lowest accuracy was observed in the MSEC method, which is mainly caused by the scaling of these methods. The Yu method offers an interesting threefold classification of the damage degree. However the criteria assumed for the risk evaluation with this method considerably generalize the sensitivity of buildings. The Polish method, as compared with other analyzed methods, turned out to be relatively inaccurate. It can be concluded that in the case of high uncertainty of variables determining the risk factors, a higher congruence between observed and predicted damage was obtained for the simplest methods, basing on such variables as: building's length and predicted horizontal strains. The accuracy of those methods undoubtedly also depends on the intervals assumed for the risk factors and damage degree values. The shape of curves defining the categories is also important (Burland method). The presentation and applicability of risk evaluation methods in excavation-induced areas created bases for finding shortcomings of those methods. The main causes of their low accuracy could be: wrong scaling of risk factors, excessive generalization of damage degree, multitude of risk factors or inadequately assumed shape of plot for risk categories. The study reveals that in the case of areas differing in magnitude of continuous strains or types of buildings, (e.g. copper ore or coal exploitation) the applied methods perhaps should be adapted to local conditions. Promising results of risk evaluation were obtained with the use of the NCB, W&S and Burland methods, which may give premises for a similar categorization of mining areas, where the applied methods do not bring about satisfactory results.

Despite some criticisms of the point methods in Poland, the presented study indicates that this method can be successfully applied in a number of countries. The efficiency of this method can be increased by its regionalization, depending on the local basin conditions.

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