Rafał Szymiczek
Panattoni Europe
Elżbieta Kokocińska-Pakiet *
Katedra Mostów Geotechniki i Procesów Budowlanych
Wydział Budownictwa i Architektury
Politechnika Opolska

Foundation of multifamily building in an area at risk of mining damage

KEYWORDS

ABSTRACT
The article presents the problem of modelling the foundation slab multifamily building located on the site at risk mining damages. The model calculations were made in Robot Structural Analysis Professional 2014 (RSAP 2014) and a change in the elasticity coefficients of the soil was used to represent the phenomenon of a sinkhole. This program is not perfect for this type of issue, but the authors nevertheless decided to use it. The foundation slab was calculated in the first case as being on stable soil. In the next step, the occurrence of mining damage – a sinkhole – was modelled by reducing the elastic coefficient of the soil under a part of the foundation slab. This second case made it possible to analyse the behaviour of the building foundation under failure conditions.

1. Introduction

Hard coal is one of the natural resources extracted in Poland. Its extraction is associated with a serious violation of the rock mass structure, which results in changes in the topography of the land and vibrations of the ground. All of these changes mentioned above have a negative impact on the buildings (exceeding the limit states of load-bearing capacity and serviceability, uneven settlement of the foundations, scratches, cracks etc.), and they also affect the safety and comfort of the residents. In Poland the problems mentioned above mainly concern the areas of the Upper Silesian Coalfield and the Legnica-Glogow Copper District, where the exploitation is so large that the changes made below the surface translate into damage on the outside [1], [2], [3].

In Poland the criteria for the new buildings are formulated by the Construction Law [4], but we should also take into account all the regulations contained in the Geological and Mining Law [5] as well as in the Acts on the Protection and Shaping of the Environment and on Urban Development [6]. Additional help is also provided by the entries in the Institute of Construction Technology industry guides, discussing the technical requirements for facilities in the mining areas [7], [8], [9].

In practice the construction of the new buildings primarily consists in checking the limit states of load-bearing capacity and serviceability, taking into account the predicted effects of the mining impacts in computational load combinations [10]. The limit state of load-bearing capacity refers to the partial or complete degradation of the construction, while the limit state of the serviceability consists of: the deformation of the construction or the footing, scratches and excessive vibrations of the construction.

Mining areas require a special, multi-pronged approach to designing because knowledge of the classic issues of building mechanics, rock mass mechanics, geophysics, soil mechanics and hydrogeological issues is needed here. Rock mass mechanics defines the processes occurring from the bedrock all the way to the subsurface layer of the rock mass, such as ground deformations (continuous or discontinuous) or paraseismic phenomena caused by the rock bursts. Geotechnics, on the other hand, deals with the change of the assumed deformations and vibrations of the ground into the internal forces in the construction.

2. Requirements for new buildings

According to the standard [12], the issue of a nuisance for buildings located in mining areas was introduced. This term refers to the acceptable level of difficulties and discomfort of using a building in mining areas depending on the profitability of the assumed exploitation by a local community. This relativity is presented in Table 1 [3].

Table 1.
Degrees of inconvenience of building use in mining areas [3]

Inconvenience	Interference with normal use	Human perception of the effects of operation	Remediation of damage
Not perceptible	Practically non-existent	Negligible	There are no impacts requiring removal
Minor	Insignificant	Noticeable	As part of periodic maintenance
Medium	Impedes use	Causing adverse reactions	At end of life
High	Interruption of use may occur	Annoying	There is a need for ongoing interventions

Since the classification presented in table 1 is quite imprecise, one more division was made, but taking into account the impact of the continuous terrain deformations on the deviations of objects from the vertical T_b, the width of the individual cracks d, and the angle of the shear deformations of the building walls γ_k. This is presented in Table 2 [3].

Table 2.
Degrees of inconvenience in the use of buildings in mining areas [3]

Implications in the building	Inconvenience			
	Not perceptible	Minor	Medium	High
T_b [mm/m]	$T_b \leq 10$	$10 < T_b \leq 15$	$15 < T_b \leq 20$	$20 < T_b$
d [mm]	$d \leq 1$	$1 < d \leq 3$	$3 < d \leq 8$	$8 < d$
γ_k [rad]	$\gamma_k \leq 10^{-3}$	$10^{-3} < \gamma_k \leq 2 \cdot 10^{-3}$	$2 \cdot 10^{-3} < \gamma_k \leq 3 \cdot 10^{-3}$	$3 \cdot 10^{-3} < \gamma_k$

3. The impact of the mining activity on the building structures

It is extremely difficult to avoid the negative effects of mining damage on urban development, even if the mining impact is taken into account in the designed buildings and the use of mining and construction prevention in the existing buildings. This is due to the randomness of the occurrence of the mining influences, and the damage observed as a result of them, in most cases, significantly exceeds the scale of the failures as a result of normal use. Therefore, it is important to carry out regular inspections of the technical condition and ensure that the building can be used for its intended purpose.

The most common causes of mining damage include:

– the inaccuracy of the mining impact forecasts and thus significant discrepancies in the assumed values of the ground deformation, or the underestimation of the impacts (e.g. discontinuous deformations such as the formation of fissures, craters, sinkholes not being included in the forecast),
– the lack of regular inspections of the technical condition of the facilities and the abandonment of immediate repairs in the event of damage,
– the design and the execution errors of the newly built facilities exposed to the mining impacts,
– the poor assessment of the resistance of the existing objects, most often resulting from the use of approximate methods.

The authors are not known of a calculation method that gives 100% certainty of how mining impacts will accrue, therefore the effects of the mining have a diverse impact on the construction. However, it is possible to systematize typical damages in building structures, however it should be remembered that they occur with varying intensity.

4. General requirements for the designed buildings

The structure located in the area subjected to the mining influences should be characterized by a symmetrical cross-section, as extensive a projection as possible (in the case of buildings located on the ground at risk of discontinuous deformations) and a shape similar to a cuboid. Therefore, in order to enable the free operation of the structure and protect the building against the formation of new forces (resulting from the deflections of objects and settling of the foundations on the mining basin), structures of irregular shape are divided into smaller elements (segments) separated from each other by the expansion joints. The fixed spacing of the expansion joints in the structure, at the same time, specifies the length of the individual modules of the building. Deformable objects may have longer segments than rigid structures, while the maximum length of a single segment should not be larger than 30÷40 meters [3], [7], [8], [9].

Foundations are the structural elements of key importance when taking over the influence of mining exploitation, as in the case of the buildings in the non-mining areas. Properly designed and made, they become the basic guarantor of the safety of the construction.

Foundations for the buildings affected by the mining influences should, as a rule, be constructed as direct ones, and only in extraordinary situations in the form of piles or wells. It should also be mentioned that, unlike the typical foundations of objects, the foundations in areas where the effects of the mining are noticeable, in addition to vertical loads, must also transfer the horizontal effects of the mineral extraction.

The foundations of the buildings in areas affected by the mining should be compact and symmetrical. Foundations of the entire structure or its single module at different levels of depth should be avoided. But in cases where it is not possible to embed the building on one level, the main axis of the segment should pass through the centre of gravity of the planned recess (Picture 1. a). In addition, it is possible to use vertical or horizontal (using a sliding layer) expansion joints. Examples of possible solutions are shown in Figure 1.

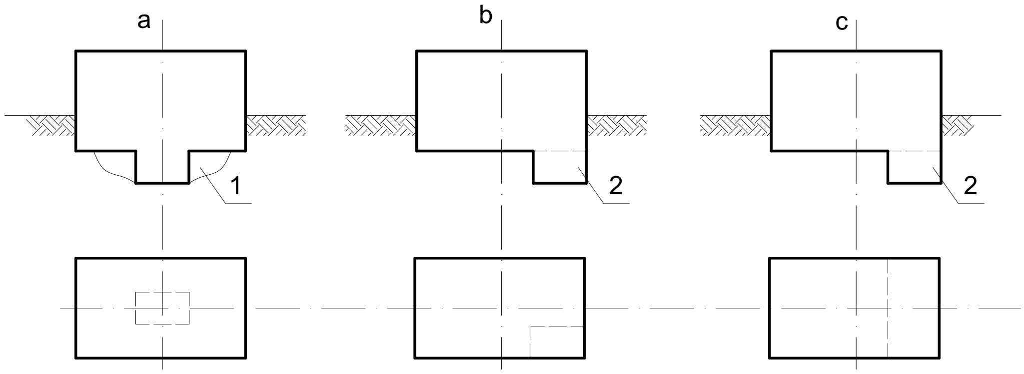


Figure 1. Examples of variants for shaping the foundations of buildings at different depth levels: a – central recess, b and c – asymmetrical recess of the building section; 1 – compacted sand or lean concrete, 2 – horizontal expansion joint with slip layer [11], [12]

5. Geotechnical parameters of the subsoil

The geotechnical parameters of the substrate were determined for the designed building, based on the data obtained from the borehole. The analysis of the soil sample showed that the thickness of the overburden is 163 m (including the quaternary – 46 m represented by the sands and the clays and the tertiary – 117 m represented by the sands and the clays). The extent of the layers from east to west, the drop ~ 14° north. No dislocation and soil erosion.

The calculations made assumed soil – coarse and medium sand, moist. At the investment implementation stage, after excavations for the foundations are made (before the final foundation is made), the adopted design assumptions should be assessed and the adopted dimensions of the foundations should be verified.

It was established that in the area covered by the design works, soil and water management may be disturbed as a result of the mining deposits being exploited. However, the mining and the geological opinion excludes the impact of the changes in the water relations on the conditions of the use of the facility. The values of the deformation indices for the performed and designed exploitation are presented in Table 3.

Table 3.
Values of deformation factors [13]

Depressions	**Slopes**	**Deformations**	**Damage category**
W [m]	**T [mm/m]**	**ε [mm/m]**	**[-]**
EXPLOITATION CARRIED OUT			
9,322	37,9	-16,0	V
PROJECTED EXPLOITATION			
8,596	8,0	6,8	III(T), IV(ε)

The building was designed as a multi-family residential building (detached), with three above-ground storeys – residential and one underground storey. The body of the building is compact in a plan, with simple shapes, divided into two identical segments. In each segment, there are 15 apartments with a total area of 2,141 m^2. Building area 671 m^2. The roof with an angle of inclination of 35^o is covered with metal tiles [13].

The access to the building is directly from the ground floor on the south side. In the basement, there is an underground garage for eight vehicles and utility rooms for the use of the residents. Exit from the garage on the north side, at the back of the building. The projection of the ground floor, first floor and attic are a repeatable floor with an identical layout of apartments.

Figure 2 shows the plan of the basement with the main load-bearing walls marked.

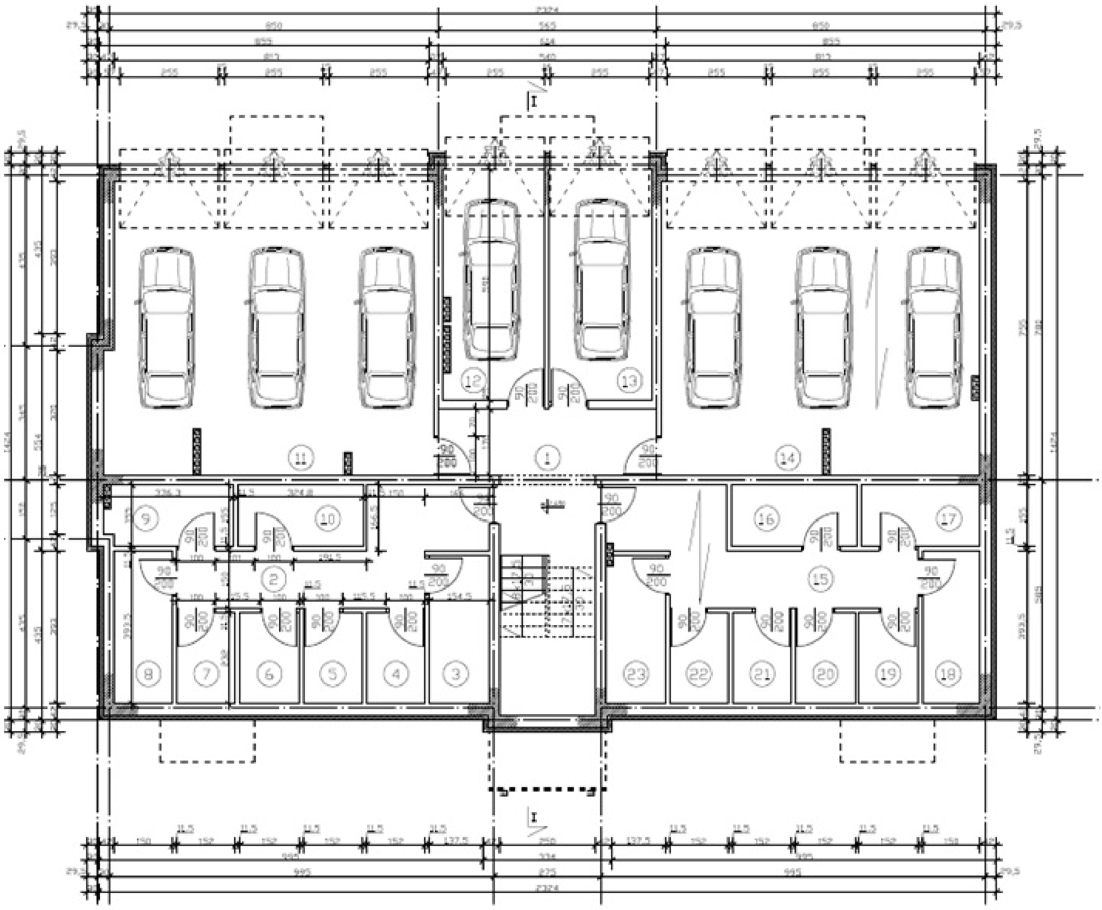


Figure. 2. Basement drawing of the designed building [13]

6. Calculations

In the work [13], two variants of the foundation were analysed. The first is in the form of reinforced footings, and the second is on the foundation slab. The article presents only the analysis of the foundation plate because its solution was considered more interesting, and the results obtained in the program can be an interesting beginning for further analyse.

The foundation slab was modelled in the FEM program: Robot Structural Analysis Professional 2014 (RSAP 2014). This program allows you to model objects only on the elastic Winkler foundation, which is a significant simplification in the case of buildings located in the areas affected by mining exploitation. Nevertheless, guidelines [3] and [14] allow such a solution, and the obtained results can be a certain determinant at the design and the execution stage in the investment implementation process.

The foundation slab was modelled in two stages:

1) In the first stage, it was assumed that the slab foundation – due to its size – would safely transfer forces from the horizontal deformations of the terrain. Therefore, the slab was calculated only taking into account the previously compiled forces for the load-bearing wall of the basement. The dimensions of the slab were assumed to be 24,0 x 15,0 m in accordance with the spacing of the load-bearing walls of the building (approximately 0,5 m added on each side). Slab height h=0,3 m. Equivalent wall load of 281,03 kN/m.
2) In the second stage, the formation of a sinkhole in the ground was simulated. The slab was divided into four equal parts, and in one of them, the loosening of the soil layer was assumed by reducing the elasticity coefficient by 25%. As a result, the load-bearing capacity of the soil decreased, and the foundation itself suffered additional deformations.

Calculations of the foundation slab – variant I

The coefficient was calculated using the building soils – calculator module of the RSAP 2014 program. The average coefficient of the elasticity for the stratified soil was K = 25931,70 (kN/m^3), while the equivalent coefficient of the elasticity for a 24m x 15m foundation slab with the estimated foundation load: 100,00kPa was KZ = 25931,70 (kN/m³).

In the axes of load-bearing walls, an equivalent load of 281,03 kN/m. A manual combination of loads was created in the program, taking into account the self-weight of the slab and the equivalent load from the building walls. The load diagram is shown in figure 3, the maps of moments in figure 4 and 5, and the deflections and deformations respectively in pictures 6 and 7. Figure 8 is presented the theoretical distribution of reinforcement in the variant I slab.

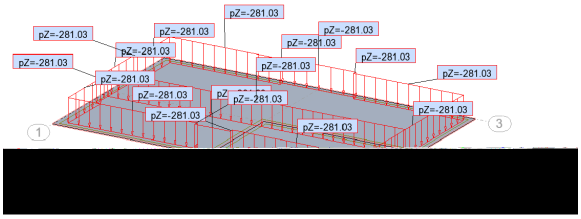


Figure 3. Load combination taking into account slab weight and load from bearing walls [13]

Figure 4. Map of bending moments in the XX direction [13]

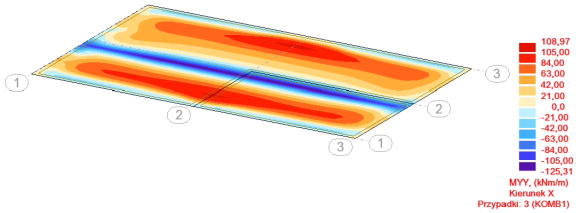


Figure 5. Map of bending moments in the YY direction [13]

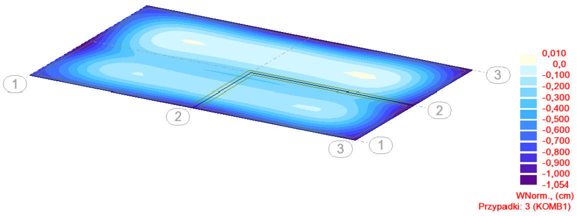


Figure 6. Map of the deflection of the foundation slab in the Z direction [13]

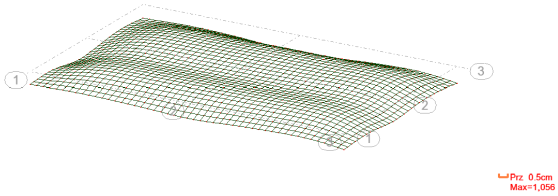


Figure 7. Deformation of the foundation slab working on elastic ground [13]

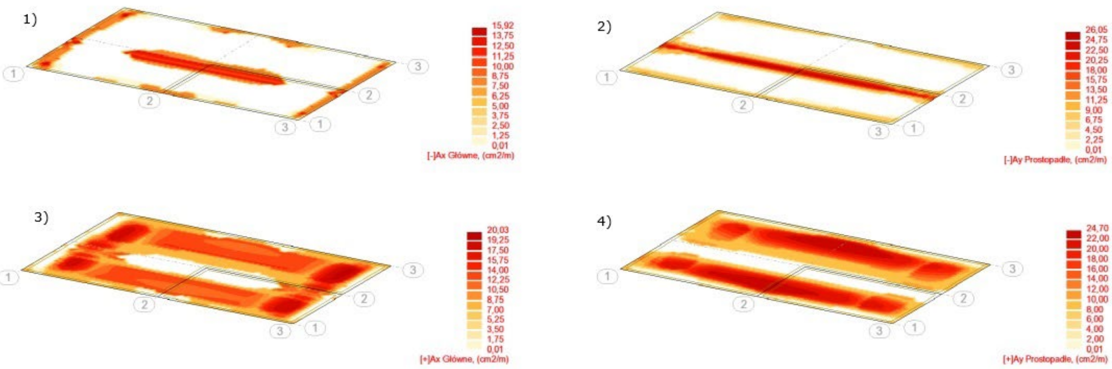


Figure 8. Reinforcement compaction maps: 1) bottom in direction X, 2) 1) bottom in direction Y, 3) top in direction X, 4) top in direction Y, (ROBOT program option - theoretical selection of reinforcement) [13]

Calculations of the foundation slab – variant II

In this variant, loosening of the soil layer under a part of the foundation slab was assumed by reducing the elasticity coefficient by 25% (to a value equal to K_Z=19500kN/m³). Approximately, the above assumption can be treated as a simulation of the formation of a mining subsidence basin or sinkhole in the ground.

In the first stage of the analysis, the above slab was calculated for the same parameters as in variant I. In order not to exceed the limit state of deflections, the program automatically corrects it. With this operation, the RSAP 2014 program proposed to increase the amount of reinforcement by an average of 34,61%. Such compaction of the reinforcing insert was unacceptable for implementation reasons. With such increased reinforcement, the deflection of the foundation slab and the values of the opening of the surface cracks on the upper and lower surfaces of the slab were comparable. Maps of diagrams of moments, deformations and deflections for the second variant are shown in the drawings below, maps of moments are shown in pictures 9 and 10, and deflections and deformations respectively in pictures 11 and 12.

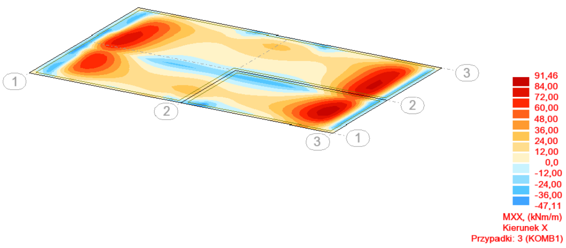


Figure 9. Map of bending moments in the XX direction variant II [13]

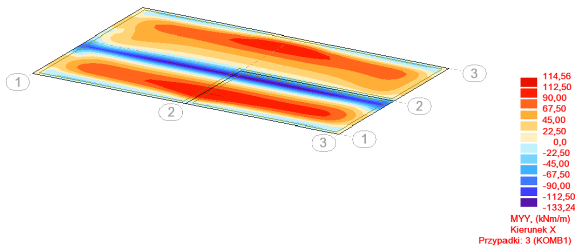
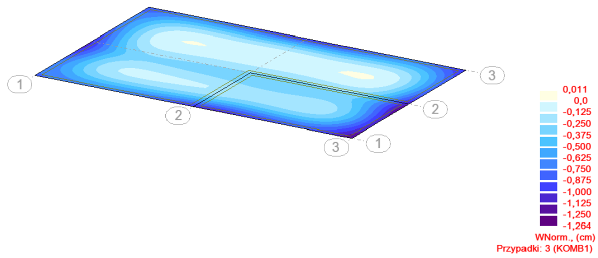


Figure 10. Map of bending moments in the YY direction – variant II [13]



1.
Figure 11. Map of the deflection of the foundation slab in the Z direction – variant II [13]

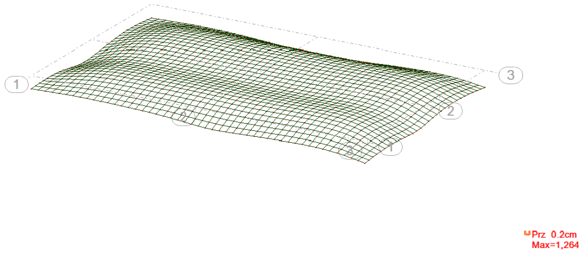


Figure 12. Deformation of a slab working on elastic substrate with simulated collapse under part of the object – variant II [13]

Figure 13 is presented the theoretical distribution of reinforcement in the variant II slab.

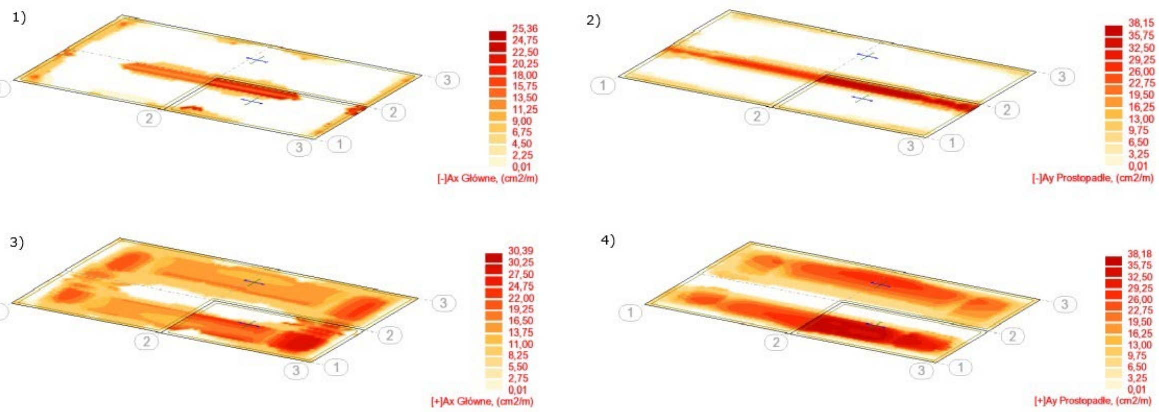


Figure 13. Reinforcement compaction maps: 1) bottom in direction X, 2) 1) bottom in direction Y, 3) top in direction X, 4) top in direction Y, (ROBOT program option – theoretical selection of reinforcement) [13]

The values of deflections and the size of the resulting cracks calculated in the program are listed in table 4, where the values obtained for the above parameters were compared with the permissible ones and their values obtained in individual calculation variants. This comparison may not be adequate because the programme adjusted the amount of reinforcement after automatic correction.

Table 4.
Comparison of the design results of the two variants after application of the recommended reinforcement [13]

SLS	Variant I	Variant II
Deformation of a slab	|f(+)| = 0,05cm <= fdop(+) = 6,00cm |f(-)| = 5,98cm <= fdop(-) = 6,00cm	|f(+)| = 0,00cm <= fdop(+) = 6,00cm |f(-)| = 5,87cm <= fdop(-) = 6,00cm
Scratching of the upper part of the slab	ax = 0,30mm <= adop = 0,30mm ay = 0,30mm <= adop = 0,30mm	ax = 0,30mm <= adop = 0,30mm ay = 0,30mm <= adop = 0,30mm
Scratching of the bottom part of the slab	ax = 0,16mm <= adop = 0,30mm ay = 0,30mm <= adop = 0,30mm	ax = 0,00mm <= adop = 0,30mm ay = 0,29mm <= adop = 0,30mm

However, it should be remembered that the proposed reinforcement distribution is a computer visualization, therefore the resulting data should be subjected to further verification [15].

7. Conclusions

This work contains the most important considerations on the foundation of the foundation in the area affected by the mining damage. After the calculations, the data that could be used for the actual construction of the foundation of a multi-family building located in mining areas was obtained.

The calculations in the ROBOT program required a two-stage approach: first, the forces acting at the foundation level were determined, and then the spread foundation was designed.

The article considers a variant of direct foundation on a reinforced concrete foundation slab. Consideration of such a foundation required the use of the FEM program. RSAP 2014 does not include mathematical models of the ground subsoil to reflect the behaviour of the ground when a sinkhole occurs, it only allows the modelling of structures on Winkler's elastic subsoil. The formation of the mining sinkhole was replaced by the calculations in a simplified way with the change of the KZ coefficient under the part of the foundation plate. Designing a reinforced concrete foundation slab, due to the discontinuous and delayed deformations, should be partly based on the probabilistic methods and analysis of the risk of sinkhole formation in a given area, which requires a multi-track and multi-stage approach.

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