RULES OF CREATING ADEQUATE COMPUTATIONAL MODEL FOR SYSTEMS BUILDING – MINING SUBSOIL

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Abstract

Problems related to evaluation of the behavior of subsoil subject to mining deformations substantially differ from other basic geotechnical problems. Stresses in the subsoil loaded with the construction foundations usually increase, whereas in the subsoils that are subject to mining deformations, phenomenon of initial stresses decrease may take place. It is usually related to the occurrence of deformations loosening subsoil and it leads to change of subsoil state.

Presented research shows and interprets, by means of critical state model (MCC), phenomenon present during mining subsoil deformation, resulting here from displacement of mining basin displacement. It is a phenomenon of a building additional settlement, observed in situ state that in certain situations may lead to the state posing a threat on this building. ABAQUS software was used for numerical calculations.

Streszczenie

Zagadnienia związane z oceną zachowania podłoża podlegającego deformacjom pochodzenia górniczego różnią się w znaczący sposób od innych podstawowych zagadnień geotechnicznych. Naprężenia w podłożu obciążonym fundamentami konstrukcji ulegają zwykle zwiększeniu, podczas gdy w podłożach podlegających deformacjom górniczym może wystąpić zjawisko spadku naprężeń początkowych. Jest to zwykle związane z pojawieniem się odkształceń rozluźniających podłoże gruntowe i prowadzi do zmiany stanu gruntu. W przedstawionej pracy, wykorzystując model stanu krytycznego (MCC) pokazano i zinterpretowano zjawisko towarzyszące deformacjom podłoża górniczego, wynikające tu z przemieszczania się niecki górniczej. Jest to obserwowane w stanie in situ zjawisko dodatkowego osiadania budowli, mogące prowadzić w pewnych sytuacjach do stanu zagrażającego jej bezpieczeństwu. Do obliczeń numerycznych wykorzystano program ABAQUS.

Keywords: **Numerical analyses; Building-mining subsoil systems; Critical state models; Normal consolidation and overconsolidation of subsoil.**

1. INTRODUCTION

Credibility of the numerical analyses results for boundary problems such as building – mining subsoil requires determination of certain unambiguously formulated rules used to create interactive computational model of building – mining subsoil (B)-(P_g) system.

In system (B)-(P_g) subsystem (B) – represents building, subsystem (P_g) – mining subsoil understood as subsoil subject to deformations resulting from carried out exploitation of minerals.

The following were taken into account while formulating the above referred rules:

1) geometry, i.e. size of modeled subsoil area,
2) constitutive relations describing work of soil, as well as
3) method of realisation of boundary conditions, being of displacement nature in the discussed problems.

Practical feature of presented discussion is the fact that most of the experiences resulting from the above systems analyses can be applied in construction of numerical computational models used to evaluate behaviour of buildings exposed to negative effects of redistribution of already agreed internal forces subject to changes in case of subsoil displacement.

In case of mining areas methods of the construction effort analysis as well as evaluation of its safety can generally be qualified as compliant with:

I. Classical procedure – "deformative", in which anticipated deformations of free area surface (so called free area) are indirectly transferred to building construction; where transfer is carried out in accordance with specific rules (e.g. in accordance with [1]).

II. Developed procedure – related to numerical analysis of the system building-mining subsoil under deformation, later called (B)-(P_g) system.

Properly carried out computational analysis compliant with procedure (II) shall employ numerical model of subsoil (of proper constitutive relations) in the form of appropriate size area and properly introduced boundary conditions. Therefore, a very essential problem – both for cognitive reasons as well as possibilities of engineering applications – is search for solutions providing reliable description of analysed problem.

Fig. 1 presents general illustration of the problem of boundary conditions determination for (P_g) subsoil model. It shows, using the same scale, two analysed areas:

1) area (G), external – used in analyses of geomechanics problems [2],
2) area (P_g), internal – representing subsoil in civil engineering boundary analyses where displacement boundary conditions result from solution to external problem [3].

The paper presents significant conditions for evaluation of reliability of the analysis results for system (B)-(P_g) work which need to be met for subsystem (P_g) representing mining subsoil. Phenomenon occurring during subsoil deformations and related to mining basin displacement has been shown and interpreted with the use of critical state model Modified Cam-Clay. It is phenomenon of a building additional settlement observed in "in situ" state which in certain situations may lead to state threatening its safety. ABAQUS software based on finite elements method [4] has been used in numerical calculations.

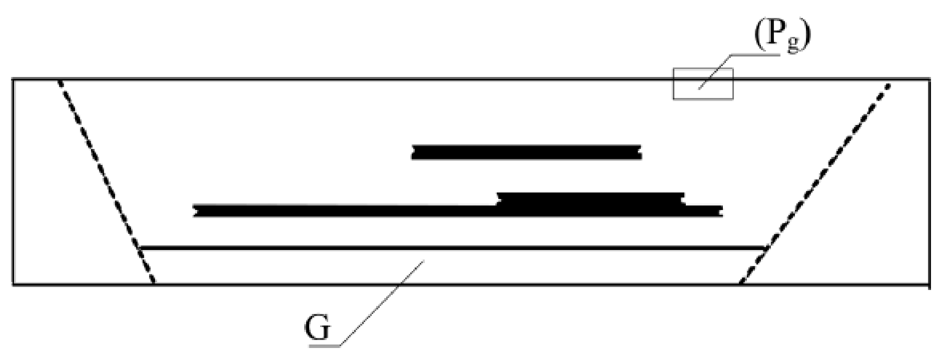


Figure 1.
Mining subsoil (P_g) model area in the rockmass (G) numerical model

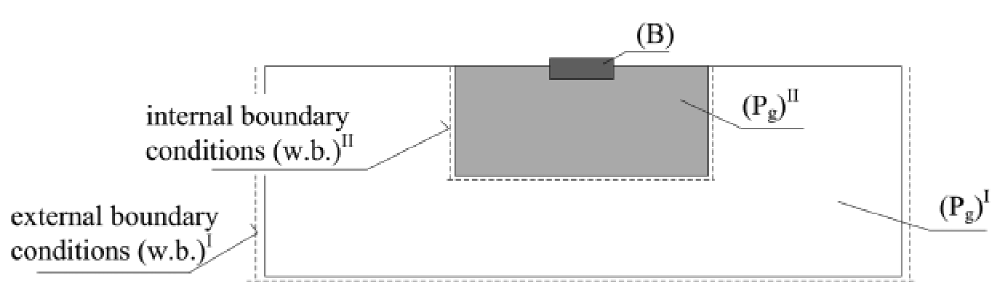


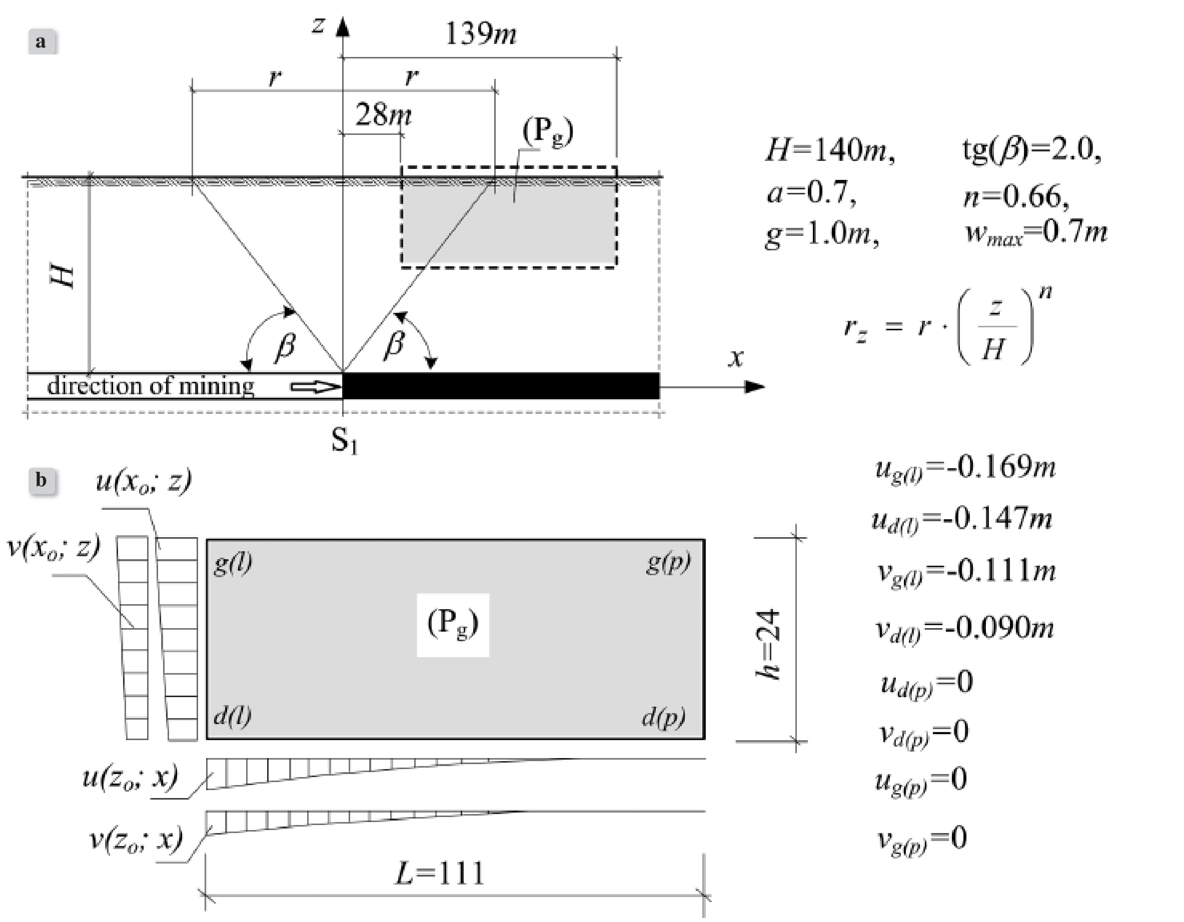
Figure 2.
Condition of compliance of (B)-(P_g) systems solutions

2. PROBLEMS OF APPROPRIATE INTERPRETATION OF KINEMATIC BOUNDARY CONDITIONS IN THE ANALYSES OF BUILDING-MINING SUB-SOIL SYSTEMS

The essence of the contact task in fig. 2 is – in the sense of reliable evaluation of the building construction work on the mining subsoil – for subsystem (B) to "take over" part of the state of strain as well as stress arisen in subsoil (P_g), caused by displacement boundary conditions $\{u_b, v_b\}$. Simultaneously subsystem (B) transmits a total load Q at the subsoil-subsystem (P_g).

While describing the boundary value problem those above referred facts have been expressed as the co-action at the (P_g) area of a structure loading $Q^{(B)}$ and displacements u_b, v_b, that are given on the boundaries (P_g). Theoretically, the following can be assumed.

If $\{u_b^{(Q)}, v_b^{(Q)} \cong 0\}$ takes place on the boundaries of subarea $(P_g)^{II}$ – with accuracy suitable for the given analysis, depending on the employed constitutive model [5] – then, as a result of numerical realization of boundary task$\{Q^{(B)} + u_b, v_b\}$, satisfactorily close pictures of the area behaviour of the direct interaction between construction and subsoil subject to deformations both in the first computational system (B)-$(P_g)^I$, as well as in the second one (B)-$(P_g)^{II}$; will be obtained. Therefore, numerical evaluation of the subsoil behaviour under construction as well as evaluation of the construction work, resulting from the subsoil deformation can be found to be tantamount. However, it needs to be noted that the above statement can be true only in case of subsystem (P_g) with boundary conditions resulting from the external solution (fig. 1); yet such case does not have direct application in the analyses of utilitarian nature.



$$r_z = r \cdot \left(\frac{z}{H}\right)^n$$

Figure 3.
a) Conditions of exploitation employed in the presented analyses, b) boundary conditions appointed in accordance with Budryk-Knothe theory

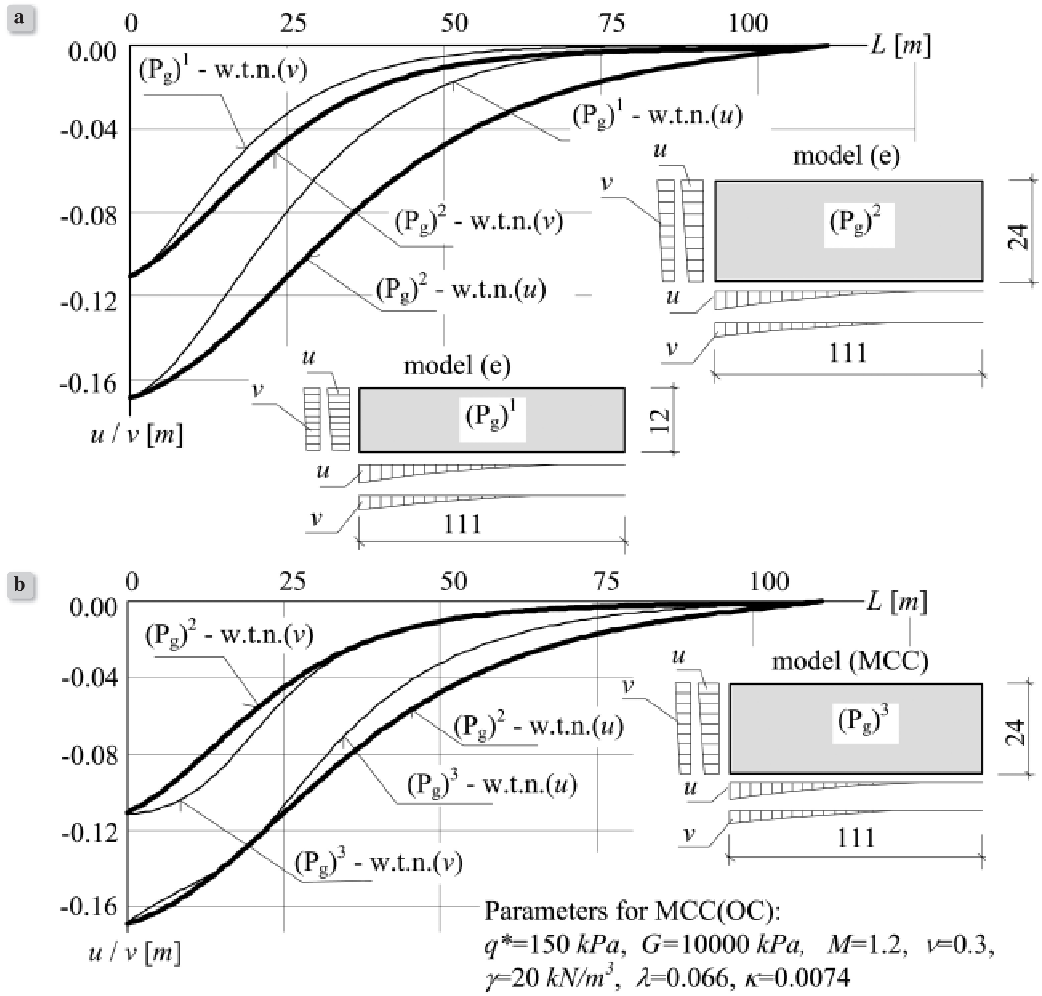


Figure 4.
Functions of free area deformations: a) for various heights of the mining subsoil, b) for various soil constitutive models

One of commonly used methods of the surface behaviour forecasting can be used for the civil engineering purpose – geometrical, integral Budryk-Knothe method [6] enabling simultaneous determination of both vertical and horizontal displacements under the area surface.

Fig. 3a shows location of the analysed (P_g) subsoil area relative to carried out mining. For this area (fig. 3b) kinematic boundary conditions (*w.b.*) have been appointed with the use of Budryk-Knothe method (denotations according to [6]). Conditions of exploitation employed in the example constitute very simplified picture of actual process of the area surface deformation forecasting, though sufficient for the purpose of the presented analysis.

The result of numerical analysis investigating behaviour of subsoil is related to subsoil constitutive model and it is an obvious fact presented in the literature on this subject. Therefore, the choice of a constitutive model shall be closely linked to the class of "importance" of the examined problem. In the analyses of contact problems an additional factor frequently affecting quality of solution is selection of the appropriate size area (P_g), representing subsoil (e.g. [5,7]).

The above referred problems have been presented by means of simple simulation in fig. 4.

It shows that the following have impact on "forecasting" of the free area surface deformations in the form of numerical functions (w.t.n.)

a) subsoil (P_g) model height; with agreed constitutive soil model, fig. 4a,
b) selection of soil constitutive model; fig. 4b.

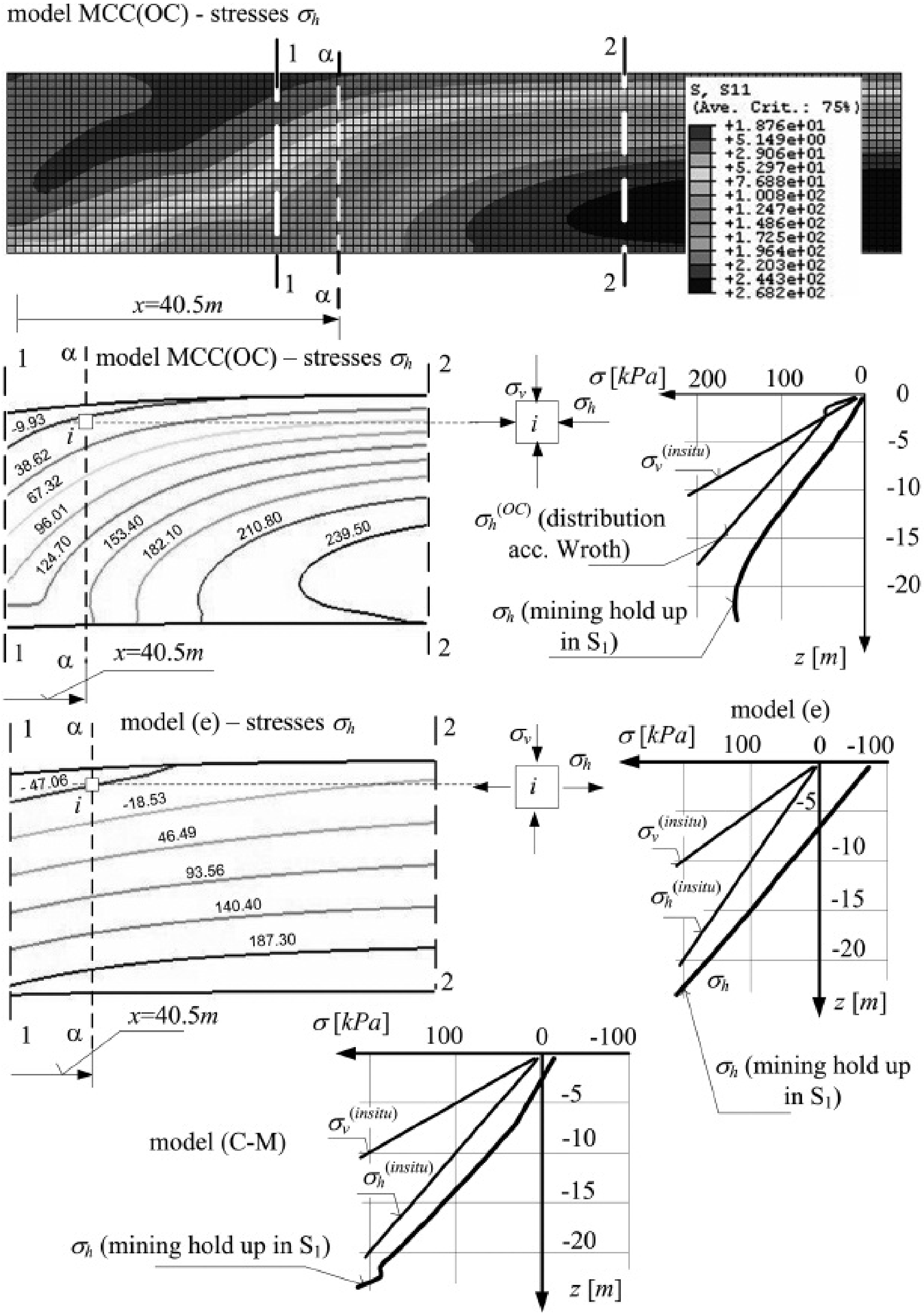


Figure 5.
State of stress analysis in mining subsoil subject to deformation a) by means of the described model (MCC), b) by means of models (C-M) and (e)

Presented simulation shows that it is a complex problem to lent credence to the results of analyses of building-deforming mining subsoil systems. Location of the investigated area (P_g) corresponds to conditions in fig. 3a at which suspension of the exploitation front in point S1 resulted in moderate deformations of the area surface, including only part of the examined subsoil (P_g) area.

Then credibility of numerical description of some in situ phenomena, known from observation, taking place in mining subsoil is considered. To reconstruct the behaviour of mining subsoil, represented by model (P_g) in fig. 5, two groups of basic models of soil constitutive description have been used:

- group (A) – which includes elastic model (e) as well as elastic-perfectly plastic Coulomb-Mohr (C-M) model, and
- group (B) – including critical state Modified Cam-Clay (MCC) model.

Positive effect of the application of model taking into account history of loading in the past (model MCC) is shown in the state of stress presented in fig. 5. (This state corresponds to suspension of exploitation under point S1 in fig. 3a).

Tensile stress in the subsoil surface layer received in Coulomb-Mohr model (as well as in the elastic model) – suggesting possibility of boundary balance state forming in the surface zone – constitute unrealistic forecast against state of strain [8, 9] ensuing there.

3. CHANGE OF THE SOIL STATE VS. SAFETY OF THE BUILDING – MINING SUBSOIL SYSTEM

Threat to the safety state of the building located on the mining subsoil may be related to both

1) possibility of another initiation of (already finished) process of the building settlement in the area of building – mining subsoil contact, as well as
2) phenomenon of mobilization (locally) of maximum shearing stresses in the subsoil due to subsoil displacements forced by exploitation

In case (2) limit state may occur both in the area of the construction and subsoil interaction, as well as directly in the construction (earthen structure).

Occurrence of boundary state in this case may be the result of e.g.:

- exceeding values of deformations anticipated for given area, and thus strains (ε_x) in the surface layer of subsoil,
- or existence of "imperfection" in the constructional system (B)-(P_g), causing "internal slips" and failure of the system during the subsoil deformations development.

In case (1) record of the building displacements in the area is usually a total description of the phenomenon:

- of displacements resulting from subsoil mining deformations, as well as
- possible settlements activated by change of the subsoil state.

Therefore, reconstruction of the soil behaviour in computational model shall realistically connect description of the stress state and volumes changes.

In critical state models evaluation of the ground strength in stresses is linked with record of change of volume deformations in space (p,q,V) or (p,q,e); where p,q – are invariants of the state of stress, V or (e) – specific volume (or void ratio).

Evaluation of danger caused by additional settlements resulting from change of the subsoil state is therefore recorded in model (MCC) by means of subsoil transition from preconsolidation state (OC) to normal consolidation state (NC). The transition is related to locally occurring change of the subsoil rigidity.

Figure 6 shows process of formation of areas in which state of ground changes at the transition from preconsolidation state to normal consolidation state in mining deformed subsoil which interacts with building construction.

The following phases of subsoil area (P_g) were employed in the analysis presented in fig. 3.

1) Transfer incrementally to the subsoil of particular history of loading in the past (erosion loading $q^*=150$ kPa) loads from the construction $Q=80$ kPa; MCC (OC) model parameters have been provided in fig. 4,
2) Incremental realisation of kinemathic boundary conditions, corresponding to deformation of subsoil (P_g) for exploitation wall suspended in point S_1,
3) Incremental realization of mining basin displacement from the phase of hold-up in point S_1 to location S_2 employed in the analysis (fig. 6b).

Figure 6a show successively:

- area of soil state change – obtained after realisation of phases (1) and (2) and expressed by values of plastic strains present during soil transition into normal consolidation state,
- paths p,q – for selected points of subsoil, and standardized diagrams e/e_{cs} – representing changes of void ratio taking place in the selected points during subsoil deformation.

Figure 6b presents area of soil state change – expressed by values of plastic strains – obtained as a

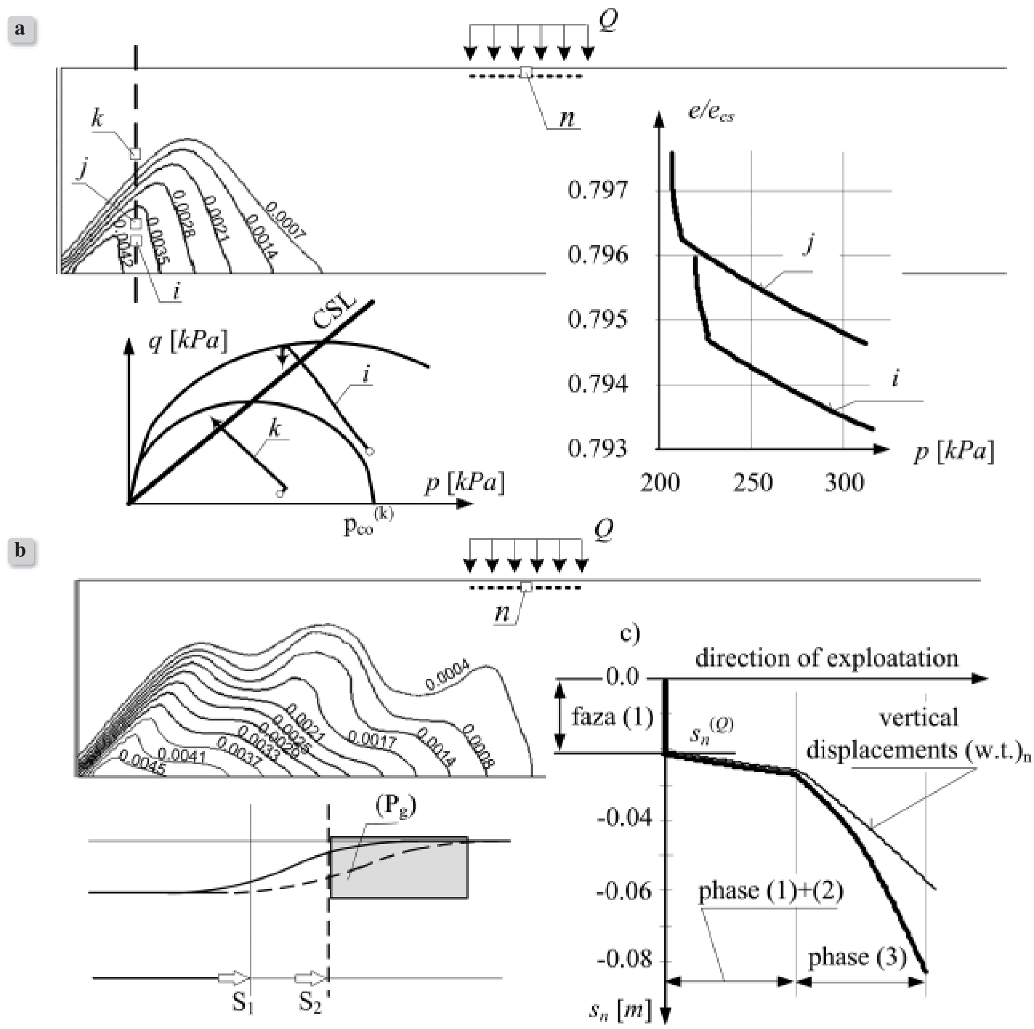


Figure 6.
Analysis of the areas of subsoil state change in mining subsoil subject to deformations: a) at stopped front of exploitation in point S1, b) at displacement of exploitation front within the range S1–S2, c) impact of another commencement of exploitation on the construction additional settlements

result of realisation of phase (3) after phases (1) and (2).

The effect of the expansion of area in which subsoil rigidity changes up to the building and subsoil interaction area, is an occurrence of additional settlements of construction, recorded in particular point *n*.

This state is recorded "against the background of" diagram of free area vertical displacements $(w.t.)_n$ – fig. 6c.

Changes of soil state and additional displacements of building caused by them were observed in system (B)-(P_g), in which construction was of linear nature and rigidity was comparable to the rigidity of subsoil. To examine impact of subsystem (B) rigidity on the phenomena observed in the model two cases presented below have been considered.

Response of (B)-(P_g) system, in which loading transferred from the building to the subsoil was increased to the value $Q=160$ kPa at maintained constitutive description of soil, was subject to the analysis

Rigidity of the construction:

1) In first case it remained the same – fig. 7,

2) In second case it was substantially increased – fig. 8,

In both above referred analyses situation observed earlier is repeated – realization of phase (3) in the subsoil (P_g) causes activation of the process of build-

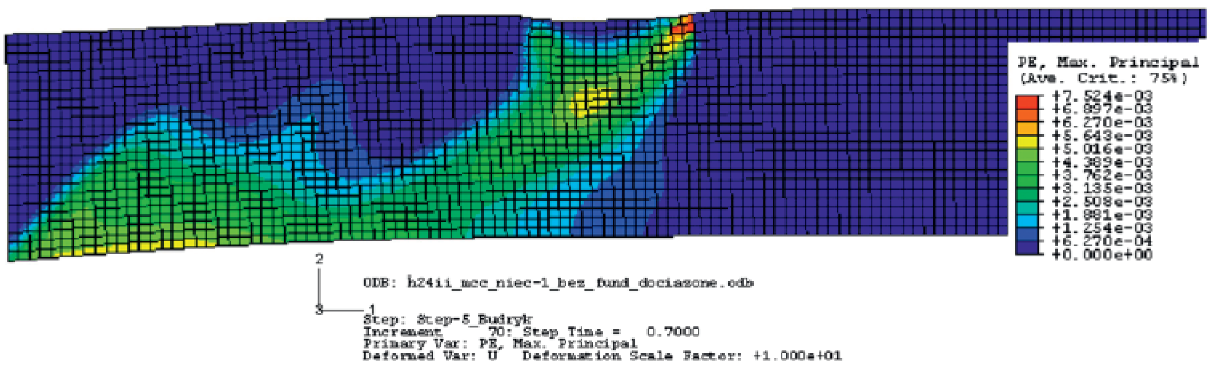


Figure 7.
Map of plastic strains in the area (P_g) at interaction with fragile construction, Q=160 kPa

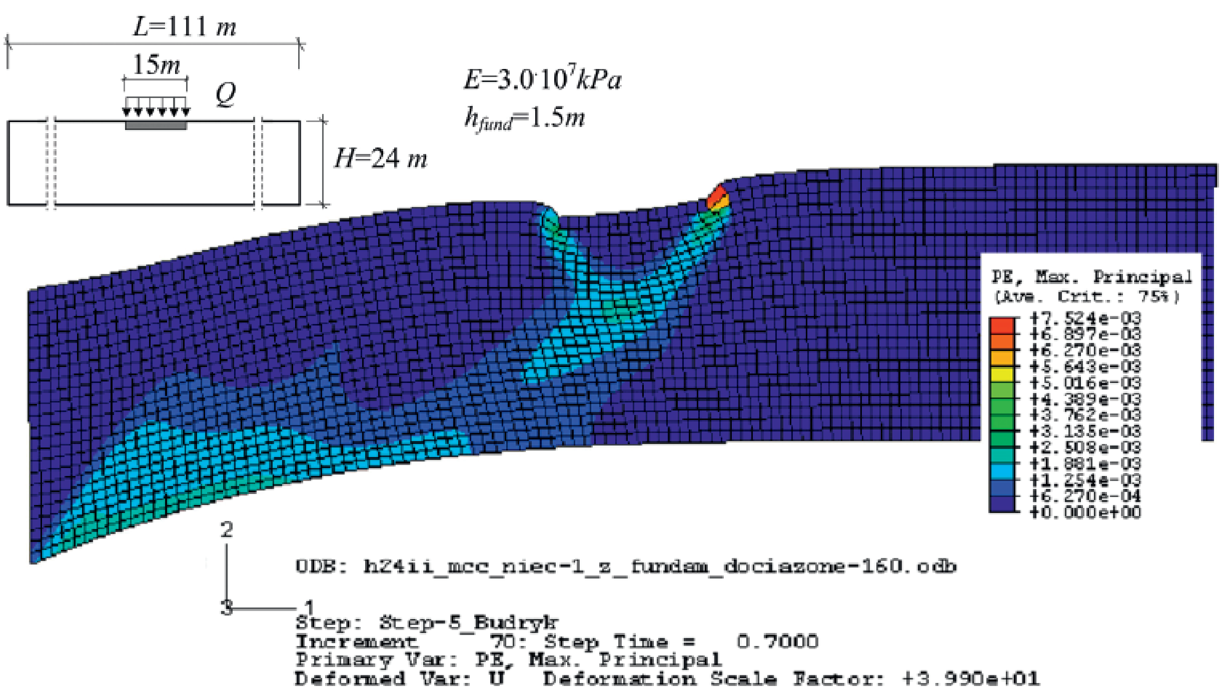


Figure 8.
Map of plastic strains in the area (Pg) at interaction with rigid construction Q=160 kPa

ing additional settlements; where phase (3) represents in the research state of mining basin displacement directly into the area of building and subsoil interaction.

Therefore such analysis enables evaluation of the threat level to the system's stability loss at specific values of loading, building rigidity, subsoil preconsolidation degree as well as given exploitation conditions causing subsoil deformation state (P_g).

Clear impact of the construction rigidity increase on reduced threat to system (B)-(P_g) stability loss can be observed by comparing maps of plastic strains appointed in the model of subsoil (P_g) interaction with building:

1) of small rigidity – fig. 7,

2) of substantially increased rigidity – fig. 8.

4. CONCLUSIONS

Along with the increase of mining subsoil deformations, soil loosening and reduction of horizontal stresses σ_h values takes place (in the specific phase of mining basin formation on the area surface). Assessment of the danger of limit state occurrence in mining subsoil needs to be made by means of a model taking into account soil preconsolidsation.

Describing subsoil by means of Modified Cam-Clay critical state model allows to present changes of soil state ensuing in the subsoil as a result of mining deformations as the areas of soil transition from preconsolidation state to normal consolidation state.

Appointing areas of soil state change, developing in the subsoil during exploitation relocation towards the area of building interaction with subsoil may constitute basis for assessment of:

- threat of activation of additional settlements process (not compliant with values of displacements of free mining area) as well as,
- anticipating, in which phase of exploitation additional settlements may take place.

Credibility of evaluation of the construction additional settlements on mining subsoil is directly related to the area of subsoil (P_g) numerical model. This is a phenomenon that shall be subject to control in each numerical analysis of building-subsoil contact problem [7].

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