SERVICEABILITY CRITERIA FOR BUILDINGS IN MINE SUBSIDENCE AREA - ADJUSTMENT TO EUROCODES[1]

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Abstract: Due to ground deformations caused by underground mining, building structures in mining areas are frequently subjected to considerable deformations and damage to the finishing and structural elements. As a consequence, serviceable values of such structures are distinctly diminished, and in extreme cases, seriously damaged structures may be exempted from further service. These problems are not duly represented in the existing building standard codes. It is also important to determine relationship between damage stage and value of the building, and hence the strategy for reconstruction or renovation works. The paper presents proposals concerning serviceability criteria of building structures in mining areas, in terms of basic standard requirements valid in building in Poland, as well as proposals of Eurocodes. Building structures under consideration have been divided into structures designed to resist mining influences and existing structures, not adapted to conform to these influences at the design and erection stages.

Additional Key Words: building in mining areas, limit states, building serviceability, structure deformations.

Characteristics of the Problem

According to Eurocode 1 (1993), calculations of building structures should be made using the limit states method, assuming possible occurrence of: Ultimate Limit States (ULS), i.e. load states that, if surpassed, cause damage to the building structure or its part; and Serviceability Limit States (SLS), i.e. load states that, if surpassed, result in excessive deformations of the structure,limiting its further serviceability as intended in the design; SLS are described by the deformations and displacements of the structure. In the application of structure design in mining areas, the standard criteria of ULS usually require a wider analysis compared to the design for structures outside the mining areas, which results from the specific character of loading and behavior of structures in subsidence - prone areas.

ULS of a structure determine its safety and must show a sufficient margin of load capacity. SLS may undergo some transitional modifications. In the narrow sense, SLS imply technical serviceability viewed from user's standpoint (e.g. doors and windows opening well) and proper functioning of machinery and equipment. In the broad sense, it implies satisfying the psychological and esthetic habits (e.g. no large tilts or deflections). Some questions of durability are also involved here (e.g. cracks in reinforced concrete). Finally, it concerns situations where damage to minor elements entailing repair works should not occur (e.g. partition walls or linking layers).

In reference to designed structures, the analysis of SLS is generally limited to changes in some parameters (mostly movements or deformations), that are allowed by building and engineering design standards. From the viewpoint of loading and strength values accepted for verification of SLS, the probability that these states will occur is greater than that of ULS.

Extensive observations of buildings designed to withstand the effects of mining have shown that, usually

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during the serviceable period of structures (hereafter referred to as structure service), allowable values of parameters determined in standards defining the accomplishment of SLS are exceeded. Despite this fact, building failure is very rare.

In principle, existing structures behave likewise in mining areas.When more intensive ground deformations occur, the structures undergo great deformations and damage, the extent of which is usually greater than in structures designed with respect to mining effects, and may surpass many times the allowable values, as determined for SLS by appropriate design standards. Such situations do not necessarily mean building failure. Despite considerable damage to some elements (e.g. walls affected by cracking), emergency hazard may not occur with respect to the structure as a whole (e.g. though walls are damaged, there are no floor failures). Structure serviceability conditions may be considerably deteriorated, but the building can sill fulfill its original purpose. Consequently, in both designed buildings and in buildings already existing, the interval between destruction of the building and the state of (acceptable) service standard is considerable.

The problems of structure service in mining areas are also important legally. Damage to a structure resulting in comfort deterioration and service impediments lead to a reduction in market value of the structure.

Basis for Determination of Serviceability Criteria

Structures Designed for Mining Loads

In general, two radically different concepts of structure building in mining areas can be considered. The first concept, which is more likely to be introduced due to regulations in force, is that new structures should be designed in such a way as to satisfy the requirements specified by ULS and SLS over the whole period of their service. With regard to the present mode of building in mining areas, this concept necessitates a considerably larger range of protection to ensure better structure preparation to compensate for subsoil deformations (e.g. increased construction rigidity compared with that used at present; rectification of habitable buildings on a general basis).

The second concept refers to the temporary design situation anticipated by Eurocodes, and would require that building design be based on the conditions of ULS and requirements of SLS mitigated temporarily during periods of mining effect activation. In the course of structure service, some damage and impediments may arise,but may pose no threats to its safety. Once the ground has settled, repair work will begin to restore basic parameters of SLS.

From the viewpoint of economic effectiveness of building in mining areas, the second concept is more rational. Less means and materials are used, and they are limited to situations that really require intervention. Time gained through shifting the intervention until later allows mineral extraction to proceed, which generates money that can be used to repair damage. On the other hand, it implies discomforts or even occasional threats to structure service.

The authors of this paper are in favor of the second concept of building in mining areas and suggest that Temporary Serviceability Limit States (TSLS) be worked out and introduced, as explained in Fig. 1a.

With program loadings typical of regular areas, the structure is designed in accordance with required standard states of ULS and SLS. While mining ground deformation effects are activated, the structure must still meet the requirements of ULS, allowing however at that time increased deformations of construction defined by TSLS. Calibration of TSLS level must result from two prerequisites as follows:

- structure deformations can cause impediments in its service to a commonly accepted degree and do not eliminate any structure part from service,
- deformations and structure damage are repairable and economical.

After most subsidence has occurred, the structure is returned to the initial state, satisfying the SLS requirements. A structure characterized by deformations that exceed the SLS level should be repaired. It is also possible to assume a strategy advocating restoration of structure serviceability parameters, for buildings that can not withstand the effects of mining (existing structures).

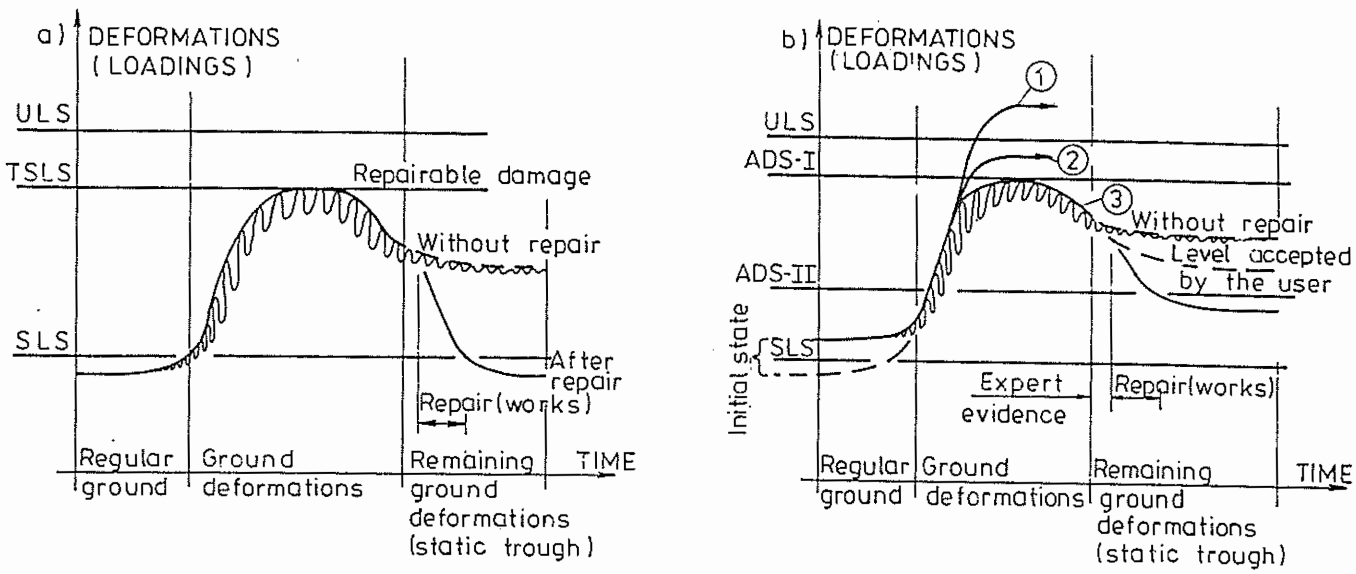

Figure 1. Deformations observed for a) structures designed to withstand effects of mining and b) existing structures.

Existing structures

Similar arguments can be carried out with regard to existing structures. In this case, ULS should include building structure, together with elements for preventing damage by mining effects (e.g. steel bowstrings, reinforcement bowstrings). In both concepts of structural maintenance, it is necessary to apply the range of precautions to hinder the destruction of the structure or its part. Yet, the range of these precautions can vary,depending on the nature and intensity of structural deformations and damage, resulting from the repair costs and damage level acceptable by the user (e.g. if certain specified damage to masonry of cellar walls is accepted, only the above-ground building part is protected). Apart from certain cases where following specific technological incentives are necessary, reasonable technical and economical action in regard to existing structures must lead to abandoning the idea of satisfying the conditions of SLS, obligatory for designed structures. Serviceability of these structures necessitates, however, providing the user a specific level of utilization comfort. This, on the other hand, is indicative of the need for introducing an extended equivalent of TSLS with regard to existing structures, that can be referred to as Allowable Deformation States (ADS). Fig. 1b illustrates this procedure. Initial state of deformations in existing structures is usually higher than the level accepted for designed structures. In individual cases, when the structure "has been constructed" with no consideration for present requirements of SLS, the structure deformations may exceed the SLS level. Mining loads resulting from ground deformation generally lead to the following situations:
(1) - ULS are exceeded, which results in destruction of the structure,
(2) - the structure has undergone so much damage that its repair is uneconomical; the structure should be demolished or its service mode changed,
(3) - structure deformations are limited, and their range justifies repair works.

As for the last situation, constituting the core of our investigation, structure deformations can not at the same time exceed some boundary values enabling structure service in an appropriate way. This level of deformations can be determined as 1st ADS (ADS-I). This state is of transitional character, and the level of these deformations need to be determined in detail with reference to TSLS level. It can be supposed that with regard to some deformation parameters of structure not protected against the effects of underground mining, the level can exceed the TSLS level. After subsidence abates, damage and repair requirements should be estimated.

Consequently, the structure should be brought to a commonly accepted deformation state, that is, the state exempted from all negative influences on the substantial number of users (e.g. construction tilt imperceptible as major discomfort to the majority of users). This deformation level would be of permanent nature, and can be defined as 2nd ADS (ADS-II). The difference between ADS-II level and the initial state should be considered a social cost resulting from underground mining. The range of repair works that does not have to meet ADS-II level could, in such a case, be established in the form of individual agreement between the mine and the owner (user). The last stage comprising also the expert evidence can be also applied to existing buildings that have been designed to withstand the effects of mining.

Parameters of Serviceability States in Apartment Buildings

With reference to other types of structures, the following factors describing serviceability states in mining areas should be assumed as a basis for formulation of deformation parameters :
- characteristic deformations of structures subjected to the effects of mining,
- general requirements concerning SLS and legal standard norms for structures situated on grounds outside the mining effects,
- current norms of legal standards concerning mining areas,
- recommendations of technical literature with regard to allowable deformations and damage to structures,
- possibility of calculable evaluation and calibration of accepted parameters of structure deformations.

The suggested parameters of structure deformations determining serviceability states of apartment buildings and public buildings in mining areas according to the general concept presented in Fig. 1, are discussed below.

Designed structures

SLS are checked regardless of loading caused by mining effects; these requirements should also be met during remaining ground deformations, although it can be conditioned by the need to repair the structure.

TSLS are obligatory during the subsidence; they can be determined by corrected (mitigated) values of parameters describing SLS, including in particular:
1) Allowable ground deformations associated with the occurrence of cracks and deformations of wall supporting structure, or filling of frame constructions, defined by the characteristic (averaged) relative deflection of structure:

$$\gamma_k = \frac{2f_k}{L}$$

where: f_k - structure's deflection hogging (Fig. 2a) or sagging (Fig.2b)

2) Allowable tilt of building, T_b
3) Allowable width of cracks in reinforced concrete elements.

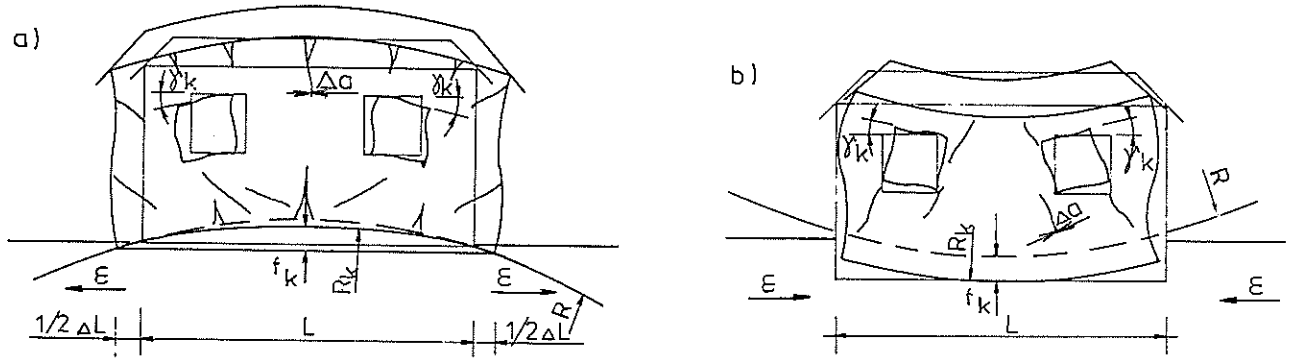

Figure 2. Deformations of a building caused by a) hogging and b) sagging

Existing structures

ADS I are required during the activation period of main mining effects, and are characterized by :
1) Allowable structure deformations connected with occurrence of cracks and deformations that attenuate climactic resistance(tightness) or other wall functions (e.g. acoustic resistance, deformations of conduits and distortion twists of windows and doors), determined by the following parameters of structure deformations (Fig. 2):
a) characteristic value of relative deflection of structure, γ_k,
b) index of total structure elongation, ΔL,
c) degree of plaster cracks and other fittings, p, possible to be determined only after damage occurrence, e.g. as the ratio of cracked surfaces to the whole surface of the wall (walls) or ceiling.
2) Allowable width of single wall cracks, Δa,contributing to considerable attenuation of building tighness.
3) Allowable tilt of building, T_b.

ADS II are required after most mining effects are past, during the occurrence of remaining ground deformations, or when the structure is influenced by the static mining trough, and are described by:
1) Allowable - general deformation of structure defined by the characteristic value of relative deflection of structure, γ_k,
2) Allowable width of single wall cracks, Δa, contributing to the reduction of building tightness,
3) Allowable tilt of building, T_b.

Factors Determining the Values of Allowable Deformations and Damage of Building

Limitations of building structure deformations result from the need to satisfy serviceability states, generally determined by :
a) the possibility of structure service respectively to its purpose,
b) the limitation or elimination of impediments in structure service,
c) the aesthetic reasons, and
d) requirements concerning durability or tightness of structure.

According to the presented concept, in structures situated in mining areas, particularly during the period of mining effects activation, and in some cases also after their regression, it is possible to mitigate standard requirements of SLS. It necessitates calibration of new values of structure deformations that can generally be referred to as allowable deformations.

Taking into consideration the above conditions, the allowable deformations must be in compliance with condition "a", but they may lead to certain lowering (mitigation) of requirements specified by conditions "b", "c" and "d". The problem of value determination of allowable building structure deformations concerns, in principle, all cases of structures built on subsiding grounds, and in particular on grounds subsiding more intensively and irregularly. Thorough and extensive research conducted in this field leads only to the determination of correlation between the deformation state and structure damage, (Skemptom and Mac Donald 1956). It is difficult,however, to define the level of allowable deformations of building structures as meant in this paper. Such a formulation implies subjective character, and is dependent on the requirements and habits of the individual user (resident).

According to Eurocode 7 (1992), the following factors should be taken into consideration in determining the allowable deformations values:

- the degree of confidence, wherewith the acceptable (tolerated) boundary values can be determined,
- type of structure,
- type of structure material,
- type of foundation,
- kind of ground,
- anticipated manner of structure service.

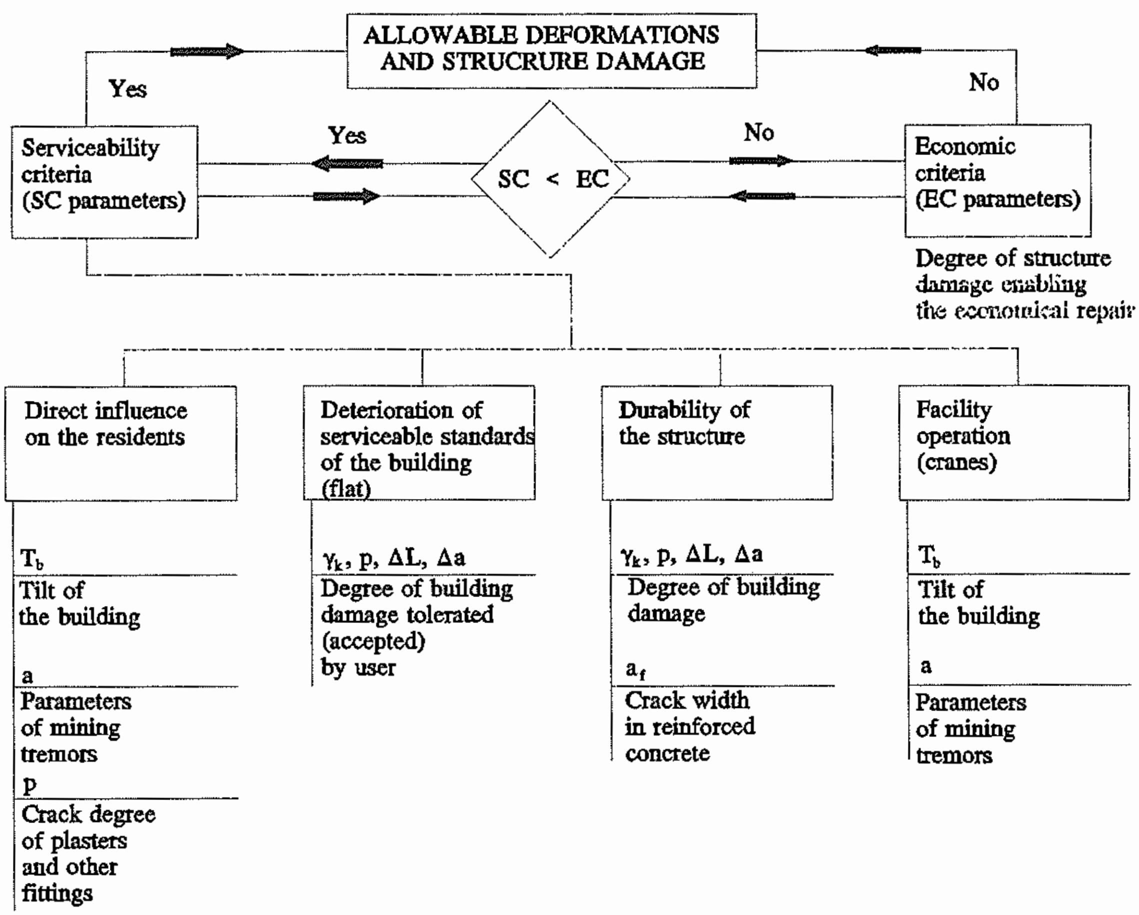

Figure 3. The scheme of allowable deformations and structure damage criteria.

The proposed criteria defining allowable deformations and structure damage, as well as corresponding deformation parameters in apartment buildings are presented in Fig. 3. Allowable structure deformations should be determined by serviceability criteria and economic criteria. The latter should be understood as the degree of damage to the structure whereof the repair and the maintenance are still economical.

Concluding Remarks

The presented concept necessitates definition and determination of values of allowable parameters describing service of designed structures and existing structures on subsided grounds, especially in areas subjected to the effects of underground mining.

The determination of allowable deformation values will certainly be difficult and may be controversial, depending on the criterion. Yet, the necessity to work out and calibrate such values seems to be imperative and legally necessary. Due to substantial costs of protecting of building structures in the erection stage, aimed at preventing damage occurrence not exceeding parameters of SLS, it may soon turn out that extraction of minerals is unprofitable, or location of building structures in mining areas surpasses the investors' financial possibilities. With reference to the existing building structures in mining areas, a wider range of repairs might be demanded (e.g. along with straightening of tilted buildings), even with a relatively small level of structure deformation.

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