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## 1. Aim and scope of the project

The scope of the project is giving the theoretical explanation of the impact that mining exploitation cause in the ground, both surface and subsoil, as well as its effect on the structure of nearby buildings.

Mining exploitation produces unfavorable effects in the environment. The project will focus on the coal mining industry as Poland is one of the biggest coal producers in the world.

Subsidence is an inevitable consequence of underground mining. It may be small and localized or extend over large areas; it may be immediate or delayed for many years. Deformation that occur on the ground due to mining exploitation produce new forces that affect to the structure of buildings located in the area of effect of the mining exploitation. Due to the damage that subsidence can cause to the structures, communications and agricultural lands is important to know how to predict ground movements, determine the effects of such movements on structures and minimize the damage due to subsidence.

The project is divided in three parts. The first part explains how deformations occur and its impact on the land surface. As deformation of the ground due to mining exploitation is unavoidable, the second part describes damages on buildings and construction techniques employed to reduce the damage to buildings. The project focuses on residential buildings, as rigid structures, both new and existing buildings. The last part of the project consists in a practical case and explains how to calculate the forces acting on the building foundation due to impact of area horizontal deformation and protection design of the foundation framework.

# 2. Introduction

## 2.1 Overview of coal industry in Poland

In 1970 Poland became the biggest coal producer in Europe, with an annual output of around 150 million tonnes. At the end of 1970, USA was the largest coal exporter in the world, followed by Poland, exporting around 40 million tonnes/ year. Poland exportations declined in 1980 although the output was maintained at a considerably elevated level compared with other European countries, exporting around 193 million tonnes in 1988. [1]

**Total Coal Primary Production**

1. China
2. United States
3. India
4. Indonesia
5. Australia
6. Russia
7. South Africa
8. Germany
9. Poland
10. Kazakhstan
11. Colombia
12. Turkey
13. Canada
14. Ukraine
15. Greece

Figure 1 – Total primary coal production in 2012. [2]

**Top Ten Coal Producers (2012)**

| | | | |
|---|---|---|---|
| 1. China | 3549 Mt | 6. Russia | 359 Mt |
| 2. United States | 935 Mt | 7. South Africa | 259 Mt |
| 3. India | 595 Mt | 8. Germany | 197 Mt |
| 4. Indonesia | 443 Mt | 9. Poland | 144 Mt |
| 5. Australia | 421 Mt | 10. Kazakhstan | 126 Mt |

Figure 2 – Top coal producers in 2012. [3]

Poland is the second-largest coal-mining country in Europe; Germany is the first one, and the ninth-largest coal producer in the world. Coal mining in Poland produced 144 million metric tons of coal in 2012, providing 55% of the country primary energy consumption, and 75% of electrical generation. Nowadays, Poland is no longer a major coal exporter as the country consumes almost all the coal production. [4]

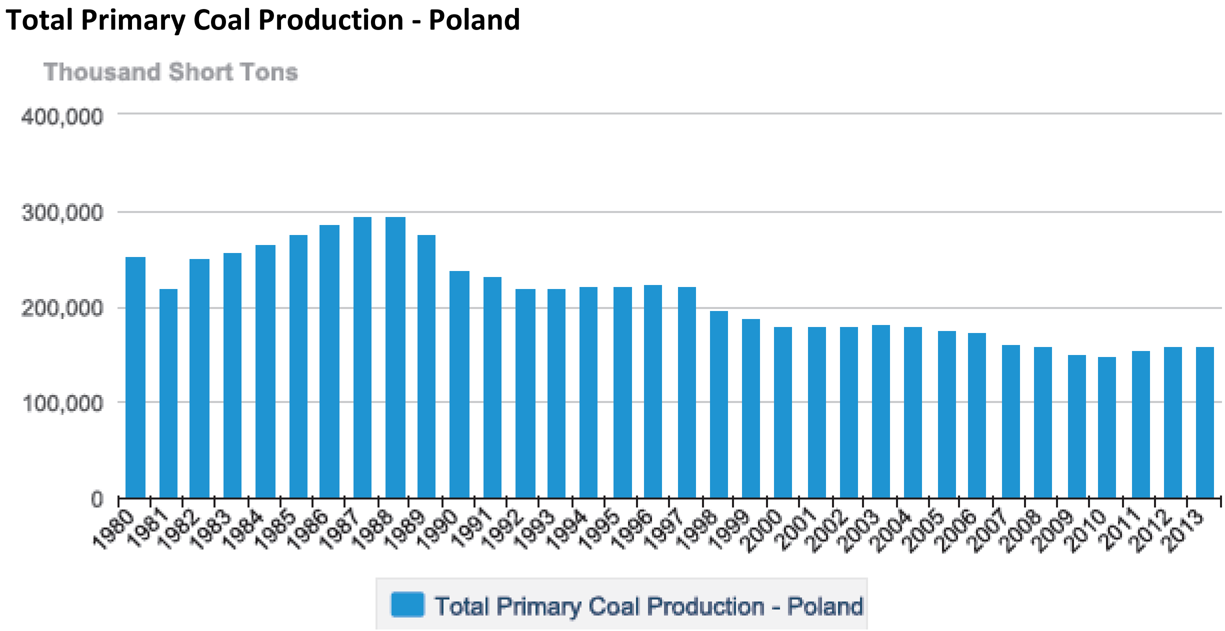



Figure 3 – Total primary coal production in Poland. [2]

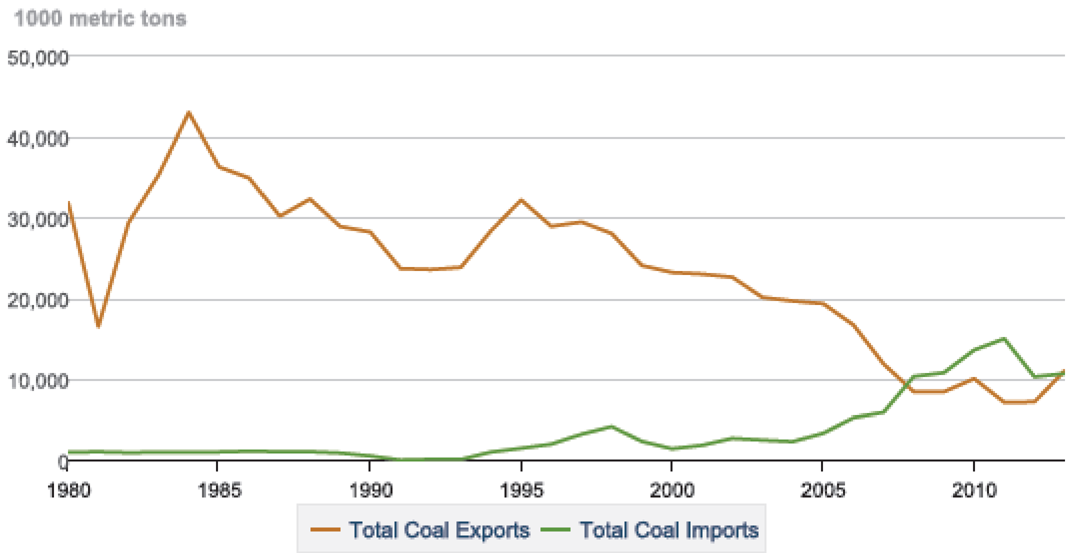



Figure 4 – Total coal exports and imports. [2]

At present, the mining industry has declined in Poland. The main reasons are the decreasing coal demand and the shortage of coal resources, in addition to the reduction of subsidies for coal mines in the country. With the intention of reducing the operation costs of the mining industry, around the thirty oldest coal mines operating in urbanized areas and with unfavourable mining and geological conditions have been closed. [12]

## 2.2 Coal basins in Poland

Coal is a sedimentary rock, formed during the Carboniferous Period by geological processes over millions of years.

The four types of coal are classified by the degree of transformation of the original plant material to carbon. According to this classification, lignite is the coal with least carbon and highest degree of moisture content while the anthracite, on the opposite side, has the highest percentage of coal and less moisture content.

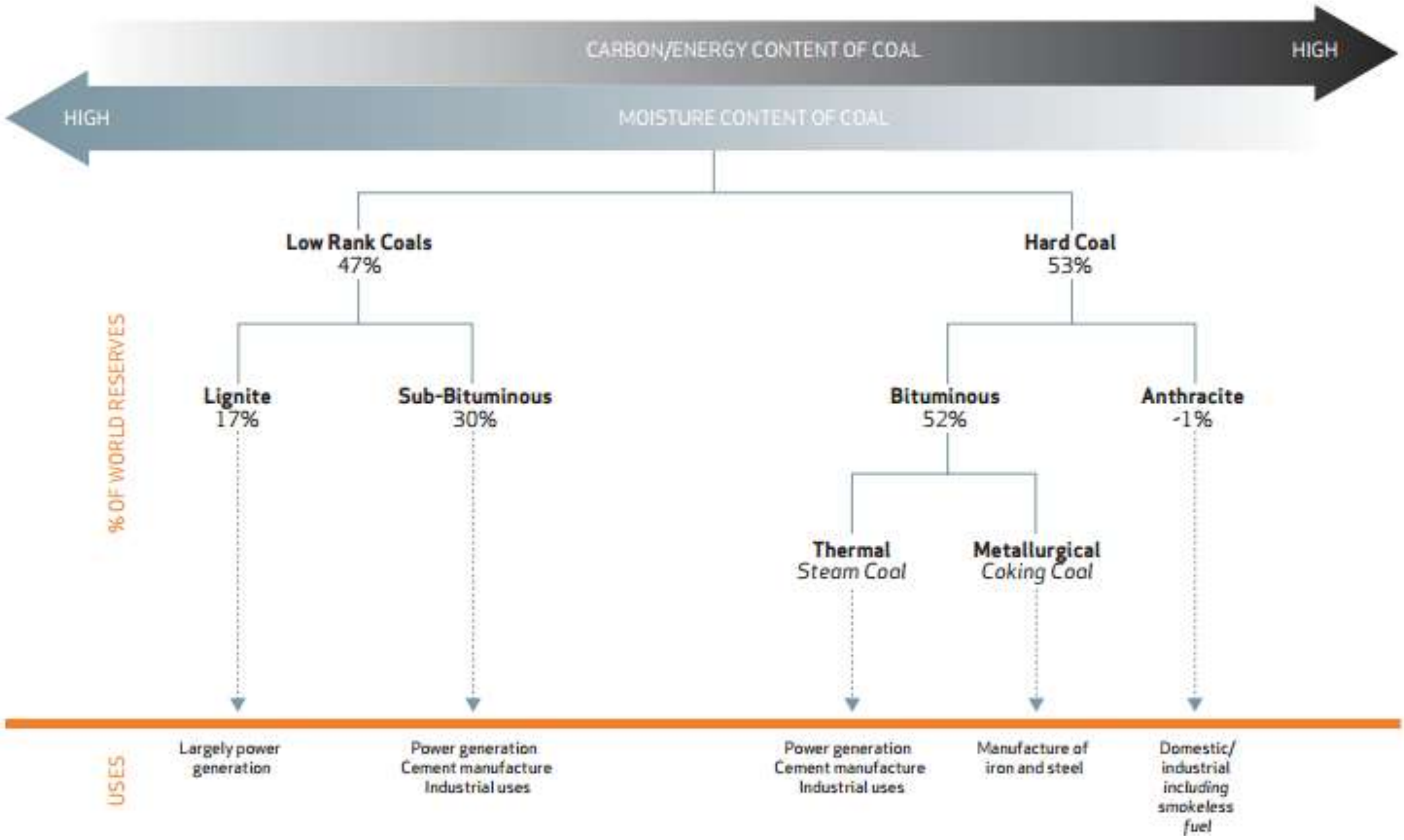



Figure 5 – Types of coal, world reserves and uses. [7]

### 2.2.1 Hard coal

As stated before, anthracite has the lowest degree of moisture and highest energy content but is not available in Poland.

Polish hard coal deposits belong to the Carboniferous Euro-American coal province. In Europe this province is represented by two belts of coal basins [6]:

1. A belt of paralic coal basins that originated near the sea in depressions along the front of the Variscan fold belt which was forming in these times
2. A belt of limnic basins, with coals accumulating in closed basins and intermontane depressions with disconnected internal river systems.

In Poland, coal deposits of the Carboniferous age occur in three basins (Figure 6):

Two basins of the paralic type:

- The Upper Silesian Coal Basin (USCB)
- Lublin Coal Basin (LCB)

One of the limnic type:

- The Lower Silesian Coal Basin (LSCB).

In the first two basins, UCB and LCB, extraction of coal is still being carried out in the actuality; nevertheless, LSCB is closed since year 2000.


Figure 6 – Location map of the hard coal basins. [8]

**Production of Bituminous Coal - Poland**

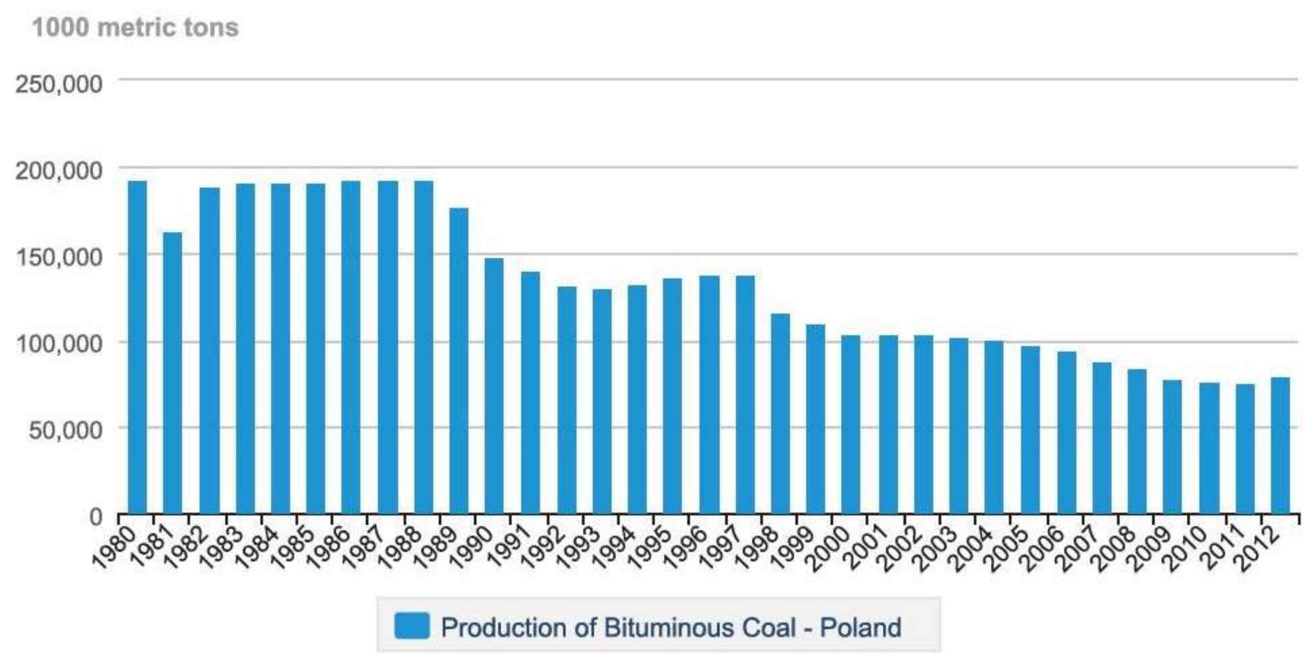



Figure 7 – Production of bituminous coal in Poland. [2]

**Upper Silesia Coal Basin (USCB)**

The region of Upper Silesia is situated in the center of Europe, southern part of Poland and has borders with the Czech Republic and Slovakia. Coal mining industry in this region has existed for over 150 years.

The Upper Silesian Coal Basin (USCB) is the main geological structure in this region, being also the major coal basin in Poland and one of the largest in Europe. Most of USCB is located in Poland and continues into the Czech Republic. It extends over an area of approximately 6100 km$^2$, out of which 5600 km$^2$ are in Poland.

All the coal mines operating in the country are located in the USCB except one, the bogdanka mine, which is operating in the LCB. [6]

Regarding to the geological structure of the Upper Silesian Coal Basin, the Carboniferous basin was formed on a Precambrian crystalline massif characterized by considerable subsidence. The Carboniferous mudstone and sandstone complex with numerous coal seams has a thickness of up to 8000 meters. Overlying them, in the northern part of the basin, a Triassic carbonate formation can be found; while in the southern and western parts only Miocene argillaceous and arenaceous faces with evaporates overlie the Carboniferous sediments. The folded Carpathian massif of the Alpine orogeny partially overthrusted the basin in its southern part. [12]

Within the basin Quaternary sediments form a discontinuous cover of glacio-fluvial sediments several dozen meters in thickness.

The best conditions for coal exploitation take place in the north and south-west of the basin, where tectonic uplifting occurred exposing a part of the Upper Carboniferous coal – bearing formation.

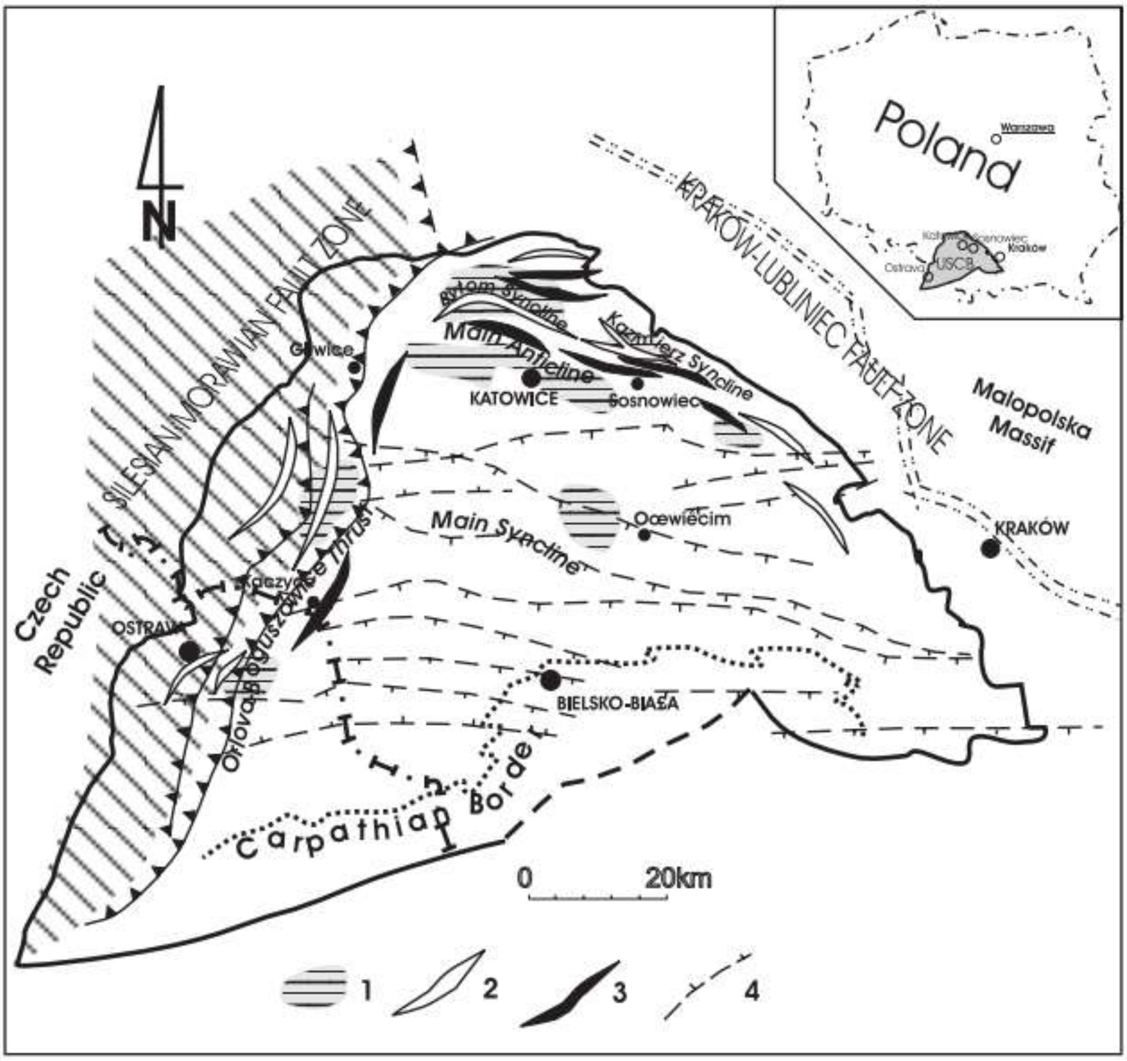



Figure 8 – Geological sketch of the Upper Silesian Coal Basin (USCB). Compiled after Jureczka & Kotas (1995). 1 – areas of intensive coal exploitation, 2 – synclines, 3 – anticlines, 4 – tectonic faults. [12]

**Lublin Coal Basin (LCB)**

Lublin Coal Basin is located in the southeast of Poland, in the border with Ukraine and has an extension of about 9,100 km$^2$.

The seams are moderate structurally disturbed in contrast to the USCB coalfields.

LCB has bituminous coals with low ash and sulphur contents with different coking properties. Large reserves of black coal have been recently discovered in the LCB and it will be the most important supplier in the future.

Nowadays, is in an early stage of exploration and the Bogdanka mine is the first and only mine operating in LCB. The exploitation of the deposit covers an area of approximately 77 $km^2$, which corresponds to 0,8 % of total area of LCB. [6]

This basin is a pericratonic depression within the East-European Platform. The coal bearing lithostratigraphic sequence of the Lublin Coal Basin is difficult. The upper part is formed with continental sediments, the middle part is paralic and the lowest part is of marineparalic origin. [8]

**Lower Silesian Coal Basin (LSCB)**

The Lower Silesian Coal Basin covers an area of about 350 $km^2$ and is characterised by a considerable thickness variability and small horizontal and vertical extension of the coal formations.

The LSCB is much smaller than the Upper Silesian Coalfield and contains thinner seams, about 30 coal beds with a thickness exceeding 1 meter.

Coal seams are highly tectonised. The Pennsylvanian coal measures of the Lower Silesian Coal Basin are grouped in two main lithostratigraphical units, the Walbrzych and Žacler formation. These units are of Namurian and Westphalian age. [8]

The Lower Silesian Coalfield has been an important supplier of coking coal but today the mining is closed. Coal exploitation ceased in the year 2000. The works at the last active field, the Słupiec coal field of the Nowa Ruda mine, ended due to the difficult geological and mining conditions because the remaining reserves are very deep and were resulting in too high operation costs. [6]

### 2.2.2 Lignite

Poland is the second largest lignite producer in Europe [8].

The coal production is mainly located in four areas: Adamów, Belchatów, Konin, and Turów. In Poland, the mining extraction of lignite deposits is exclusively carried out in opencast mines.

Deposits of lignite, also called brown coal, are found in young geological formations, mainly from the Tertiary.

Seams of older brown coals are often situated too deep underground for opencast mining and require underground mining. This is also the case of coal seams located in glacitectonic folds. The methods of underground mining were lately used in Poland to mine coals in the Babina and Sieniawa [6] deposits but the first one is already closed [10] and in Sieniawa the open-pit method is currently used. [11]

**Production of Lignite Coal - Poland**

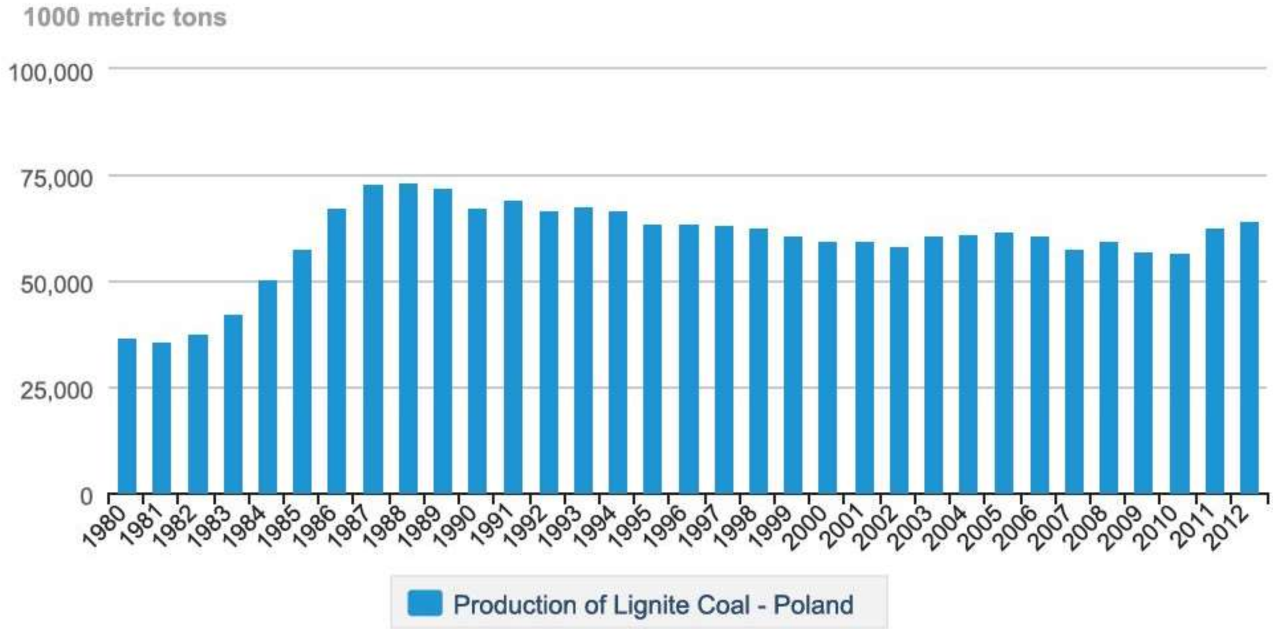



Figure 9 – Production of lignite coal in Poland. [2]


Figure 10 – Coal mining regions in Poland. Lignite and hard coal. [32]

### 2.3 Mining methods

The choice of the mining method depends mainly of the geology of the coal deposit.

In Poland, depth of coal seams generally ranges between 500 and 1000 meters and are normally exploited through longwall method. [13]

There are different methods of mining coal divided between surface mining and underground mining. Main methods of underground mining are room-and-pillar and longwall mining.

About 60% of world coal production is mined through underground mining methods. However, several important coal producing countries, as USA or Australia, commonly employ surface mining methods. [7]

#### 2.3.1 Underground mining

Hard coal exploitation in Poland is only carried out by underground mining methods due to the coal seams conditions. [5]

There are two main methods of underground mining:

- Longwall mining method
- Room and pillar method

#### 2.3.2 Longwall mining method

The longwall mining method, most commonly used in Poland, involves the complete extraction of coal from a section of the seam employing mechanical shearers.

Longwall mining is a continuous process. The mechanical shearers move along the coal section cutting a slice of coal on each pass. When the shearer reaches the full length of the coal face, it changes direction and displaces back along the coal section cutting another slice. A face conveyor runs along the total length of the coalface and serves to carry the coal and discharge it onto the belt conveyor, which carries the coal out of the mine.

Normally, coal panels are around 150 to 300 meters wide, 1000 to 3000 meters long and 2 to 5 meters thick [15].

Mining exploitation carried out by longwall mining method requires the use of self-advancing hydraulic roof supports. As its name indicates, its function is to hold up the roof during the coal extraction. When coal has been extracted from the working area, the shearing machine, the face conveyor and the hydraulic roof supports move forward allowing the roof of the already mined area to collapse into the void.

The collapse of the roof into the void, also called goaf, produce fractures and settlement of the directly above rocks (Figure 12) and progresses through the overlying strata to the near surface rocks causing subsidence of the land surface.

Continuous or trough subsidence results from the longwall mining of coal but has also been associated with the extraction of a wide variety of other minerals. [14]

**Advantages of longwall mining**

- Longwall mining productivity is potentially higher than room and pillar mining.
- The employment of hydraulic roof supports during coal extraction provides major security for the miners
- Can reach higher depths because in room and pillar mining at greater depths larger pillars are needed, resulting in smaller coal recovery.

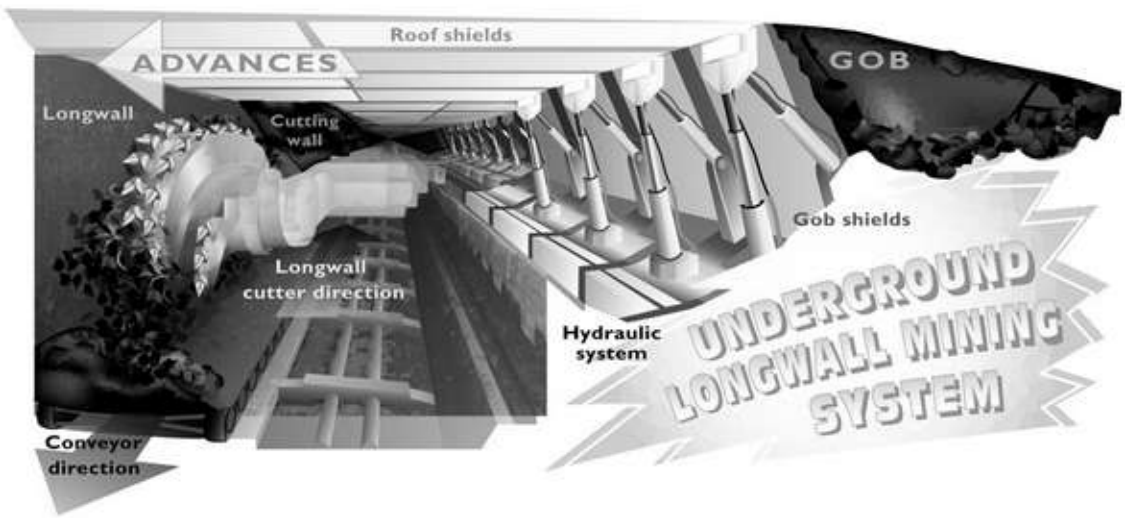



Figure 11 – Longwall mining system. [9]

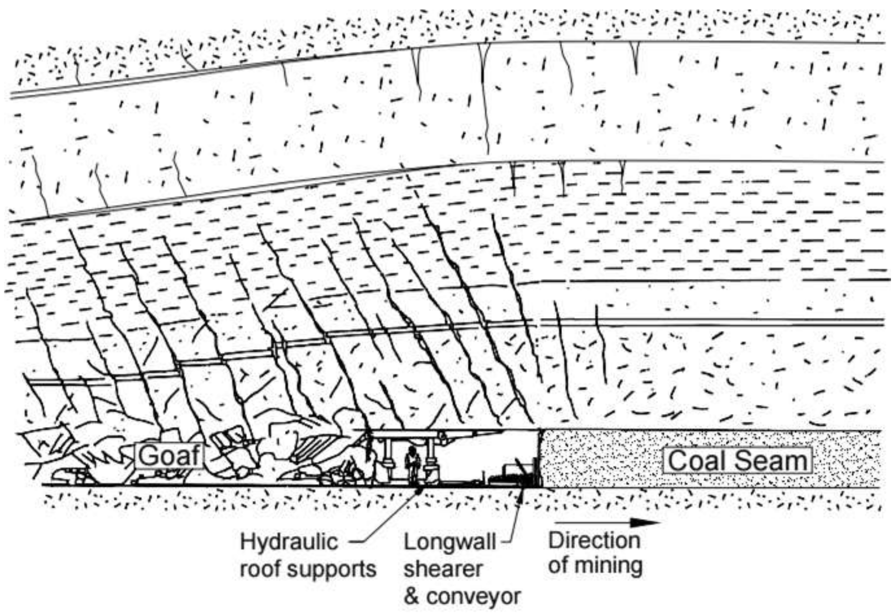



Figure 12 – Cross section of a typical longwall face. [15]

### 2.3.3 Room and pillar method

As its name indicates, it is a pillar supported method; it means that coal is mined by cutting rooms into the seam and leaving behind protective pillars of coal supporting the roof.

The rooms are the empty areas from which coal has been mined. As mining advances, a grid pattern of rooms and pillars is formed. It is preferable to arrange pillars in a regular grid, to simplify planning, design and operation of this method.

For a successful development of room and pillar method, coal deposits must be relatively shallow to avoid oversized pillar which would result in a small coal recovery. Coal pillars may include 40% of coal in the deposit and sometimes can be recovered later.

When mining reaches the end of a panel, retreat mining begins. During retreat mining, the workers mine as much coal as possible from the remaining pillars until the roof falls in. Once retreat mining is completed, the mined area is abandoned.

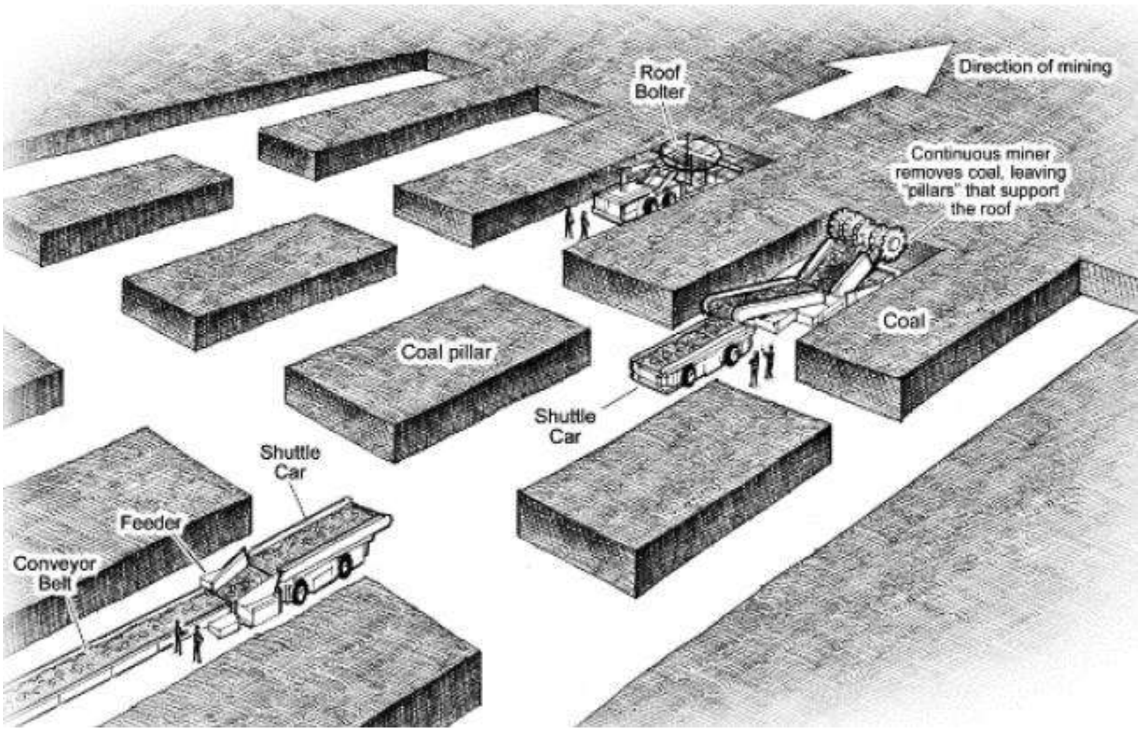



Figure 13 – Room and pillar mining. [22]

**Advantages of room and pillar mining**

- Costs for equipment and installation are much lower than for longwall mining.
- Allows faster start of coal production by using mobile machinery.

# 3. Basic information about mining

## 3.1 Definition of mining subsidence mechanism

This section aims to explain the mining subsidence mechanism, briefly explained during the longwall method section, and on the basis that subsidence is an inevitable consequence of underground mining.

The process begins due to the creation of an empty space in the rock mass, where previously there was rock. The creation of a void in the subsurface, produced by mining, involves changes in the stress state of the surrounding strata.

These changes will produce deformations and displacements of the strata, magnitudes of which depend on the degree of the stress change, the spatial extent over which it occur and the characteristics of the strata.

Large changes in the stress state can cause the collapse of the rock around the mine excavation into the mined void (Figure 14). Fractures and settlement of the rock, associated with such collapse propagate to the ground surface, resulting in deformations and displacement of the surface characteristics of the mining subsidence phenomena.

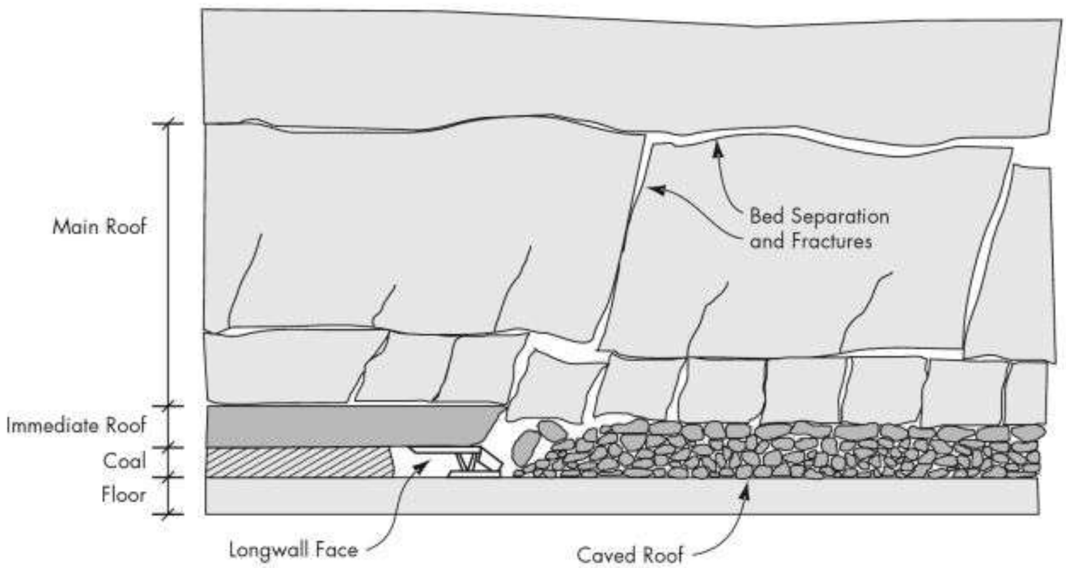



Figure 14 – Caving and fracturing behind and above a longwall face. [20]

Talking about mining subsidence, generally include both, vertical and horizontal movements. It can be continuous, when the surface deforms softly and slowly over large areas, or discontinuous, which is totally different and produce violent and quick impacts in particular areas. Also involves hydrological changes and subsoil vibrations.

In the case of longwall mining, the most common method employed in Poland, the greatest subsidence follows the exploitation front. The area affected by subsidence depends on the size of the exploitation field and its depth.

In the region of Upper Silesia, subsidence can reach velocities of few centimeters per month, however many areas experience greater subsidence with values of 1 cm daily or more. Such rate usually appears between 3 to 6 months after the mine exploitation and gradually ceases during next 2 years. If subsidence has already happened in the area, due to mining in coal seams above the current exploitation, the subsidence will be faster and will stop in a shorter period. [16]

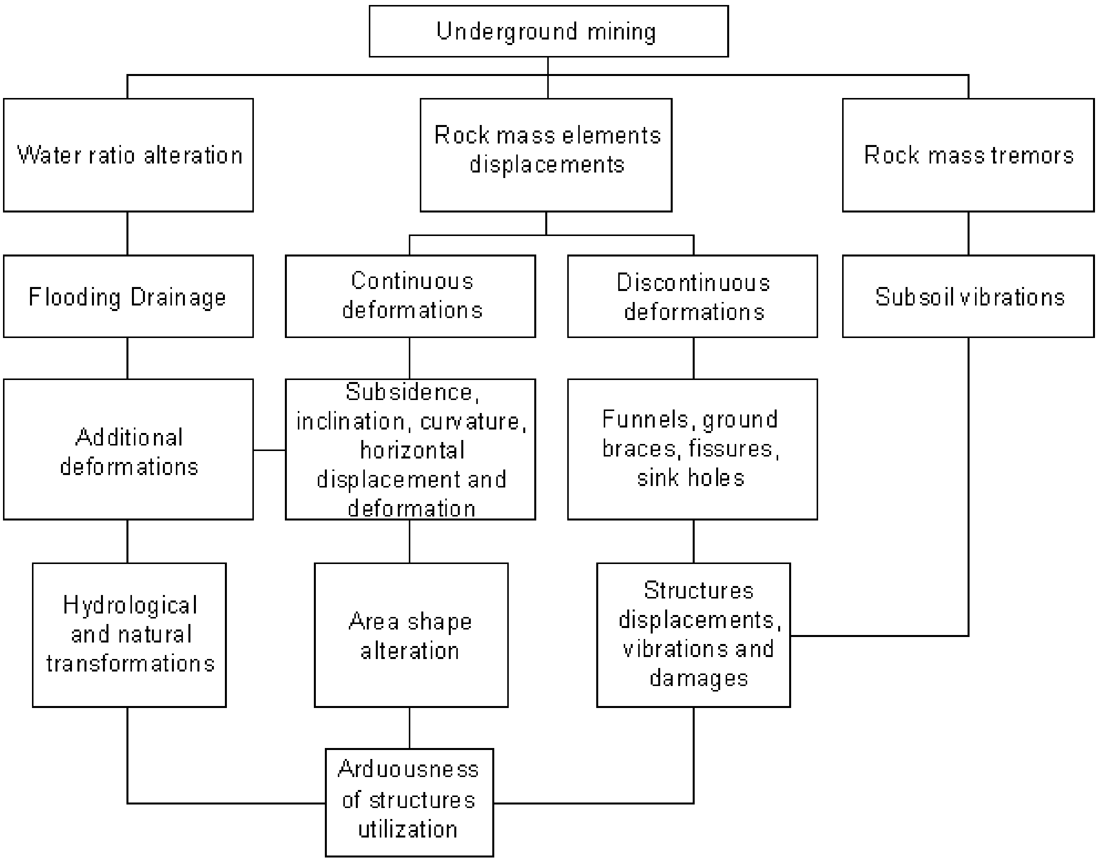
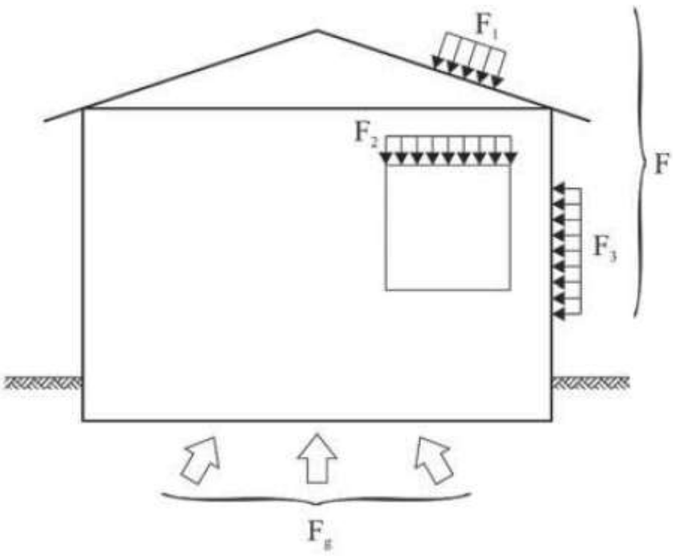



Figure 15 – Classification of mining impacts due to underground mining. [18]

## 3.2 Building construction in mining areas

The buildings in mining areas are subject to additional impacts resulting from the deformation of the surface or ground vibrations.

These interactions, called mining impacts, are transmitted from the ground to the building and cause the occurrence of additional loads besides regular impacts (Fig 16).




F (F1, F2, F3) – loads and impacts determined on the basis of standards;

$F_g$ –mining impacts, deformations or vibrations caused by mining exploitation.

Figure 16 – Building in mining areas. [19]

The protection of buildings in mining areas requires not only knowledge of building structures, but also knowledge of the issues with the mechanics of the rock mass and geotechnics, and increasingly, hydrogeological issues.

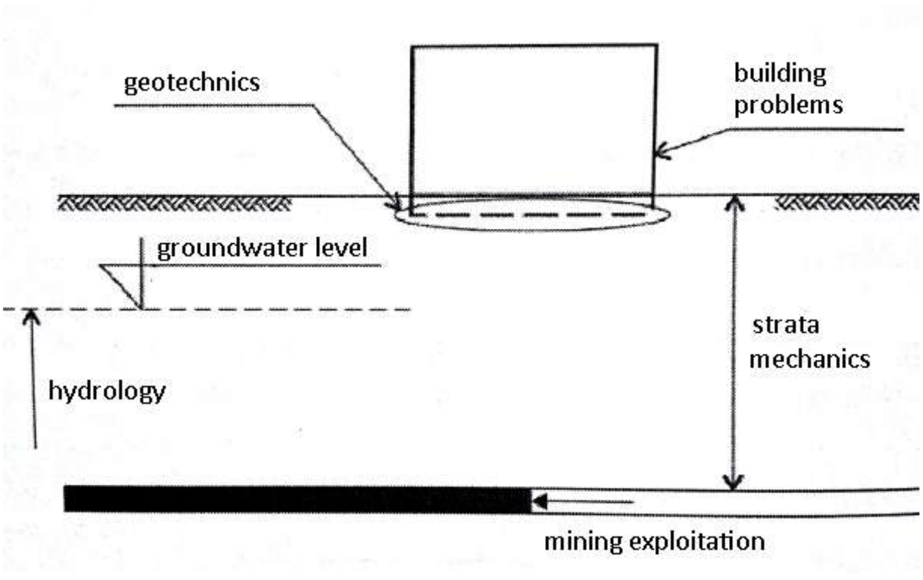



Figure 17 – Problems in buildings in mining areas. [19]

Rock mechanics mainly provides information about:

- Characteristics and intensity of the surface deformations.
- The vibrations of the land surface caused by mining tremors.
- Possible protection methods to protect buildings from the impact of mining.

The deformation of the surface and ground vibrations are transmitted to the building causing deformation and therefore, internal forces appear in the structure.

Increasingly, the impact of mining on the surface produces hydrogeological problems. This is because many areas have experienced significant depressions. The continuation of mining exploitation in these areas will cause additional land subsidence, which can cause changes in the groundwater and leading to flooding in these areas.

The main problems related to construction in mining areas are the calculation and construction of new buildings as well as proper maintenance of existing buildings subject to the influence of mining.

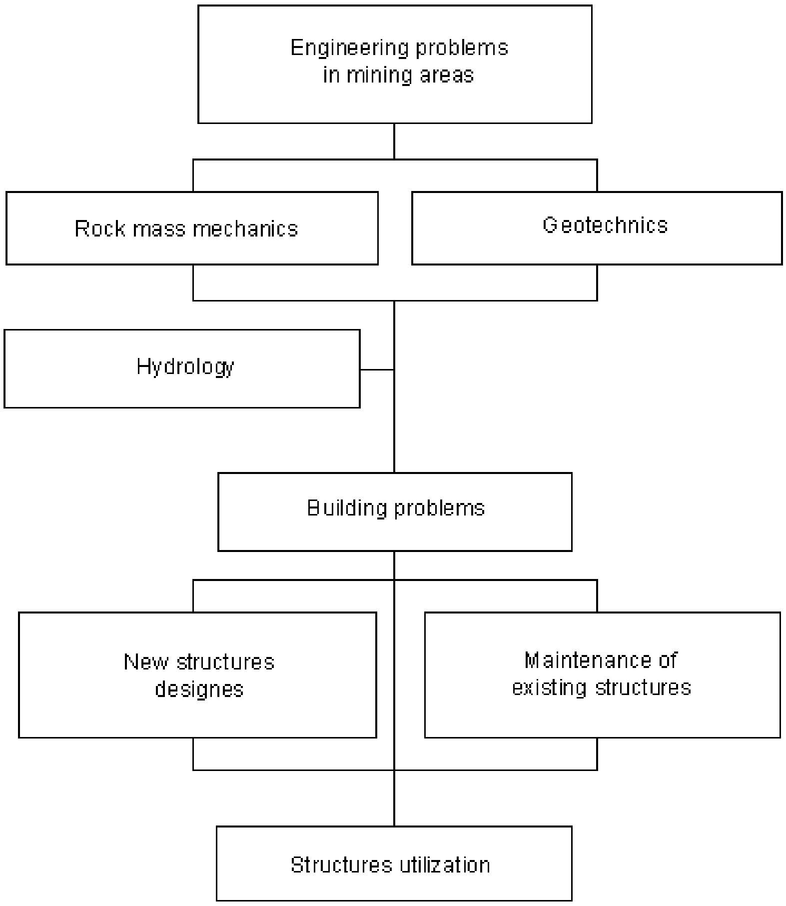



Figure 18 - Problems related to the construction in mining areas. [18]

In the construction of new buildings, the design is adapted so that buildings can withstand the impact of mining. This is achieved by appropriate design of structural elements.

The building structures are designed in accordance to the Ultimate Limite States (ULS) and Serviceability Limit States (SLS) allowable values but SLS can be modified in the mining areas, giving the possibility to minimize this criterion for the use of buildings.

Existing buildings can be adapted to withstand the impacts of mining. There are also many buildings that have not been adapted to these impacts because the area where they were built was not planned as a future mining area.

The possibility of mining exploitation affecting existing buildings involves periodic evaluation of its resistance to the effects of mining, understood as the capacity to absorb the impacts of mining maintaining the safety of the structure and the possible occurrence of damage not having a significant impact on the use of the building according to its main purpose.

Problems associated with surface deformations and tremors caused by mining are random phenomena. As a result, determining the resulting impact on the buildings, in terms of structural safety assessment and to determine the risks of damage to existing buildings, must be done in a probabilistic manner.

In current practice, to calculate the influence of mining on the surface, safety factors are taken to determine the design values of the impact of mining in the buildings.

### 3.3 Damage caused by mining and its systematic.

In spite of designing new buildings to withstand the impact of mining and take precautions to carry out mining activities under existing buildings, the occurrence of adverse effects caused by mining activities is inevitable. These adverse effects, that is, damages produced by mining in buildings, have a size and range, usually greater than the damage caused to buildings from other causes. In short, the mining has a great impact in buildings.

The damages caused by mining are mainly because of:

- Inaccuracy in forecasting the effects of mining on the surface, the expected values can be quite different from the actual values. In addition, by the occurrence of sudden events as discontinuous ground deformation.
- Insufficient control of the behavior of buildings and the lack or delay in the intervention of the structures.
- Mistakes in the design and / or execution of the buildings at the time to adapt them to withstand the impacts of mining.
- Inaccuracy calculating the approximate resistance of buildings, especially in cases where mining is located under large groups, such as urban districts or industrial plants.

The severity of damage depends mainly on the adaptation of the design of the buildings to the impacts of mining and intensity of these impacts.

Damage caused by mining in buildings can be classified in (Figure 19):

- Damage to building elements or fittings (architectural finishes), which are subjected to more attrition than if they were not affected by mining.
- Arduousness of use, which reduces the performance of the building and also reduces the comfort of the inhabitants.

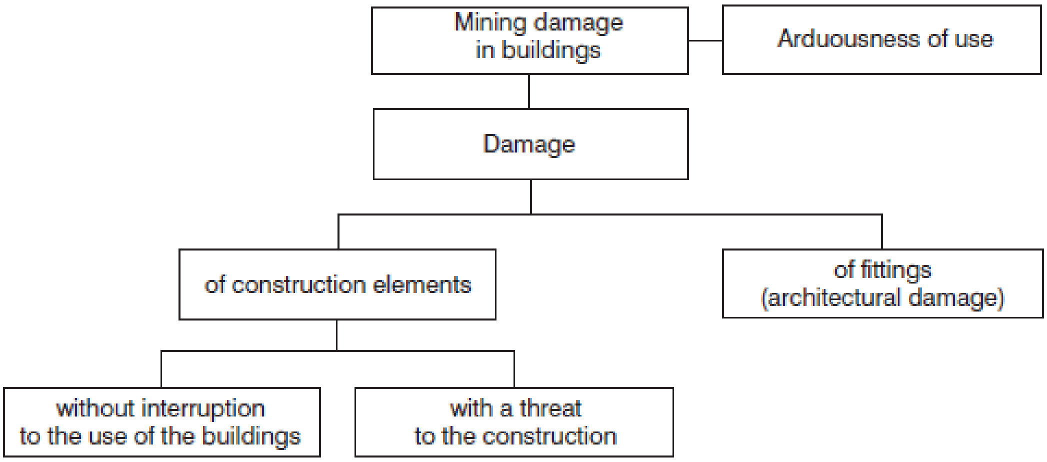



Figure 19 - Damage caused by mining to buildings. [19]

At the same time, damage to building elements can be divided into:

- Insignificant damages to the use of the building and do not imply a hazard to its stability. If it is forecasted that damage will not go further, then it is not necessary to implement technical actions.
- Structural damage that threaten the stability of the building and, therefore, technical actions are required.

Damage to the architectural finishes, known as architectural damage, usually only causes arduousness of use. In rare cases it can affect the safety of users, such as when a large piece of plaster can fall from the ceiling.

Lesions causing arduousness of use are:

- Deformations of the building and its elements, including all the elements causing restrictions on the proper functioning of doors and windows, etc.
- Disruptions in the use of the building due to the necessity of performing reparations for the damage caused to the building or architectural finishes.

In general, two types of mining threats affecting the construction of buildings can be distinguished:

- Local
- Extensive

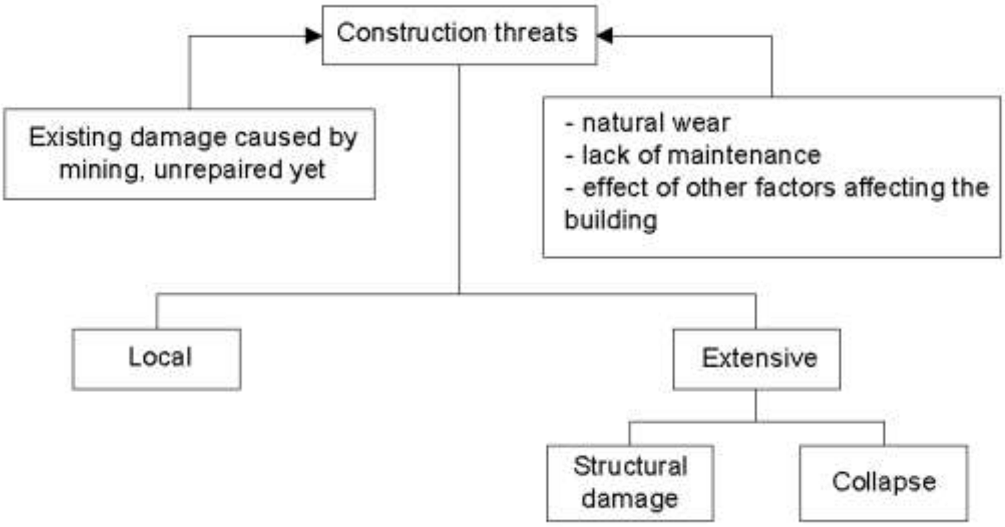



Figure 20 - Mining threats affecting the construction of buildings. [19]

Local threats involve damage to elements, resulting in local defects in the building but do not affect the safety of the entire building. Damage of this type may require some technical interventions. Examples of local threats are cracking of lintels or walls.

Damages due to extensive threats can cause:

- Structural failure or damages to structural elements. Significant deterioration in the use of the building and could suppose a danger to the lives of inhabitants.
- Catastrophe or sudden collapse of the structure preventing further use. It can suppose tragic consequences for inhabitants and generally also great material losses.

The first case, structural failure or damages to structural elements, occurs in the case of significant damage to the ceilings of the building or to the lintels of windows and doors. If the damage intensifies, threatening to collapse parts of the building, then it would face risk of catastrophe or sudden collapse of the structure, as it is stated in the second case.

Should be noted that in the threat assessments of existing buildings must also consider the effects induced in the structure, it is (Figure 20):

- Existing damage caused by mining until now.
- Factors not related to the influence of mining activities, such as:
    - Natural process of wear.
    - Lack of maintenance.
    - Effect of other factors that also affect the building.

The impact of mining is characterized by the variability of their values over time. Consequently, it also changes the combination of interactions. Taking into account the impacts of mining and impacts from other origins affecting the structure, in mining areas takes place a complex situation of loads on the buildings, which affects their security.

This is particularly noticeable in buildings not adapted or not properly adapted to withstand the impact of mining. In the event that the building is not adapted or not properly adapted to absorb the additional impacts resulting from the deformation of the ground, the building is more exposed to damage.

As it is shown in the next figure, Depending on the evolution of impacts of mining activity, and the resistance of the same construction facing these impacts, the development of risks and resulting damage to the structure may also vary its course.

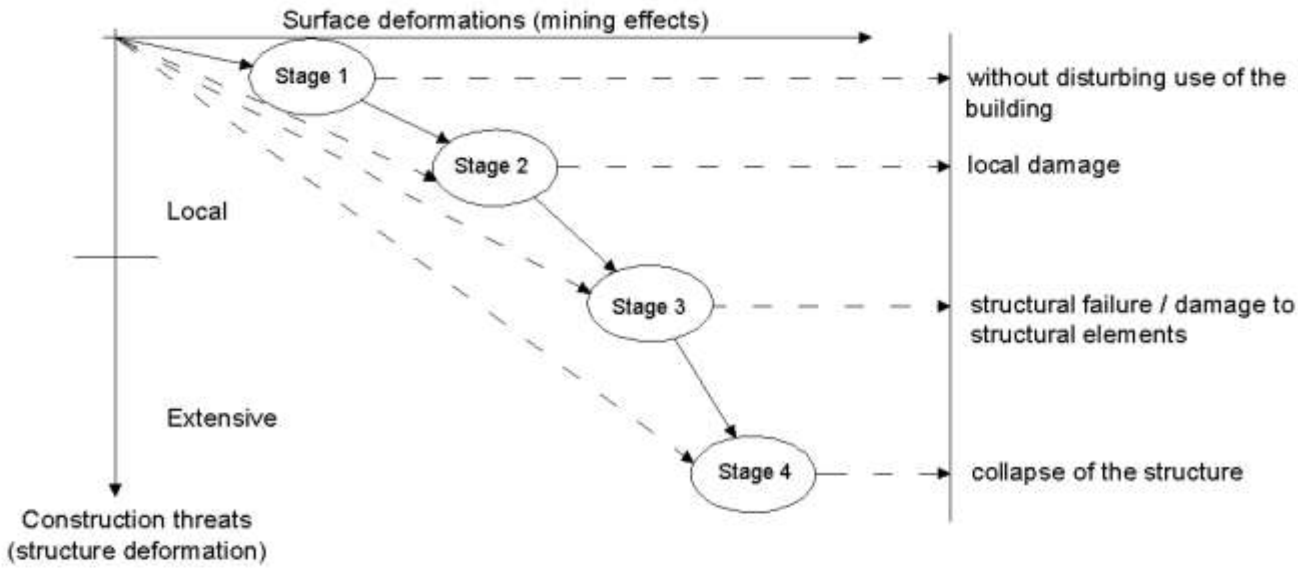



Figure 21 - Development of the risks caused by the impact of mining. [19]

- In stage 1 is taken into account progressive damage that affects the building over time and does not cause significant interference in the use of the building.
- When stage 2 is reached local defects appear.
- Resulting in stage 3 when these are intensified.
- Finally, in stage 4, the catastrophe or sudden collapse of the structure occurs.

In the case described above can be seen as damages to the building intensify and pass through the four phases. However, it is possible that, depending on the damage, the building fits directly in one of these phases without passing through the previous stages.

# 4. Mining impacts on the land surface.

## 4.1 Classification of the effects of mining on the surface.

Deformations occur in the ground as a result of underground mining exploitation. It can also induce seismic shocks, called mining tremors, and changes in the water conditions.

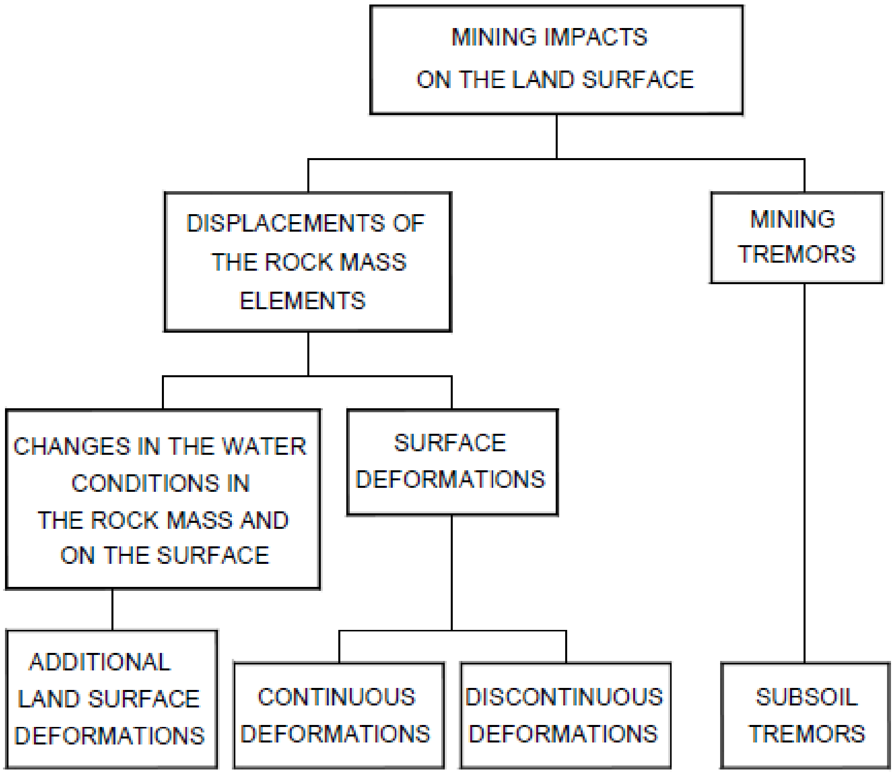



Figure 22 - Classification of the effects of mining on the surface. [27]

The movements of the rock mass elements cause surface deformations that can be continuous or discontinuous. The main difference between them is that continuous deformations develop slowly over large areas while the discontinuous deformations are local deformations occurring violently and quickly.

In many mining areas, mainly due to coal mine exploitation for a long time that results in significant depressions in the ground, mining operations can cause changes in the water regimen conditions in the rock mass and on the surface. Those changes can produce drainages or flooding.

Mining exploitation can also induce mining tremors, know as a dynamic phenomenon, caused by the rapid displacement, cracking or breakage of the rock layers. Mining tremors produce vibrations in the ground, similar to earthquakes, but in the case of mining tremors vibrations lasts for less time.

The progress of works into the mine starts producing the depression of the ground. Normally, after the coal has been extracted, the roof is allowed to collapse and this produces changes in the land surface. There are three different parts in the area of depression:

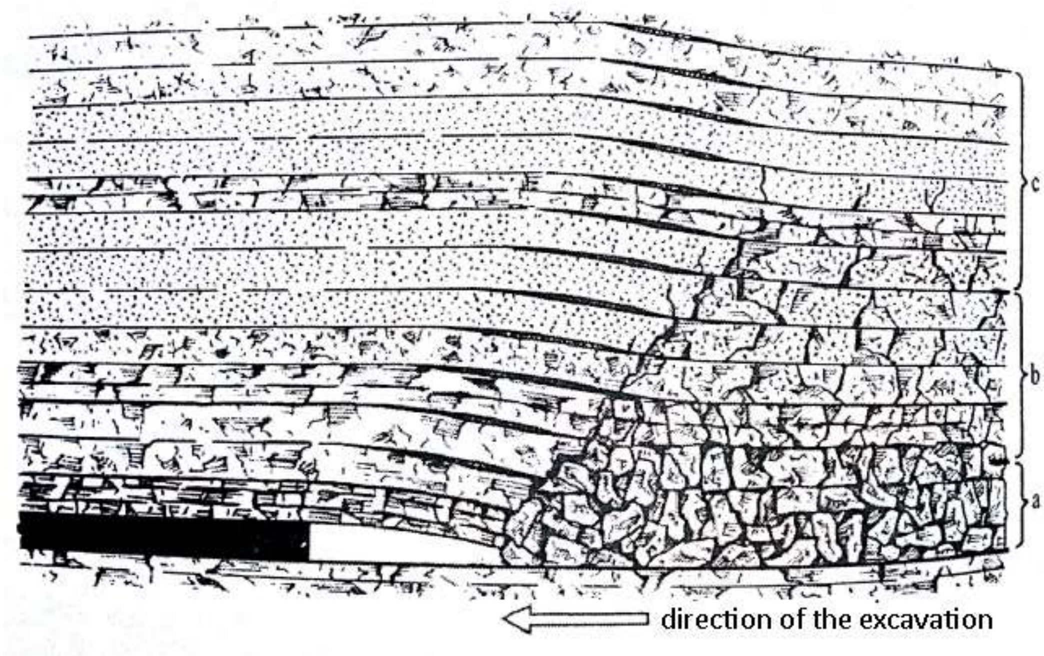



Figure 23 - subsidence due to longwall mining operations. a – goaf zone, b – cracks zone, c – bending zone [21]

Formation of depressions in the ground is related to development of continuous deformations while fractures in the ground indicate the appearance of discontinuous deformations. The appearance of continuous or discontinuous deformations primarily depends on the depth of the mine, method of coal excavation and the characteristics of the surrounding rock mass.

Previous experience in the area of Upper Silesian Coal Basin (USCB) showed that during the operation of the mines at shallow depths, up to 150 m, essentially discontinuous deformations occur. At greater depths, continuous deformations will appear, developing bowl-shaped depressions in the surface. [19]

Surface deformations caused by mining exploitation are usually classified by:

- their relationship with the mining works (direct, indirect and secondary),
- the manner of its occurrence (continuous and discontinuous)

## **4.2 Classification of surface deformations according to their relationship with the works in the mine**

- Direct,
- Indirect,
- Secondary.

Direct impacts arise as a result of movement of the elements of rock into the void that is produced during the mining, causing surface deformations.

Indirect impacts usually occur accompanied by displacements and deformations resulting from direct impacts. They occur, among other things, by changes in the ground water, as well as changes in the properties of the subsoil.

Secondary impacts are the result of the activation of previous impacts not fully developed due to the currently in progress mining operations. Elements, machinery, etc. used during mining operations would prevent the full development of these impacts in its initial moment. Secondary impacts may occur due to, both direct and indirect impacts, resulting in discontinuous surface deformations of the surface.

The appearance of indirect and secondary impacts can significantly affect the final deformation of the surface.

## 4.3 Classification of surface deformations according to the manner of its occurrence

There are two main types of mine subsidence impacts on surface, continuous and discontinuous deformations. Their appearance depends on depth of strata deposition, method of coal excavation and types of rocks strata. Ground movement can appear as a long and soft process (continuous deformations) or as a rapid in form of funnels, fissures or sinkholes (discontinuous deformations).

### 4.3.1 Continuous deformations.

Mine subsidence phenomena, related to longwall mining operations is the gradual lowering of the land surface due to collapse of bedrock into underground mined-out areas and subsequent sinking of surface unconsolidated materials like sand, gravel, silt, and clay.

#### 4.3.1.1 General information.

The most common deformations caused by underground mining are continuous deformations in the form of unequal land subsidence.

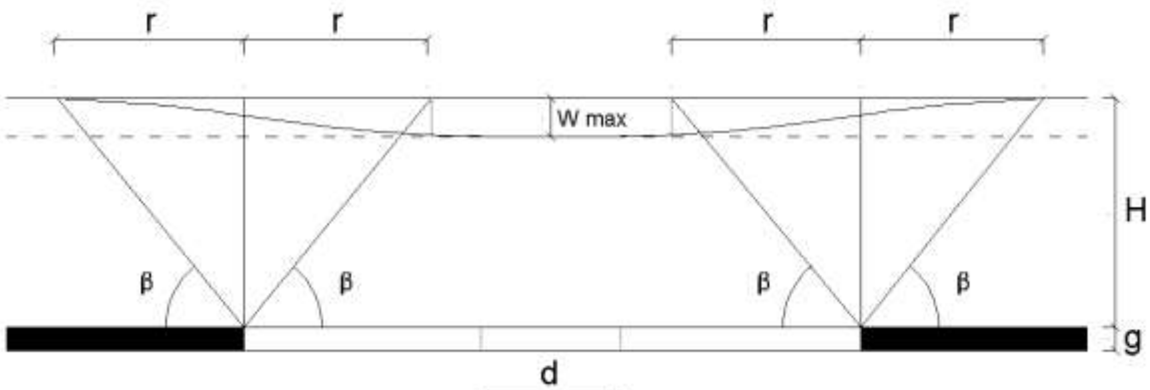



Figure 24 – Continuous deformation of land surface. Subsidence basin. [19]

The value "r" is the main influence range (r = H/tg β), which depends on H (exploitation depth) and the properties of the rocks located above the mine, described by the angle of main influence or angle of draw β.

The angle of draw is one of the most important magnitudes of the Budryk – Knothe theory. The angle of draw depends on the depth of cover to the coal seam and the strength and composition of the overburden strata, as well as mining configurations. In the USCB tg β ≅ 1.5 ÷ 3.2. Value of tg β ≅ 2,0 is normally accepted.

Considering the question in the space, can conclude that the points experience horizontal and vertical displacement, it means, an arbitrary point P on the surface is moved to the position P ' (Figure 25). Relative to the coordinates x, y, z from the displacement vector PP ', in the general case it can be described using the components u, v, w. These are given in function of time t:

$$u = u\ (x, y, z, t)$$

$$v = v\ (x, y, z, t)$$

$$w = w\ (x, y, z, t)$$

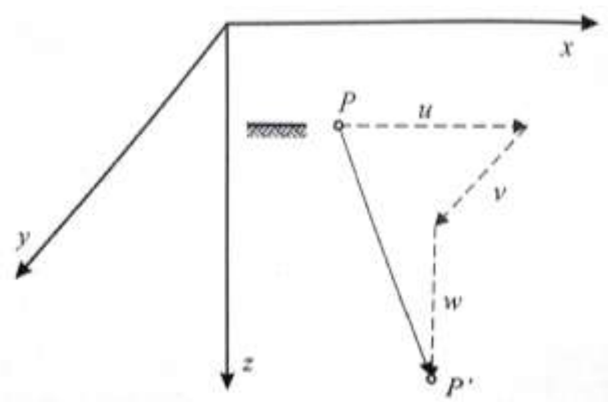



Figure 25 – Displacement components of any point P on the surface. [19]

The size of the surface deformation depends mainly:

- Depth of exploitation: with small depths there is the possibility to appearance of discontinuous deformations. If the depth is greater, the influences will be softer,
- Height of selected space: the larger height the greater deformations appear,
- Way of filling of exploited void: the use of backfill materials with low compressibility results in a significant reduction of the deformation,
- Shape and size of the field: subsidence and inclination of surface increase with the size of the field, up to the maximum values that are reached above the large-sized field,

- Speed of the progress of the front of exploitation: for the rapidly progressive front extreme deformations are smaller, but the speed of their growth is higher,
- Geological structure of the over-lied rock mass: the more compact rock mass the greater range of influences, but less deformations; disturbances in the form of faults can contribute to the formation of discontinuous deformations,
- Inclination of bed: effects are shifted in the direction of bed dip, larger deformations occur at the lower deposited part of the bed.

The deformation of the basin depends on the following factors:

- g – Thickness of the seam exploited,
- H – The depth of the seam,
- $\beta$ – The angle of draw,
- a – settlement coefficient, calculated for exploitation method and way of cavity filling (according to table 1).

Maximal subsidence is calculated approximately from the following formula:

$$W_{max} = a \cdot g$$

Maximal exploitation depth which can causes discontinuous deformations:

$$H = 70\, a \cdot g$$

When excavation depths are greater, discontinuous deformations does not appear.

Table 1 – Value of coefficient “a”. [22]

| Methods of removal of after-excavation space – exploitation system | Value of coefficient “a” |
|---|---|
| Fall of the roof | 0,7 – 0,85* |
| Dry filling – full made of provided material | 0,5 – 0,6* |
| Dry pneumatic filling | 0,4 – 0,5* |
| Hydraulic filling made of sand | 0,15 – 0,25* |
| Hydraulic filling made of broken stone (e.g. Haidex) | 0,3 |
| Partial exploitation in strips, in 50% with hydraulic filling | 0,02 – 0,03* |
| Partial exploitation in strips, in 50% with fall of the roof | 0,1 |

* Larges values should be employed in case of repeated exploitation.

#### 4.3.1.2 Subsidence parameters

Every point of a subsidence trough is subjected to vertical displacement "w" (subsidence) and horizontal "u" displacements. These displacements cause deformations of the land surface and influence the damage to surface structures. The deformations are described by the following ratios:

- Slope or tilt (T),
- Curvature (K) → curvature radius (R = 1/K),
- Horizontal deformation (ε).

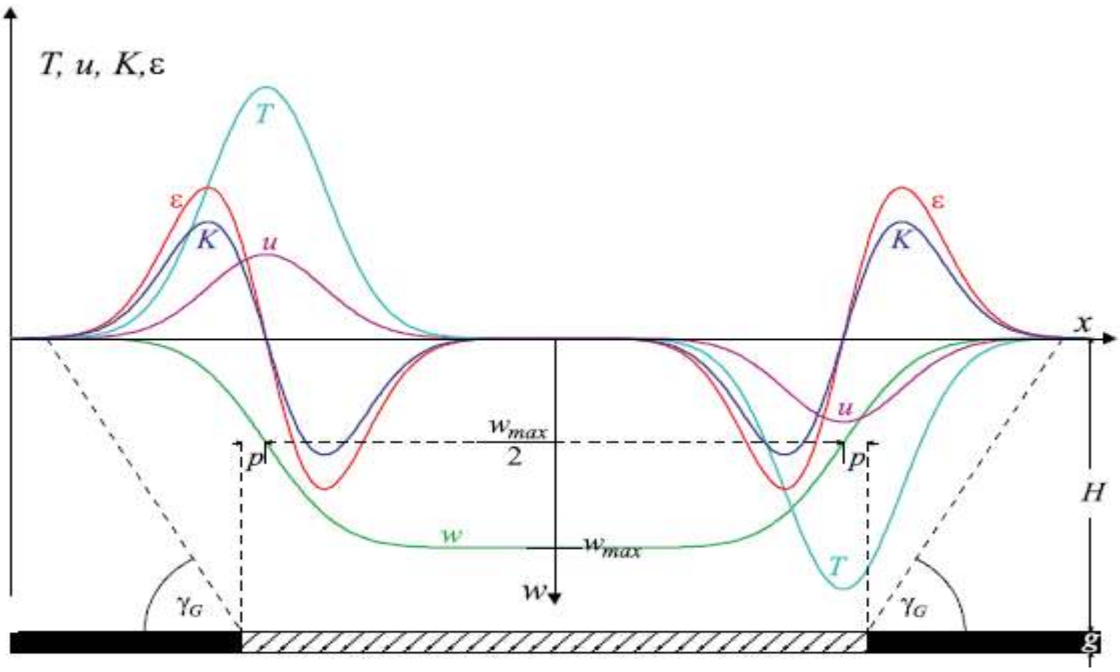



Figure 26 – diagram of the subsidence parameters above single longwall panel. [22]

**Vertical displacement "w" (subsidence)**

As stated before, subsidence include both, vertical and horizontal displacements. In fact, when subsidence is small, horizontal displacements can be greater than vertical displacement.

Profile of edge part of basin can be described by mean of following equation:

$$w(x) = \frac{w_{max}}{r} \int_{x}^{\infty} e^{-\frac{\pi x^2}{r^2}} dx$$

Vertical subsidence is expressed in millimetres [mm].

Knowledge of the equation describing the profile deformation of basin allows to determine deformation in any point of the profile. Taking into consideration that subsidence w(x) direction is opposite to additional direction of z axis following variables characterizing subsidence basin can be calculated.

**Tilt (or slope) "T"**

Tilt is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is also the first derivative of the subsidence profile.

$$T(x) = \frac{dw}{dx} = -\frac{w_{max}}{r} e^{-\frac{\pi x^2}{r^2}}$$

Maximum tilt (Figure 28.c) occurs at the point of inflection in the subsidence trough, where the subsidence is almost equal to one half of the maximum subsidence, and decreases to outside and inside of exploitation area. Calculated from the following formula:

$$T_{max} = -\frac{w_{max}}{r}$$

Tilt is expressed in millimetres per metre [mm/m].

**Curvature "K"**

Curvature is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is also the second derivative of subsidence:

$$K(x) = \frac{d^2w}{dx} = +\frac{2\pi w_{max}}{r^3} \cdot x \cdot e^{-\frac{\pi x^2}{r^2}}$$

Maximal curvature is calculated from the following formula:

$$K_{max} = \pm\sqrt{\frac{2\pi}{w}} \cdot \frac{w_{max}}{r^2} = \pm 1{,}52 \frac{w_{max}}{r^2}$$

Curvature is expressed in [$km^{-1}$].

Curvature is convex (hogging) over the edges and concave (sagging) in the bottom of the subsidence basin. Usually is assumed that convex curvature is positive and concave curvature negative.

The value of curvature can be inverted to obtain the radius of curvature R:

$$R(x) = \frac{1}{K(x)} = +\frac{r^3}{2\pi w_{max}} \cdot \frac{1}{x} e^{\frac{\pi x^2}{r^2}}$$

Minimal radius of curvature (Figure 28.d) is determined by:

$$R_{min} = \pm\sqrt{\frac{e}{2\pi}} \cdot \frac{r^2}{w_{max}} = \pm 0{,}66 \frac{r^2}{w_{max}}$$

Maximal curvature of basin, as well as minimal radius of curvature, occurs at the distance:

$$l = \pm \frac{r}{\sqrt{2\pi}} \approx \pm 0{,}4r$$

Radius of curvature is expressed in [km].

**Horizontal displacement "u"**

Horizontal displacements due to mining subsidence occur in such way that points on the surface generally move towards the centre of the subsidence trough.

$$u(x) = \frac{w_{max}}{\sqrt{2\pi}} e^{-\frac{\pi x^2}{r^2}}$$

The horizontal displacement is greatest at the point of maximum tilt, which is the point of contra flexure, and declines to zero at the limit of subsidence and at the point of maximum subsidence (Figure 28.b):

$$u_{max} = \frac{w_{max}}{\sqrt{2\pi}} = 0{,}4 w_{max}$$

Horizontal displacement is expressed in [mm].

**Horizontal deformation "ε"**

Horizontal deformation is caused by bending and differential horizontal movements in the strata. Is calculated as a change of horizontal displacement between two points divided by distance between those points from the following formula:

$$\varepsilon(x) = \frac{du}{dx} = -\frac{\sqrt{2\pi \cdot w_{max}}}{r^2} \cdot x \cdot e^{-\frac{\pi x^2}{r^2}}$$

Maximal horizontal deformations (Figure 28.e) are calculated from the following formula:

$$\varepsilon_{max} = \pm \frac{w_{max}}{r} e^{-1{,}5} = \pm 0{,}6 \frac{w_{max}}{r}$$

The unit of measurement adopted for horizontal deformation is millimetres per metre [mm/m].

Maximal horizontal deformations occur at the distance:

$$l = \pm \frac{r}{\sqrt{2\pi}} \approx \pm 0{,}4r$$

The maximum tensile strains occur close to the edges of the basin while the maximum compressive stains occur at the center of the subsidence basin.

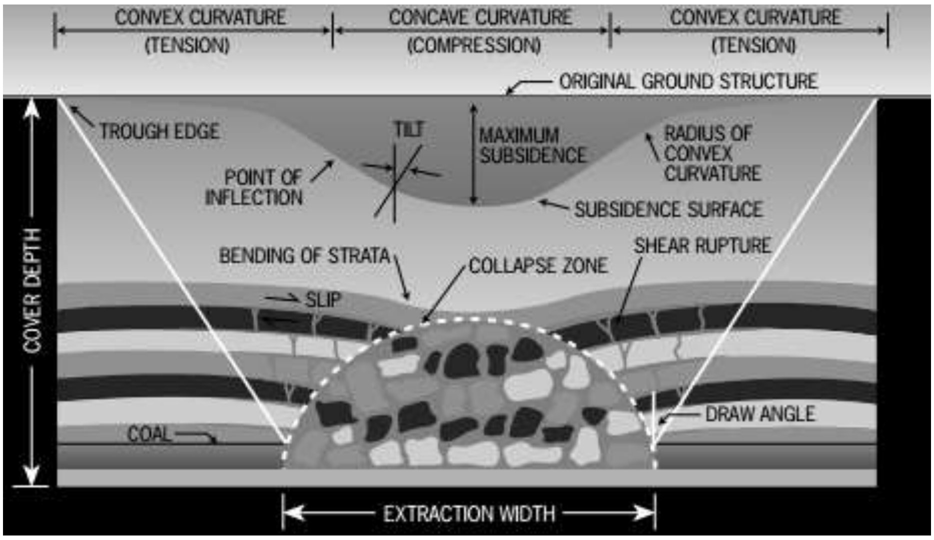



Figure 27 – Surface effects of longwall mining. Cross section. [23]

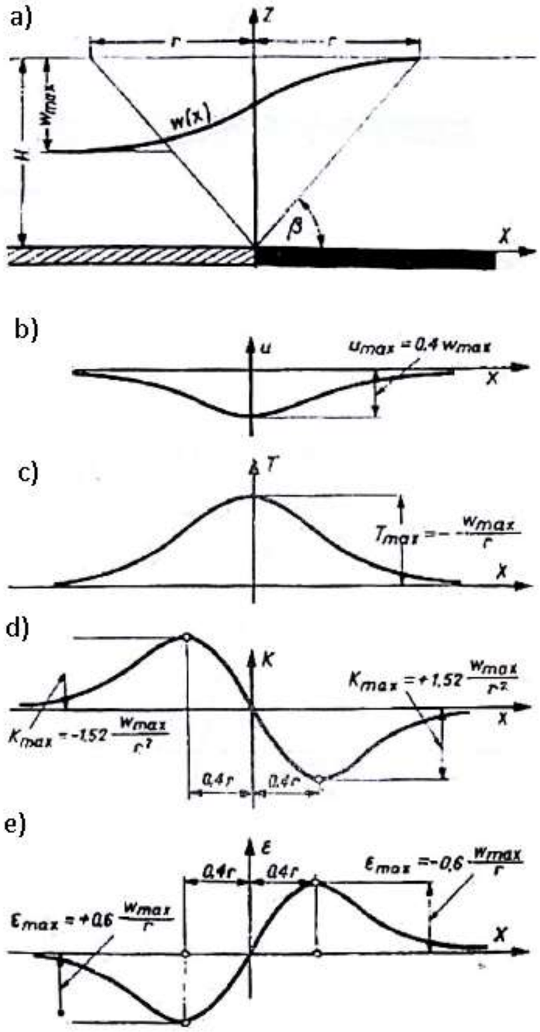



Figure 28 – Deformation and displacement distribution according to Budryk - Knothe theory.

According to the intensity of deformation ratios, the lands exposed to the impact of regular subsidence troughs have been divided into six categories, in accordance with the following table.

Table 2 – Land categories. [24]

| Category | Limit values of land deformation ratios | | |
|---|---|---|---|
| | Slope T [‰] | Curvature radius R [km] | Horizontal strain ε [‰] |
| 0 | $T \leq 0,5$ | $\|R\| \geq 40$ | $\|\varepsilon\| \leq 0,3$ |
| I | $0,5 < T \leq 2,5$ | $40 > \|R\| \geq 20$ | $0,3 < \|\varepsilon\| \leq 1,5$ |
| II | $2,5 < T \leq 5$ | $20 > \|R\| \geq 12$ | $1,5 < \|\varepsilon\| \leq 3$ |
| III | $5 < T \leq 10$ | $12 > \|R\| \geq 6$ | $3 < \|\varepsilon\| \leq 6$ |
| IV | $10 < T \leq 15$ | $6 > \|R\| \geq 4$ | $6 < \|\varepsilon\| \leq 9$ |
| V | $T > 15$ | $\|R\| > 4$ | $\|\varepsilon\| > 9$ |

**4.3.1.3 Determination of mining interactions due to continuous deformations.**

The characteristic values of mining impacts ($T_k$, $\varepsilon_k$, $K_k = 1/R_k$) is assumed to be equal to the values projected in the case of gradients T. It means, $T_k = T$.

With respect to the horizontal deformation ε and terrain curvature K (radius of curvature R = 1 / K), the characteristic values are obtained by multiplying a predicted value of this indicator by a factor of working conditions $k_{wp}$.

The $k_{wp}$ factor will be calculated according to the diagram shown in the next figure. It depends on the ratio between the length of the building (segment) L and radius major influence "r" (r = H/tg β). When L/r < 0,3 can be assumed $k_{wp} = 1$.

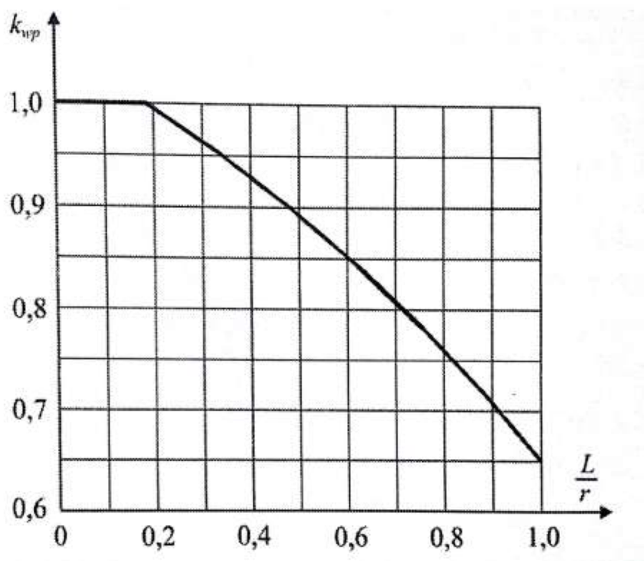



Figure 29 – factor of working conditions $k_{wp}$. L - length of the building, r – radius of major influence. [24]

The calculation of the values of the mining is done Impacts with the following formulas:

- horizontal deformation:

$$\varepsilon_d = \varepsilon_k \cdot \gamma_{f\varepsilon}$$

- curvature (radius) terrain:

$$K_d = 1/R_d = K_k \cdot \gamma_{fK}$$

- slope:

$$T_d = T_k \cdot \gamma_{fT}$$

Where:

- $\varepsilon_d$, $K_d$ ($R_d$), $T_d$ : calculated values,
- $\varepsilon_k$, $K_k$ ($R_k$), $T_k$ : characteristic values,
- $\gamma_{f\varepsilon}$, $\gamma_{fK}$, $\gamma_{fT}$ : partial safety factors, table 3.

Table 3 - Values of partial safety factors. [24]

| Indicators | Factor $\gamma_f$ |
|---|---|
| Area horizontal deformation, $\varepsilon$ | 1,3* |
| Area curvature, K =1/R | 1,7* |
| Area inclination T:<br>– High structures of base dimension smaller than 15 metros and building height exceeds at least twice the size of the shorter side of the horizontal projection of the structure,<br>– Other structures | <br>1,5<br><br>1,2 |

* exception of objects of short length L ≤ 9 m

Area deformation impact on the structure is considered as live load entirely of short duration, and mining tremors impact as special load.

#### 4.3.1.4 Critical, subcritical and supercritical width

The mining of a theoretical single point P (Figure 30) located at the seam level, will affect a circular area on the surface. The extent of the circular area is defined by an inverted cone with P as its apex and the angle of draw as the semi-angle of the cone.

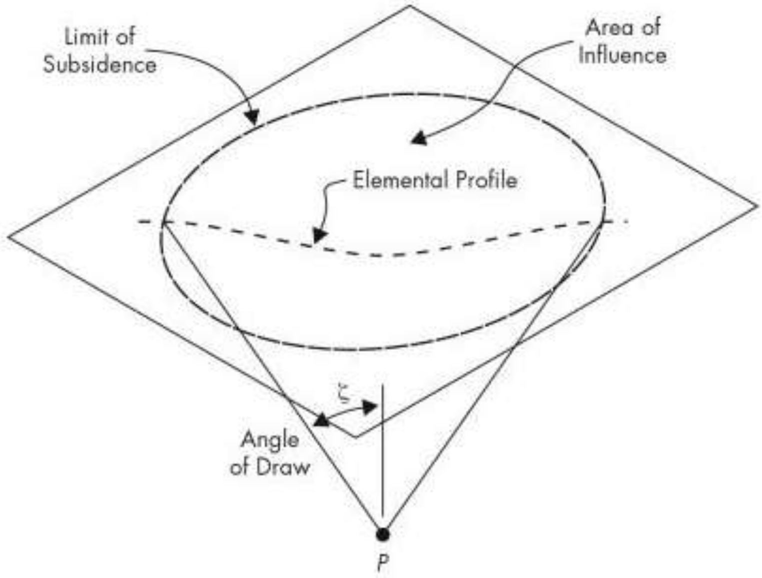



Figure 30 – Effect on surface by mining at point P. [17]

If this cone is inverted, the mining of any point situated on its base will influence the subsidence of its apex P (figure 30). Then, the circular are is called the area of influence.

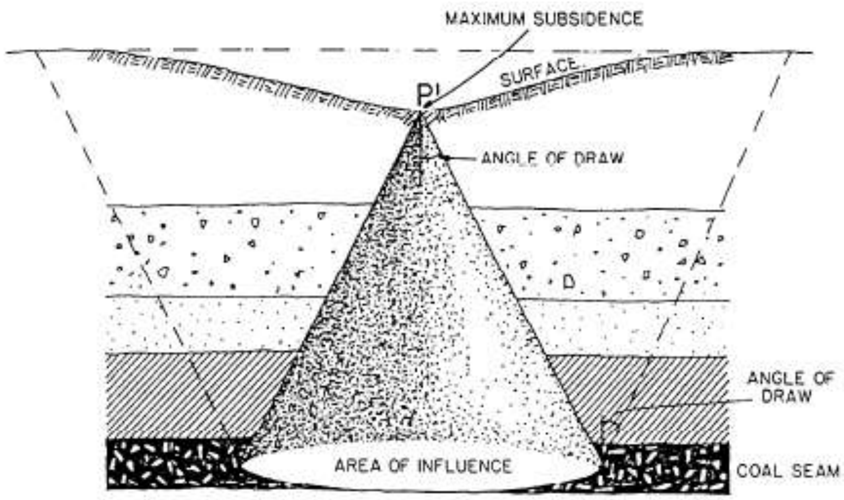



Figure 31 – Concept of area of influence. [17]

This implies that the diameter of the area of influence is given by:

$$2D \tan \xi$$

Where:

D – Depth of the seam below the surface,

ξ – Angle of draw.

The diameter of the area of influence also defines the critical width. Critical width is exactly the minimum width that needs to be mined to reach the maximum subsidence in the center of the basin. If the width is minor, it will be called subcritical and, therefore, if is greater, it is called supercritical.

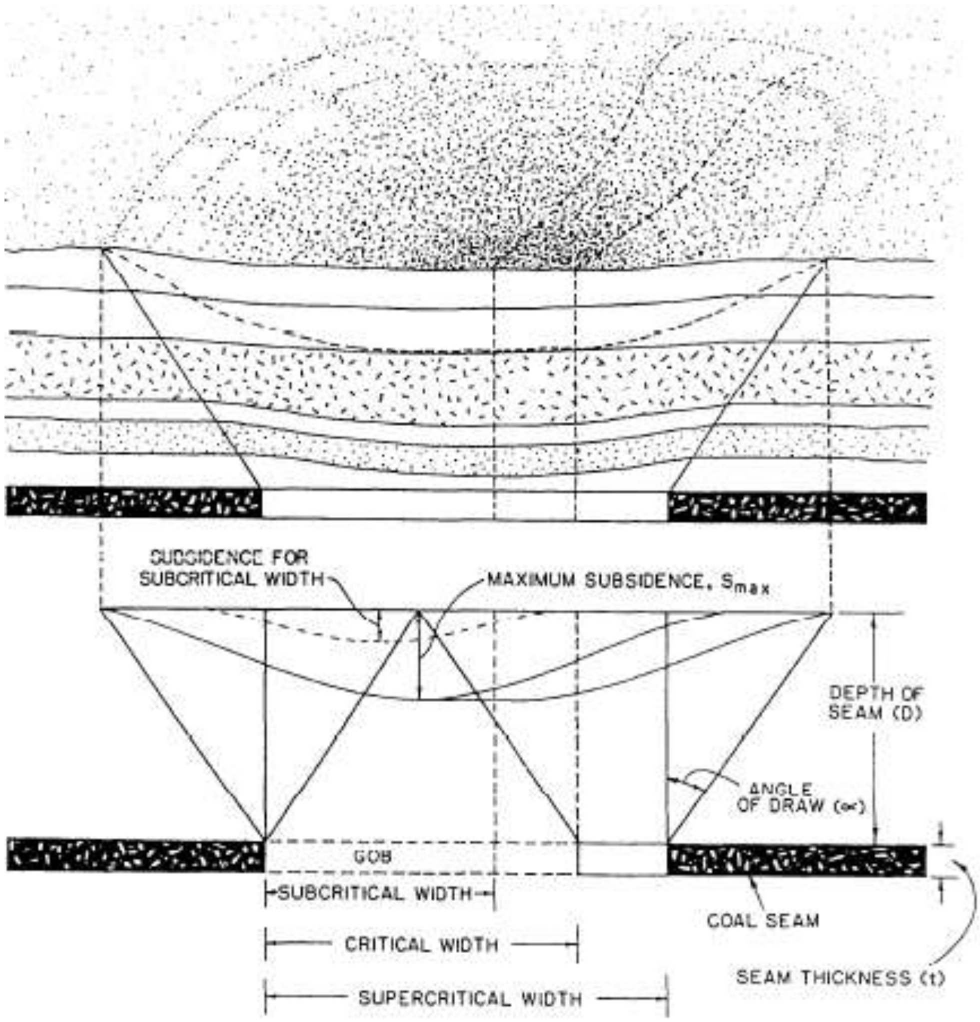



Figure 32 – Influence of extraction width on subsidence. [17]

These are three classifications of extraction area that influence the characteristics of the subsidence trough. These classifications are expressed in terms of the extraction width/depth of cover ratio (W/H). The three classifications are:

- Subcritical extraction,
- Critical extraction,
- Supercritical extraction.

Subcritical extraction has a W/H ratio less than 1.4. As the mined width is less than critical, maximum possible subsidence will not occur in any point of the basin.

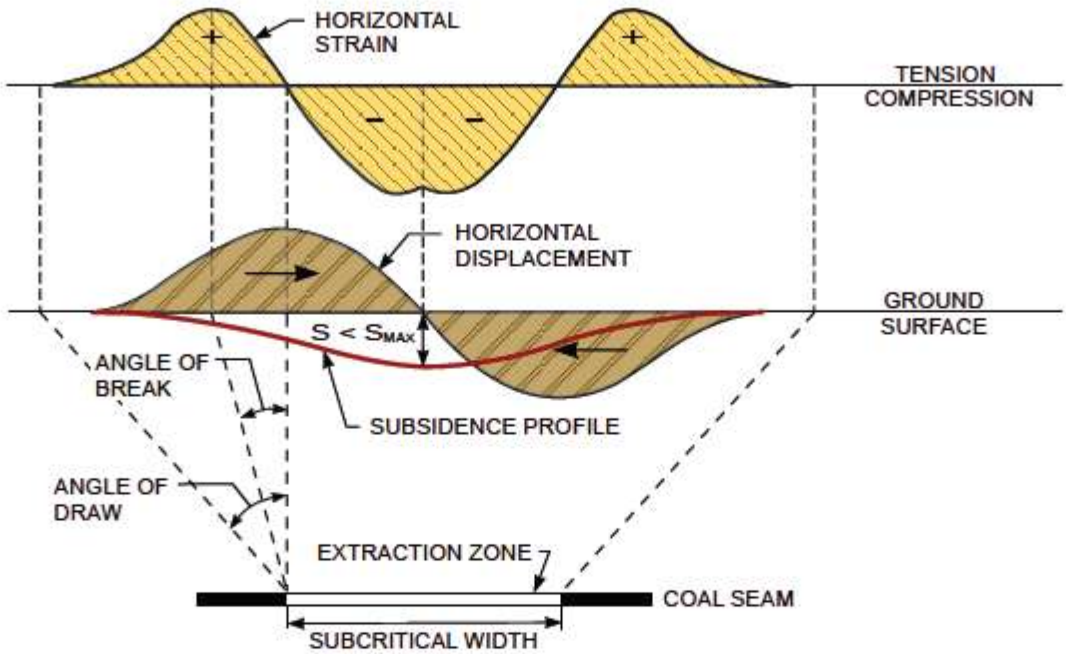



Figure 33 – Subcritical width. [25]

Critical extraction has a W/H ratio of approximately 1.4 – 2.0. Maximum subsidence will occur in the center of the basin.

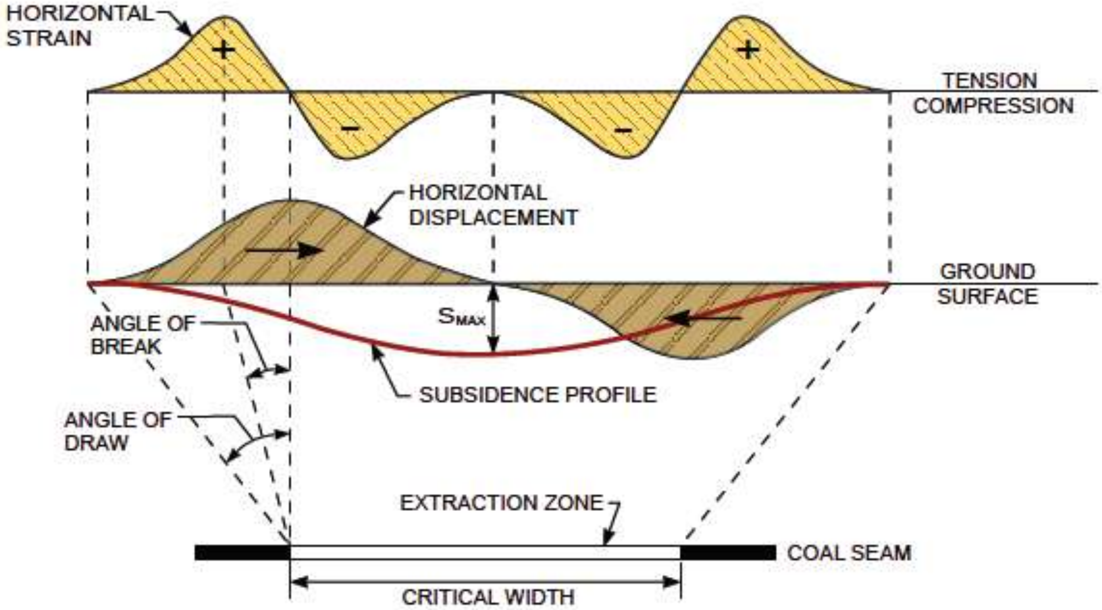



Figure 34 – Critical width. [25]

Super-critical extraction has a W/H ratio larger than 2.0. As the width excavated is greater than the necessary for maximum subsidence, a flat-bottomed depression will appear in the central part of the basin.

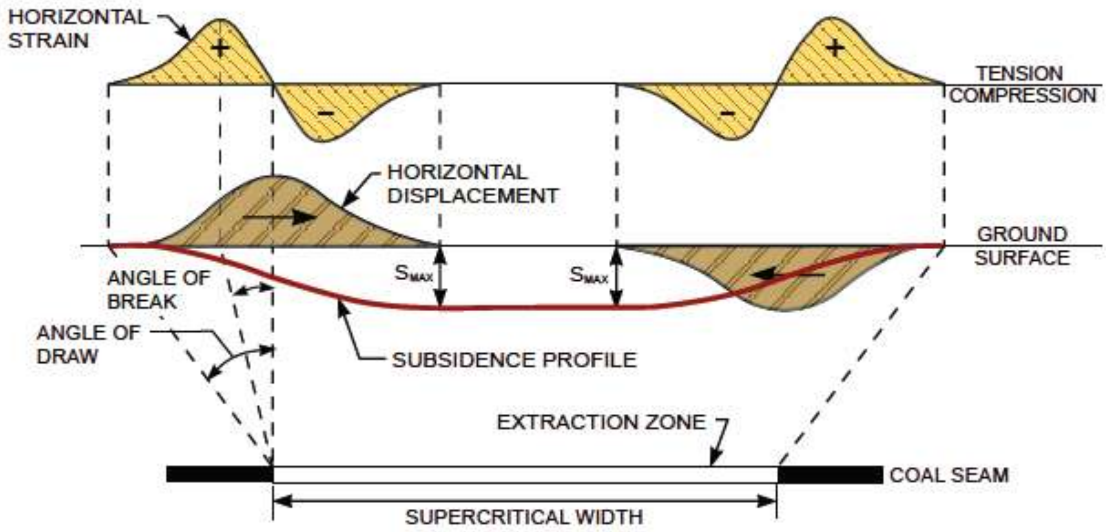



Figure 35 – Supercritical width. [25]

**4.3.1.5 Stationary and dynamic subsidence profiles.**

There are two types of subsidence profiles, stationary and dynamic. Looking at a longwall panel, it is possible to draw its profile in two directions, across the longwall panel (transverse) and along the longwall panel (longitudinal).

Transverse profiles are considered stationary profiles because their extension is always between the already mined extraction edges and associated movements are permanent.

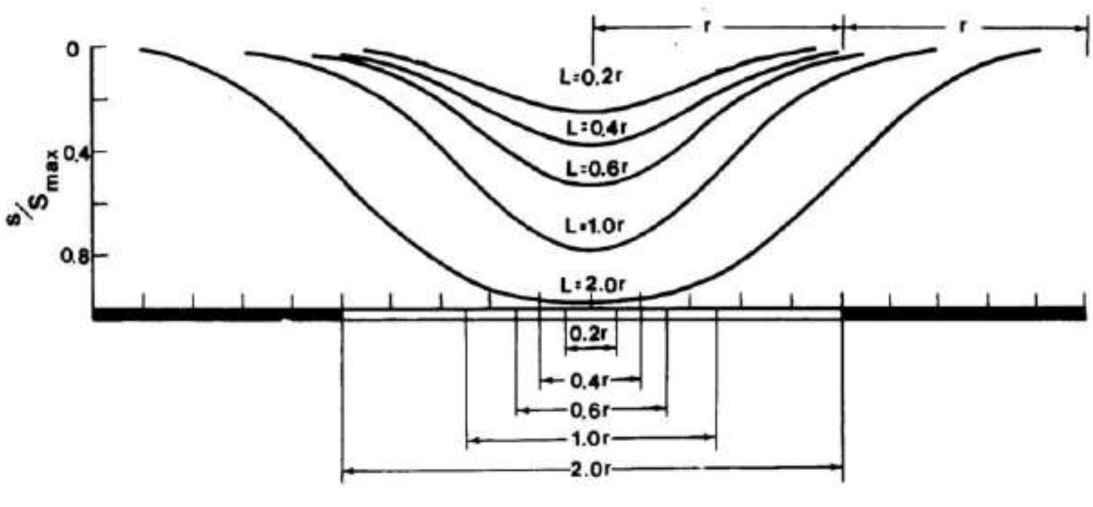



Figure 36 – Stationary subsidence profile. [26]

On the other hand, longitudinal profiles are considered dynamic profiles because their extension changes, following the advancing of the longwall face.

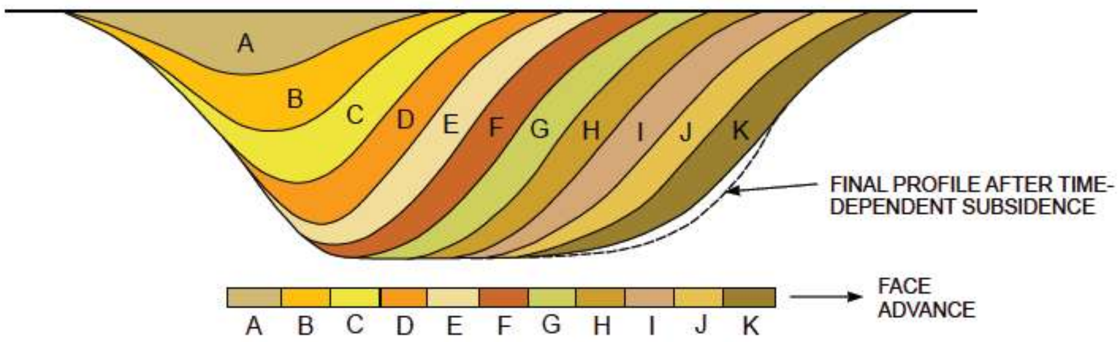


Figure 37 – Dynamic subsidence profile. [25]

Movements associates with dynamic profiles are variable, it means, horizontal tensile and compressive strain regions move laterally with the mining.

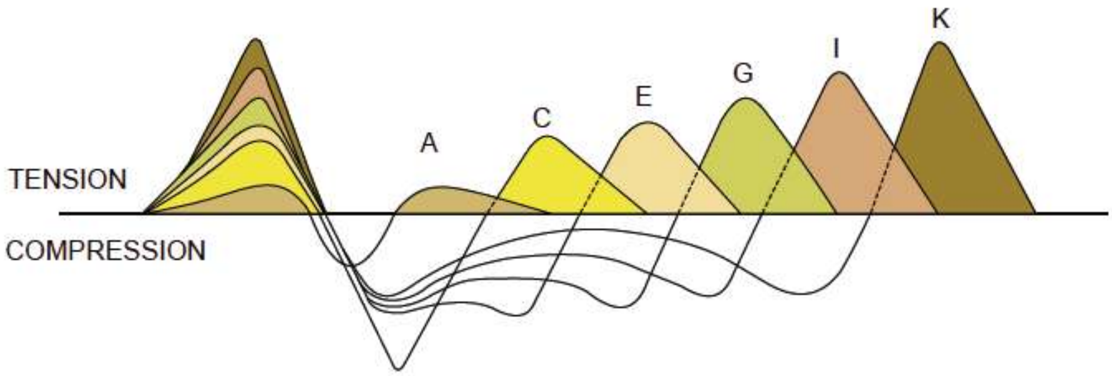


Figure 38 – Traveling strain curve. [25]

## 4.4 Discontinuous deformations

### 4.4.1 Characteristics and classification.

Discontinuous deformations are divided into two basic types:

- Surface deformations,
- Linear deformations.

The group of surface deformation includes:

- Sinkholes, most often take the form of conical funnels or cylindrical irregular holes with steep edges. The horizontal size can reach several meters,
- Landslides, caused by soil movements on inclined surfaces,
- “Local deformities”, having the shape of regular little hollows in the form of extensive and deep troughs.

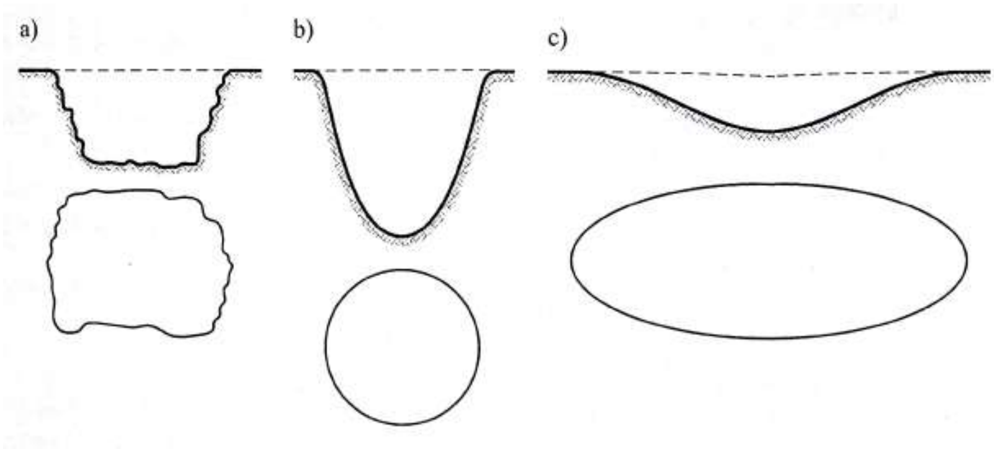



Figure 39 – Surface deformations. A – sinkhole, B – funnel, C – local deformity [19]

The group of linear deformation includes:

- Ditches, or sinkholes in linear form,
- Fissures, occurring as cracks in the subsoil layer,
- Ground braces, present in the form of a vertical or almost vertical line, reaching up to several tens of centimeters.

Fissures and ground braces often occur simultaneously.

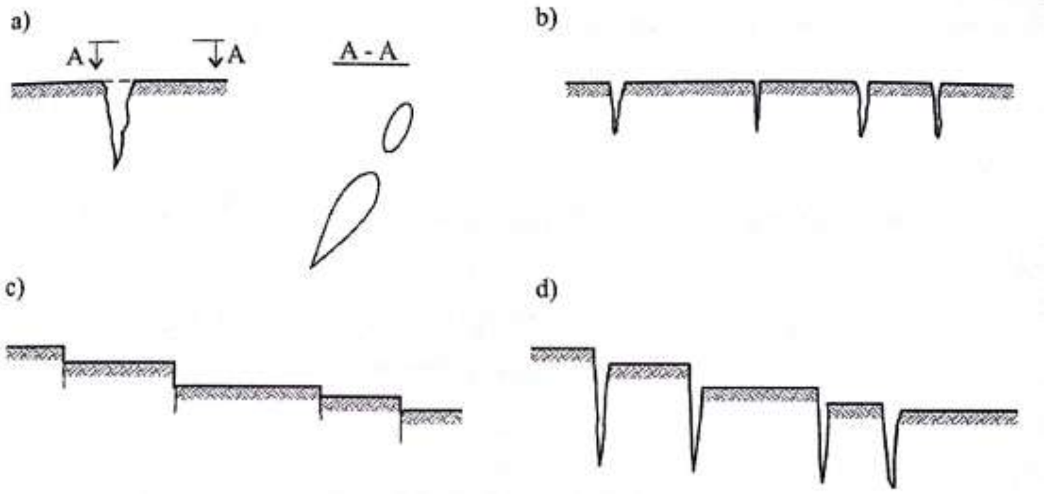



Figure 40 – Linear deformations. A – ditches, B – cracks (fissures), C – ground brace, D – fissures and ground braces occurring at the same time. [19]

Discontinuous deformations in polish mining areas occur mainly in:

- In some parts of the Upper Silesian Coal Basin (USCB),
- Rybnickiego Okręgu Węglowego (ROW),
- Olkusko-Bolesławskiego Zagłębia Rud Cynkowo-Ołowianych.

The lands exposed to the hazard of discontinuous deformations offer very unfavourable conditions for building development.

## 4.4.2 Conditions for the appearance of discontinuous deformations

As opposed to continuous deformations that develop slowly, discontinuous deformations often occur suddenly. The entire process usually occurs within minutes or hours, sometimes days.

Besides landslides, the most common cause of discontinuous deformation is shallow mining operations. Factors that favor the appearance of continuous deformations are:

Most commonly, the causes of the occurrence of discontinuous deformations include:

- Impacts from mining works resulting in values of deformation ratios falling into category V,
- Mining seams located at shallow depths,
- Mining works conducted in the zone of faults,
- Secondary impacts, usually near the surface (Figure 41) but sometimes also at considerable depths, which may induce mining tremors (Figure 41 b) or change the balance on the ground (Figure 41 c),
- Mechanical or chemical suffusion, causing water to leak into the mine through cracks and fissures in the rock mass, dragging small particles in its path. (Figure 42).

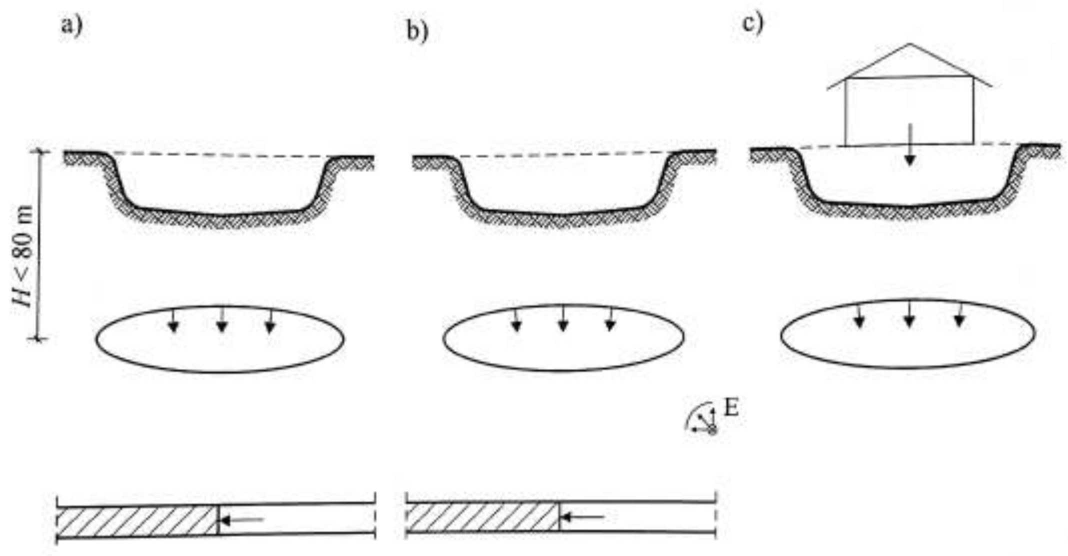



Figure 41 – Secondary impacts – as a result of work at shallow depths, due to: a – works that are currently underway; b – mining tremors; c – changes in conditions of existing balance. [19]

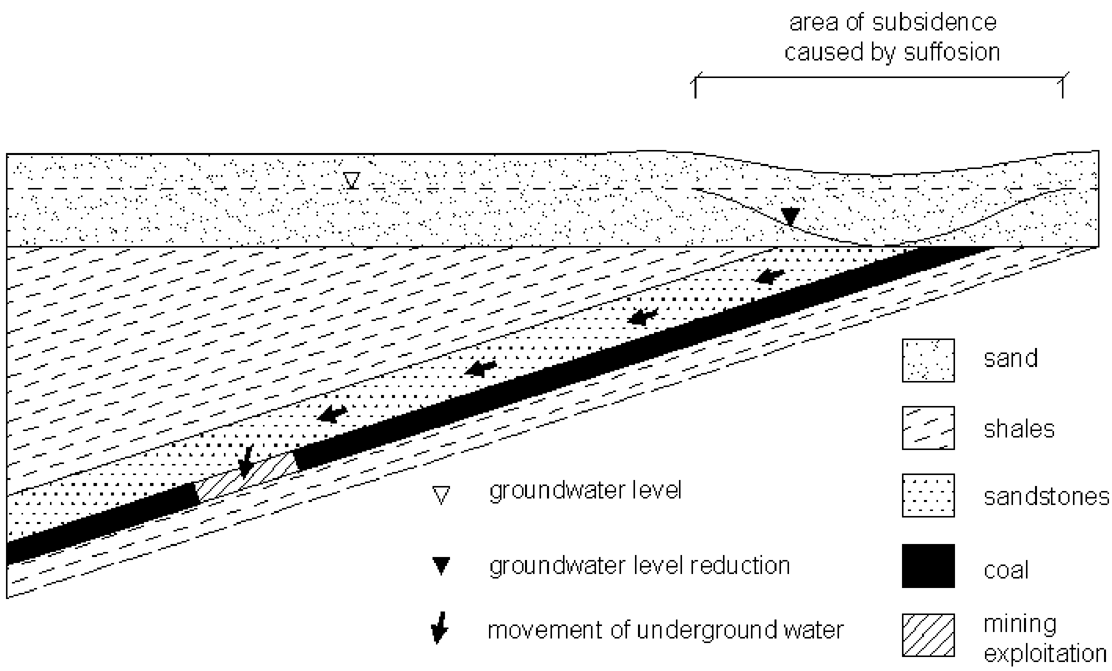



Figure 42 – Water seepage into the mine. [21]

The probability of occurrence of discontinuous surface deformations and shape of the edges depends largely on the type and thickness of the cover (soil layer above the mine). At higher thicknesses, especially when the roof is formed by loose soil, the probability of discontinuous deformations occurrence decreases and favors the formation of smoother edges. Otherwise we find thinner cover and more consolidated

## 4.5 Mining tremors.

### 4.5.1 The genesis of mining tremors

Mining tremors consist in violent movements of the rock mass, lasting for short time and it is noticeable both underground and in the surface. In general, mining tremors can be:

- Tectonic, when they are caused by phenomena occurring in the subsurface, unrelated to mining activities,
- Operational, when they are causally linked to mining.

The immediate causes of mining tremors are dynamic fractures of the rock mass, where mining operations has disturbed equilibrium. These phenomena occur only in blocks of rock characterized by high strength and with the possibility of a large accumulation of elastic energy. Mining tremors mainly occur when mining operations are carried out at greater depths. Part of the released energy is converted into seismic energy, causing mining tremors, the intensity of which depends on the following factors:

- Physical and mechanical properties of the rocks,
- The depth of rocks deposit,
- Spatial geometry of the deposit and voids in the rock mass.

In Poland, mining tremors occurs in these regions:

- Legnica-Glogow Copper District (LGOM),
- Bełchatowskiego Okręgu Przemysłowego (BOP),
- Upper Silesian Coal Basin (USCB).

### 4.5.2 Characteristics of mining tremors

The most important parameter is the seismic energy released in its hypocenter (the origin). The epicenter is the point on the Earth´s surface directly above the hypocenter and the distance to any point on the surface is called epicentral distance.

The USCB mining tremors are divided into two groups:

- Operational, directly related to ongoing mining works; outbreaks of these shocks move with the progress of the works,
- Regional, occur as a result of many years of mining operations and are usually high-energy tremors. Outbreaks of these tremors often occur far from the mine but mining operations are an important triggering factor of these mining tremors.

In the construction industry, to know the characteristics of the vibrations that affect the surface and to evaluate the security against mining tremors the following parameters are used:

- Vibration acceleration, a (t)
- Vibration velocity, v (t)
- Vibration frequency, f
- Duration of vibration, t (intensive phase)

**4.6 Changes of water conditions.**

Mining operations can result in drainage of surface water and groundwater or may result in an apparent increase of free water level underground.

Water drainage occurs when there is not any waterproof layer in the rock mass to provide insulation against the flow of water into the mine workings.

Raising water level occurs when in the rock layer are one or more waterproof layers that produce water isolation in the surface or close to the surface. Under these circumstances, depending on the relationship between the maximum reduction and depth of the water level "g", may form bayous.

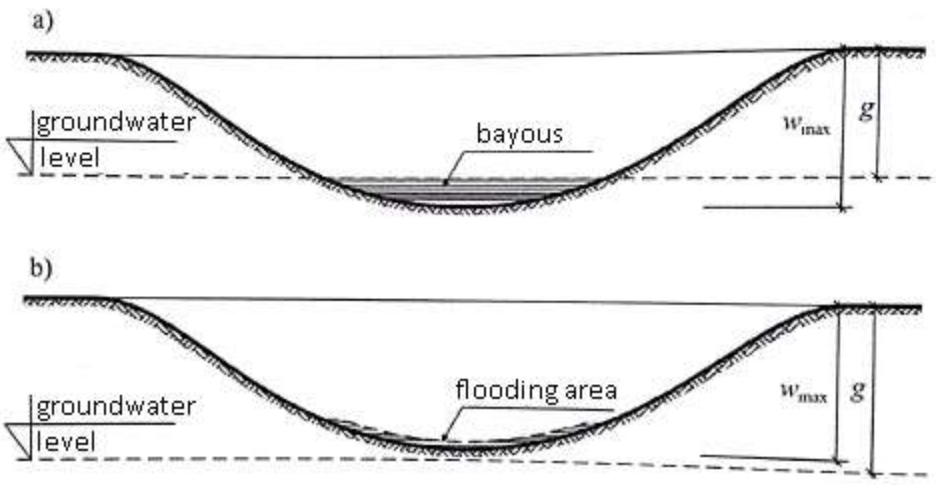



Figure 43 – Changes in the water conditions. a – bayous, b – flooding area. [19]

In the USCB, dewatering of the mines is continued even in closed mines. This is due to many mines in the USCB are connected by galleries and stop dewatering closed mines could cause problems in the nearby mines which still operating.

Cessation of mines dewatering will be possible after all mines in the region are close. Then, some parts of the subsided surface could be flooded due to the rising of groundwater. It is more possible to occur in areas with shallow groundwater level and where there is not any waterproof layer in the rock mass to provide insulation against the rising if groundwater. [12]

# 5. Mining impacts on the buildings

## 5.1 Classification of buildings in mining areas.

The behaviour of the building facing the mining impacts depends mainly on the type of the structure; most important features are the shape and size of its horizontal projection and the deformability of the structure. The following table shows the classification applied in construction. In the event that the structure is divided into segments, these properties are applied to each segment.

Table 4 – Classification of structures in mining areas. [34]

<table>
<tr><th>Classification base</th><th colspan="6">Features of structures (segments)</th></tr>
<tr><td>shape of structure horizontal projection</td><td colspan="2">compact</td><td colspan="2">linear</td><td colspan="2">surface (extensive)</td></tr>
<tr><td>Structure deformation ability on deforming subsoil</td><td colspan="3">rigid</td><td colspan="3">deformable</td></tr>
<tr><td>Structure functional sensitiveness to mining exploitation impacts</td><td colspan="2">very sensitive</td><td colspan="2">little sensitive</td><td colspan="2">insensitive</td></tr>
<tr><td>Maintaining utilization safety and utilization values</td><td colspan="2">resistant</td><td colspan="2">partly resistant</td><td colspan="2">non-resistant</td></tr>
<tr><td>Range of use</td><td colspan="3">mass</td><td colspan="3">unique</td></tr>
</table>

Attending to the shape of structure horizontal projection, residential buildings, our case of study, are included in the group of structures with a compact horizontal projection.

In the second group, dominant linear dimension of structures is their length. This group includes pipelines, cable lines, etc. Superficial (extensive) structures are characterized by significant dimensions of the horizontal projection; these are mainly industrial facilities and some public buildings (most sacred objects).

While deformable structures can significantly change its shape upon deformation of the substrate (figure 44b), in the case of rigid structures, as residential buildings, their deformation ability due to subsoil deformation is little sensitive and irrelevant. When ground deformation occurs, due to mining impacts, these structures do not change noticeably its geometric shape. Rigid structures include buildings with walls made of masonry or reinforced concrete, monolithic and prefabricated elements, as well as frame structures with masonry fulfillment.

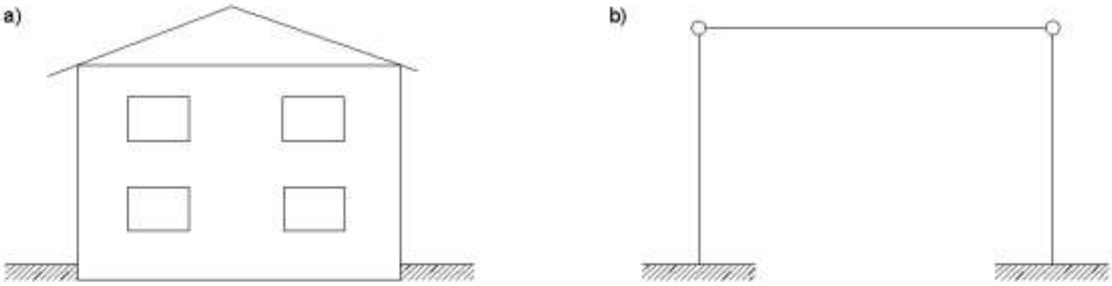



Figure 44 – Structure types. a – rigid structure, b – deformable structure. [19]

## 5.2 Continuous deformations.

The next example shows the result of ground deformation caused by mining subsidence, a structure from the initial position 1-2-3-4 (figure 45a) moves to the position 1´-2´-3´-4´ (figure 45b)

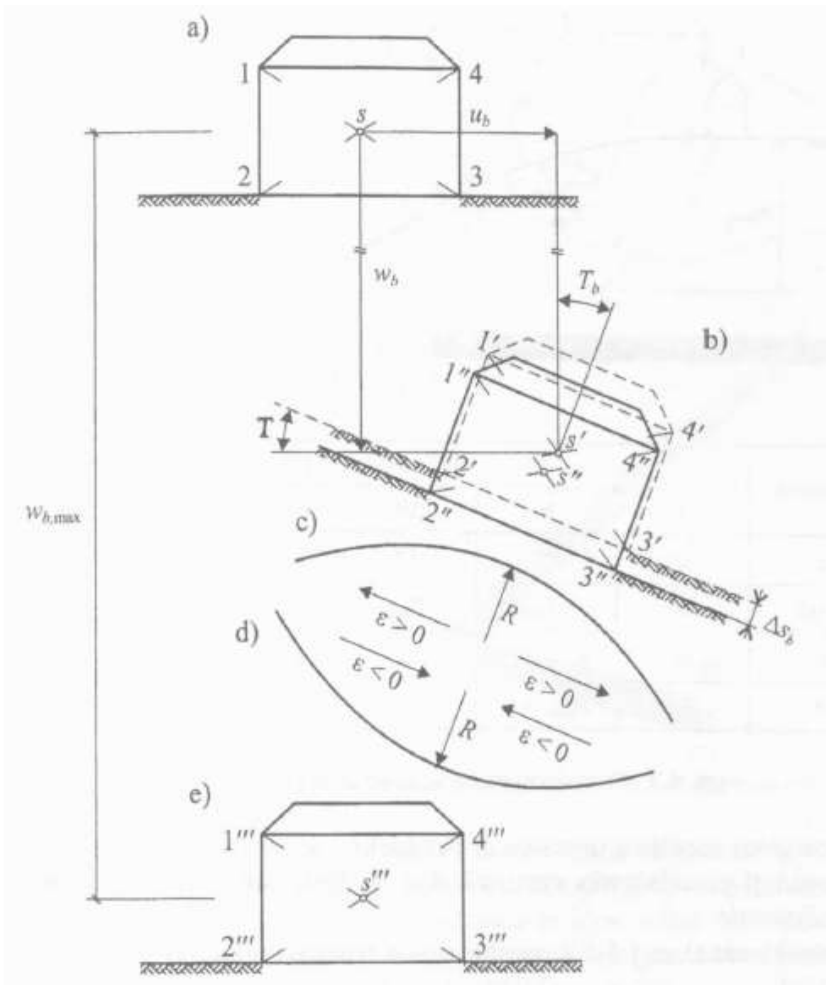



Figure 45 – Displacement of a building on the mining basin. a – initial position, b – position after displacement, c – convex edge of the basin, d – concave edge of the basin, e – final state. [19]

During this process where the structure is treated as a rigid object, the structure is subjected to vertical subsidence ($w_b$) and horizontal displacement ($u_b$), and furthermore, the geometric center "S" suffers a rotation determined by its tilt from position ($T_b$). It may occur additional sinking, causing the object to assume the position 1´´- 2´´- 3´´- 4´´.

In this position there are two states of interaction:

- Convex (ε+, R+),
- Concave (ε-, R-).

The following figure shows the transmission of disturbances due to effects of transient phases in the basin edges, also explained in the next figure:

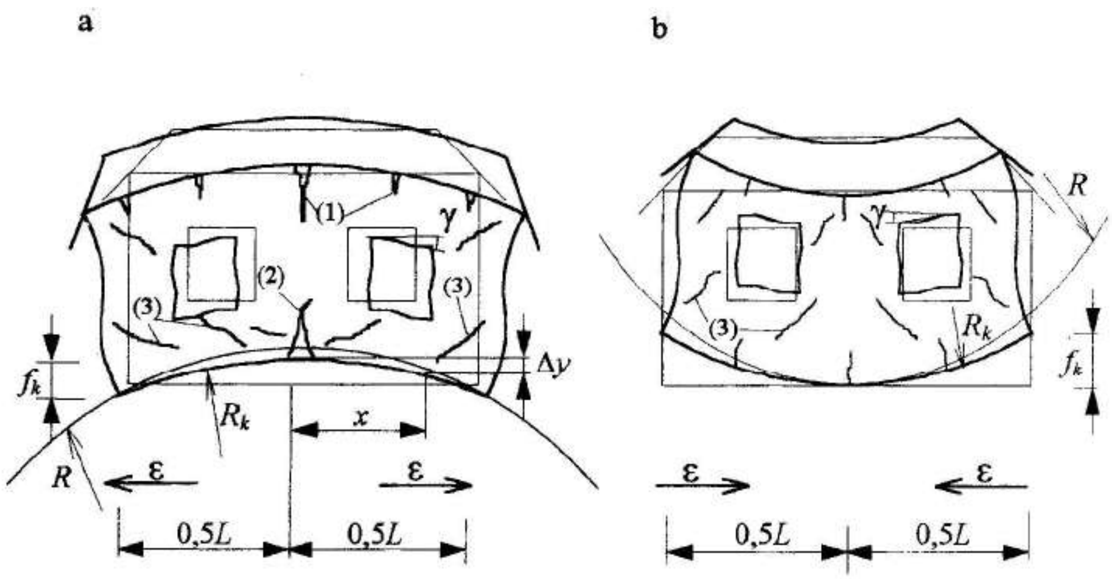



Figure 46 - Effects of transitional phases that occur at the edges of the basin, transmission of disturbances. a - convex edge of the basin, b – concave edge of the basin. [33]

As a result, internal forces evoked by horizontal strains "ε" and land curvature (obtained from K = 1/R), are generated in the structure of the building.

In practice, it is required to protect compact structures, and therefore buildings, against influence of curvature "K" and horizontal strain "ε". Inclination "T" affects especially to high and particularly sensitive buildings. Horizontal displacements "u" may affect only to linear structures.

The process of displacement of a building on the mining basin can be divided into 5 points or positions (Figure 47):

- Position I, initial state,
- Position II and IV, extreme values of ground deformation ($\pm \varepsilon_{max}$, $\pm R_{min}$),
- Position III, maximum tilt ($T_{max}$),
- Position V, final reduction ($w_{max}$).

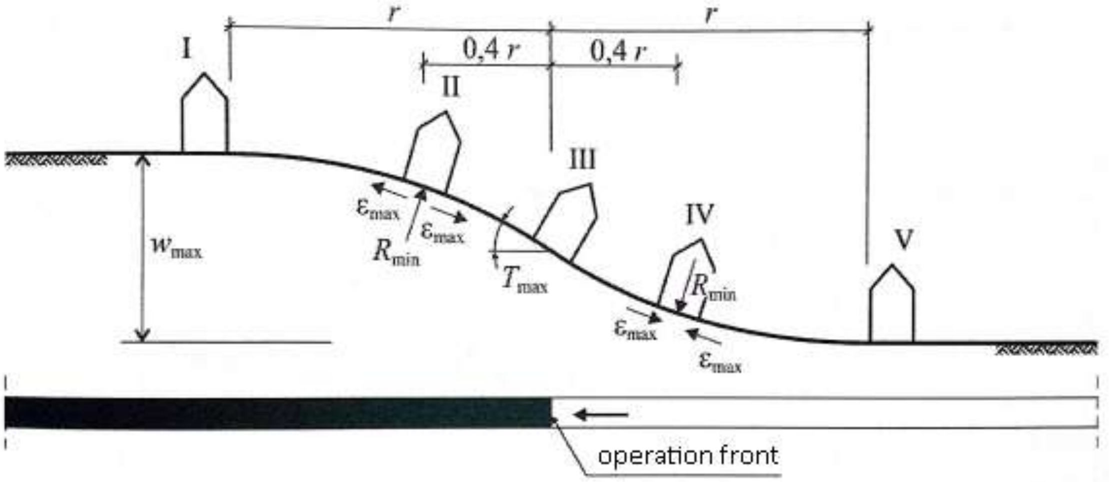



Figure 47 – Displacement of an object on the mining basin. [18]

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| $w_x$ | 0 | $0 \leq w_x \leq 0{,}5\ w_{max}$ | $0{,}5\ w_{max}$ | $0{,}5\ w_{max} \leq w_x \leq w_{max}$ | $w_{max}$ |
| $\varepsilon_x$ | 0 | $\varepsilon_{max}$ | 0 | $\varepsilon_{min}$ | 0 |
| $R_x$ | $\infty$ | $+R_{min}$ | $\infty$ | $-R_{min}$ | $\infty$ |
| $K_x$ | 0 | $K_{max}$ | 0 | $K_{min}$ | 0 |
| $T_x$ | 0 | $0 \leq T_x \leq T_{max}$ | $T_{max}$ | $0 \leq T_x \leq T_{max}$ | 0 |

Table 5 – Values of subsidence parameters for each position on the subsidence basin. [18]

The design of buildings in areas under the influence of continuous deformations, involve a study to determine deformation parameters expected in the area where the building will be located:

- maximum subsidence, $W_{max}$
- maximum inclination, $T_{max}$
- extreme horizontal strains, $\varepsilon_{max}$, $\varepsilon_{min}$
- extreme curvatures, $K_{max}$, $K_{min}$ → (R = 1/K)

It is also important to know information about the conditions of the rock mass and mining operations in the area.

For the protection of the existing buildings will be done in the same way. Knowledge of these parameters, and therefore, the classification of the ground, and information about the rock mass and the mining works will influence the technical and economic decisions when developing a protection plan for buildings.

**Damage due to vertical displacement "w" (subsidence)**

If vertical subsidence occurs uniformly, the buildings are left at a lower level, but subsidence has little or no impact upon them. Drainage systems and services to a building also subside with the building, so damage only appears when differential subsidence occurs. [29]

**Damage due to tilt "T" (inclination)**

Ground tilt normally does not produce damage upon buildings structures, although it can lead on larger impacts upon high buildings, which are more sensitive to tilt.

Single storey buildings will normally still serviceable when residual tilts are less than 7 mm/m. Severe tilts can cause serviceability problems, such doors closing themselves or drainage problems. [29]

**Damage due to Curvature "K"**

The ground curvature changes into the basin. It is convex (hogging) over the edges and concave (sagging) in the bottom of the subsidence basin and it causes two types of stresses on the building structure, shear strain and bending or flexure.

Shear strains produce angular changes and tends to distort the geometric shape of the building. Bending or flexure induces strains on load-bearing building elements. [29]

**Damage due to horizontal displacement "u"**

In the same way that vertical displacement, if the ground and structure move together, it will not have adverse impacts upon the structure. However, if a part of the building structure is moved differently relative to the other parts, then tensile or compressive stresses appear in the structure. [29]

**Damage due to horizontal deformation "ε"**

The most important damages that occur in rigid residential buildings are produced by ground curvature and horizontal deformations.

According to the previous paragraph, differential horizontal displacements produce ground stresses; however, most of the horizontal displacements are related to ground curvature.

Tensile stresses appear with convex curvature and compressive stresses with concave curvature. The appearance of tensile or compressive stresses can cause cracking in the building structure but tensile stresses can cause larger impacts because structure elements are weaker in tension than compression.

The transfer of ground horizontal deformation into the building structure occurs through friction on the underside of its foundation and ground pressure on the sides of the foundation. The transfer is dependent upon the type of foundation employed and its orientation with respect to the subsidence basin. It is recommended to locate the building with its longitudinal axis perpendicular to the front of exploitation.

The transfer also depends on the type of soil below the foundation. Foundations built directly onto bedrock suffer greater impacts due to horizontal deformation because these soils tend to transmit the total amount of ground stresses. On the other hand, when buildings are located on sandy soils, the ground stresses are not fully transmitted into the structure and the impact upon the building is more dependent on ground curvature rather than horizontal deformation.

Tensile stresses tend to produce vertical and steplike cracks in masonry, generally across and along the mortar joints. The cracks, normally start near the base of the structure and propagate from weak elements, as doors, windows or construction joints. Tensile stresses can also produce cracks in plaster covering the walls, break joints in plumbing and separation at joints in paving.

High levels of compressive strain can cause spalling of faces in masonry walls, closure of door and window openings and buckling of pipes, floors, ceilings, wall linings, and external paving. [29]

**Damage due to strain and curvature combinations**

In practice, structural impact results from combinations of ground curvature and strain.

When subsidence occurs, the foundation settles and deform with the ground. Cracks appear on the structure when the shear or tensile strength of the element is exceeded.

In case of masonry walls, cracks normally extend along the mortar joints, either vertically or diagonally in steps.

The appearance of cracks on the building depends on the extent of vertical displacement, the length/height ratio of the walls, the structural capacity of the elements and the shear strength and stiffness of the foundations.

Cracks can also appear due to bending moment and shearing stresses affecting a wall due to curvature and ground deformation.

It is important to consider the length of the building because longer buildings will experience greater extension due to ground deformation and, therefore, the impact upon them will be increased.

Normally, combination of convex curvature and tensile stresses will produce worse impacts than concave curvature and compressive stresses because structure elements are weaker in tension than compression.

Bending produced from convex curvature of the ground is dependent upon the height of the building, H, and the radius of curvature of the ground, R, and can be expressed as H/R (Figure 48). It is assumed that convex curvature will result in bending about the underside of the foundation.

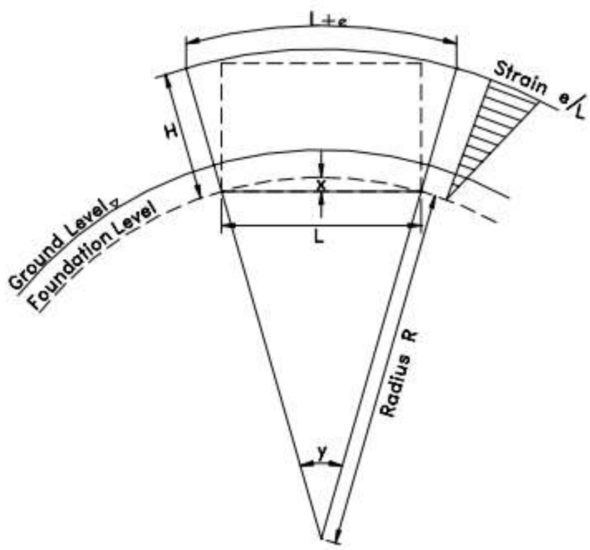



Figure 48 – Dependence of bending strain to the height of the building, H, and the radius of curvature of the ground R; case of convex curvature. [29]

In the case of concave curvature, the foundations will provide resistance against bending. Also, the lower part of the walls will provide some resistance. It is assumed that walls will bend about their centre line when subjected to concave curvature.

## 5.3 Discontinuous deformations.

When discontinuous deformations of considerable intensity occur, the damage to the building may cause the loss of stability of a part or the whole structure. Figure 4.16 shows examples of possible damage to buildings may suffer because of discontinuous ground deformation.

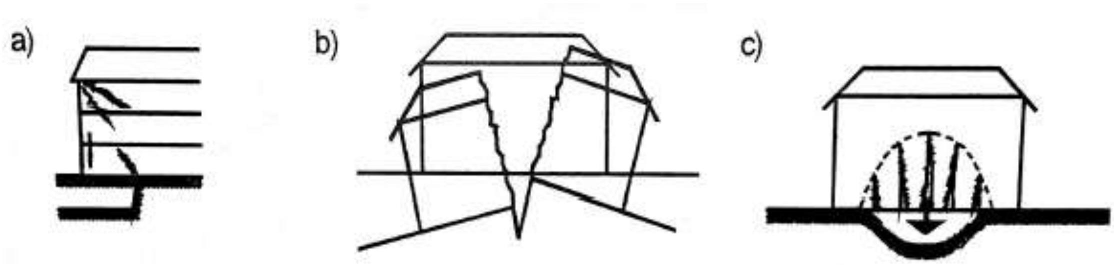



Figure 49 – exemplary damages of buildings caused by discontinuous deformations. a – cavity under the outside edge, b – cavity under the central part, c – ground brace under the central part. [27]

The lands exposed to the hazard of discontinuous deformations offer very unfavourable conditions for building development. There is a very high probability that the buildings built in areas where discontinuous deformations occur suffer major damages. In any case, construction in these areas should consider:

- An analysis of the rock mass looking for anomalies. There are different methods; the most accurate consists of drilling the rock mass, allowing the location of the holes more precisely,
- The possible occurrence of deformations in addition to their shape or size,
- Performing a proper design of the building, taking into account the most unfavourable position of the building with respect to the possible deformations of the surface and provide the necessary rigidity to the structure.

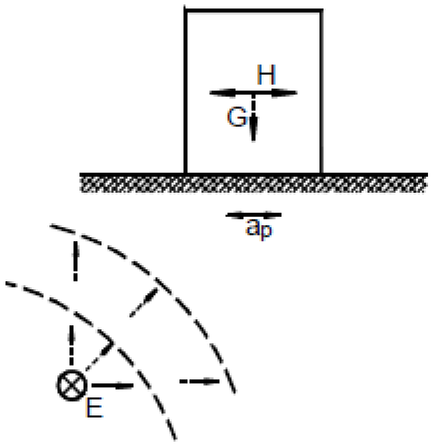
A specialist with necessary knowledge and experience is required to determine the best position of the building. Forecasts of possible discontinuous deformations are made based on the mine maps to collect information on the conditions of the rock mass.

The most effective protection against the discontinuous deformations consists in eliminate its causes. In the case of works in shallow mines, removal of the causes is achieved by filling the voids in the rock mass. Such works are characterized by a different degree of complexity and, sometimes, is not possible to fill the existing voids.

The process of eliminating the causes of discontinuous deformations is a complex technical and economic process. The financial calculation should prove that building adjustment method or the elimination of the deformation causes are cost-effective. Often the most rational solution involves the choice of locate the building elsewhere.

## 5.4 Mining tremors.

The impacts caused by mining tremors cause horizontal forces “H”, dependent on the weight of the structure “G”, its geometrical features $\eta$ and subsoil tremors maximal acceleration “$a_{p, max}$.”




$$H = f(G, a_p, \eta)$$

Figure 50 – impacts of mining tremors on the building. [27]

It is difficult to generalize the nature of the property damage caused by the influence of mining tremors.

Observations of residential buildings have shown that, depending on the design damage appears:

- In masonry buildings, cracks between ceilings and walls or between walls. Plaster rarely falls off walls,
- In buildings with large prefabricated elements: cracking in the bonding regions and falling panels.

In practice, when we ran into urban areas where the rock mass can suffer mining tremors, it is necessary to forecast the impact it will have on the surface to evaluate the impact that the vibrations may have on the safety of buildings.

Impacts caused by mining tremors can be omitted in the analysis, if the value of the vibration acceleration "$a_p$" $\leq 250$ mm/s$^2$ for rigid buildings with a continuous stiffening wall and height up to 11 floors.

The evaluation of the impact of mining tremors is performed by approximate methods. Initially the MSK scale as used, which was developed to assess the impact of earthquakes on buildings. The problem lies in the differences between earthquakes and tremors mining, particularly the length of earthquakes is much longer than the vibrations caused by mining tremors. In consequence, the use of the MSK scale generally overestimates the effects on existing buildings.

With the increase of mining tremors in the area of LGOM and USCB, with intensities above the reach of existing classifications, it was very important to predict the effects of these intense vibrations on buildings.

As a result, the Central Mining Institute developed the GSI scales based on the effects observed in the buildings of the area LGOM. Subsequently, these scales were also developed for the area of the USCB. An important difference with the previous scales is that GSI scales take into account the dependence of the effects of vibration and their duration, not included in the previous evaluation methods.

The GSI scales differentiate four levels of intensity for the impacts that vibrations can have on buildings:

- Level 0: vibrations do not cause any damage to buildings,
- Level 1: vibrations do not cause any damage to buildings but may increase the cracks and others damages,
- Level 2: vibrations can damage the building finishes,
- Level 3: vibrations may cause the damage described above and other more serious as rupture of cornices, the fall of roof tiles or cracks in walls.

Moreover, mining tremors may have a negative impact on the inhabitants of the buildings without causing notable effects in the building. The SGI scales also reflect the inconvenience in the performance of buildings as perceived by their inhabitants.

Levels of inhabitants reactions are:

- Level 0: sensitivity: negligible / appreciable; nuisance: Small
- Level I: sensitivity appreciable / adverse reactions; nuisance: Small
- Level II: Sensitivity: adverse reactions; nuisance: Normal
- Level III: sensitivity disturbing / cause fear; nuisance: High

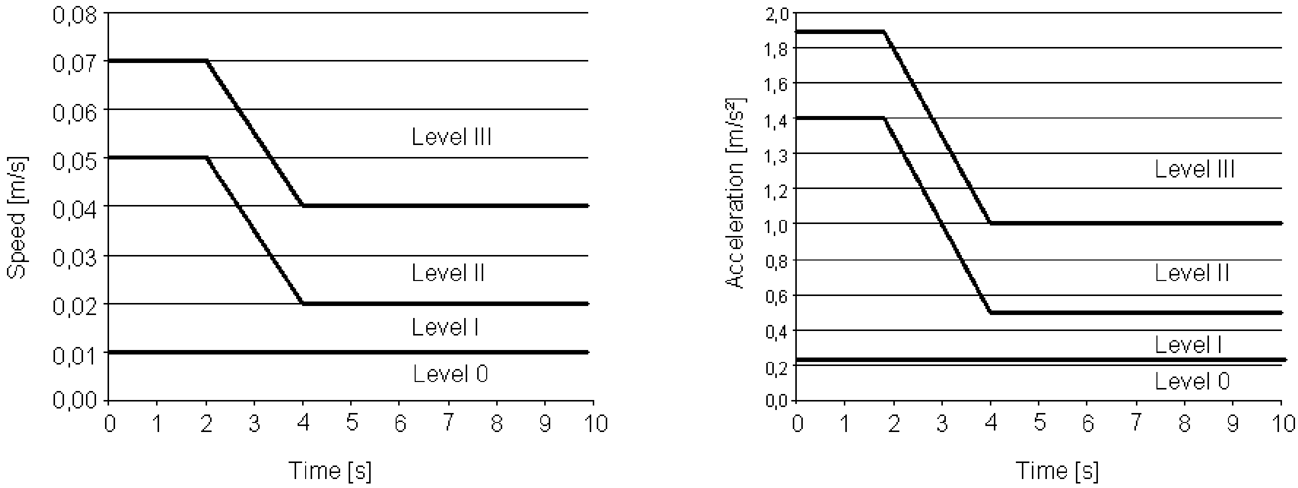



Figure 51 – Scales GSI-2004 for areas LGOM.
a – speed GSI-V, b – acceleration GSI-A

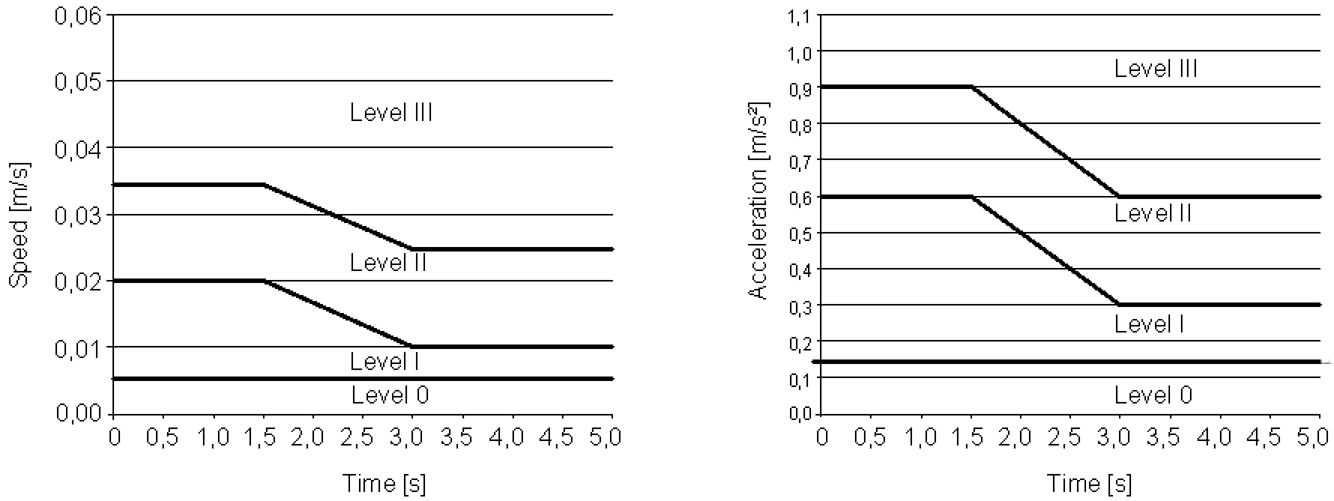



Figure 52 – Scales GSI-GZW for areas USCB.
a – speed GSI-V, b – acceleration GSI-A

Lands exposed to the impacts of continuous deformations falling into categories 0-IV and to the impact of mining tremors with the acceleration up to 1000 $m/s^2$ are suitable for building development.

## 5.5 Changes of water conditions.

The possibility of the building being damaged due to the increasing level of groundwater depends on the depth of the foundation "h". Flooding occur if $g \approx w$.

The impact of ground deformations on the water conditions can also produce damage on the buildings. The so called phenomenon of relative rise of the ground water level may lead to the hazard of flooding buildings.

Changes in the water conditions require proper forecasts. When flooding occurs, a waterproof membrane or proper drainage may be needed. In any case, this may be insufficient in the event that part of the foundation or basement is located below the level of groundwater, when "g" < w + h.

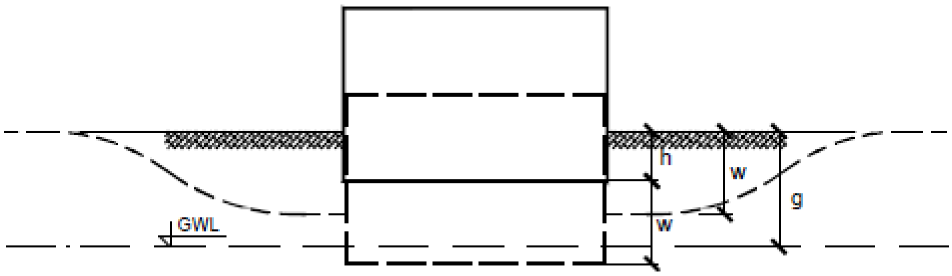



Figure 53 – Building lowered below the groundwater level (GWL): h- foundation depth, g-groundwater level, w - ground subsidence. [27]

It is important to take into account changes in the level of groundwater during the evaluation of the physical-mechanical properties of the soil as this can involve the total exclusion of the ground or require preventive measures during the development of the technical project, as insulation or additional drainage.

## 5.6 Post mining areas.

The areas where mining operations have been interrupted and the concession to carry out the exploitation of the mine expired, are called post-mining areas. The concept of post-mining areas has emerged during last years due to the liquidation of the mines. In these areas still required to accomplish the specifications required for buildings located in mining areas.

The consequences can be:

- Delayed development of continuous deformations of the subsurface rock layers,
- Discontinuous surface deformation due to the existence of shallow holes produced by mining works. In this case, discontinuous deformations did not appear before because works in the mine did not allow its development,
- Possibility of occurrence of overflow and flooding.

The development of continuous deformations is extended in time so that, after finishing mining activities, movements of the ground surface will continue for a while. The length of this process depends on the composition of the rock mass.

The main causes that can prolong the development of continuous deformations are:

- Slow filling of empty voids, usually it is assumed that after 10 years since the last mining process it has been completed,
- Changes in the water,
- Mining tremors and tectonic movements.

Also, consider the presence of tectonic faults in post-mining areas because its activation could cause discontinuous deformations.

# 6. Protection of buildings in mining areas

## 6.1 Introduction

As explained in previous sections, the deformation of the ground surface as a result of subsidence can produce damage upon the structure of the buildings. The damage that occurs is a result of a combination of some or all of the subsidence parameters. Curvature and horizontal deformation are the main parameters which cause damage to the building, but tilts can also affect the serviceability.

In normal circumstances, the movements caused by mine subsidence are not completely transmitted to the buildings and structures on the surface. In any case, buildings should be designed assuming a full transfer of impacts from the ground to the structure.

## 6.2 Principles shaping rigid buildings

Should have [18]:

- Cubicoid shape of constant height and horizontal projection shape in the form of convex polygon.
- Superstructure must rectangular with symmetrically distribution of stiffening elements.
- Proper joined construction elements (walls, floors, foundations).
- Ceilings storey in the form of closed foundation box.
- Staircases located in the middle of segments length.
- Appropriate use of construction static scheme may significantly lower value of internal forces in particular elements.
- In the case of scheme of flat rigid rod construction, additional moments caused by subsoil deformation appear except for internal forces values caused by programme loads.
- Shaping rod construction as deformable we get rid of additional internal forces caused by subsoil deformation. However, particular attention should be paid to construction stability.

In the case of rigid buildings, the rigidity of the structure is achieved by proper design of the following structural elements:

- Foundation,
- Floor basement,
- Floors above ground level,
- Beams and slabs.

The necessary rigidity can not be provided only by the underground part of the building. This solution is unacceptable in the case of mining tremors.

### 6.3 Design principles in mining areas

Underground extraction of hard coal in Poland has been led under high urbanized areas. This fact causes many problems with possible mining damages to the buildings, especially those built with rigid construction.

#### 6.3.1 General rules

##### 6.3.1.1 Segments and expansion gaps.

One possible solution to this problem is the division of big rigid buildings into smaller independent parts (segments) by using expansion gaps. Reducing dimension of the segments also reduces the horizontal forces acting on the foundations of the building and consequently limiting the amount of reinforcement required.

Expansion joint is a gap in the building spreading on the whole height, usually between walls or load-bearing structures of adjacent segments. The main task of expansion gap is to isolate neighbouring segments in such way, when mining subsidence occur at the building location, should not be any direct contact between them. The shape of parallelepipeds is recommended for the segments.

The maximum length of the segments will be as follows:

- Maximal length of individual segment of building rigid construction up to 30 m, for mining category above II,
- Maximal length of individual segment of building deformable up to 36, for mining category above II,
- Maximal length of individual segment of building with deformable construction up to 48, up to mining category II.

Regardless of the length of the segments is also recommended design expansion joints in the following cases:

- Changes in structures height alternation more than 20%,
- In the spot alternation to building horizontal projection (simple segment shapes should be separated, e.g rectangles),
- Changes in physical and mechanical characteristics of the subsoil ($E1 \neq E2$ ).
- Changes in the depth of the building foundation.

Rules for joints:

- Smallest distance between segment foundations is 5 cm (for mining tremors 8 cm) and walls 10 cm (for mining tremors 13 cm), unless calculations indicate use of bigger gaps,

- Expansion gaps should be protected from littering or backfilling during construction as well as during utilization,
- Expansion joints should be covered for energy, humidity and acoustic reasons.

Subsidence produce changes on expansion joints aperture, as it shown in the next figure.

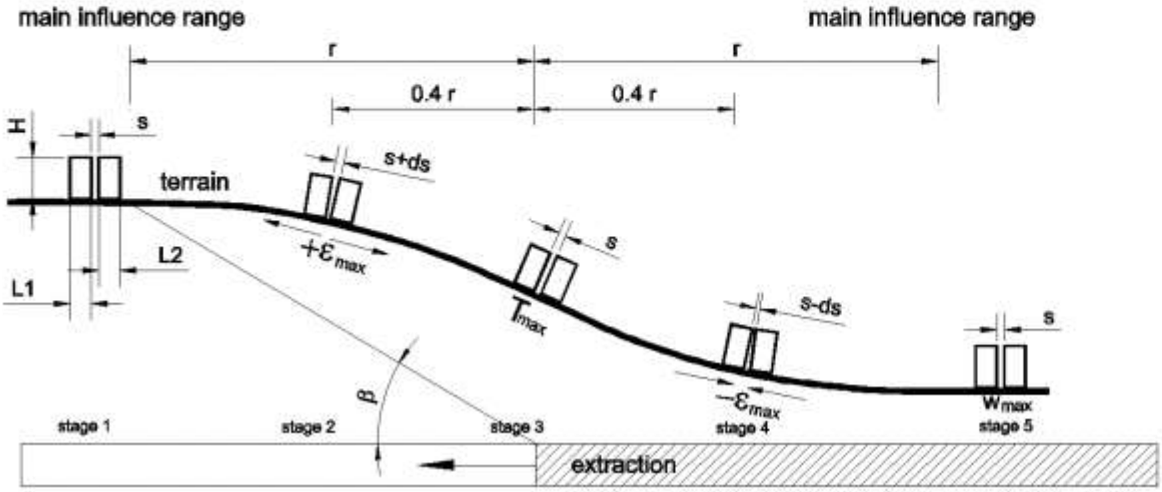



Figure 54 – Phases of the expansion gap behaviour under mining influences. [30]

Five stages according to the deformation of a building built with expansion gaps [30]:

- Stage 1: The building is out of influence range. The width of expansion gap is in its initial distance “s”,
- Stage 2: Maximum horizontal tensile strain “$+\varepsilon_{max}$”. When extraction edge takes the position approx. 0,4 of the main influence range “r” in front of the considered gap, the expansion gap increases its width till reaches its maximum value,
- Stage 3: Maximum terrain tilt “$T_{max}$”. The extraction edge is located directly under expansion gap. The gap width goes back to the initial distance “s”,
- Stage 4: Maximum compressive strain “$-\varepsilon_{max}$”. When extraction edge takes the position approx. 0,4 of the main influence range “r” behind considered gap, the gap width decreases till reaches minimum value,
- Stage 5: Final reduction “$w_{max}$”. The building is out of influence range. The width of expansion gap goes back to its initial distance “s”.

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| Top | s | $s+\varepsilon l+\frac{H}{R}l$ | s | $s-\varepsilon l-\frac{H}{R}l$ | s |
| bottom | s | $s+\varepsilon l$ | s | $s-\varepsilon l$ | s |

Table 6 – changes in expansion gaps depending on the position of the building in the subsidence basin. [18]

The basic requirement regarding buildings adjacent to each other is adequate size of expansion gap. Building dimensions as well as parameters of mining basin edges, in particular horizontal deformation and radius of curvature, decide about adequate size of expansion gap.

- In general:

$$S \geq 0$$

- The minimum width of expansion gap between two segments is determined by the following formula:

$$S = \left(\varepsilon_d + \frac{H}{R_d}\right)\frac{L_1 + L_2}{2}$$

- In practice:

$$S = 0{,}1\left(\varepsilon_{max} + \frac{H}{R_{min}}\right)\frac{L_1 + L_2}{2} + (5\ to\ 10\ cm)$$

Where:

* S = expansion gap width [cm],
* ε = area horizontal deformation [mm/m],
* H = height of lower building from foundations to roof ridge [m],
* R = radius of curvature [km],
* $L_1$,$L_2$ = segment lengths [m].

- If mining tremors are expected:

$$S_1 = 3 + 0{,}4\,(H - 5)$$

Where:

* $S_1$ = added width expansion join due to tremors [cm],
* H = Building height.

**6.3.1.2 Calculation analysis**

For the calculation of the building structure all mining interactions (ε, R, T) should be taken into account. While it is not necessary to calculate the internal forces of the structure caused by:

- Horizontal ground deformation ε, if the structure is designed in the mining category 0 ($E \leq 0.3$ ‰),
- Curvature area R, in the case of rigid buildings, when the ground deformation module $E_0 \leq 80$ MPa computational analysis of the effects of the curvature of the earth can be omitted, according to the length of the segment L and the radius of curvature R, shown in the next table:

| $E_0$ [MPa] | Admissible length of segments L [m], with forecasted radius of curvature \|R\| [km] | | | |
|---|---|---|---|---|
| | \|R\| ≥ 20 | \|R\| ≥ 12 | \|R\| ≥ 6 | \|R\| ≥ 4 |
| ≤ 10 | 36 | 36 | 30 | 27 |
| ≤ 20 | 36 | 30 | 24 | 18 |
| ≤ 50 | 27 | 24 | 15 | 12 |
| ≤ 80 | 24 | 18 | 12 | 10 |

Table 7 – Length segments "L" of rigid objects, with which are not required to calculate the influence of the curvature of the land. [24]

- Inclination T, if these forces do not have a significant impact on the conditions of load bearing capacity of the structure.

Buildings designed without calculations should be developed and constructed taking into account the guidelines about minimum reinforcement structure specified in the standard Eurocode 2.

It is important to consider that:

- Minimum longitudinal reinforcement of foundations in order to resist the impact of horizontal deformation of the land should be 0,002bh, where b and h are cross-sectional dimensions of the foundation,
- Minimum reinforcement diameter, 12 mm.

#### **6.3.1.3 Structural analysis**

The value of internal forces caused by the impact of mining can be calculated separately for each deformation parameter. For the design and dimensioning of the structure, should take the most unfavorable combination of loads that can occur simultaneously on the structure. The most unfavorable combination of loads is determined by the limit states.

The design of the building should be calculated for an unknown position in the subsidence basin. In general, this will consider three situations (Figure 55).

It is recommended locate and orientate structures so that the building expose its shortest dimension to a subsidence though and avoiding faults. It means, the longitudinal axis of the building should be perpendicular to the exploitation front.

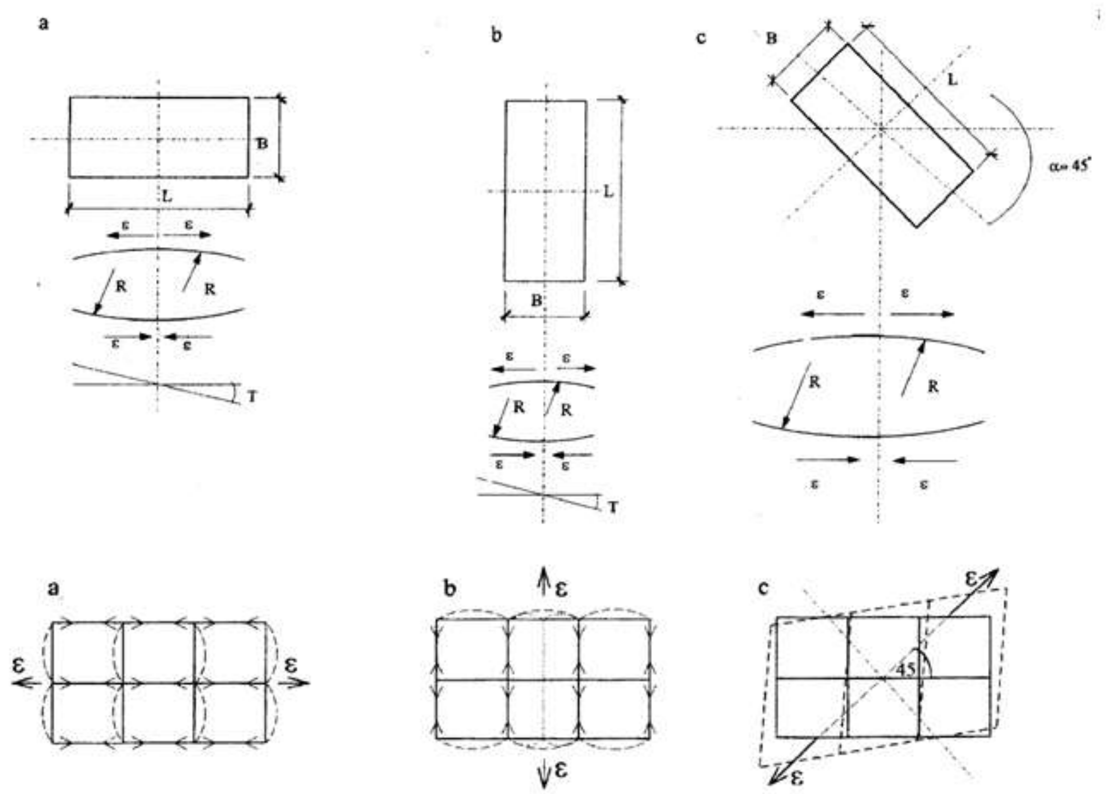



Figure 55 – Design situation with unknown location of the building on the mining trough. a – parallel to the longitudinal axis of the horizontal projection, b – parallel to the transverse axis, c – oblique direction at an angle $\alpha$ = 45 ° to the axis of the horizontal projection. [24]

### 6.3.1.4 Superstructure and stiffness

The building can be designed as wall structure or as a frame structure with masonry fulfillment. The frame structure is made of reinforced concrete or steel.

Stiffening of the building can be designed as:

- Load-bearing transverse walls, with longitudinal reinforcing walls.
- Load-bearing longitudinal walls, with transverse reinforcing walls.
- Mixed, with load-bearing walls in both directions.

In case of frame structure with masonry fulfillment, it is recommended that the distance between columns is up to 6 m.

To ensure the rigidity of the building in the vertical plane, it is not recommended to design buildings braced only by the construction of the basement.

The stiffening in the longitudinal plane is achieved by a continuous wall along the entire length of the building. At least one of these walls should be located near the longitudinal axis of the building. In the transverse direction, the distance between the walls must not exceed 12 meters. These walls must be performed throughout the width of the building.

The arrangement of the load-bearing walls should be symmetrical relative to the longitudinal and transverse axe. The figure below shows the allowable asymmetry for interior walls. The displacement of the inner wall to the longitudinal axis of the horizontal projection (a1) will not exceed 0.1 times the transverse dimension of the building (that is, 0.1B) and not greater than 1.2 meters. In the transverse axis, displacement of the bearing wall (a2) should not exceed 0.6 meters

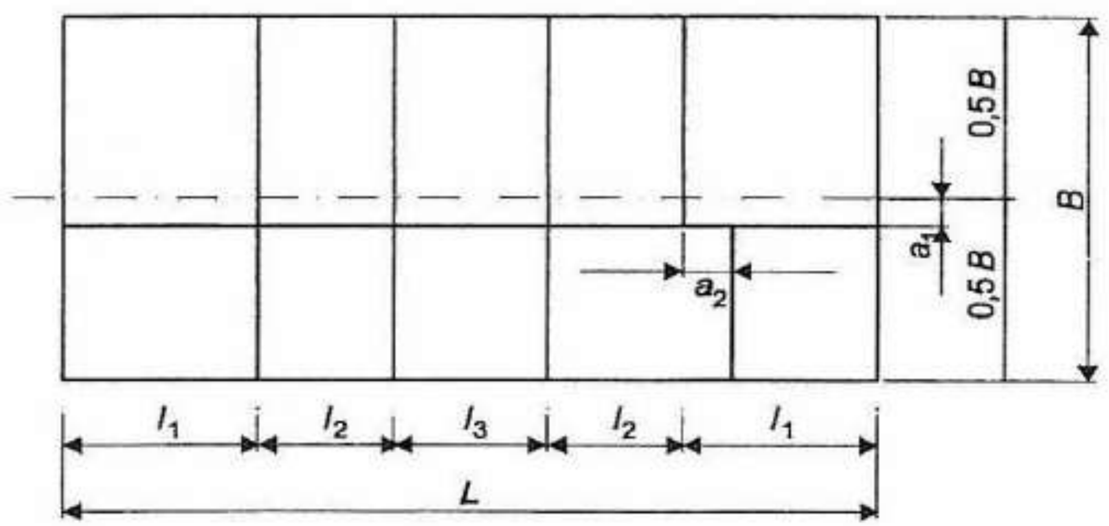



Figure 56 – Allowable asymmetry relative to longitudinal and transverse axe. [24]
$a_1 \leq 0{,}1B$ or 1,2 m; $a_2 \leq 0{,}6$ m.

It is recommended to limit the drilling of the basement walls. Any necessary openings in basements should be deployed symmetrically to the axis of the building.

The location of the openings in the external walls should not interfere with the continuity of the ring beam at ceilling level.

This particularly applies to window and door openings in the exterior walls. Avoid locating the holes in the walls at the expansion joints. If necessary, their execution must be sealed with expansion joint around openings in such a way as not to obstruct freedom of mutual movement of the segments.

It is recommended to locate the stairs and elevators in the middle of the segment. Its dimension in the horizontal projection must not weaken the slab by more than 40%. The staircase can not go beyond the contour of the external walls of the building and should not cut the continuity of the beams at the height of the ceilings.

#### 6.3.1.5 Foundations

The design of the foundation is one of the most important factors for protecting the buildings against mining impacts. For buildings built in mining areas is recommended shallow foundation.

In general, ground strains are transferred into footing systems by friction on the underside of its foundation and ground pressure on the sides of the foundation. The best solution is to reduce such friction and, if possible, separate the foundation from the soil to allow the ground to move without damaging the structure.

The foundation must be built at the same level across the extension of the building (segment). If for some reason a part of the foundation is deeper, it is recommended to place the recessed part in the central area of the building (segment), symmetrically with respect to its axis (figure 57.a). It is also necessary to perform a horizontal expansion joint and employ a sliding layer (figure 57.b, c).

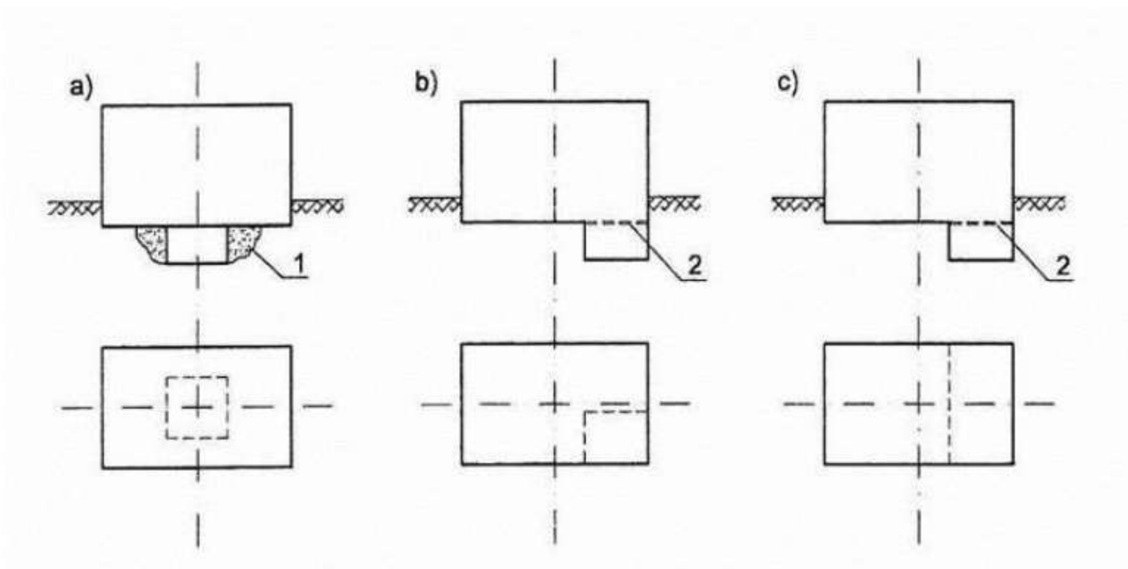



Figure 57 - Building foundation at different depths. 1 – Lean concrete. 2 – Sliding layer. [24]

It is highly recommended to place the foundation on sandy soils because the transmission of forces to the structure decreases. It is not recommended to place the foundation on rocky soils, in the case of soils with high load capacity and small deformability, the transmission of forces to the structure is greater. In case of locating the foundation on soils of this type is necessary to use a layer of sand under the foundation.

Layer of sand will be made with medium sand “Pr” or coarse sand “Ps”, in the absence of this material can be made with sand and gravel “Po” or gravel “Z”. The use of silts or fine sand is not allowed. The layer of sand will have a degree of compaction Id <0.6

The thickness of sand layer depends on the length of the building (segment).

| Material type | Minimum thickness of sand layer [m] | | | |
|---|---|---|---|---|
| | L < 10 m | L = 10 – 20 m | L = 20 – 30 | L > 30 m |
| Pr – Ps | 0,30 | 0,40 | 0,50 | 0,60 |
| Z - Po | 0,40 | 0,50 | 0,60 | 0,70 |

Table 8 – Minimum thickness of sand layer [m], depending on the length of the building L. [24]

It is important to take into account that employment of a sand layer under the building foundation is not recommended in areas where mining tremors occurs. If is necessary to use a layer of sand, it will be as thin as possible.

**6.3.1.6 Construction materials**

All materials employed in the production of construction elements used in mining areas should help to achieve the minimum strength and rigidity required by the building.

The finishes and insulation materials should be selected taking into account the expected deformation of the structure caused by ground deformation (eg, plasterboard Instead of plaster).

Minimum characteristic resistance "$f_k$" in masonry walls should not be less than 3 MPa. It is recommended using lime and cement mortar or cement mortar. The average compressive strength "$f_m$" of mortars should not be less than 5 MPa. The vertical joints of the walls are always filled.

In buildings exposed to simultaneous influence of ground deformation and mining tremors, it is recommended to use structural concrete at least grade C16/20

To reinforce concrete elements that must withstand loads caused by the impact of mining (eg membranes and continuous footings, tie rods in foundation level, the basement or ground floors of the building, beams) it is recommended to use steel class AI St3SY. Steel classes A-II 18G2 and A-III 34GS can also be used.

## 6.4 Design of buildings

### 6.4.1 Building foundations

#### 6.4.1.1 Foundation framework

One method of protecting structure against impact of area horizontal deformation is called Foundation framework. Foundation framework consists in interconnected continuous footings (Figura 59 a,b).

Foundation framework absorbs tensile forces and bending moments, and their combination, which can occur in the plane of the foundation due to mining impacts. It also absorbs internal compression forces.

Continuous footings need to be reinforced to withstand tensile forces and horizontal bending moments that occur in the plane of the foundation, as shown in Figure 59 b.

Figure 58 shows the cross section of the necessary reinforcement "As", positioned along the base and sides of the continuous footings.On the vertical edges of the continuous footings should be placed reinforcements to absorb bending moments "$A_{s,M}$" and the remaining reinforcement along base "ΔAs = As - $A_{s,M}$".

Figure 59 d shows a method of anchoring in the corners of the continuous footings for these longitudinal reinforcements.

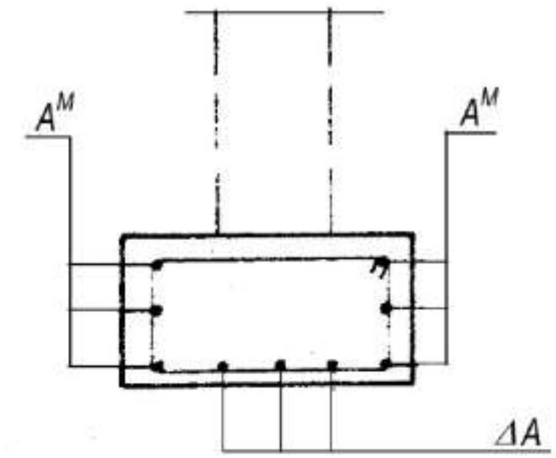



Figure 58 – Distribution of reinforcement for bending moments in continuous footings.
As – area, in cross section, of reinforcement; $A_{s,M}$ – area, in cross section, of reinforcement for bending moments at the level of the foundations, ΔAs = As - 2$A_{s,M}$; $l_{b,d}$ anchorage length. [18]

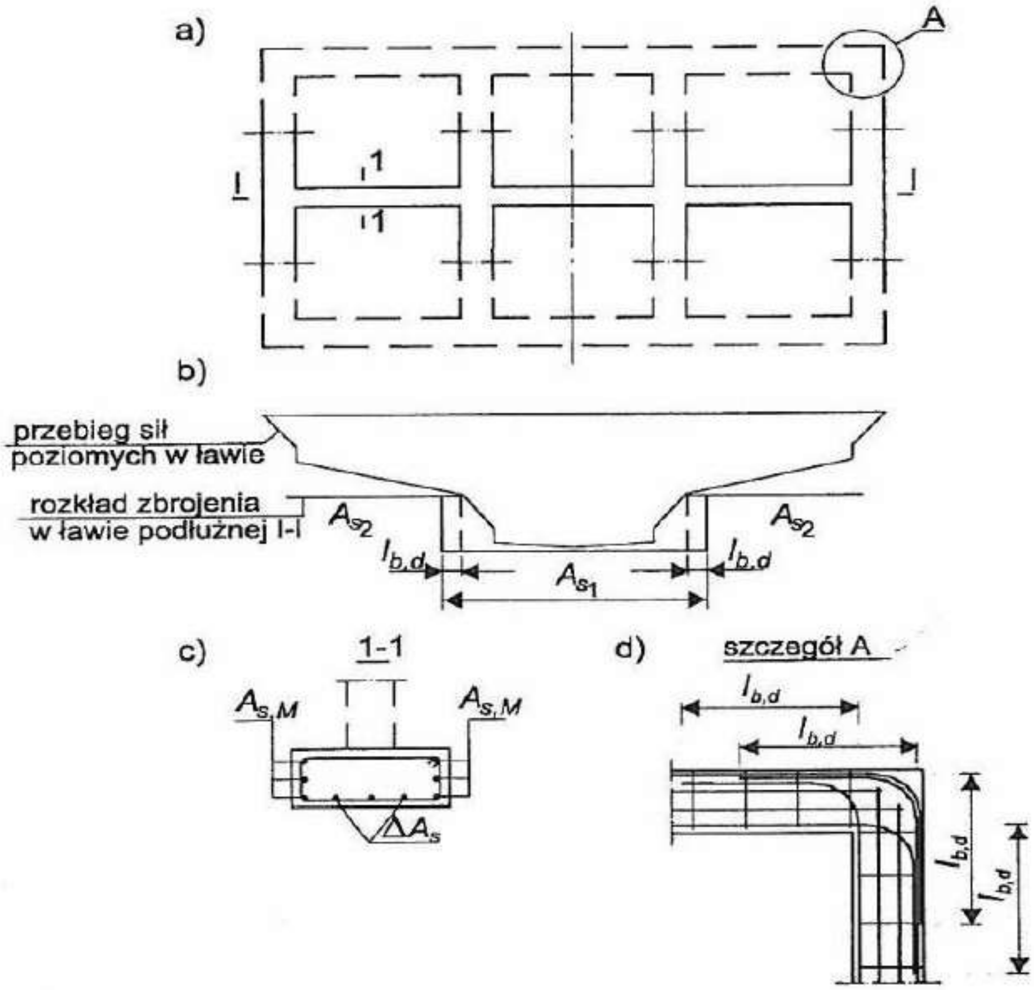



Figure 59 – Foundation framework. a – foundation framework scheme; b – distribution of horizontal forces and disposition of longitudinal reinforcement in continuous footing (I-I); c – disposition of reinforcement in cross section (1-1); d – detail reinforcements in the corner of continuous footings. [24]

Tie rods can be used to ensure the stiffness of the foundation in its horizontal projection. Is always recommended, using tie rods, when the distance between continuous footings of the foundation framework is greater than 6 meters. Figure 60 shows examples of foundation frameworks stiffened by tie rods (60 a, b) and the method of anchoring of the tie rods in the continuous footings of the main foundation (60 c, d).

Tie rods foundation should be designed to transfer axial tensile forces. The minimum cross-section of reinforced concrete tie rods should be 20 cm x 20 cm. The reinforcement of the tie rods will be symmetrical respect to the major axis of its cross-section.

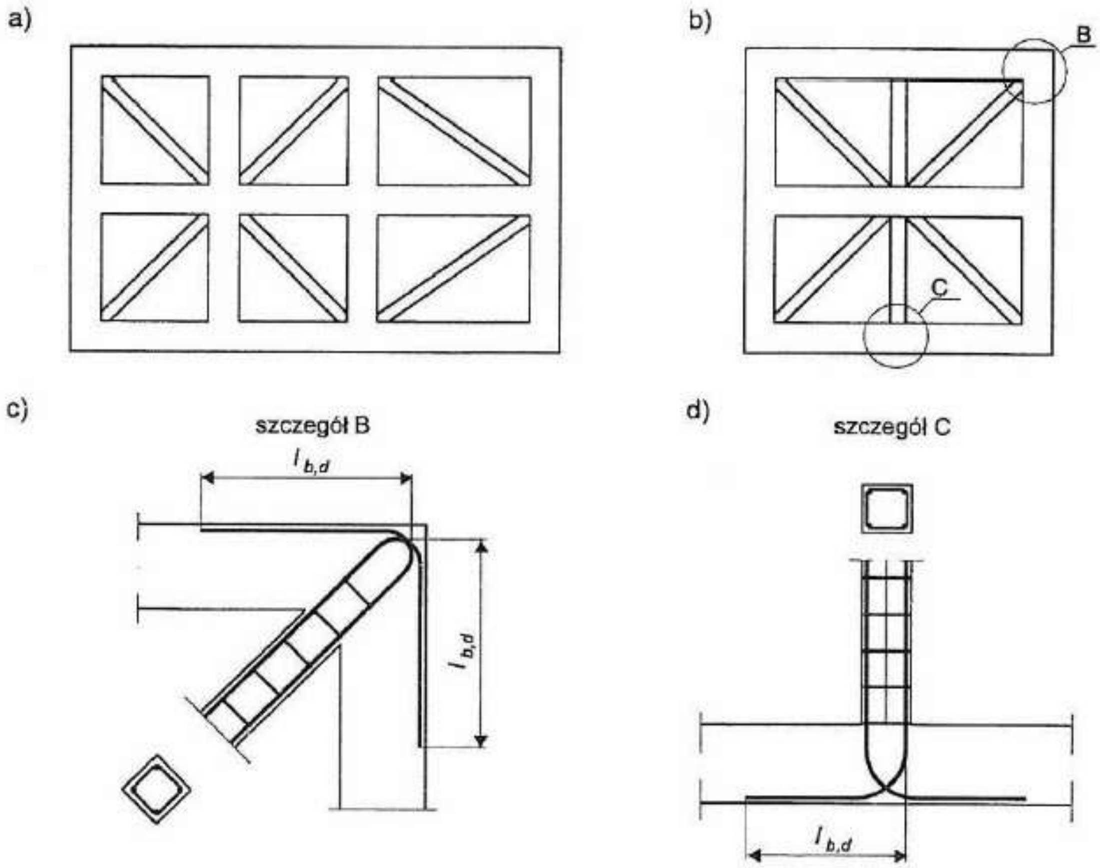



Figure 60. a, b – examples of foundation frameworks stiffened by tie rods of square cross-section. c, d – anchoring method of tie rods. [24]

**Calculation of reinforcement**

Minimal reinforcement for continuous footings tension:

$$A_S^R = \frac{N}{f_{yd}}$$

Where:

N – Tensile force.

$f_{yd}$ – Design strength of steel.

Minimal reinforcement for continuous footings bending:

$$A_S^M = \frac{M}{f_{yd} \cdot \varsigma \cdot d}$$

Where:

$$\varsigma = 1 - 0{,}5 \cdot \xi$$

$$\xi = 1 - \sqrt{1 - 0{,}5 \cdot S_c}$$

$$S_c = \frac{M}{f_{cd} \cdot h \cdot d^2}$$

Reinforcement for big and small eccentric tension (symmetric reinforcement):

Static eccentric:

$$e_s = \frac{M'}{N'}$$

Distance from the middle of reinforcement:

$$e_o = \frac{d - a}{2}$$

Big eccentric if $e_s > e_o$

Small eccentric if $e_s < e_o$

Case of big eccentric:

Compression zone height:

$$x_{eff} = \frac{N'}{\alpha \cdot f_{cd} \cdot h}$$

Tensile reinforcement:

$$A_{s1}^{MR} = \frac{N'(e_s - e_o)}{f_{yd}(d - a)}$$

Case of small eccentric:

$$A_{s1}^{MR} = \frac{-N'(e_s - e_o)}{f_{yd}(d - a)}$$

Length of rods anchorage:

$$l_b = \frac{\phi}{4} \frac{f_{yd}}{f_{bd}}$$

Where $f_{bd}$ is the design bond strength.

### 6.4.1.2 Reinforced concrete slab (RC membrane).

Another method of protecting structure against impact of area horizontal deformation is called reinforced concrete slab, ensure the stiffness of the foundation and it can be used as a basement floor.

The concrete slab has a thickness of 10 cm and is reinforced over its entire surface. The reinforcement is placed in a layer in the middle of its thickness, in the longitudinal and transverse axis and is calculated only for tension. Usually below the bearing walls is necessary to increase the section of the reinforcement in the direction parallel to the walls. The minimum reinforcement bars are Ø 6 mm, arranged each 25 cm in both directions.

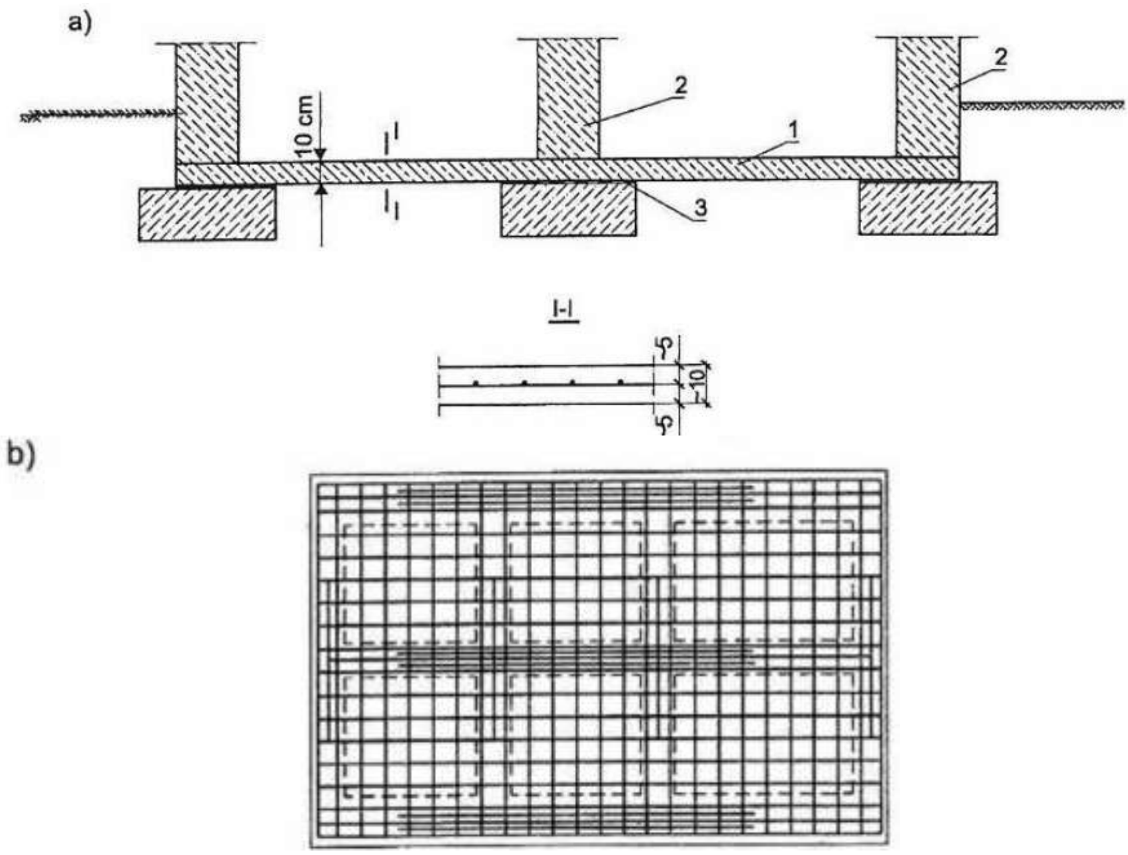



Figure 61 – Reinforced concrete slab. a – cross section; b – horizontal projection of the slab reinforcement. 1 – diaphragm; 2 – basement walls; 3 – sliding layer. [24]

The slab, in all its extension, will be placed at the same level. Located between the foundation and the foundation walls. Between the slab and the foundation is placed a sliding layer. The coefficient of friction of the sliding layer must be taken according to next table.

| Description of sliding layer | Value of friction coefficient [f] |
|---|---|
| Two layers of roofing felt (without spacers), normal stresses: | |
| σ = 0.1 MPa | 0.7 |
| σ = 0.15 MPa | 0.6 |
| σ = 0.20 MPa | 0.5 |
| σ = 0.25 Mpa and more | 0.4 |
| Two non-sanding tar board layers with interlayer made of: | |
| Smoking-box dust | 0.4 |
| soot | 0.3 |
| Powdered graphite | 0.2 |
| Artificial foils with interlayer made of graphite grease: | 0.15 |

Table 9 – Friction coefficient of the sliding layer. [24]

In case of the presence of humidity, should be placed a waterproof layer under the concrete slab.

Continuous footings under the walls, under the slab, do not need to be calculated for horizontal deformation impacts but only for vertical ones (if such reinforcement is required).

When reinforced concrete slab is employed, it is necessary to measure tension on the foundation and soil, due to the eccentric load that may result from horizontal displacement of the base with respect to the basement walls.

**Calculation of reinforcement**

$$A_{s1} = \frac{T}{f_{yd}}$$

Where:

T – Tensile force.

$f_{yd}$ – Design strength of steel.

Arrangement of reinforcement:

- Reinforcement of footing strips should be concentrated under the wall.
- Reinforcement of fields between footings should be distributed over the entire width of the strip.
- Minimum reinforcement: Ø6 each 250 mm.

### 6.4.1.3 Use of expansion joints in the foundation

The use of expansion joints in the foundation must allow the independence of adjacent segments. It is recommended that the foundation walls separated by an expansion joint are situated on the same foundation. The foundation must be separated from the footings by a sliding layer. Next figure shows examples of the use of expansion joints in foundations.

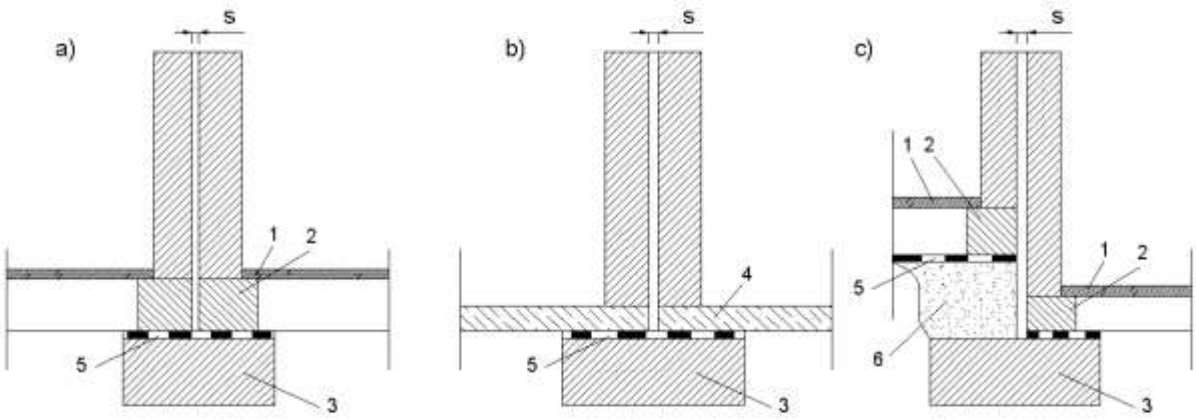



Figure 62 – Use of expansion joints in foundations. a – Foundation framework; b – RC membrane; c – segments at different heights. 1 – basement floor; 2 – continuous footings of foundation framework; 3 – reinforced concrete foundation; 4 – reinforced concrete slab; 5 – sliding layer; 6 – lean concrete. [24]

### 6.4.2 Basement floor

#### 6.4.2.1 General principles

The basement floors form a monolithic structure with floors and walls of reinforced concrete. Basement walls can also be made with precast concrete, masonry or frame structure with masonry fulfillment. Masonry walls are recommended for buildings whose upper floors are also made of masonry.

The use of frame structure with masonry fulfillment is recommended only in mining areas of category II or less.

#### 6.4.2.2 Partially different foundation level

When there is a partially different foundation level, a expansion joint with a sliding layer should be created. The part of the structure located above the expansion joint will be reinforced with a reinforced concrete ring-beam. To prevent damage to the basement, the recessed portion of the structure is performed, as shown in the following figure. Directly below the sliding layer must be placed a beam and footings must be adapted to transfer horizontal forces derived from deformation of the soil.

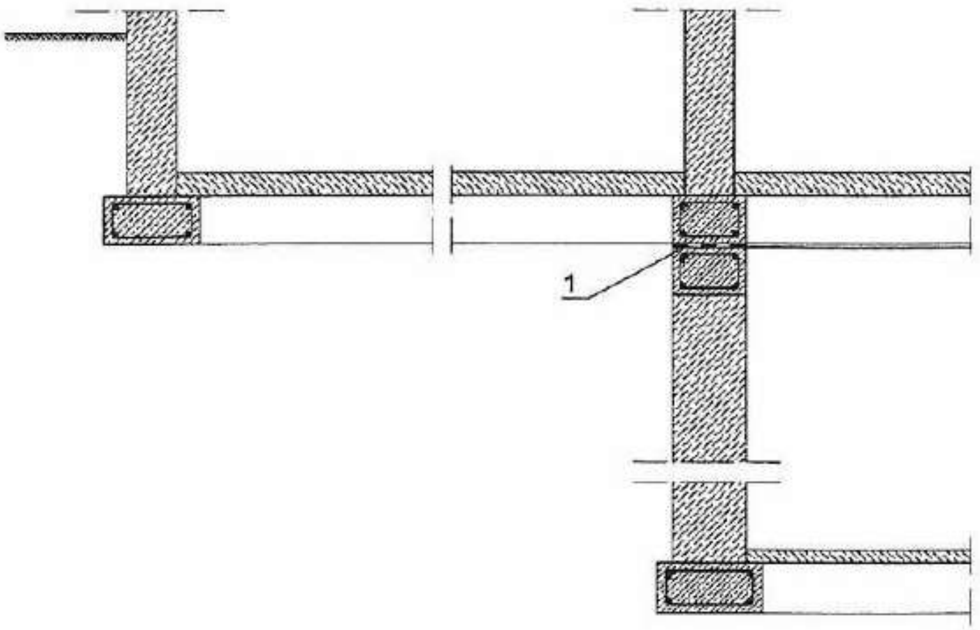



Figure 63 – Partially different foundation level. 1 – sliding layer. [24]

### 6.4.3 Structural walls of floors above ground

#### 6.4.3.1 Wall structures

Built monolithically and providing spatial rigidity to the entire building.

Masonry buildings must be made of the same material in all its extension.

In relation to the requirements contained in the manual ITB 341/96, for mining areas it is recommended to increase the number of anchors that connects the exterior wall with the inside of the structure:

- 5 anchors/m$^2$, up to second category,
- 6 anchors/m$^2$, above the second category.

#### 6.4.3.2 Frame structure with masonry fulfillment

This type of structure is considered rigid when the radius of curvature of the structure $R_b$ is not smaller than the limit radius $R_{gr}$:

$$R_{gr} = \frac{L-a}{2000\Theta_b} \leq R_b$$

Where:

L – Segment length [m].
a – Distance between columns in extreme fields [m].
$\Theta_b$ – Deflection of the structure walls, induced by land surface curvature.
$R_b$ – Radius of curvature of the structure [km].

## 6.4.4 Reinforced concrete slabs and beams, lintels

### 6.4.1.1 Reinforced concrete slabs and beams

The building slabs should be designed as monolithic elements. Reinforced concrete beams made "in situ" around the perimeter (ring beams) and along the load-bearing walls.

To ensure the transfer of the normal and tangential forces it is recommended use reinforced concrete slabs.

The slab above the basement need reinforcement arranged perpendicular to its axis. Minimum diameter of reinforcement is 5.5 mm placed every 25 cm and anchored in the beams. In justified cases it may also be necessary to reinforce the slabs of higher floors.

Slabs made of precast elements are allowed if the connections between the slab and walls ensure the correct transmission of loads. These slabs are finished with a layer of concrete of not less than 3 cm thick and reinforced in the direction perpendicular to the longitudinal reinforcement of the precast elements.

The ring-beams cooperate in the transmission of horizontal traction forces that occur in the slabs. Hence, the continuity of the reinforcement of the ring-beams is required. It is recommended to connect the bars by welding, especially in the case of buildings exposed to mining tremors.

In buildings made of precast elements is recommended to use ring-beams made in situ to increase the stiffness of the structure.

Minimum reinforcement for beams is 4 bars with a diameter of 12 mm.

In case of making an opening in the slab with a size greater than 6 times the width of the floor (stairwell or elevator shaft), must be placed a concrete beam around the perimeter of the hole to ensure the transfer of horizontal forces.

In the same way, openings in walls must have a reinforcement made of reinforced concrete, around the perimeter or at its bottom. The figure below shows how to perform these constructive solutions.

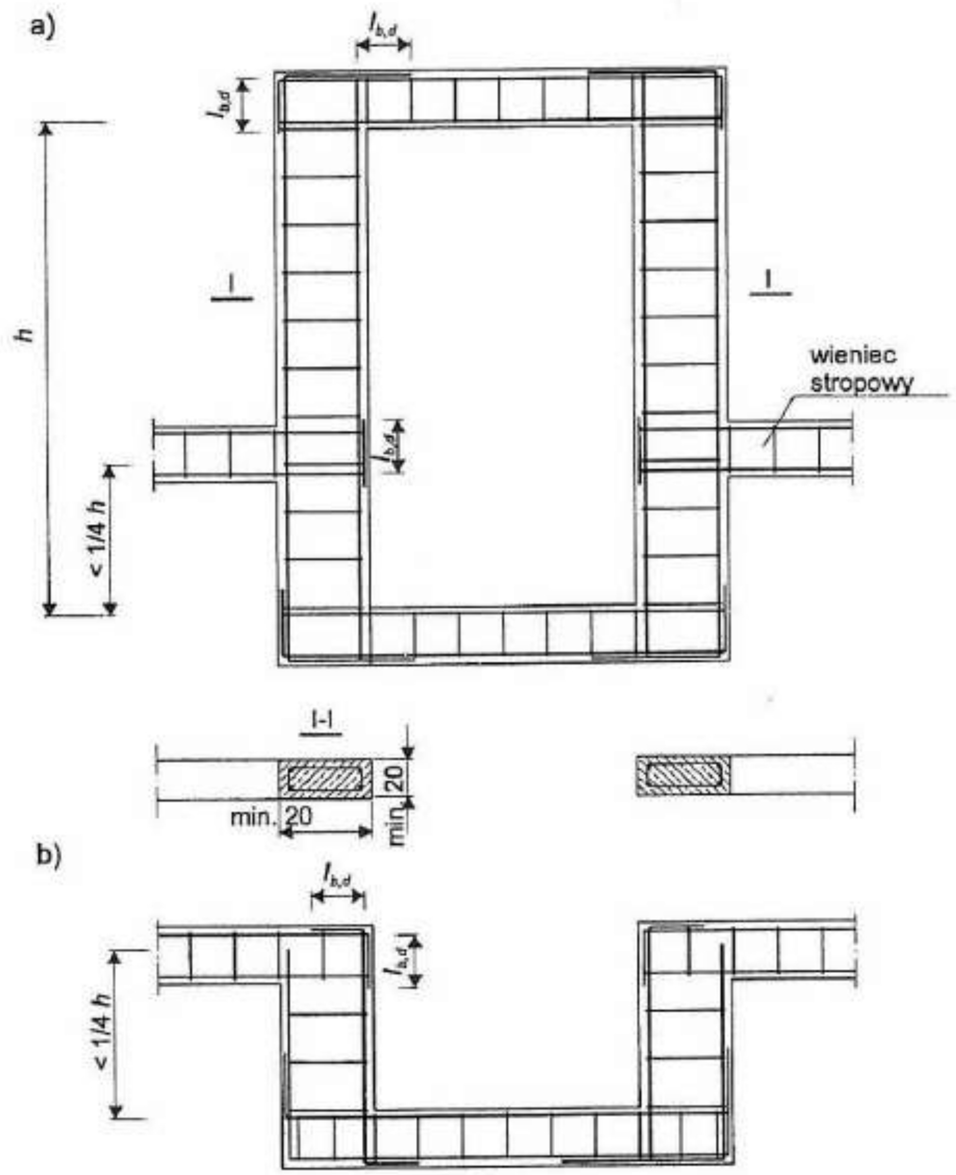



Figure 64 – Opening in a wall, interrupting a beam. a – beam height ≥ ¼ h, b – beam height < ¼ h; h – opening height, $l_{b,d}$ – anchorage length. [24]

**6.4.1.2 Lintels**

Window and door openings in masonry walls must have lintels above them. If the opening is located near to the ceiling, it is recommended to connect the lintel to the beams of the slab. Otherwise, the lintel should be embedded in the wall at least 25 cm.

In the case of reinforced concrete walls, reinforcement will be placed in the outline of the openings.

The next image shows an example of lintels performed above the openings. Lintels combined and single lintels. Also can be seen a window opened through a beam, breaking its continuity.


Figure 65 – Lintels above the openings. [35]


Figure 66 – Lintel connected to the beam. [36]


Figure 67 – Lintel connected to the beam. [36]

## 6.5 Modifications of existing buildings.

- Cutting out a part of the building or removing an entire building from a row of buildings, to provide space for compression.
- Digging trenches around the building, filled with compressive material weaker than the surrounding soil, reduce the damage due to horizontal strains, especially compression. The trenches reach greater depths than the foundation level and must be carried out without disturbing the foundation. Trenches may be covered with concrete slabs.
- Slotting rigid pavements in floors and paved areas to provide adequate compression space. Concrete floors are difficult subjects but wood, brick or stone do not present difficulties.
- Provide temporary support or strengthening to parts that may experience damage. Support partitions and ornaments independently of the walls and floor.
- Use of tie rods to prevent walls from succumbing to lateral forces. Abusive use of tie rods may disfigure the building. Stress concentration at tie rods bearing plates may pull these through the wall.
- Install pre-tensioned steel mesh around the exterior walls of the building. It can be dismantled later and re-used.

The overall lateral stability of the building is provided by the perimeter walls (brick walls or reinforced concrete walls).

Masonry residential buildings have been the most traditional solution employed in Poland. However, during the last decades, use of brick wall structures decreased in favour of reinforced concrete structures.

### 6.5.1 Steel tie rods

Steel tie rods attached to anchor plates are employed in masonry walls (brick, block, etc.) to carry tensile loads and save the walls from succumbing to lateral forces. Tie rods are positioned at ceiling levels and increase the overall stiffness of the structure. These are often seen from the outside of the walls as a cross or rotates S shapes. Sometimes the rods pass right through the building; others are embedded into an internal wall.

However, this system is not always ideal as abusive use of tie rods may disfigure the building and cause additional cracks. Stress concentration at tie rods bearing plates may pull these through the walls.

## 6.5.2 Trenches

This method consists in the reduction of the earth pressure generated by compressive strain in the ground by the construction of a deformation zone.

This is achieved by digging trenches around the building. The trenches are backfilled with compressive material which is strong enough to support the sides of the excavation but more compressible than the natural soil. Compressible material into the trenches allows the absorption of horizontal strain, and therefore, decreases the impact of the ground deformation. Expanded polystyrene foam, vermiculite or cork can be used to fill the trenches.

The trenches are placed as near as practical to and reach greater depths than the foundation level. The excavation of these trenches must be carried out without disturbing the foundation and can be covered with concrete slabs.

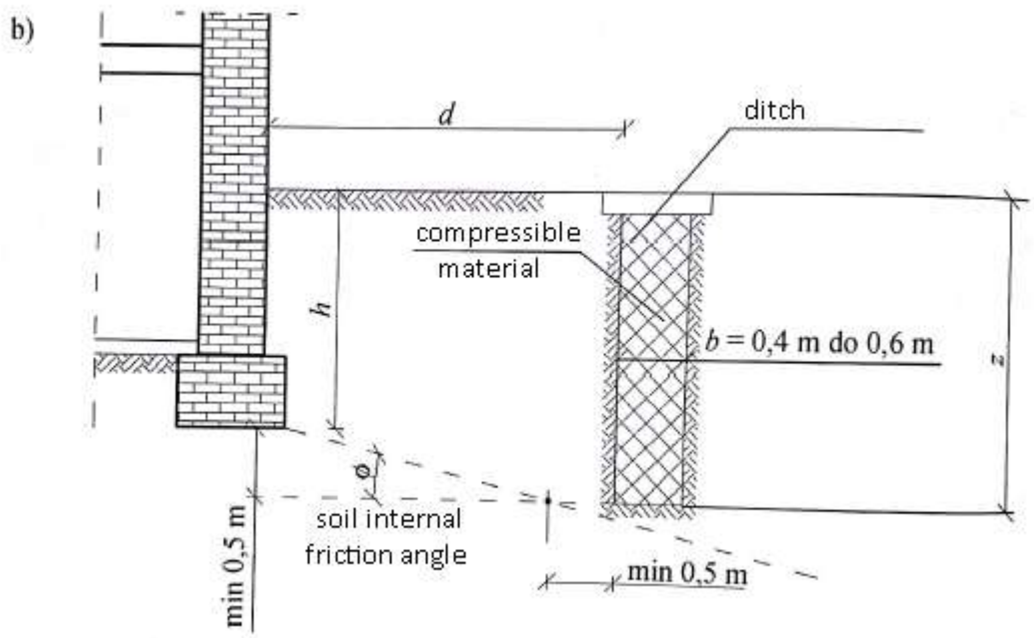



Figure 69 – Location of trenches around the building.

In relation to the depth, an analysis proved that the reduction of subsoil strain acting on the foundation was more effective using a deeper trench.

In calculations using a trench reaching 1 m below the building foundation depth, the value of strain acting on the foundation was reduced by 40%, whereas, for a trench reaching 3 m below the foundation depth, the reduction was more than 70% of the strain value, as compared to the unprotected building [31].

# 7. Limit States

## 7.1 Introduction to Ultimate Limite States (ULS) and Serviceability Limit States (SLS)

According to Eurocode 1, building structures should be calculated taking into account the Ultimate Limite States (ULS) and Serviceability Limit States (SLS):

- ULS, load states that will cause damage to the structure or its parts if exceeded.
- SLS, load states that will result in excessive displacements and deformations of the structure if exceeded, and therefore, will reduce the performance of the building.

ULS of the structure determine its safety while SLS involves the serviceability and proper functioning of the building according to the purpose for which it was designed.

Existing structures, that have not been designed to withstand the impact of mining, experience greater damage than structures designed for it. When ground deformation occurs due to mining subsidence, the allowable values determined for SLS can be exceeded. Although it does not necessarily involve the failure of the structure but generally lead in some damage to building elements which can affect its serviceability conditions and comfort of the inhabitants.

It is very probable that buildings located in mining areas, exceed the allowable values of SLS even if it is designed to withstand mining impacts. The probability of exceed values for ULS, which involve structure failure, is much lower because it is determined with a great margin of load capacity.

Factor determining the values of allowable deformations and damage to buildings:

- Possibility of structure performance according to the purpose for which it was designed,
- Limitation or elimination of impediments in structure service,
- Esthetic and comfort reasons,
- Requirements affecting durability or tightness of structure.

The regulations establish that new structures should be designed to satisfy the requirements specified by ULS and SLS, always, under any circumstances. This fact implies a high degree of protections to ensure that the structure can withstand the deformation of the soil without exceeding the allowable values of ULS and SLS.

On the other hand, the concept of Transient Serviceability Limit States (TSLS) has been developed. This criterion involves a different point of view where buildings are still designed with respect to the USL and SLS allowable values but SLS can be exceeded during ground deformation caused by mining impacts. This means that some damages can occur to the building, producing impediments to its serviceability in a small degree, but these damages will never be a threat to the building safety. Damages will be repaired after ground settlement to meet again the values of SLS.

This concept of limit states is more practical and economical but it can involve some discomforts for the users.

## 7.2 Transient Serviceability Limit States (TSLS)

The concept of TSLS pretends to determine the level of damages and deformations acceptable for the inhabitants of the building.

TSLS include these effects:

- Tilt of building $T_b$ induced by the land slope,
- Width of single cracks $a_w$ in the walls without protection against mining impacts,
- Deflection of the structure walls $\Theta_b$ induced by ground curvature.

| Effects in buildings | | Degree of inconvenience | | | |
|---|---|---|---|---|---|
| | | Imperceptible | Low | Medium | High |
| Tilt | $T_b$ [‰] | ≤ 10 | 10 - 15 | 15 - 20 | 20 - 25 |
| Width of single cracks in walls | $a_w$ [mm] | ≤ 1 | 1 - 3 | 3 - 8 | 8 - 30 |
| Deflection of the walls | $\Theta_b \cdot 10^3$ | ≤ 1 | 1 - 2 | 2 - 3 | 3 - 5 |

Table 10 – Degree of inconvenience for the inhabitants of the building. [27]

For designed buildings, temporally low levels of inconvenience are acceptable for tilt and width of single cracks, not for deflection of the walls. In case of long term deformations, imperceptible levels of inconvenience should not be exceeded.

In case of existing buildings, temporally medium levels of inconvenience are acceptable. For long term deformations, low levels of inconvenience should not be exceeded.

# 8. Impact of area horizontal deformation on building foundations

## 8.1 Foundation framework

Total tensile force in continuous footing:

$$N = Z + Z_b + J + H$$

Where:

Z – Shearing stresses in the base of calculated foundation.

$Z_b$ – Shearing stresses on the foundation side surfaces.

J – Shearing stresses in the base of adjacent footings.

H – Normal stresses (pressure forces) on the side surfaces of adjacent continuous footings.

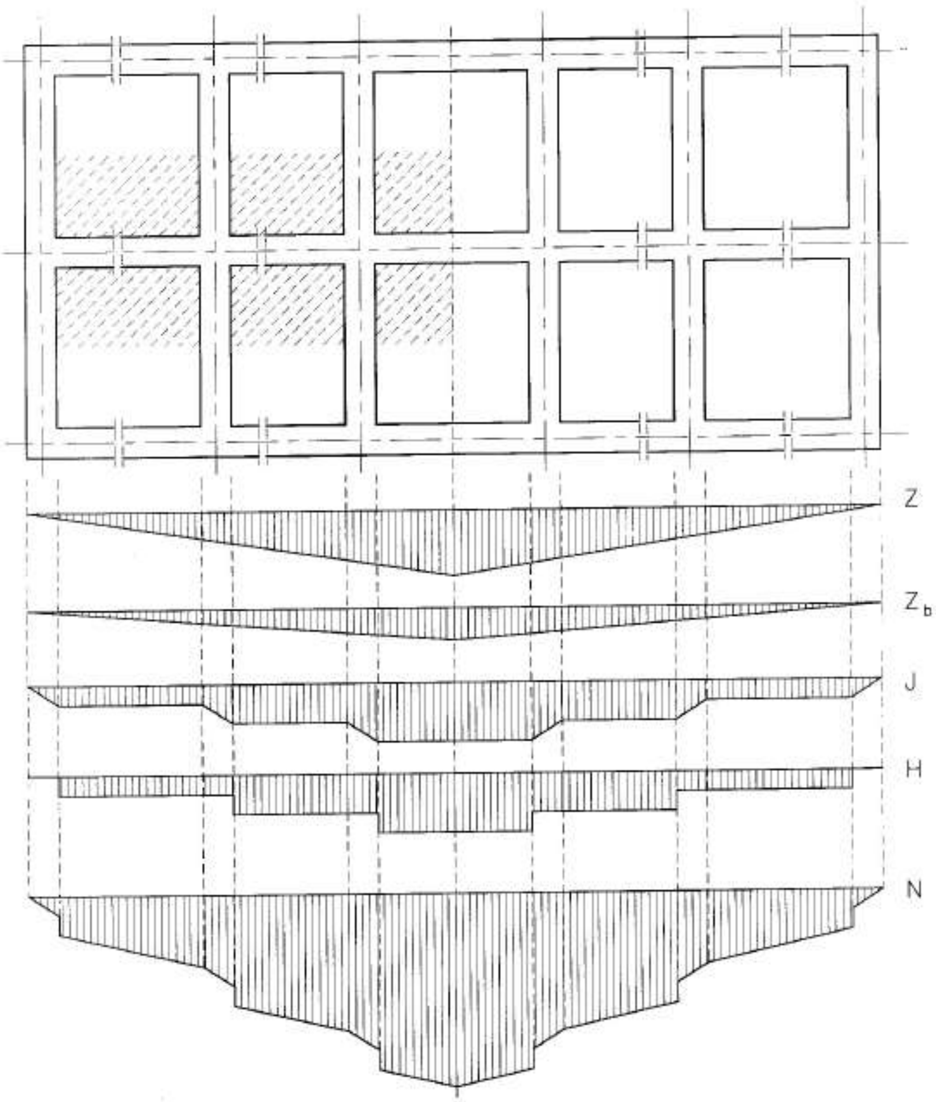



Figure 68 – Example total tensile force acting on continuous footing. [18]

**8.1.1 Shearing stresses in the base of calculated foundation (Z)**

The distribution of stresses under foundation, in the direction parallel to the deformation of the ground, depends on the horizontal deformation "ε" value.

The graphs shown in the figure 69 can be used in buildings (segments) with a length up to 36 meters.

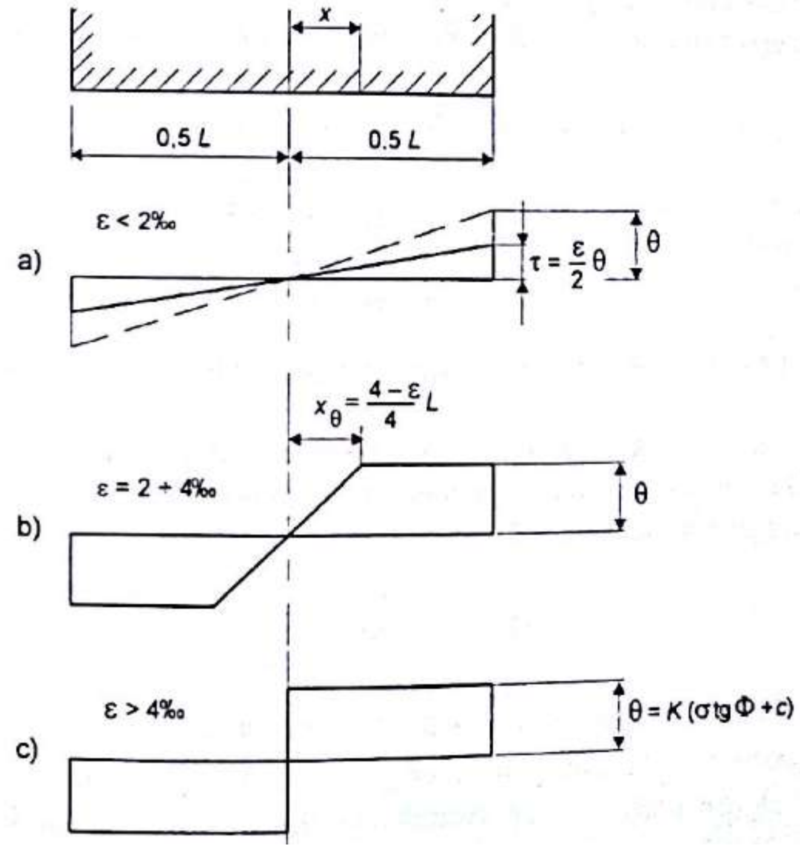



Figure 69 - distribution of stresses under foundation. [24]

Value of stresses under calculated continuous footing:

$$\Theta = K_1(\sigma\,\mathrm{tg}\phi + c)$$

Where:

$\Theta$ – Shearing stresses under calculated continuous footing.

$\sigma$ – Normal stresses under continuous footing.

$\phi$ – Soil internal friction angle.

c – Cohesion of soil.

$K_1$ – coefficient, it can be calculated in two ways:

Method 1 – Graph:

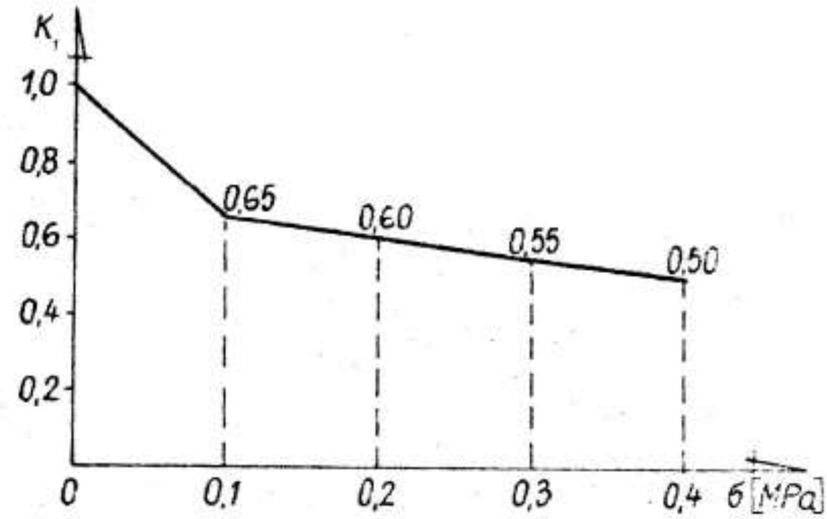


Figure 70 – Coefficient $K_1$ depending on the value of σ. [24]

Method 2 – Formulas:

Value of coefficient $K_1$ can be calculated from the formula:

$$K_1 = -3{,}5\sigma + 1 \text{ ; when } \sigma \leq 0{,}1 \text{ MPa.}$$

$$K_1 = -0{,}5\sigma + 0{,}7 \text{ ; when } \sigma > 0{,}1 \text{ MPa.}$$

Where σ is the normal stress under continuous footings:

$$\sigma = \frac{g_o}{b}$$

$g_o$ – Load of load-bearing walls in continuous footing levels.

b – Employed width of continuous footings, according to:

$$b = \frac{g_o}{q_{fn}}$$

Where:

$g_o$ – Load of load-bearing walls in continuous footing levels.

$q_{fn}$ – Limiting passive soil pressure.

If there is deformable soil (or sand sub-crust), between foundation footing and rocky subsoil, of thickness “t” smaller than:

- for continuous footings and foundation frameworks:

$$t \leq 0{,}5\text{m and } 1{,}5b$$

- for slabs:

$$t \leq 0{,}5\text{m}$$

And then, coefficient K = 1

Value of tensile force Z on continuous footing length:

$$Z_x = b \cdot (0{,}5 \cdot L - x) \cdot \Theta$$

Where:

x – Length of any point.

Maximal value of force Z for case “A”:

$$Z_{max,A} = 0{,}25 \cdot b \cdot L \cdot \tau$$

Maximal value of force Z for case “B”:

$$Z_{max,B} = 0{,}5 \cdot b \cdot \Theta \cdot (L - x_{\Theta})$$

Maximal value of force Z for case “C”:

$$Z_{max,C} = 0{,}5 \cdot b \cdot L \cdot \Theta$$

Where:
b – Continuous footing width.
L – Continuous footing length.
$\Theta$ – Shearing stresses under calculated continuous footing.
$\tau$ – According to graph 1a)
$x_o$ – According to graph 1b)

### 8.1.2 Shearing stresses on side surfaces of calculated continuous footing ($Z_b$)

When continuous footing are made with permanent shuttering and the remaining spaces are backfilled after removal of this shuttering (almost every case), force Zb is equal to 0.

### 8.1.3 Shearing stresses in the base of adjacent continuous footings (J)

$$J = \sum_{i=1}^{n} J_i S_i$$

Where "n" is the number of continuous footings adjacent to the calculated footing, in the section from a particular cross-section to the end of continuous footing.

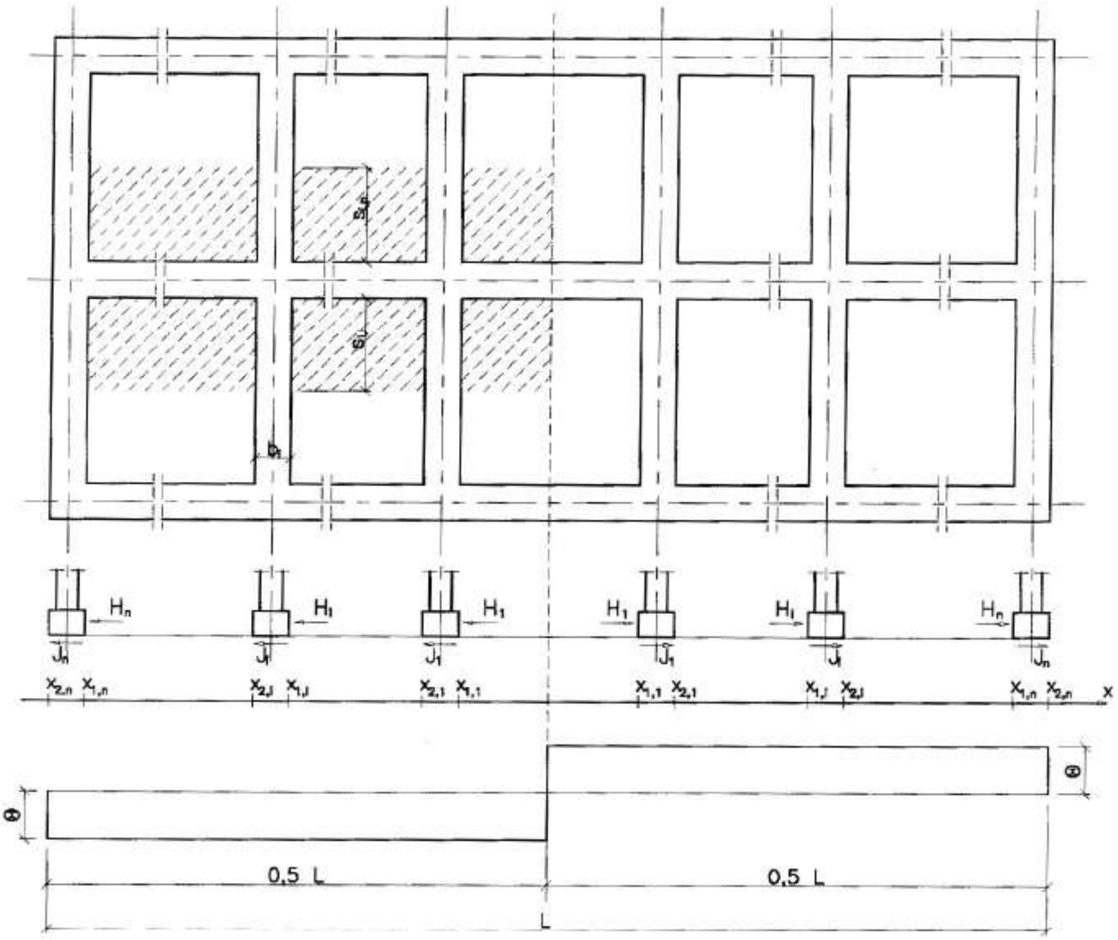



Figure 71 – Particular cross-section of continuous footing. [18]

Value of $J_i$ is calculated from the following formula:

$$J_i = b_i \cdot \Theta_i$$

Where:

$b_i$ – Width of adjacent continuous footing.

$\Theta_i$ – Shearing stresses under adjacent continuous footing.

Adjacent continuous footing shearing stresses are calculated with the use of the formula:

$$\Theta = \mathrm{K}_2(\sigma\ \mathrm{tg}\phi + \mathrm{c})$$

Where:

$\Theta$ – Shearing stresses under calculated continuous footing.

$\sigma$ – Normal stresses under continuous footing.

$\phi$ – Soil internal friction angle.

c – Cohesion of soil.

$K_2$ – coefficient, it can be calculated in two ways:

<u>Method 1 – Graph:</u>

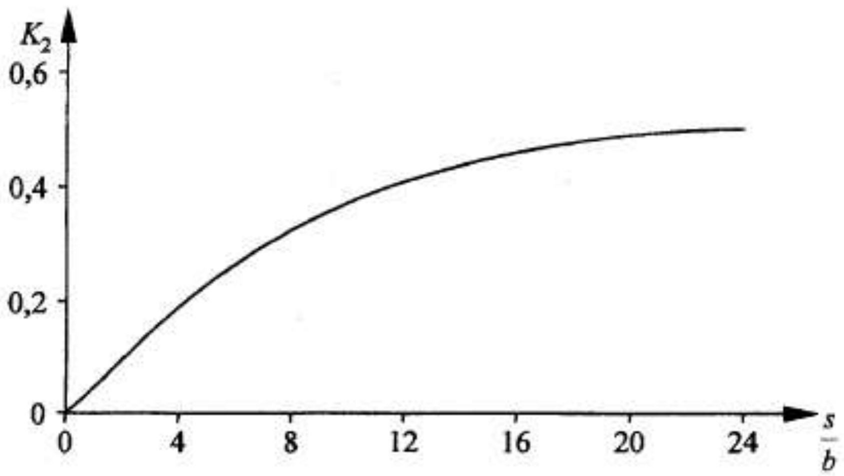



Figure 72 – Coefficient $K_2$ depending on the value of the ratio s/b. [18]

<u>Method 2 – Formula:</u>

$$K_2 = 0{,}9 \cdot \frac{\frac{s}{b}}{17 + \frac{s}{b}}$$

Where:

s – Length of considered continuous footing (between perpendicular continuous footings and parallel to the ground deformation direction).

b – Width of continuous footing.

Value of $s_i$ is calculated from the following formula:

$$s_i = s_{i,l} + s_{i,p}$$

Where $s_{i,l}$ and $s_{i,p}$ are lengths of adjacent continuous footings employed for calculations from the left and right side of calculated continuous footing.

### 8.1.4 Force from pressure on the surface of adjacent continuous footings (H)

$$H = \sum_{i=1}^{n} H_i S_i$$

To obtain the value of $H_i$ is necessary to calculate the value of $H1_i$, $H2_i$ and $H3_i$. The smallest value will be used as $H_i$.

$$H1_i = 0{,}85\sigma_o \cdot (x_{1,i} - x_{2,i-1})$$

Where:

$x_{1,I}$ and $x_{2,i-1}$ – Distance between continuous footings (size of the field between continuous footings)

$\sigma_o$ – Normal stress in fields between continuous footings calculated from the formula:

$$\sigma_o = p + \gamma_1 h_1 + y_2 h$$

Where:

p – Cellars useful load.

$h_1$ – Thickness of cellars floor.

$\gamma_1$ – Bulk density of cellars floor.

h – Continuous footing height.

$\gamma_2$ – Bulk density of soil in field between continuous footings.

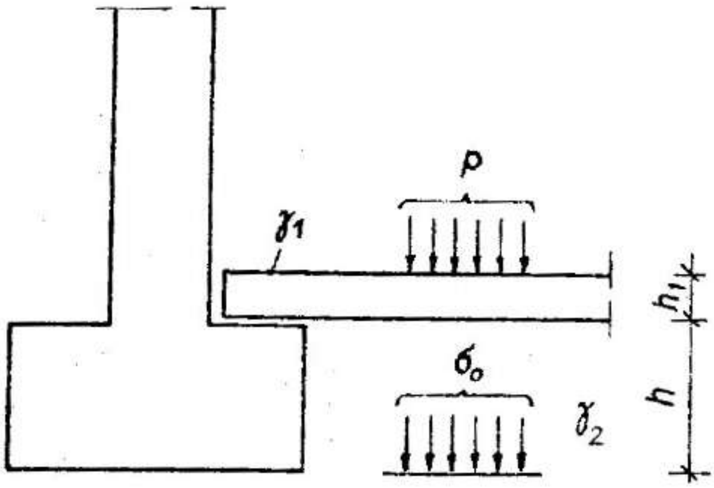



Figure 73 – Normal stress in fields between continuous footings. [18]

If soil in the field between continuous footings was replaced, the value of force $H1_i$ can be decreased to 0,7.

Condition of not exceeding shearing stresses in the soil:

$$H2_i = (\sigma_o\, tg\phi + c)(x_{1,i} - x_{2,i-1})$$

Condition of limiting pressure force on continuous footing side surfaces:

$$H3_i = P_b K_{b,i}$$

Where:

$P_b$ – Passive soil pressure according to the formula:

$$P_b = h\left[\left(p + h_1 \cdot \gamma_1 + \frac{1}{2} \cdot h \cdot \gamma_2\right) \cdot tg^2\left(45^o + \frac{\phi}{2}\right) + 2 \cdot c \cdot tg\left(45^o + \frac{\phi}{2}\right)\right]$$

$K_{b,I}$ – coefficient, coefficient, it can be calculated in two ways:

<u>Method 1 – Graph:</u>

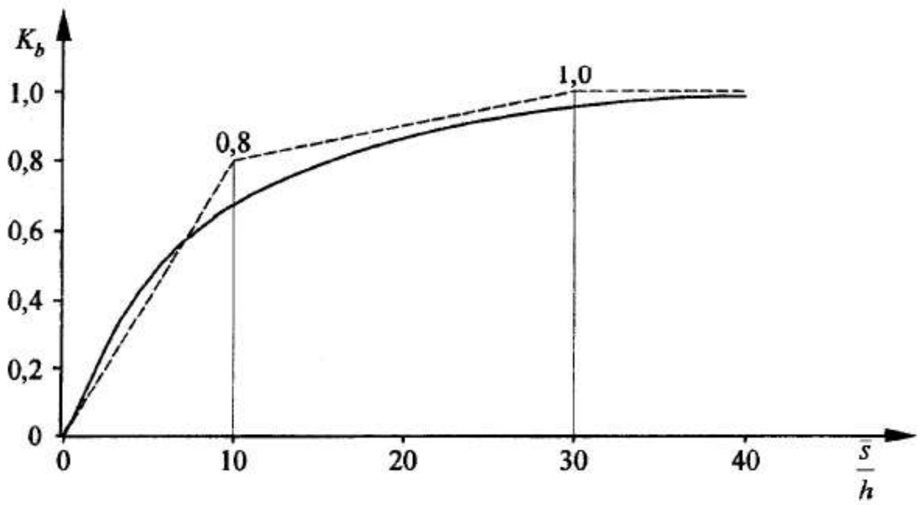



Figure 74 – Coefficient $K_b$ depending on the value of the ratio $x_i/h$ [24]

<u>Method 2 – Formula:</u>

$$K_{b,i} = 1{,}2\frac{\frac{x_{1,i}}{h}}{7{,}7 + \frac{x_{1,i}}{h}}$$

## 8.1.5 Additional comments

If continuous footing loading is asymmetric on the length, axial forces should be calculated on both sides, $N_l$ and $N_p$.

$$N = 0{,}5\ (N_l + N_p)$$

While tension is calculated for particular continuous footing, bending occurs in adjacent ones. Bending moment should be calculated from the formula:

$$M = \frac{J_i + H_i}{16} l_i^2$$

If exploitation direction is unknown, values of tensile forces N and bending moments M are calculated for each continuous footing assuming two perpendicular directions. Oblique direction of exploitation should be employed and values of continuous footing loading are calculated as:

$$N' = 0{,}5 \cdot N$$

$$M' = 0{,}5 \cdot M$$

Reinforcement of each continuous footing should be calculated for three impacts:

– Axial tension with force N.
– Bending with moment M.
– Eccentric tension with coupled pair of forces N´ and M´.

In case of big influences occurring at long continuous footings, elements facilitating work of the construction – tie rods – should be employed.

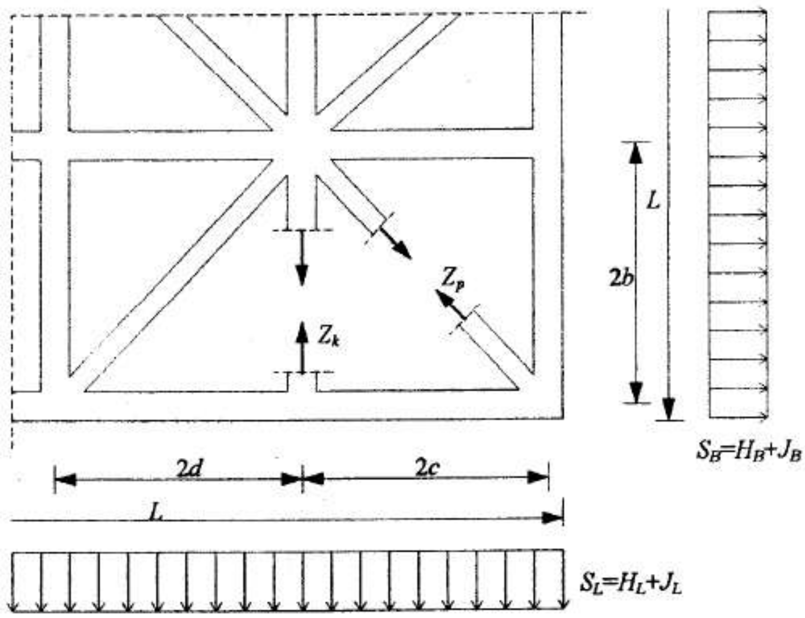



Figure 75 – tie rods in continuous footing. [24]

Value of tensile force in anchor tie rods:

$$Z_k = (c + d) \cdot (H_L + J_L)$$

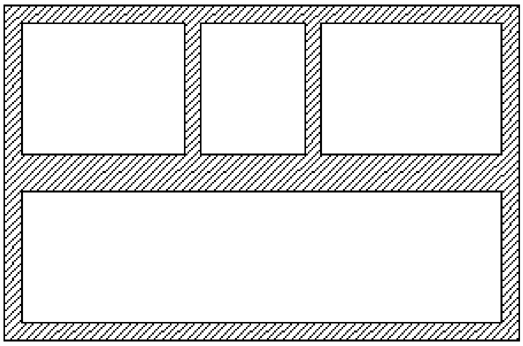
Value of tensile force in diagonal tie rods:

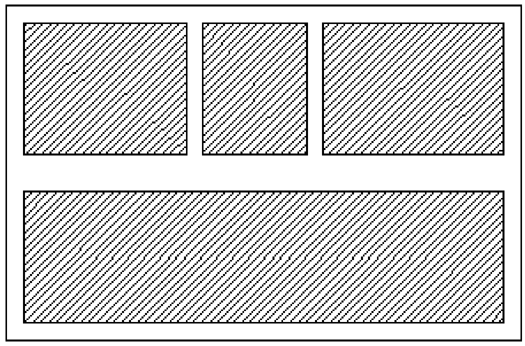
$$Z_p = \sqrt{[(H_L + J_L) \cdot c]^2 + [(H_B + J_B) \cdot b]^2}$$

Tie rods are calculated only for axial force impact, tension.

## 8.2 Reinforced concrete slab (RC membrane).

In the case of reinforced concrete slabs is necessary to difference between two areas, the area of footing strips and the area of the fields between footings.





### Footing strips

Axial forces in the membrane:

$$T = G \cdot f \leq Z$$

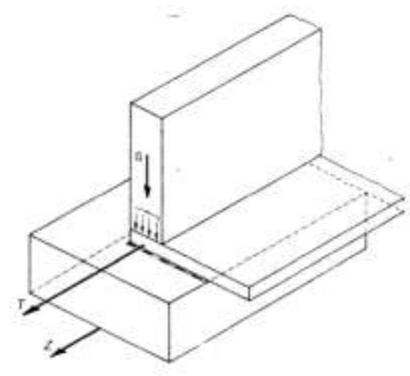
Where:

G – Dead and live load at the level of sliding layer.

f – Friction coefficient of sliding layer.

Z – Horizontal force caused by continuous deformation under the footings (calculated as in the case of framework footing, P. 8.1.1).

### Fields between footings



Axial forces in the membrane:

$$T = G_m \cdot f \leq J + H$$

Where:

Gm – Dead and live loads at the level of sliding layer.

f – Friction coefficient of sliding layer.

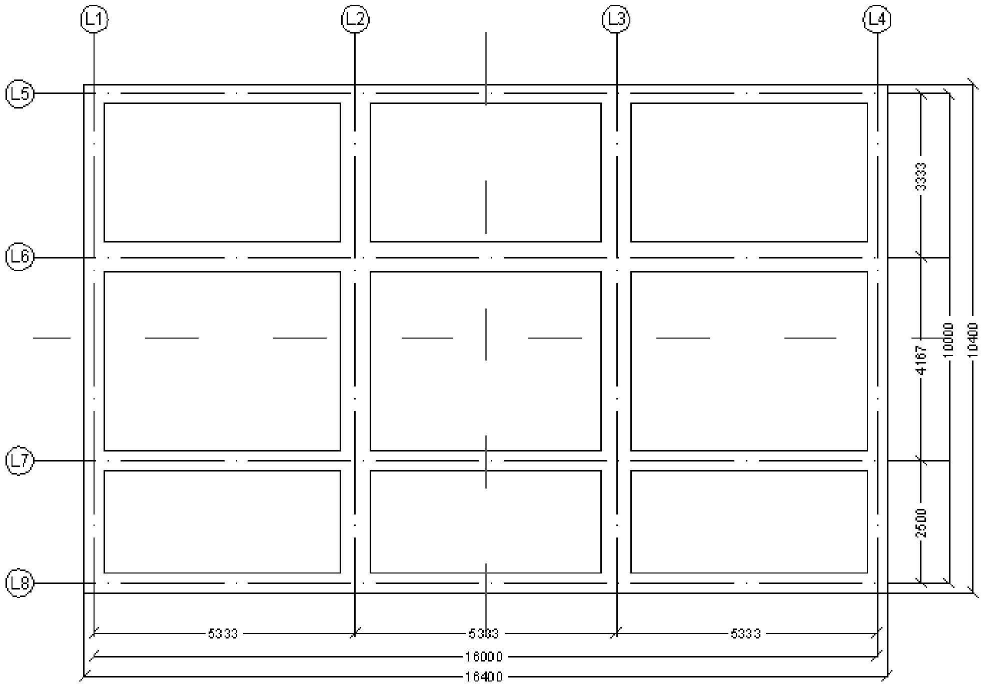
J, H – Forces from shear stresses in the base of adjacent footings and pressure on its side surface (calculated as in the case of framework footing, P. 8.1.3 and 8.1.4).

## 9. Practical case.

Impact of area horizontal deformation and protection design of the foundation framework.

Project data:

Scheme:




| No. | Continuous footings | widht [m] | Length [m] | Height [m] | Normal estress [Mpa] |
|---|---|---|---|---|---|
| 1 | L1 | 0,4 | 10,4 | 0,3 | 0,135 |
| 2 | L2 | 0,6 | 10,4 | 0,3 | 0,15 |
| 3 | L3 | 0,6 | 10,4 | 0,3 | 0,15 |
| 4 | L4 | 0,4 | 10,4 | 0,3 | 0,135 |
| 5 | L5 | 0,4 | 16,4 | 0,3 | 0,135 |
| 6 | L6 | 0,6 | 16,4 | 0,3 | 0,15 |
| 7 | L7 | 0,4 | 16,4 | 0,3 | 0,135 |
| 8 | L8 | 0,4 | 16,4 | 0,3 | 0,135 |

Internal friction angle: $\phi = 28^o$

Cohesion: c = 5kPa

Loading of cellar floor: $p_o = 2{,}1\ kN/m^2$

Floor deadweight: $g_{op} = 6{,}627\ kN/m^2$

Backfilling soil deadweight: $\gamma_g = 17\ kN/m^3$

Mining category III

Concrete 16/20

Steel B450A

Total tensile force in continuous footing:

$$N = Z + Z_b + J + H$$

Where:

Z – Shearing stresses in the base of calculated foundation. [kN]

$Z_b$ – Shearing stresses on the foundation side surfaces. [kN]

J – Shearing stresses in the base of adjacent footings. [kN/m]

H – Normal stresses (pressure forces) on the side surfaces of adjacent continuous footings. [kN/m]

**Shearing stresses in the base of calculated foundation (Z)**

Mining category III → ε = 6‰


| TENSION | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Shearing stresses in the base of calculated foundation (Z)** | | | | | | | |
| **L1** | **L2** | **L3** | **L4** | **L5** | **L6** | **L7** | **L8** |
| Coefficient K1 | | | | σ ≤ 0,1 → K1 = -3,5σ +1<br>σ > 0,1 → K1 = - 0,5σ + 0,7 | | | |
| 0,6325 | 0,625 | 0,625 | 0,6325 | 0,6325 | 0,625 | 0,6325 | 0,6325 |
| Shearing stress Θ | | | | Θ = K1 (σ tgϕ + c) | | | |
| 0,0486 | 0,0530 | 0,0530 | 0,0486 | 0,0486 | 0,0530 | 0,0486 | 0,0486 |
| Forze Z | | | | Case ε > 0,04‰ → Z = 0,5 ·b · L · Θ | | | |
| **101,01** | **165,28** | **165,28** | **101,01** | **159,29** | **260,63** | **159,29** | **159,29** |

**Shearing stresses on side surfaces of calculated continuous footing ($Z_b$)**

Continuous footings are made with permanent shuttering and the remaining spaces will be backfilled after removal of this shuttering. In this case, force Zb can be considered equal to 0.

Zb = 0

## Shearing stresses in the base of adjacent continuous footings (J)

$$J = \sum_{i=1}^{n} J_i S_i$$

$$J_i = b_i \cdot \Theta_i$$

Where:

$b_i$ – Width of adjacent continuous footing.

$\Theta_I$ – Shearing stresses under adjacent continuous footing.

Adjacent continuous footing shearing stresses are calculated with the use of the formula:

$$\Theta = K_2(\sigma \, tg\phi + c)$$

Where:

$\Theta$ – Shearing stresses under calculated continuous footing.

$\sigma$ – Normal stresses under continuous footing.

$\phi$ – Soil internal friction angle.

c – Cohesion of soil.

$K_2$ – coefficient:

$$K_2 = 0{,}9 \cdot \frac{\frac{s}{b}}{17 + \frac{s}{b}}$$

Where:

s – Length of considered continuous footing, between perpendicular continuous footings and parallel to the ground deformation direction. (drawing no. 2)

b – Width of continuous footing.

<table>
<tr><th colspan="7">Shearing stresses under adjacent continuous footings (J)</th></tr>
<tr><th colspan="7">L1 to L4</th></tr>
<tr><td>Continuous footing</td><td>Coefficient K2</td><td>Shearing stress Θ</td><td>Value Ji</td><td>Ji (right)</td><td>Ji (left)</td></tr>
<tr><td>L5</td><td>0,3814</td><td>0,0293</td><td>11,71</td><td rowspan="4">18,14</td><td rowspan="4">19,14</td></tr>
<tr><td>L6</td><td>0,1264</td><td>0,0107</td><td>6,43</td></tr>
<tr><td>L7</td><td>0,2419</td><td>0,0186</td><td>7,43</td></tr>
<tr><td>L8</td><td>0,3814</td><td>0,0293</td><td>11,71</td></tr>
<tr><th colspan="6">L5 to L8</th></tr>
<tr><td>Continuous footing</td><td>Coefficient K2</td><td>Shearing stress Θ</td><td>Value Ji</td><td colspan="2">Ji</td></tr>
<tr><td>L1 = L4</td><td>0,4865</td><td>0,0374</td><td>14,94</td><td colspan="2" rowspan="2">24,43</td></tr>
<tr><td>L2 = L3</td><td>0,1865</td><td>0,0158</td><td>9,49</td></tr>
</table>

**Force from pressure on the surface of adjacent continuous footings (H)**

$$H = \sum_{i=1}^{n} H_i S_i$$

$$H1_i = 0{,}85\sigma_o \cdot (x_{1,i} - x_{2,i-1})$$

Where:

$x_{1,I}$ and $x_{2,i-1}$ – Distance between continuous footings; size of the field between continuous footings. (drawing no. 3)

$\sigma_o$ – Normal stress in fields between continuous footings calculated from the formula:

$$\sigma_o = p_o + g_{op} + \gamma_g \cdot h$$

$$\sigma_o = 2{,}1 + 6{,}627 + 17 \cdot 0{,}3 = 13{,}827\ kPa$$

Where:

$p_o$ – Loading of cellar floor.

$g_{op}$ – Floor deadweight.

$h_1$ – Thickness of cellars floor.

$\gamma_g$ – Backfilling soil deadweight.

h – Continuous footing height.

In the calculation is considered that soil in the field between continuous footings will be replaced and the value of force $H1_i$ can be decreased to 0,7.

Condition of not exceeding shearing stresses in the soil:

$$H2_i = (\sigma_o\ tg\phi + c)(x_{1,i} - x_{2,i-1})$$

Where:

$\sigma_o\ tg\phi + c$ – Shearing stresses

$x_{1,I}$ and $x_{2,i-1}$ – Distance between continuous footings; size of the field between continuous footings. (drawing no. 3)

Condition of limiting pressure force on continuous footing side surfaces:

$$H3_i = P_b K_{b,i}$$

$$p_b = h\left[\left(p_o + g_{op} + \frac{1}{2}h \cdot \gamma_g\right) tg^2\left(45^o + \frac{\phi}{2}\right) + 2 \cdot c \cdot tg\left(45^o + \frac{\phi}{2}\right)\right]$$

$$p_b = 0{,}3\left[\left(2{,}1 + 6{,}627 + \tfrac{1}{2}0{,}3 \cdot 17\right) tg^2\left(45^o + \tfrac{28^o}{2}\right) + 2 \cdot 5 \cdot tg\left(45^o + \tfrac{28^o}{2}\right)\right] = 14{,}363 \text{KN/m}$$

$K_{b,i}$ – coefficient:

$$K_{b,i} = 1{,}2\frac{\frac{x_{1,i}}{h}}{7{,}7 + \frac{x_{1,i}}{h}}$$

Where:

$x_{1,i}$ – Calculated according to drawing no. 4.

h – Height of the continuous footing.

| **Force from pressure on the surface of adjacent continuous footings (H)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Normal stress in fields between continuous footings | | | | | 13,827 | | |
| Normal stress H1 | | | | | $H1_i = 0{,}85\sigma_o \cdot (x_{1,i} - x_{2,i-1})$ | | |
| Normal stress H2 (condition of not exceeding shearing stresses) | | | | | $H2_i = (\sigma_o\ tg\phi + c)(x_{1,i} - x_{2,i-1})$ | | |
| Normal stress H3 (condition of not exceeding limiting soil pressure) | | | | | $H3_i = P_b K_{b,i}$ | | |
| **L1, L2, L3 and L4** | | | | | | | |
| Continuous footing | $X_{1,i}$ - $X_{2,i-1}$ | **H1** | **H2** | $P_b$ | $K_{b,i}$ | **H3** | **Hi** |
| L5 | 2,833 | 23,31 | 20,84 | 14,363 | 0,8101 | **11,64** | Hi (right) |
| L6 | 1,367 | 11,25 | 10,06 | | 0,4461 | **6,41** | **18,04** |
| L7 | 2,3 | 18,92 | 16,92 | | 0,5987 | **8,60** | Hi (left) |
| L8 | 2,1 | 17,28 | 15,45 | | 0,8101 | **11,64** | **20,23** |
| **L5, L6, L7 and L8** | | | | | | | |
| Continuous footing | $X_{1,i}$ - $X_{2,i-1}$ | **H1** | **H2** | $P_b$ | $K_{b,i}$ | **H3** | **Hi** |
| L1 = L4 | 4,833 | 39,76 | 35,56 | 14,363 | 0,9258 | **13,30** | **22,02** |
| L2 = L3 | 2,367 | 19,47 | 17,41 | | 0,6073 | **8,72** | |

Value of $s_i$ is calculated from the following formula:

$$s_i = s_{i,l} + s_{i,p}$$

Where $s_{i,l}$ and $s_{i,p}$ are lengths of adjacent continuous footings employed for calculations from the left and right side of calculated continuous footing. (drawing no. 5)

| Total tensile Force in continuous footing (N) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Asymmetric** | | | | | **N = 0,5 ($N_l$ + $N_p$)** | | |
| Continuous footing | Z | Ji | Hi | Si | N (left) | N (right) | N |
| L1 | 101,01 | left side: | left side: | 2,417 | 196,19 | 188,47 | **192,33** |
| L2 | 165,28 | 19,14 | 20,23 | 4,784 | 353,66 | 338,38 | **346,02** |
| L3 | 165,28 | right side: | right side: | 4,784 | 353,66 | 338,38 | **346,02** |
| L4 | 101,01 | 18,14 | 18,04 | 2,417 | 196,19 | 188,47 | **192,33** |
| **Symmetric** | | | | | **N = Z + (J + H) · si** | | |
| Continuous footing | Z | Ji | Hi | Si | N | | |
| L5 | 159,29 | 24,43 | 22,02 | 1,417 | **225,11** | | |
| L6 | 260,63 | | | 3,25 | **411,58** | | |
| L7 | 159,29 | | | 2,883 | **293,20** | | |
| L8 | 159,29 | | | 1,05 | **208,06** | | |

Bending moment calculated from the following formula:

$$M = \frac{J_i + H_i}{16} l_i^2$$

Oblique direction of exploitation should be employed and values of continuous footing loading are calculated as:

$$N' = 0{,}5 \cdot N$$

$$M' = 0{,}5 \cdot M$$

| BENDING | | | | ECCENTRIC TENSION | | |
|---|---|---|---|---|---|---|
| Continuous footing | Ji | Hi | M | Continuous footing | N´ | M´ |
| L1 | 14,94 | 22,02 | 31,06 | L1 | 96,17 | 15,53 |
| L2 | 9,49 | 22,02 | 26,48 | L2 | 173,01 | 13,24 |
| L3 | 9,49 | 22,02 | 26,48 | L3 | 173,01 | 13,24 |
| L4 | 14,94 | 22,02 | 31,06 | L4 | 96,17 | 15,53 |
| L5 | 11,71 | 11,64 | 32,69 | L5 | 112,55 | 16,34 |
| L6 | 6,43 | 6,41 | 17,97 | L6 | 205,79 | 8,99 |
| L7 | 7,43 | 8,60 | 22,44 | L7 | 146,60 | 11,22 |
| L8 | 11,71 | 11,64 | 32,69 | L8 | 104,03 | 16,34 |

| INTERNAL IMPACTS | | | | |
|---|---|---|---|---|
| Continuous footing | TENSION (N) | BENDING (M) | ECCENTRIC TENSION | |
| | | | N´ | M´ |
| L1 | 192,33 | 31,06 | 96,17 | 15,53 |
| L2 | 346,02 | 26,48 | 173,01 | 13,24 |
| L3 | 346,02 | 26,48 | 173,01 | 13,24 |
| L4 | 192,33 | 31,06 | 96,17 | 15,53 |
| L5 | 225,11 | 32,69 | 112,55 | 16,34 |
| L6 | 411,58 | 17,97 | 205,79 | 8,99 |
| L7 | 293,20 | 22,44 | 146,60 | 11,22 |
| L8 | 208,06 | 32,69 | 104,03 | 16,34 |

Minimal reinforcement for continuous footings tension:

$$A_S^R = \frac{N}{f_{yd}}$$

Where:

N – Tensile force.

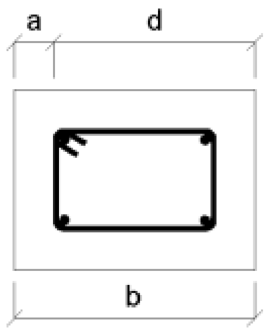
$f_{yd}$ – Design strength of steel.

| REINFORCEMENT FOR CONTINUOUS FOOTINGS TENSION | | | | |
|---|---|---|---|---|
| steel B450A | | fyd 310 | | |
| concrete C16/20 | | fcd 10,6 | | |
| Continuous footing | Minimal reinforcement A [cm$^2$] | Employed number of rods Ø16 | | Employed reinforcement A[cm$^2$] |
| L1 | 6,204 | 3,09 | 4 | 8,042 |
| L2 | 11,162 | 5,55 | 6 | 12,064 |
| L3 | 11,162 | 5,55 | 6 | 12,064 |
| L4 | 6,204 | 3,09 | 4 | 8,042 |
| L5 | 7,261 | 3,61 | 4 | 8,042 |
| L6 | 13,277 | 6,60 | 7 | 14,074 |
| L7 | 9,458 | 4,70 | 5 | 10,053 |
| L8 | 6,712 | 3,34 | 4 | 8,042 |

Minimal reinforcement for continuous footings bending:

$$A_S^M = \frac{M}{f_{yd} \cdot \varsigma \cdot d}$$

Where:




$$\varsigma = 1 - 0{,}5 \cdot \xi$$

$$\xi = 1 - \sqrt{1 - 0{,}5 \cdot S_c}$$

$$S_c = \frac{M}{f_{cd} \cdot h \cdot d^2}$$

| REINFORCEMENT FOR CONTINUOUS FOOTINGS BENDING | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Continuous footing | d | Sc [-] | ξ [–] | ς [–] | Minimal reinforcement A [cm$^2$] | Employed number of rods Ø16 | | Employed reinforcement A [cm$^2$] |
| L1 | 0,335 | 0,087 | 0,0220 | 0,9890 | 3,024 | 1,50 | 2 | 4,021 |
| L2 | 0,535 | 0,029 | 0,0073 | 0,9964 | 1,602 | 0,80 | 1 | 2,011 |
| L3 | 0,535 | 0,029 | 0,0073 | 0,9964 | 1,602 | 0,80 | 1 | 2,011 |
| L4 | 0,335 | 0,087 | 0,0220 | 0,9890 | 3,024 | 1,50 | 2 | 4,021 |
| L5 | 0,335 | 0,092 | 0,0232 | 0,9884 | 3,185 | 1,58 | 2 | 4,021 |
| L6 | 0,535 | 0,020 | 0,0049 | 0,9975 | 1,086 | 0,54 | 1 | 2,011 |
| L7 | 0,335 | 0,063 | 0,0158 | 0,9921 | 2,178 | 1,08 | 2 | 4,021 |
| L8 | 0,335 | 0,092 | 0,0232 | 0,9884 | 3,185 | 1,58 | 2 | 4,021 |

Reinforcement for big and small eccentric tension (symmetric reinforcement):

Static eccentric:

$$e_s = \frac{M'}{N'}$$

Distance from the middle of reinforcement:

$$e_o = \frac{d - a}{2}$$

Big eccentric if $e_s > e_o$

Small eccentric if $e_s < e_o$

Case of small eccentric:

$$A_{s1}^{MR} = \frac{-N'(e_s - e_o)}{f_{yd}(d - a)}$$

| REINFORCEMENT FOR ECCENTRIC TENSION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Continuous footing | Static eccentric "$e_s$" [m] | Distance from the middle to reinforcement $e_o$ [m] | Eccentricity | Minimal reinforcement A [cm2] | Employed number of rods Ø16 | | Employed reinforcement A [$cm^2$] |
| L1 | 0,162 | 0,270 | small eccentric | 1,246 | 0,620 | 1 | 2,011 |
| L2 | 0,077 | 0,470 | small eccentric | 4,672 | 2,324 | 3 | 6,032 |
| L3 | 0,077 | 0,470 | small eccentric | 4,672 | 2,324 | 3 | 6,032 |
| L4 | 0,162 | 0,270 | small eccentric | 1,246 | 0,620 | 1 | 2,011 |
| L5 | 0,145 | 0,270 | small eccentric | 1,678 | 0,835 | 1 | 2,011 |
| L6 | 0,044 | 0,470 | small eccentric | 6,022 | 2,995 | 3 | 6,032 |
| L7 | 0,077 | 0,270 | small eccentric | 3,388 | 1,685 | 2 | 4,021 |
| L8 | 0,157 | 0,270 | small eccentric | 1,403 | 0,698 | 1 | 2,011 |

| LIST OF REINFORCEMENT Ø16 | | | |
|---|---|---|---|
| Continuous footing | Tension | Bending | Eccentric tension |
| L1 | 4 | 2 | 1 |
| L2 | 6 | 1 | 3 |
| L3 | 6 | 1 | 3 |
| L4 | 4 | 2 | 1 |
| L5 | 4 | 2 | 1 |
| L6 | 7 | 1 | 3 |
| L7 | 5 | 2 | 2 |
| L8 | 4 | 2 | 1 |

Length of rods anchorage:

$$l_b = \frac{\phi}{4}\frac{f_{yd}}{f_{bd}} = \frac{0{,}016}{4}\frac{310}{2} = 0{,}62m$$

## References

**[1]** European Association for Coal and Lignite (EURACOAL)

**[2]** U.S. Energy Information Administration

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**[5]** Węglokoks S.A.

**[6]** Polish Geological Institute

**[7]** World Coal Association: "The Coal Resource - A Comprehensive Overview of Coal (2005)"

**[8]** Volkmer (2008): "Coal deposits of Poland, including discussion about the degree of peat consolidation during lignite formation", TU Bergakademie Freiberg, 2008.

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## List of figures

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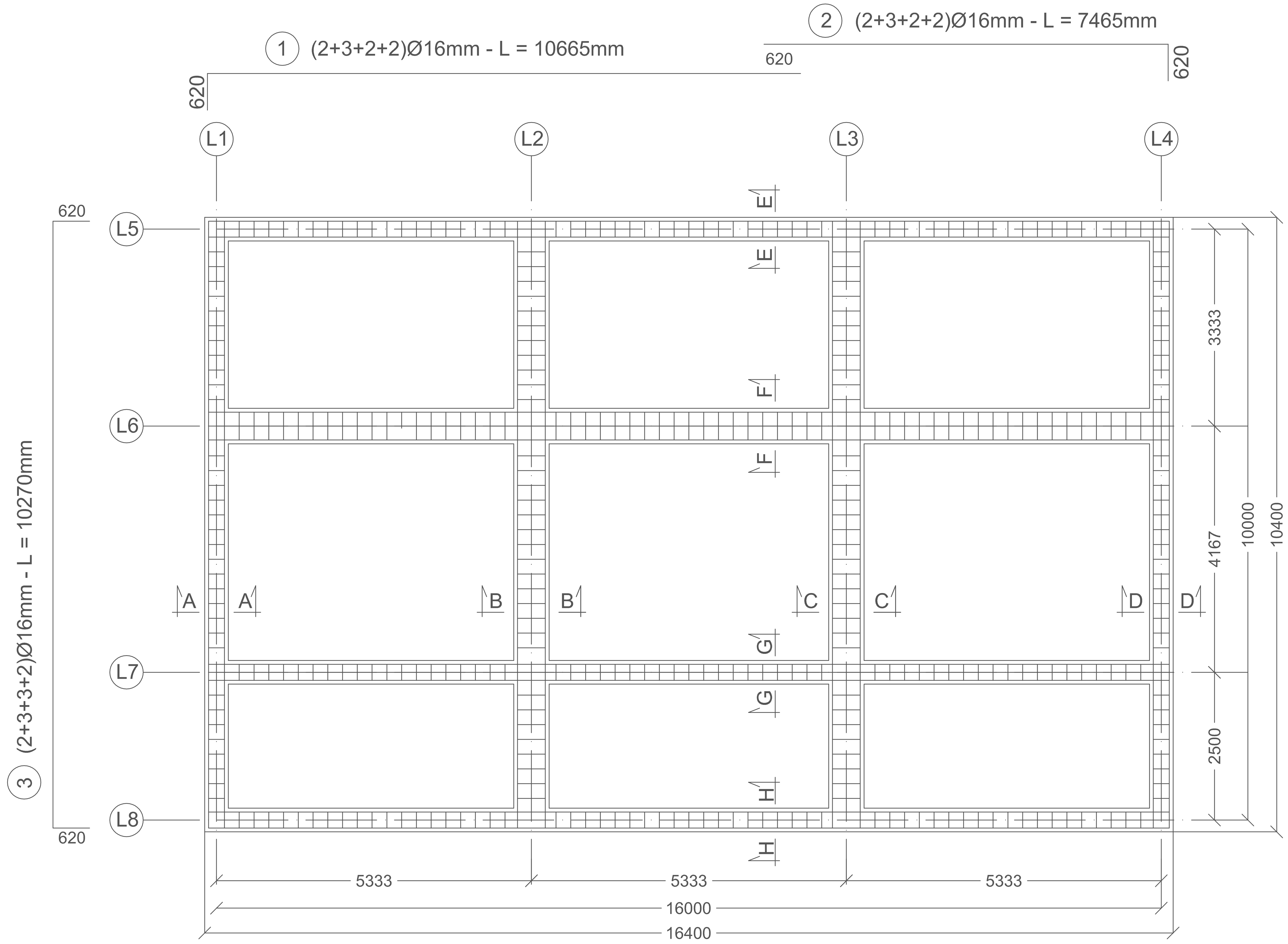


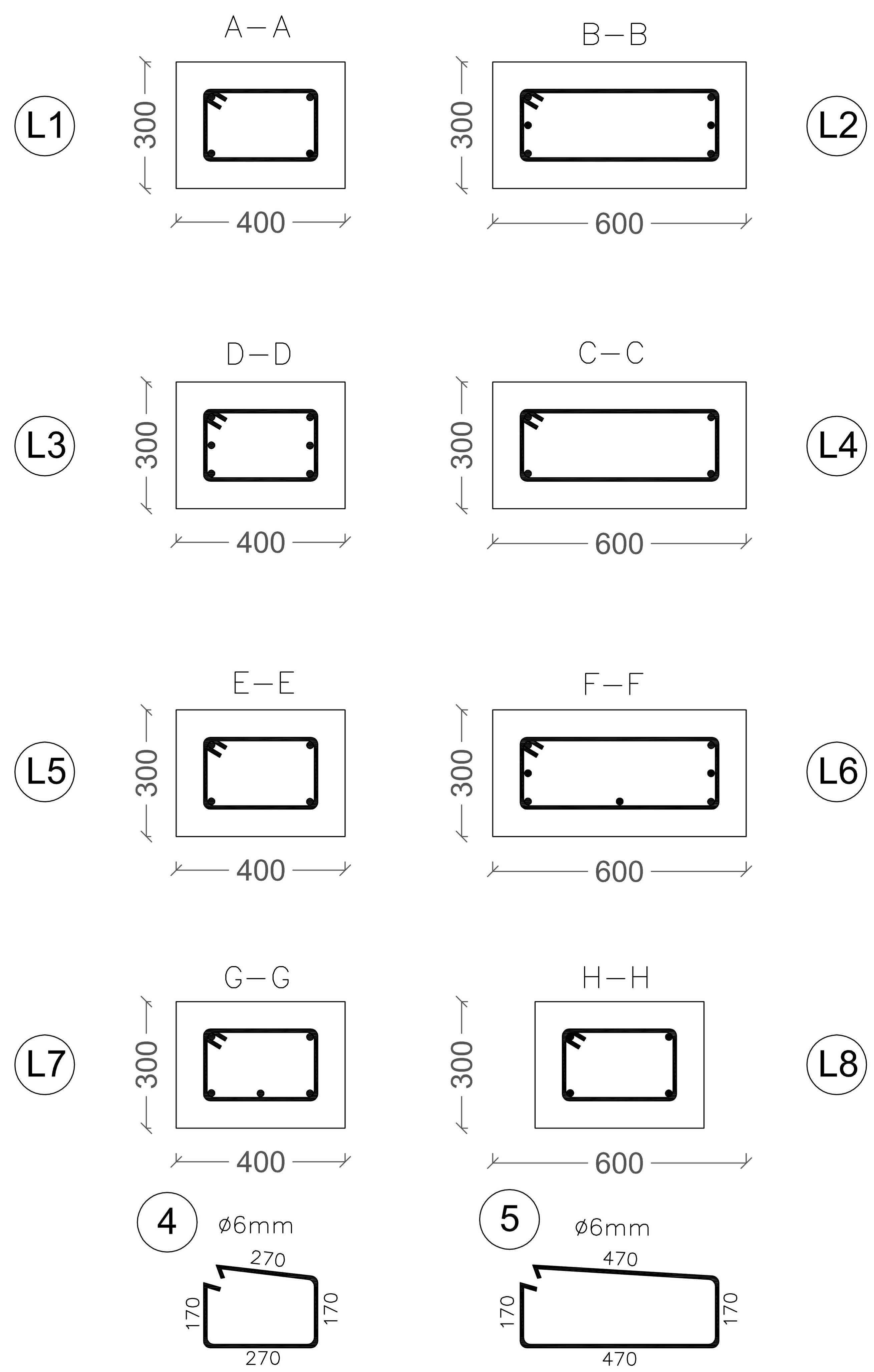


| Steel parameters | | | | | |
|---|---|---|---|---|---|
| No. | Ø [mm] | Lenght [m] | Quantity | Total lenght | |
| | | | | B450A | |
| | | | | Ø6 | Ø16 |
| 1 | 16 | 11,285 | 9 | - | 101,57 |
| 2 | 16 | 8,085 | 9 | - | 72,77 |
| 3 | 16 | 11,51 | 10 | - | 115,10 |
| 4 | 6 | 0,890 | 237 | 210,93 | - |
| 5 | 6 | 1,290 | 123 | 158,67 | - |
| Total lenght [m] | | | | 369,6 | 289,43 |
| Steel weight [kg/m] | | | | 0,222 | 1,58 |
| Total weight [kg] | | | | 82,05 | 457,30 |


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Faculty of Civil Engineering


Final Project – Ground deformation and building protection in mining areas

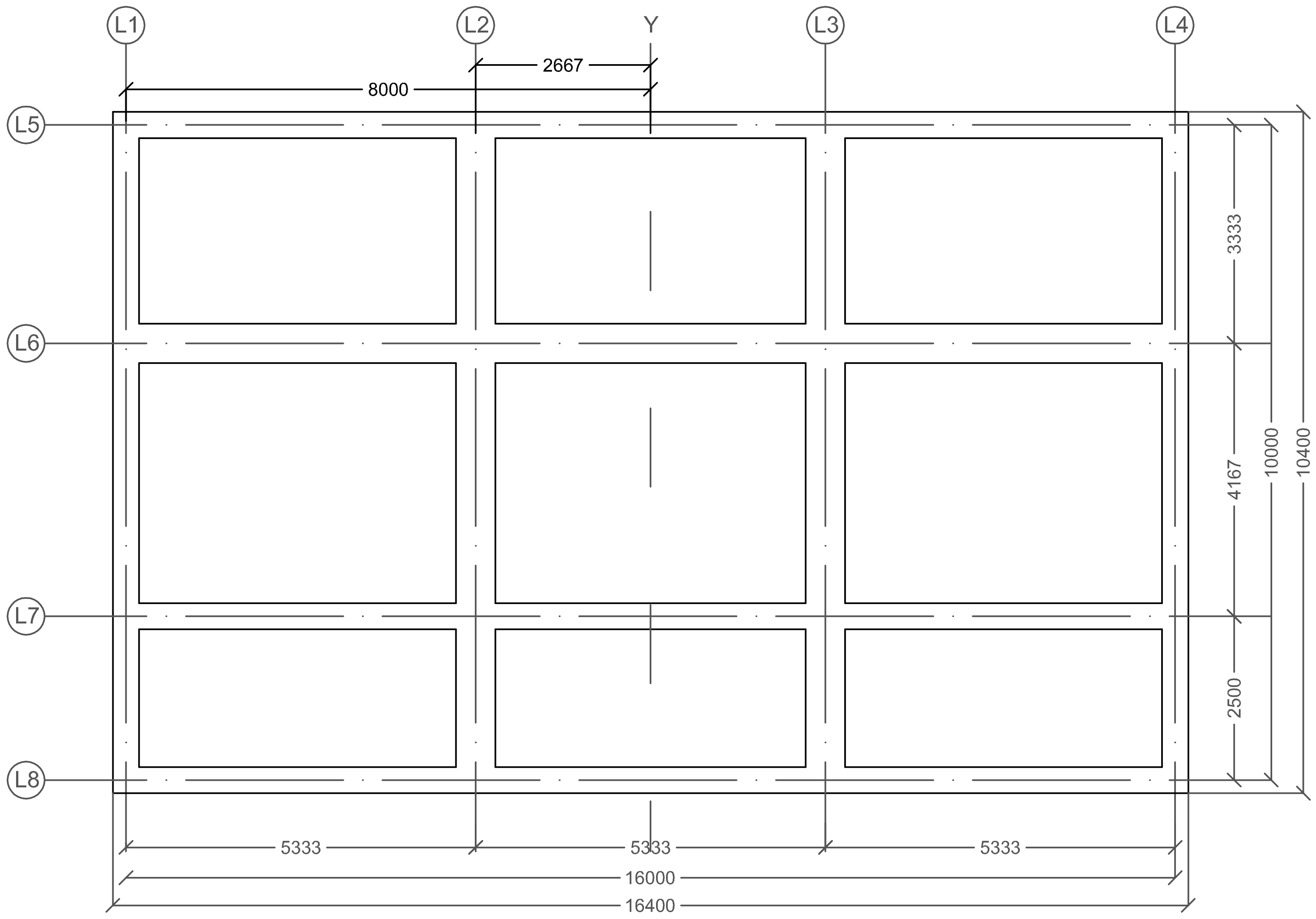
Drawing name:
Reinforcement of foundation framework

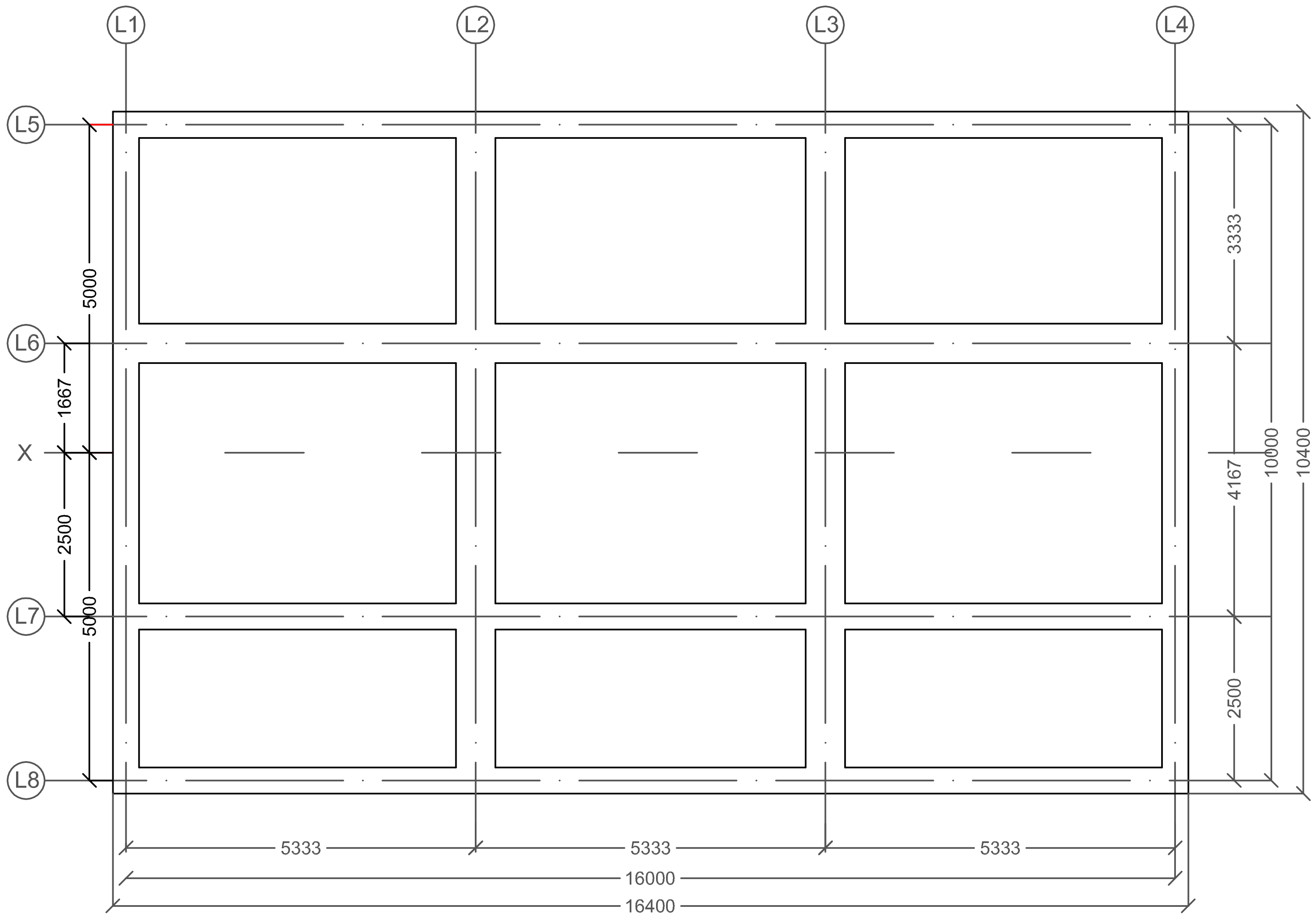

Autor: Borja Royuela Mesa


Scale 1:50 1:10

Drawing no. 1


Tutor: dr inż. Szymon Dawczyński




| Continuous footing | lenght s respect to | |
|---|---|---|
| | axis X | axis Y |
| L1 | - | 8,00 |
| L2 | - | 2,667 |
| L3 | - | 2,667 |
| L4 | - | 8,00 |
| L5 | 5,00 | - |
| L6 | 1,667 | - |
| L7 | 2,50 | - |
| L8 | 5,00 | - |

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Final Project – Ground deformation and building protection in mining areas

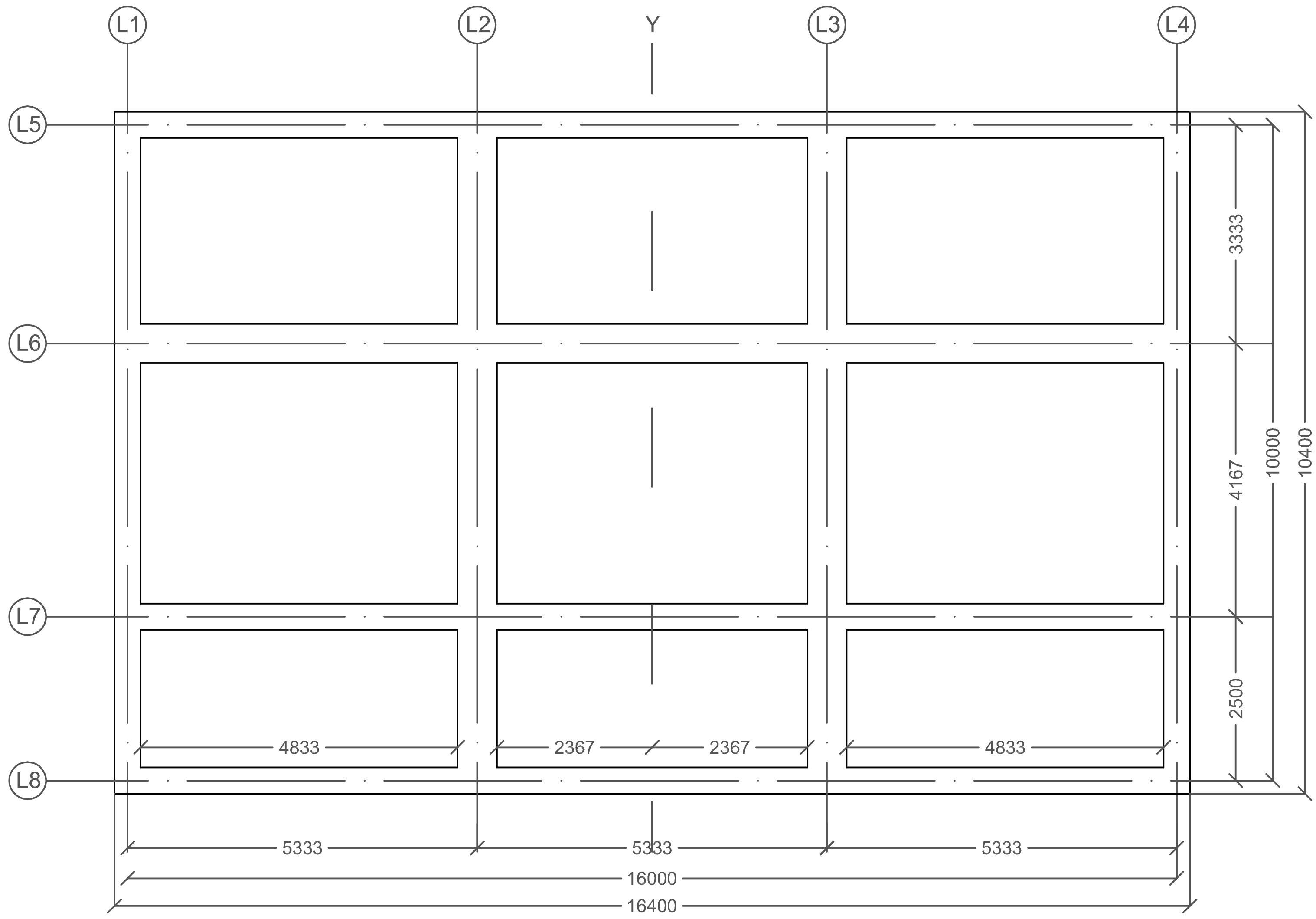
Drawing name:
Shearing stresses under adjacent continuous footings "J" – lenght s for K2

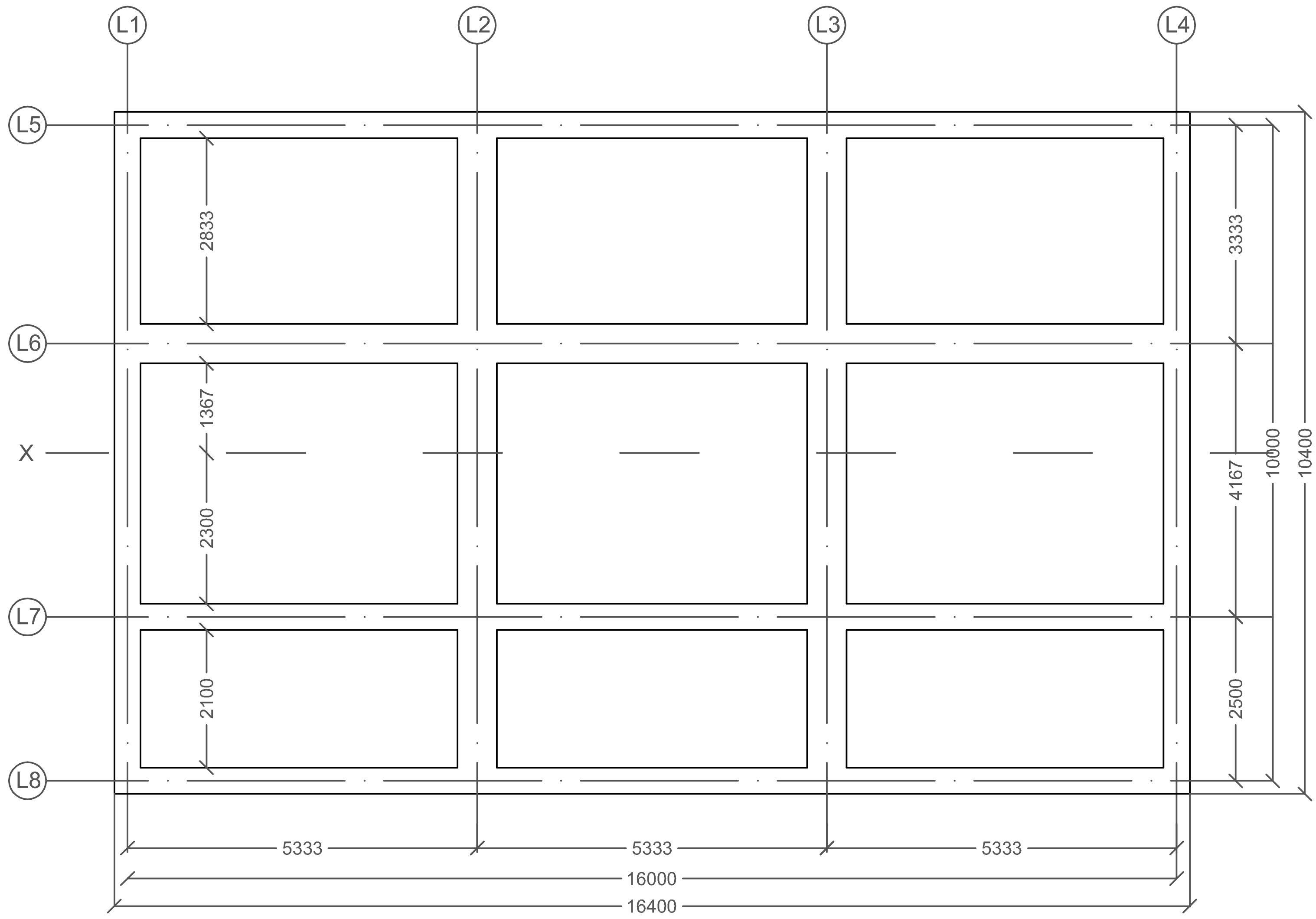
Autor: Borja Royuela Mesa

Scale 1:100

Drawing no. 2

Tutor: dr inż. Szymon Dawczyński




| Continuous footing | distance (x1,i - x2,i-1) | |
|---|---|---|
| | axis X | axis Y |
| L1 | - | 4,833 |
| L2 | - | 2,367 |
| L3 | - | 2,367 |
| L4 | - | 4,833 |
| L5 | 2,833 | - |
| L6 | 1,367 | - |
| L7 | 2,30 | - |
| L8 | 2,10 | - |

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Final Project – Ground deformation and building protection in mining areas

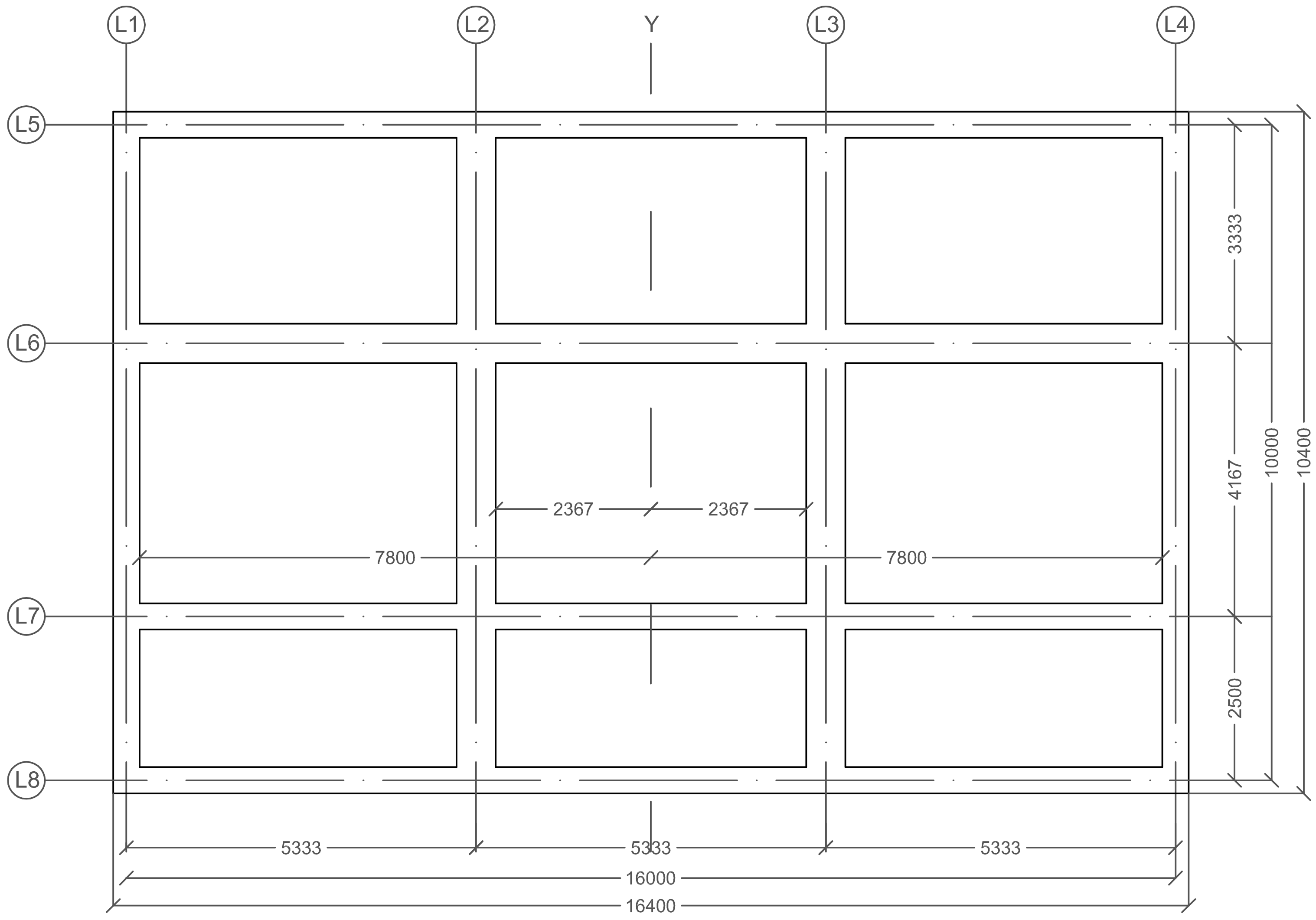
Drawing name:
Force from pressure on the surface of adjacent continuous footings "H" – distance (x1,i – x2,i–1)

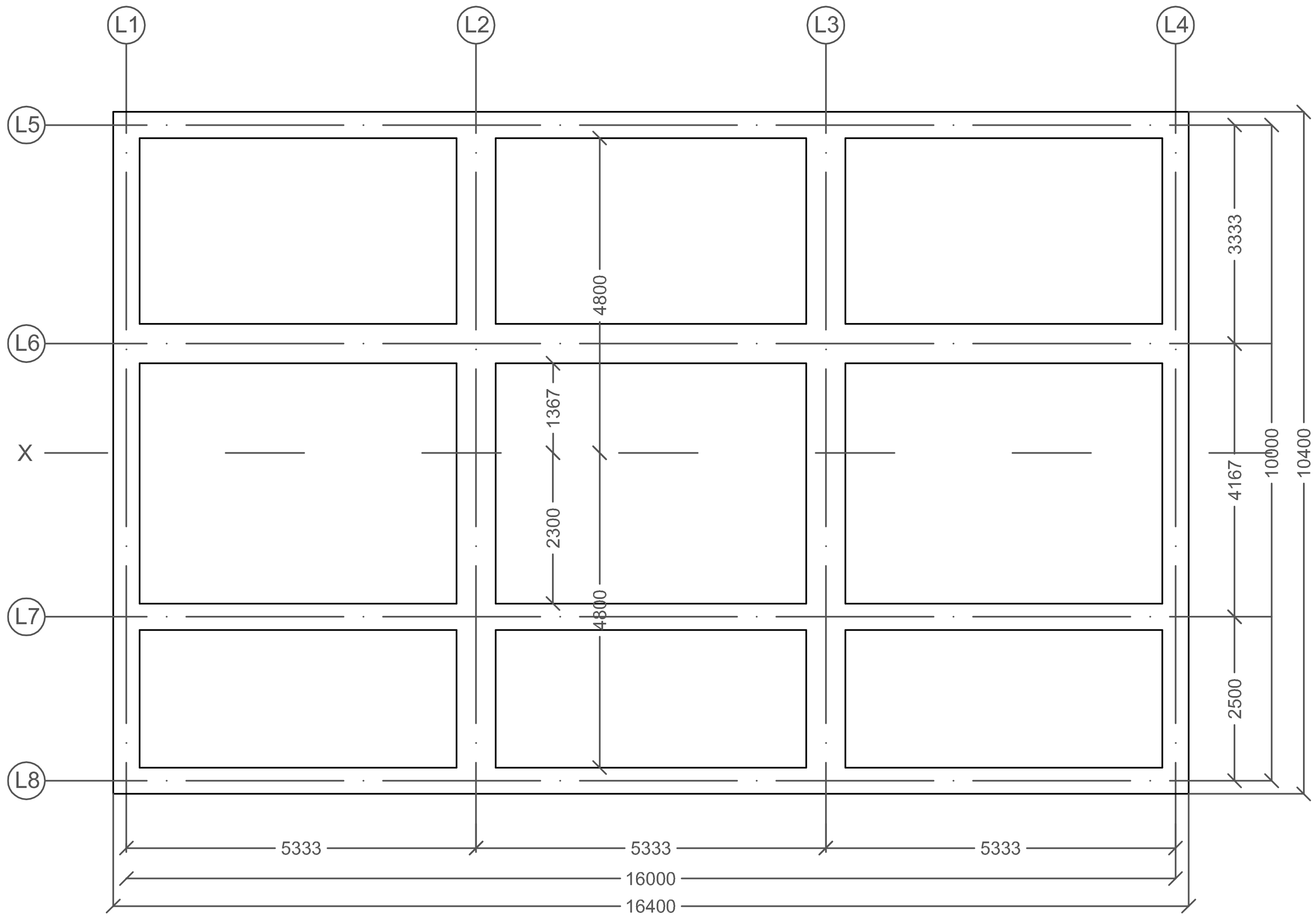
Autor: Borja Royuela Mesa

Scale 1:100

Drawing no. 3

Tutor: dr inż. Szymon Dawczyński




| Continuous footing | distance x1,i | |
|---|---|---|
| | axis X | axis Y |
| L1 | - | 7,80 |
| L2 | - | 2,367 |
| L3 | - | 2,367 |
| L4 | - | 7,80 |
| L5 | 4,80 | - |
| L6 | 1,367 | - |
| L7 | 2,30 | - |
| L8 | 4,80 | - |

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Final Project – Ground deformation and building protection in mining areas

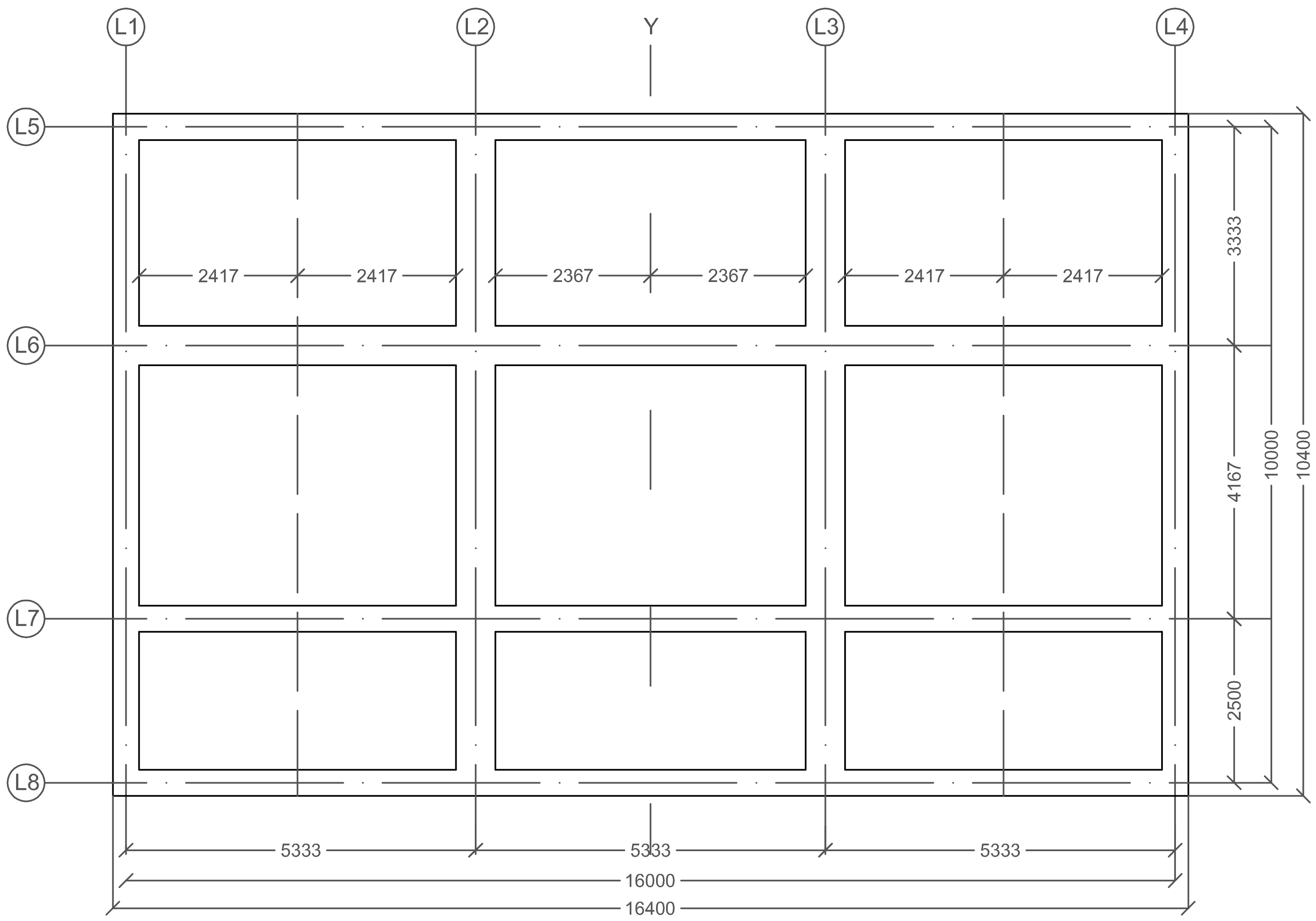
Drawing name:
Force from pressure on the surface of adjacent continuous footings "H" – distance x1,i for Kb,i

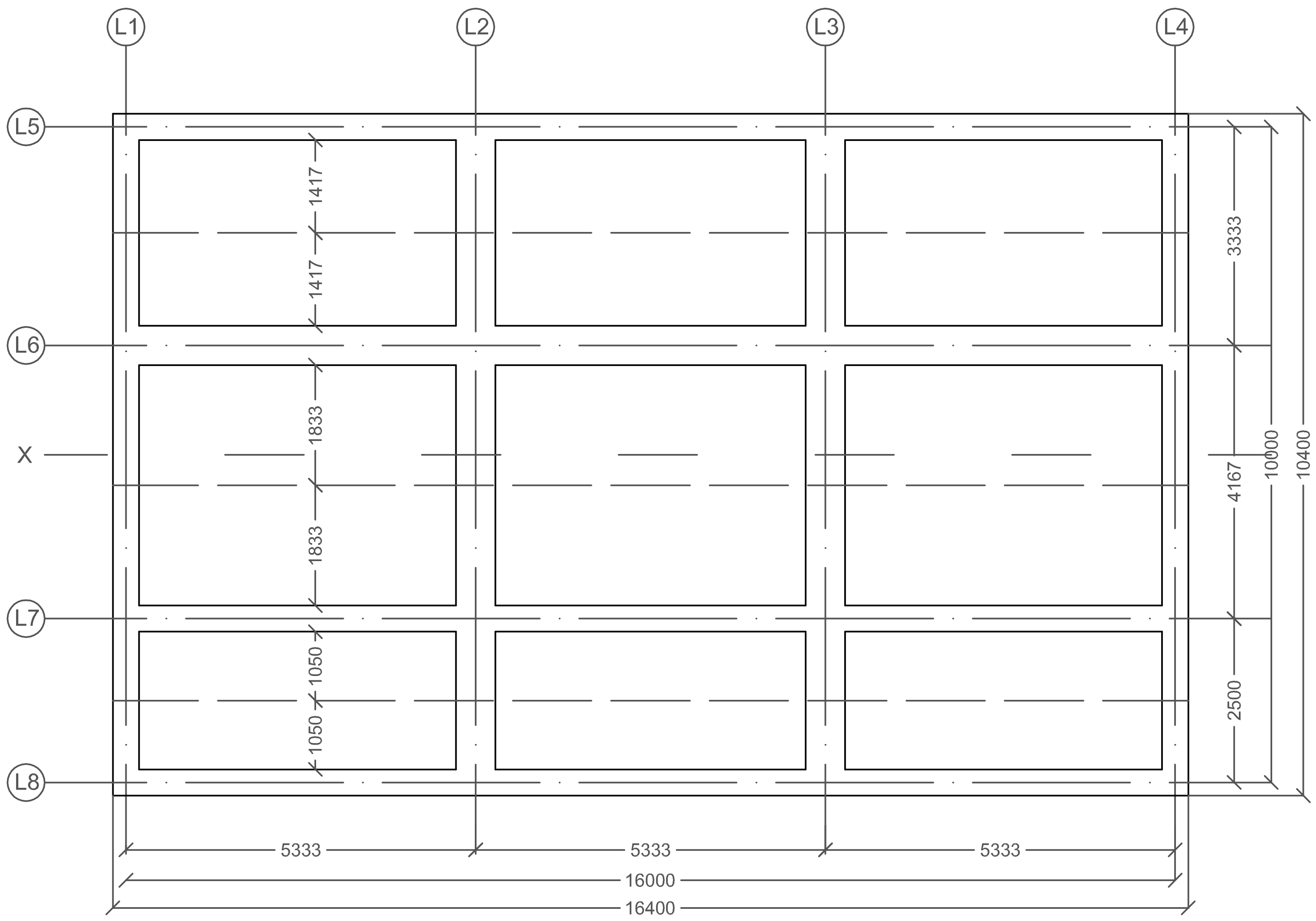
Autor:
Borja Royuela Mesa

Scale 1:100

Drawing no. 4

Tutor:
dr inż. Szymon Dawczyński




| Continuous footing | Si = Si,j + Si,p | | | | | |
|---|---|---|---|---|---|---|
| | axis X | | | axis Y | | |
| | Si,j | Si,p | Si | Si,j | Si,p | Si |
| L1 | - | - | - | 0 | 2,417 | 2,417 |
| L2 | - | - | - | 2,417 | 2,367 | 4,784 |
| L3 | - | - | - | 2,367 | 2,417 | 4,784 |
| L4 | - | - | - | 2,417 | 0 | 2,417 |
| L5 | 1,417 | 0 | 1,417 | - | - | - |
| L6 | 1,833 | 1,417 | 3,250 | - | - | - |
| L7 | 1,050 | 1,833 | 2,883 | - | - | - |
| L8 | 0 | 1,050 | 1,050 | - | - | - |

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Final Project – Ground deformation and building protection in mining areas

Drawing name:
Value Si for "H" and "J"

Autor:
Borja Royuela Mesa

Scale 1:100

Drawing no. 5

Tutor:
dr inż. Szymon Dawczyński