

*Received: March 17, 2015, accepted: April 17, 2015*

## **ASSUMPTIONS FOR THE PROPOSED METHOD OF MONITORING DEFORMATIONS IN WOODEN GRATING CASINGS IN THE CONDITIONS OF WIELICZKA SALT MINE**

Marcin SZPAK\*

KGHM CUPRUM Ltd Research and Development Centre, Generała Władysława Sikorskiego 2-8, 53-659 Wrocław, Poland

---

**Abstract:** This article describes a measuring method used for monitoring deformations in wooden grating mining casings. It is intended, in particular, to determine the degree of deflection of load-bearing elements in relation to their original position. It was prepared especially to supplement the technical evaluation of wooden supporting casings in historic mines, underground sections of tourist routes, tunnels etc. The primary reason for the development of this problem were the designs prepared in recent years for large-scale grating constructions at Wieliczka Salt Mine and those for their reconstructions (strengthenings). The article describes the assumptions for the method proposed as well as the measurement system prepared. At Wieliczka Salt Mine two chambers with grating casings were selected and these were equipped with measuring devices. This paper presents the characteristics of these structures, the distribution of the devices installed and the course of the measuring process.

---

**Keywords:** mining casing, historic excavations, wooden constructions, “Wieliczka” Salt Mine

### 1. INTRODUCTION

Of the many mine workings at Wieliczka Salt Mine, the most interesting, and at the same time the most impressive, are the large chamber excavations. The high chambers were created largely as a result of the mining of salt in large lumps or seams of great thickness. Lumps are usually built of durable green salt, known as lump salt. The mining of lumps consisted in the extraction of salt in tiers from the interiors. To

---

\* Corresponding author: Marcin Szpak, mszpak@cuprum.wroc.pl

protect the excavation a coat of varying thickness was left above. In order to ensure the stability of large-scale chambers located on the upper levels of the mine an appropriate protection was used, usually in the form of wooden supporting casings of various types. The wooden casing took the form of cribs of differing sizes, organ type structures in side walls protecting spoil rock and large gratings. It should be remembered that supporting wooden casings were flexible structures, which, visually and more seldom acoustically, revealed signs of their increased interaction with a rock formation. Observations of this kind are important and were formerly a major signal for the miners as to ongoing changes in the environment of the excavations and potential threats. As a result of long-term observations of rock formations and mining casings it becomes possible to determine both probable reasons for the slow destruction of excavations and rock mass deformation types, as well as to make predictions about the threat of collapse and monitor the technical conditions of these excavations, including the casings applied (Szpak, 2013, 2014).

In the present day also, owing to historical conditions and those relating to preservation at Wieliczka Salt Mine, the wooden casing is of great significance in the design of protections for excavations planned for tourist traffic and in the restoration of types of protection used historically. This is particularly significant when designing complex grating structures or monitoring the state of existing, historical gratings. Gratings at Wieliczka Salt Mine are examples of craftsmanship in mining carpentry, and owing to their function and historic qualities (some structures having been built at the end of the 19<sup>th</sup> century) are a subject of special interest (Fig. 1). It is worth mentioning that in 1978 Wieliczka mine was registered by UNESCO on the first UNESCO list of world cultural heritage.

In 2013 a wider analysis was performed of the technical condition of these casings. In the first phase the focus was placed on the typology and characteristics of wooden mining casings used in historic sidewalk and chamber mining excavations at Wieliczka Salt Mine. In the second phase this was placed on the identification of essential geological and engineering aspects in the design and evaluation of the technical condition of wooden grating casings. Analyzing the methods of observation and measurement currently used at Wieliczka Salt Mine and the needs arising from the inspections conducted of such structures (including during the reconstruction of a grating in Michałowice chamber, or the construction of a new grating in Gołuchowski chamber), it was assumed advisable to prepare a measurement method for periodic control and monitoring of the geometry of major structural elements of this casing.



Fig. 1. Grating casing in Michałowice chamber

A periodic monitoring of measurable parameters is a justified method for indication of the status of an interaction between a wooden casing and a rock formation in the course of its use, particularly in the context of:

- planned mining works in the environment of given chambers;
- the taking of preventive measures (a strengthening of construction);
- the acquisition of data for further design work.

It is also worth mentioning that in some cases it is possible to identify the destructive influence of a rock formation on an older casing which at one time functioned in a given chamber. Possession of such archival data on the course of changes in the geometry of a given construction can significantly improve the decision-making process when proposing additional methods for its strengthening and the design of new solutions in the field.

It is clear that the preparation of such a proposal will be initiated by the adoption of appropriate assumptions resulting from an analysis of engineering and environmental conditions.

## 2. ANALYSIS OF ENGINEERING AND ENVIRONMENTAL CONDITIONS

Each measurement method must be adapted to the environment in which it will be applied. In the context of the underground mining excavations and conditions at Wieliczka Salt Mine the following elements should be distinguished:

- requirements concerning the safety of its use (e.g. in the aspects of power supply to the system and installation of devices);
- a low level of interference in the interior and exterior of the chamber;
- resistance to difficult mining conditions, including saline moisture;
- easy readout of results;
- consideration of the impact of temperature differences (to a limited extent);
- a low purchase cost for the measurement system subassemblies.

In the context of the engineering aspects the following are of the greatest importance:

- the possibility of obtaining measurement results from sites of low accessibility, taking into account the large size of the structure;
- a high accuracy in measurement owing to the slow dynamics of the parameter changes being measured;
- the installation of devices with CE certification from the manufacturer.

According to a modern approach related to SHM (Structural Health Monitoring – monitoring of the technical condition of the structure by use of an appropriate control and measurement system), damage is defined as a change in the material and geometric properties of the object, which may, at present or in the future, interfere with the proper operation of the system. These changes should be detected at the earliest possible stage of their development (Inman et al., 2005). Among the methods used in the diagnosis of casings for mine workings the following can be distinguished:

- A. methods for geometry tests – definition of the spatial distribution of the construction and its changes over time;
- B. methods for surface tests – identification of phenomena occurring on the surface of constructional material;
- C. methods for volume tests – losses and defects identified on complete elements of the casing;
- D. methods for material tests – changes in the physico-mechanical properties of constructional material.

A summary of the physical quantities most frequently measured in the diagnosis of the casings of mine workings is given below (based on the elaboration of S. Duży, 2013):

- Measurements of displacements and deformations:
  - linear displacements
  - angular displacements
  - shape deformations (squeezing)

- Measurements of material quality:
  - strength properties
  - deformation properties
- Measurements of casing operating conditions:
  - environmental parameters (temperature, humidity)
  - aggressiveness of the environment
  - composition of air and dusting
- Measurements of forces and reactions:
  - acceleration of vibrations
  - velocity of vibrations
  - supporting forces and reactions
  - load capacity (limit tension)
  - payloads

As regards the assessment of the technical condition of a wooden grating casing, the current principal activities are based on visual observations conducted quarterly by experienced staff. Additional information brings widely popular in Wieliczka mine conditions convergence measurements.

By analyzing the symptoms which should be assessed (Szpak, 2014), the proposed method focuses on changes in the geometry of a construction, mainly in relation to load-bearing pillars and supporting struts/braces (angular displacement). The grating, as a complex spatial structure, often also spread on sidewalls, can be subject to a complicated arrangement of horizontal and vertical loads from the surrounding rock formation. For this reason some bonds may have a tendency to so-called "running away" towards the plane of ease, while braces may be subject to deflections and pillars subject to deflections and / or vertical deviations or buckling. Most often, in the conditions of Wieliczka Salt Mine, observations of this kind take place very slowly and apply only to certain areas of construction, and selected elements of it (Szpak, 2014). For this reason the measurement method is based on testing of spatial deflection of the main structural elements of a grating in relation to their original position. The physical value measured is the angular deflection in a triaxial system, using microelectromechanical sensors – MEMS accelerometers. Small devices are installed on the constructional elements of the grating casing; their coordinate system is equally oriented and they transmit data on current position. Periodic readout of the results from the network of sensors installed on a grating casing allows for the monitoring of possible geometrical changes to it, including information about the size and dynamics of this phenomenon. Accelerometric sensors are universally applied in the construction and aviation industry and the current production technology allows for their miniaturization at a relatively low purchase cost. Devices provided by two producers were incorporated into a single, integrated measurement system.

### 3. GENERAL CHARACTERISTICS OF THE MEASUREMENT SYSTEM

It was found that for the purposes of assessing the effectiveness of the proposed solution in mining conditions two types of measuring device will be applied:

- *inspection sensors*, for which the measurement consists in reading the position directly from a device placed at an appropriately marked site on the construction;
- *permanent sensors*, which are mounted permanently in sites of low accessibility and are connected by transmission wires to enable readout of the results.

The prepared measurement system therefore consists of permanent and inspection sensors (recorders), cables with strengthened endings, the power unit and a laptop with an appropriate application. For the analysis of measurement results obtained an MS Excel spreadsheet was prepared. Supplementing the results obtained from the recorders installed are measurements of humidity and temperature in the workings being analyzed, performed using a digital thermohygrometer.

The whole measurement system installed on the grating is a passive system, i.e. it is not powered until the results are collected at inspection. It is powered then with a low-voltage current from the power module to the recorders. Subassemblies of the measurement system are shown in Fig. 2.

The two types of MEMS recorder applied come from different manufacturers and differ in functional properties. Below are the most important technical parameters of these recorders:

- measuring range of up to  $\pm 30$  or up to  $\pm 80^\circ$ ;
- accuracy of measurement of  $0.05$  or  $0.1^\circ$ ;
- accuracy of indications of  $0.01^\circ$ ;
- temperature range of from  $-10$  to  $45^\circ\text{C}$ .



Fig. 2. Subassemblies of the measurement system: recorders with wires (permanent and inspection type) power module and laptop

It was assumed that the first stage of monitoring would be completed after 24 months. The measurement basis will be ca. 20 measuring points on each grating (the parameter related to the structural complexity of the casing). Frequency of readouts (inspection readout) was determined on the basis of previous experiences related to regular underground observations in the conditions of Wieliczka Salt Mine and amounts to once per quarter.

The whole measurement system is prepared for the needs of a basic functionality and allows for the application of a series of facilitations in the course of further development work on the proposed method, including remote readouts of results from all recorders, rapid identification of recorders with changes measured and recording of results with a programmable frequency.

At the present stage the main goal is the verification of the durability of the system in underground mining conditions and the analysis of the first measurement results. Two large post-exploitation chambers have been selected for the conduct of the experimental monitoring of grating geometry.

#### 4. SELECTION OF THE OBJECTS MEASURED AT WIELICZKA SALT MINE

In order to conduct the underground tests using the method of measurement proposed, the analysis covered the geological and mining conditions in the environment of chambers equipped with large-scale, wooden grating casings. In selecting the objects measured the following was taken into account:

- period of casing functioning;
- type of construction and its complexity;
- availability of chambers and their current technical condition;
- plan for protective works in neighbouring chambers;
- size of convergence;
- depth of location / position;
- construction history (damage, weak points, strengthenings and reconstructions).

It was reasonable to select two objects (gratings) with clear structural diversity. Chamber excavations being subject to underground tests have been selected in consultation with mining supervision engineers from Wieliczka Salt Mine.

The first object selected is a newly constructed wooden grating casing in Gołuchowski chamber. In the case of this chamber, following an extensive collapse of the ceiling, the grating was reconstructed, with reference to the historical protection existing in the chamber in the 19<sup>th</sup> century. The grating consists of a three-storey wooden structure of a height of 14 to 16 m, depending on the frame. It has 12 full frames and one incomplete frame (Szczap, 2003). With the exception of the stable nodes, the frames were stiffened with braces. The whole construction is equipped with galleries

for pedestrians. On their length the frames are connected to each other via longitudinals. The main load-bearing elements are the beams of stands founded on concrete footings. The beam structure is vertical. Beyond the beams of stands, load-bearing elements are provided by braces of storeys I and II and the lower cross beams in the main part of the grating. Other elements of the grating have a stabilizing function and in their ideal form do not transfer stresses. The casing is formed of  $250 \times 250$  mm squares, of pine or spruce wood. In order to ensure the buckling strength, beams (elements assembled from squares) are fastened together using steel clamps screwed every 2 m on opposite corners. The ceiling in the chamber was strengthened with an anchor casing.

The second grating casing selected is in the chamber Drozdowice III (lower). It is an older construction, executed in the early 1900s, which has been strengthened and locally rebuilt through to the present day. In the higher part of Drozdowice III, over the left ceiling shelf, the chamber Drozdowice III upper was equipped with a wooden grating casing. The grating in Drozdowice III lower is a three-storey wooden construction with a height of 15 m. It consists of 10 four-collar beam load-bearing posts, equipped with two levels of inspection galleries. The grating has three full frames, which have been strengthened with braces and connected with the use of longitudinals, and the entire structure is fully spread on sidewalls of the chamber. The casing is formed of  $300 \times 300$  mm squares, of pine. In order to ensure the buckling strength, the beams are fastened together with clamps every 2 m. The ceiling and sidewalls in the chamber are protected with an anchor casing.

In conclusion, the gratings selected in the two chambers differ in construction (side spread), period of exploitation / functioning and history of protective measures applied in the chamber. In both cases the focus was placed on the measurement of load-bearing pillars and measuring of frames on storeys I and II. A part of the measuring points is located at sites inaccessible in the conduct of regular preventive measures – measuring recorders at these sites were fitted using climbing techniques (Fig. 3, 4). Measurements began in January 2014.



Fig. 3. Readout of the results from one of the recorders in the chamber Drozdowice III



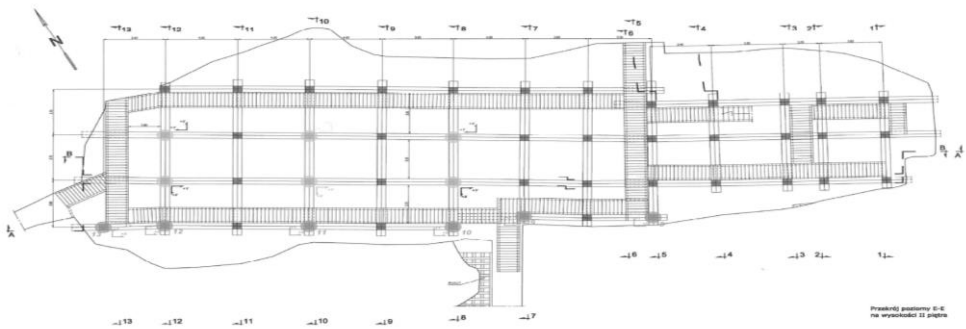


Fig. 4. Location of measuring recorders at the level of storey II in Gołuchowski chamber

#### 4. SUMMARY

Legal considerations imply the necessity of periodic inspections of excavation casings. The mine workings (including chambers with gratings) are subject cyclically to a visual assessment, which results from practical experiences and knowledge of geological and mining conditions in the vicinity of a given chamber. The dimensions of wooden gratings hinder visual assessment of their technical condition. Owing to the narrow area for direct measurements of deflections in grating elements, it was stated that it would be reasonable to begin monitoring of all gratings, particularly in the context of planned mining works in the vicinity of given chambers. The advisability of preparing a measurement methodology suitable for mining conditions has been confirmed during consultations within the trade. There is justification for periodic monitoring of measurable parameters which could indicate the status of an interaction between a wooden casing and a rock formation in the course of use, particularly in the context of planned mining works in the vicinity of old chambers and facing the need to obtain data for further design work.

In 2013 a broader evaluative analysis of the technical state of these casings was begun. In the first phase the focus was placed on the typology and characteristics of wooden casings used in historic sidewalk and chamber mining excavations in the conditions of Wieliczka mine. The second phase covered the identification of the most important geological and engineering aspects in the design and evaluation of the technical condition of wooden grating casings. Analyzing the methods for observation and measurement currently used in the conditions of Wieliczka Salt Mine and the needs arising from the inspections conducted of such casings (including during the reconstruction of a grating in Michałowice chamber, or the construction of a new grating in Gołuchowski chamber), it was considered advisable to prepare a measure-

ment method for periodic inspection and monitoring of the geometry of major structural elements of this casing.

#### REFERENCES

- DUŻY S., 2013. *Diagnostics and methods for evaluation of the technical condition of mine workings, part 2*, Budownictwo Górnicze i Tunelowe No. 1/2013, pp. 31-40 (in Polish).
- INMAN D. et al., 2005. *Damage Prognosis for Aerospace, Civil and Mechanical Systems*, Published by Wiley.
- SZCZAP J. et al., 2003, *Projekt techniczny zabezpieczenia komory Gołuchowski [Technical design for protection of Gołuchowski chamber]*, unpublished work, KGHM Cuprum, Wrocław 2003 (in Polish).
- SZPAK M. 2013. *Typology and characteristics of wooden mining casings used in historic sidewalk and chamber mine workings in the conditions of Wieliczka salt mine*, materials from the Conference of Doctoral Students and Young Scientists, Szklarska Poręba 2013 (in Polish).
- SZPAK M. 2014. *Identification of the most important geological and engineering aspects in the design and evaluation of the technical condition of wooden grating mining casings*, materials from the Conference of Doctoral Students and Young Scientists, Szklarska Poręba 2014 (in Polish).