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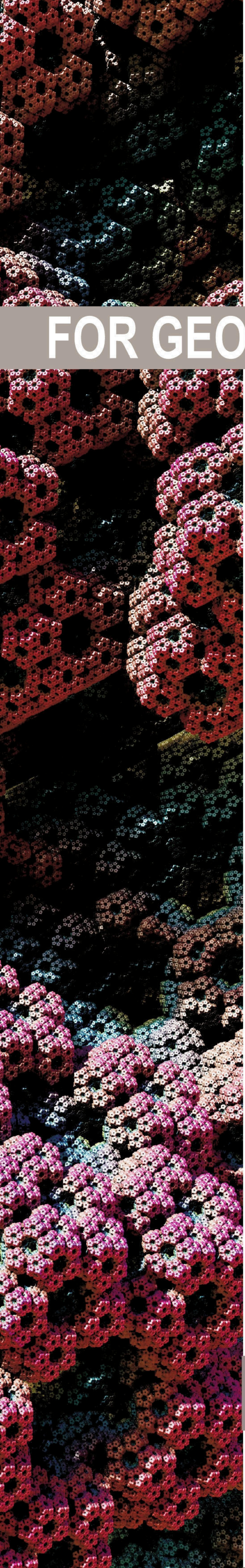

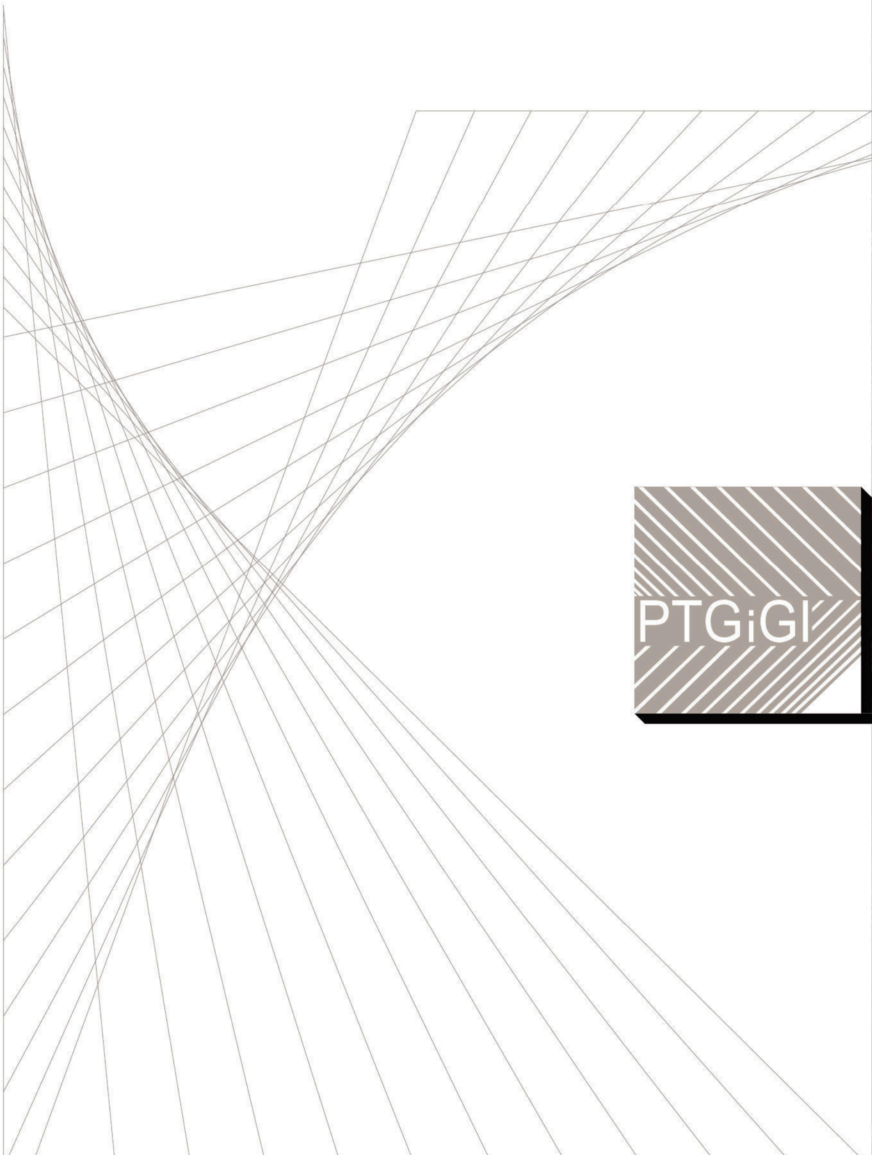

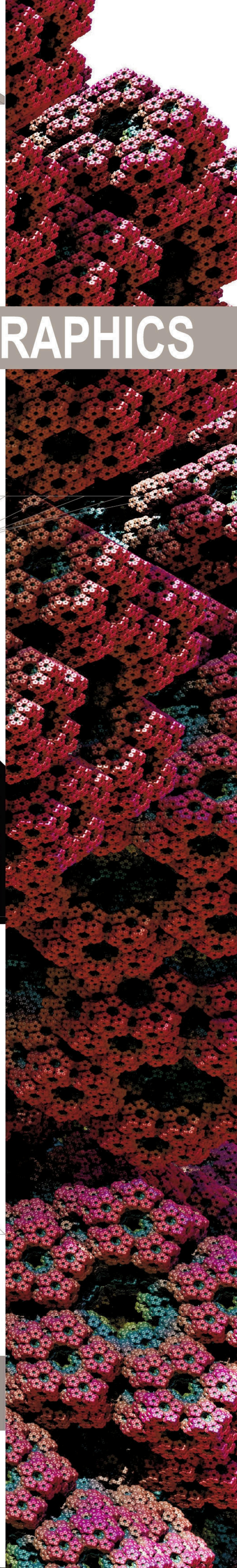

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INFLUENCE OF SPATIAL FORM OF UNDERGROUND GALLERIES ON GEOMETRY AND STRUCTURAL DESIGN OF OLD MINE SUPPORT CONSTRUCTIONS

Tomasz WIEJA

AGH Univesity of Sciences and Technology
Faculty of Mining and Geoengineering, Department of Geomechanics, Civil Engineering and Geotechnics
al.,Mickiewicza 30, 30-059 KRAKOW, POLAND

Abstract. This study examines the geometry of old mine support structures, starting from simple props and chock supports to polygonal supports to refined truss or basket supports. The focus is on spatial structures of mine supports, geometry of their structural components' cross-profiles and the locking (anchor) systems. The purpose of the present study is to define the geometric and spatial relations between the actual shape of structural elements and the man-made underground spatial structure.

Kaywords: brick lining, geometry, mine supports, steel supports, shape, timber cribs and posts, underground galleries, underground spaces

1 Introduction

Old underground galleries and workings, formed in the course of mining activities demonstrate the level of technological advancement during the exploitation of natural resources, evidencing the symbiosis of human activity and geological surroundings. A great number of them are now a part of cultural and natural heritage or natural reserve areas, some of them have been granted the status of natural monuments. The spatial configuration of underground galleries and entries, pits and caverns developed in the course of dynamic interactions between the existing rock strata and human activities in the area. On one hand it is dependent on the geology of the surrounding rock strata, one the other it is a derivative of mining methods developed throughout the history [1].

Protection of human life from natural hazards in the course of rock mining was the necessary condition (sine qua non) for opening of mining activities. Roof supports as a vital element securing underground sites can be treated as an inherent man-made component of the existing underground structures.

Roof supports were adapted to the specificity of the mining method (block mining, room and pillar mining) and availability of construction materials, their actual designs being prompted by the miners' invention and traditions as well as local conditions. Roof supports were provided alongside the progressing mining works. Their actual structure and geometry were directly related to the specificity of the underground site, developed by mining methods. There are various roof support systems, matched to the specificity of underground galleries, drifts, pits and caverns, which determined the selection of construction techniques and materials (stone, bricks, timber, steel).

2 Spatial configuration of underground galleries

Underground mine workings developed over the years are characterised by three key parameters: volume, shape and position with respect to the ground surface.

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As they were being developed in stages, their spatial configurations would vary, depending on the geology of underground strata (type of deposit) and the implemented mining methods.

There are regular, geometric shapes occurring mostly at the stage of prospecting, including linear features forming intricate drift networks (Fig. 1) or irregular features emerging during the mining operations, such as lens, seats or mineral roofs (Fig. 2).

Figure 1: A drift in an old salt mine in Bochnia (photo T. Wieja)

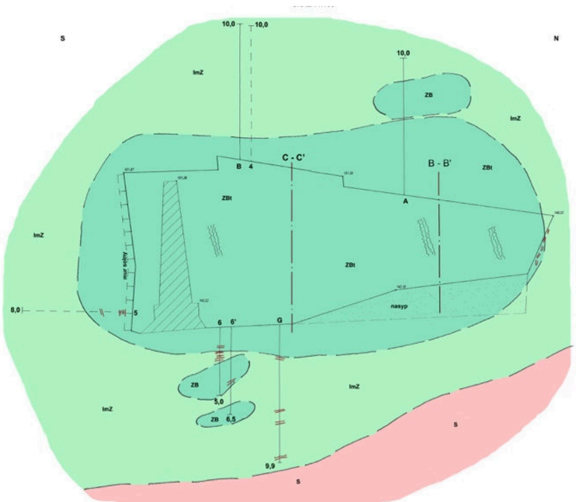

Figure 2: Geological cross-profile of a cavern – the Franciszek Karol cavern in the sale mine in Wieliczka (after J. Przybyło)

The earliest prospecting was done mostly by manual methods, resulting in circuitous galleries being driven to circumvent hard-to-mine compact rock strata.

Blasting powder which came into use in the late 17th century brought revolutionary changes to prospecting and allowed the intricate geometry of underground sites to become more regular.

Regardless of the extent of irregularity, underground voids can be categorised into three groups (Table 1), depending on the actual ratio of their height, width and length:

1. cavern-type working (mined caverns),
2. tunnel-like workings (pits, drifts, galleries and shafts),
3. deposit beds (deposits extending over large areas but with small height.

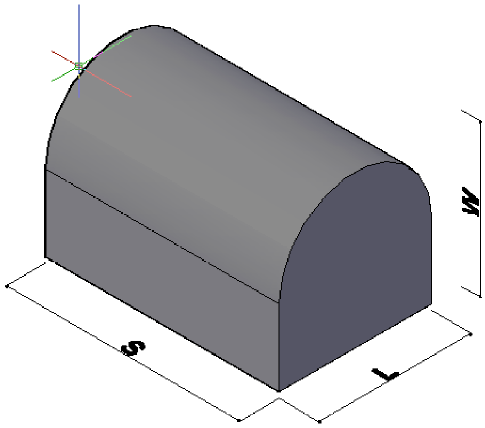

Figure 3: Spatial parameters of underground features in the rock strata

Table 1: Definition and classification of underground mine workings depending on their measured proportions [4]

Proportion	Cavern-type	Tunnel-like		Deposit beds
		Galleries	shafts	
L/S	~1	>20	~1	-
S/W	~1	~1	_	>20
W/L	-	-	>20	-
L/W	-	-	-	>20

L- width, S- length, W- height

3 Geometry and structural designs of old roof supports

Roof support- a structure aimed to ensure the stability of the mine working to keep its cross-section constant and to protect people, mining machines and equipment from rock fragments falling down from the roof or side walls, to provide protection against cave-ins and roof collapse during the mining operations.

Old historic roof supports used during the tunnelling and mining operations are an excellent example demonstrating synergy of spatial configuration of the underground site and structural geometry. It was the effect of long years' mining expertise, prompted by the need to find the optimal geometric structure to be incorporated, both in form and structure, in the underground voids. As a result, several types of roof supports emerged, dedicated to cater for the needs of particular underground sites [5].

Traditionally, roof supports in galleries were provided in the form of sets of structural elements: prop elements and ancillary components. The actual array of support elements in the tailgate or gallery is referred to as the roof support systems (parallel or normal to the face front). Extended roof supports with intricate geometry were mostly utilised in caverns. In salt mines the truss-type structures were used to enhance the load-bearing capacity of roof and side walls in caverns.

The type of roof support, its actual shape and the building material were chosen such as to best integrate it with the surrounding rock strata.

The aspects to be considered when selecting the roof support type include:

- mining and geological conditions (rock type, pressure in the rock strata, depth),
- cross-section of the mine workings,

- specific function of the underground site (transportation, ventilation),
- the time period of the mine working existence,
- economic factors.
- Other determinants of geometry of old historic roof supports include:
- roof support and rock strata interactions (supporting, stabilising, isolating, separating),
- the nature of roof support – rock strata interactions:
  - rigid support (monolith or made of rigid elements, with no elastic components, yielding only within the limits of material strains),
  - yielding support (whose structural elements can be displaced under load, without permanent deformations),
  - yielding support with limited support capacity (characterised by complex critical value of respective displacements of its structural components, when exceeded the support behaves as rigid),
  - rigid support with yielding components (roof support provided with yielding elements made of material whose deformability is greater than that of the load-bearing elements in the roof support),
  - the type of building material for the roof support and its elements (timber, bricks, stone, concrete, steel [3].

4 Timber cribs and posts

Timber roof supports were dominant in the form of supporting cribs and posts, their main function was to stabilise the rock strata in the neighbourhood of the mine working. Hence the major determinant of their geometry and form was the safety of underground mining operations.

Geometry and forms of timber supports can be categorised into simple and complex forms, associated with the analysis of the static behaviours involved in the roof support and the underground space interactions. Simple structures are provided mostly in the form of timber props supporting the roof strata, props with cross binding (Fig. 4) and horizontal elements of cross-beams set up in the seats on the side walls.

Figure 4: An example of a modern simple support structure - props with cross binding, underground tourist route Nagórzyckie Grottos (photo T. Wieja)

Geometry and form of complex roof supports is based on multiple polygon patterns (polygonal supports) inscribed in the spatial space of underground galleries or truss or basket-like structures implemented in caverns.

Complex supports were provided under conditions characterised by weak side walls and under significant horizontal or vertical or combined pressures. Such roof support structures (original or purpose-designed) are encountered in numerous underground sites (salt mines, collieries, metal and ore mines).

Depending on the load-bearing capacity and the type of mine working there are several types of complex roof supports:

– frame timbering – open-work or close-set timbering sections, incorporating close-set frames comprising props and cross bar elements with ancillary components: slabs and stull bars,
– timber supports,
– breaker row as a row of props stabilising and blocking the access to closed parts of the excavations,
– cribbing supports (Fig. 5),
– truss or basket-type supports in caverns (Fig. 6).

Figure 5: Original crib support (1857) at the crossing of the Gębaliński and Lois-2 galleries (photo T. Wieja)

Figure 6: Reconstructed truss-type support in the Gołuchowski cavern in the salt mine Wieliczka (photo ACM)

5 Geometry of timber bonds

Complex supports are implemented by connecting the prop with cross bars via bonding. The most widespread bond type in the mining industry in Poland is the Polish bond, other bond types include German or Swedish bonds.

Geometry of the Polish bond is that in which two cylindrical elements (a prop and a cross bar) are connected via a circular hole in the prop (Fig. 7) in which the cross bar in mounted. It is therefore based on the 3D analysis of structural components. In German bonds the bars are connected via a dap and the beams are configured through in-plane connections of props and cross bars.

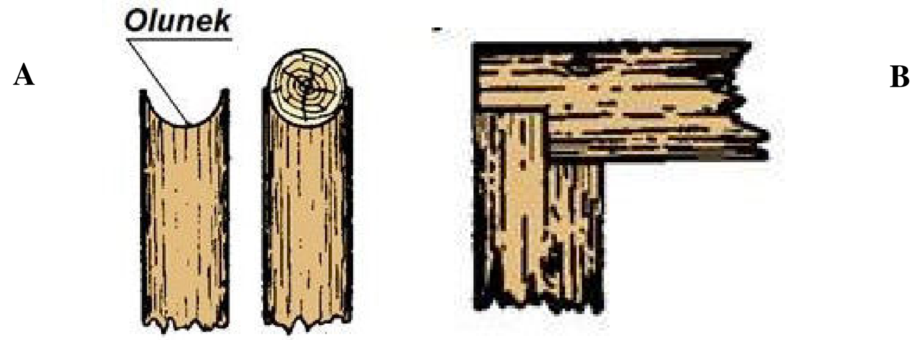

Figure 7: Geometry of the Polish bonding (A) and German bonding (B) of props and cross bars

Swedish bonds (Fig. 8) utilise two cylindrical elements (props and cross bars) interlocked at a certain angle (Fig. 8).

Figure 8: Swedish bonds

6 Brick lining

Brick lining stabilising the mining excavations is used to reinforce the timber supports. Drifts, galleries, cross –cuts, gate roads and their intersections are stabilised with brick lining, bentonite or with concrete supports. These supports are rigid, well interacting with the rock strata yet undisturbed with mining activities or unstressed.

Brick lining in a gallery comprises retaining walls and vaulting, mostly in the form of semicircular vaults, their radius extending beyond the gallery, another though rarely used solution uses full-centred arches.

Depending on the mining and geological conditions, as well as the range of pressures acting upon the support, the actual shape of the brick linings can vary (Fig. 9). Taking into account the horizontal and vertical pressures, the designed cross-profiles would be parabolic, elliptical, circular or semi-circular. From above the linings are vaulted with circular, semi-circular or parabolic arch segments.

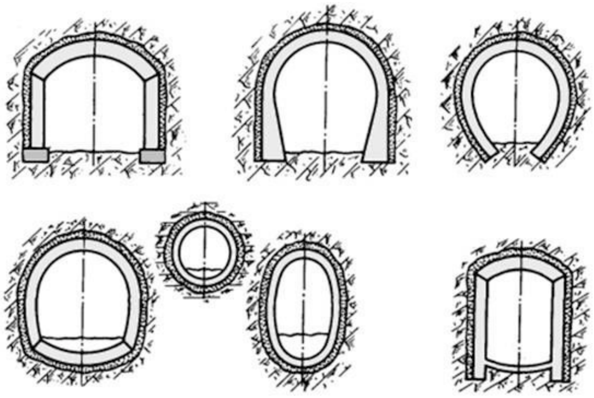

Figure 9: Geometry of brick linings [3]

7 Steel supports

Steel elements as structural components of roof supports in mining date back to the late 19th and early 20th century. At first the old scrapped railway tracks were used as cross bars reinforcing the roof timbering or brick lining.

Geometry of conventional steel supports implemented in gates and galleries was the consequence of the dedicated form and proportions of previously used roof timbering. Thus we get prop and chock systems, polygonal and arched (elliptical, parabolic, ogival) and circular supports. The first constructions had the geometry characteristic of previously employed timber supports, defined by the segment geometry and its multiples, forming polygonal structures. It was mainly the consequence of manufacturing constraints faced by the metallurgical sector and the shortage of steel with high tensile strength yet ductible which could be rolled.

Steel (metal) supports have been widely used in collieries and ore mines, they were less popular in salt mines because of aggressive environment in the salt mines. Steel elements there would soon succumb to corrosion and their functional features would vastly deteriorate.

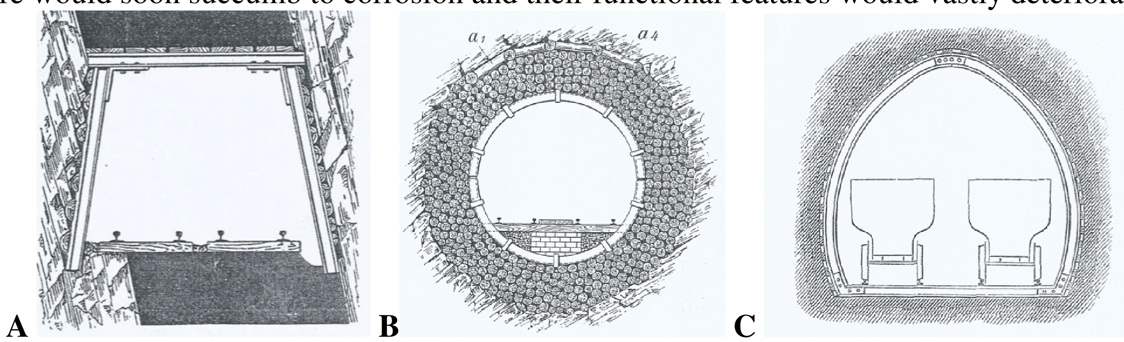

Figure 10: Geometry of steel supports: A-polygonal trapezoid made of railway track elements; B-U-profiled closed circular, ogival closed supports made of rolled profiles [4]

8 Geometry of constructional profiles and joints

Geometry or the cross-section of steel or iron components is a most interesting aspect involved in design and construction of steel supports. Starting from the early applications of disused railway tracks, further advancement in metallurgy produced new, rolled beams with intricate shapes to be used in close-set supports. As soon as high-resistance flexible steel able to withstand dynamic loads could be manufactured, profiled structural elements appeared and new types of steel supports were designed.

In old historic mines, the steel support structures used mostly hot-rolled profiles shaped like railway track, T-profiles and trough-shaped elements (Fig. 11).

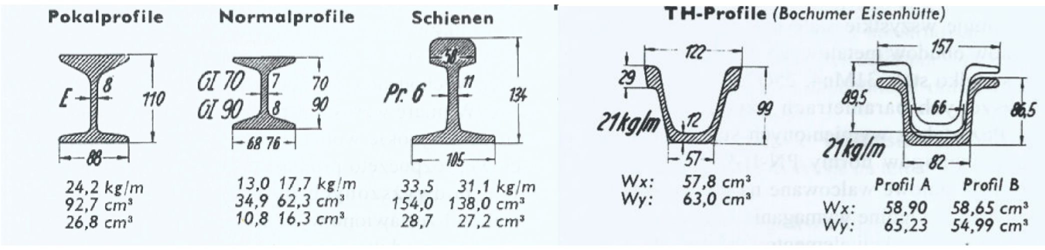

Figure 11: Hot-rolled profiled used in German mines until 1959 [4]

Apart from the profiled sections, the key constructional element in the steel supports is the joint providing a connection between structural components of the framing. Profiled sections and the type of joint determine the static behaviour of the frame in the steel support. Finding joints that would provide for secure connection and ensuring uniform distribution of the cross bar load upon the props was one of the key challenges faced by the engineers in the past.

Development of rolling steel technology and patenting the trough-shaped profiled sections gave rise to new joint solutions, such as those implemented in yielding supports with frictional joints between arched sections. That was another issue to be addressed when developing new supports that required new type of joints. Intricate shapes of steel profiles making up the support frame determined the geometry of joints which had to be designed as independent fastening connectors (Fig. 12). The actual shape of the connectors was determined by the shape of structural profiled segments, the type of framing (arched or straight) and rigid or yielding behaviour of the roof support (Fig. 13, 14).

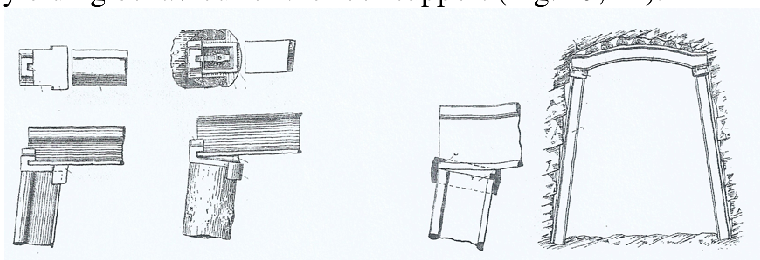

Figure 12: Prop and cross bar connection details. Z-type roller profile joint- Germany, 19th/20th century [4]

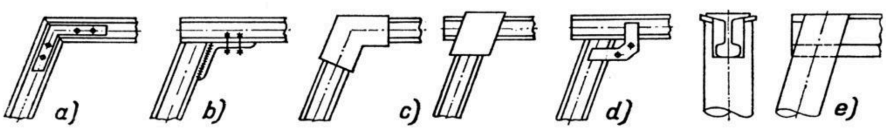

Figure 13: Joints in square rigid supports (a – locking plate, b – angle section, c – shoe, d – profiled sections; e – rail-pipe connection) [4]

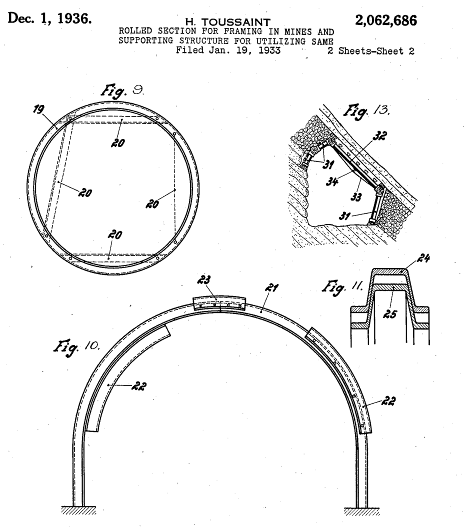

Figure 14: Original drawing of the joint for profiles in a yielding support in H. Tousseint's patent application (US 2062686A)

9 Conclusions

Synergy of man-made voids formed during the mining and exploitation of rock strata and geometry of stabilising structural elements is an inherent feature of underground mining heritage. The actual shape of implemented structures is the secondary consideration as it was adapted to the previously created spatial configuration of the voids, in particular to the cross-section of the gallery or cavern.

Of particular importance were the conditions and geology of surrounding rock strata, which created the need for a diversity of roof support geometry. The type of deposit determined the actual shape of the roof support as well as the choice of materials and manufacturing technologies.

Geometric forms were developed depending on the materials used in situ, especially timber which used to be the basic building material when constructing roof supports. Thus, the timber structures were implemented taking into account the specifications and functional parameters of this material.

Timber supports in mines are a good example of this approach. Wood is a material exhibiting anisotropy and having good compression strength, hence timber can be well used in the form of straight bale segments or square-sawn elements creating polygonal patterns inscribed in the polygonal cross-sections of galleries and caverns.

The effects of spatial configuration of underground sites on individual features of structural geometry are best demonstrated in caverns. Some of them are really works of art., forming underground 'cathedral-like' structures, featuring pillars, angle braces, longitudinal and lateral bracing systems, being vital components of vaults formed during the salt mining.

Vaulted elliptical or circular systems were mostly implemented where the roofs were reinforced with brick lining or steel supports.

Geometry of multiple structural components, adapted to the actual cross-section of the gallery, gave rise to formation of new man-made spatial structures incorporated in the natural surroundings and geology of the strata.

In multi-criterial assessment of the functional parameters, engineering aspects and aesthetic features of underground structures reference should be made to traditional engineering solutions, particularly the forms and materials used, to encourage the protection of old historic underground sites as a part of national heritage. This, in turn, should become a new inspiration for application of state-of-the-art. design solution in this field.

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WPŁYW FORMY PRZESTRZENNEJ PODZIEMNYCH WYROBISK NA KSZTAŁTOWANIE GEOMETRII STRUKTUR KONSTRUKCYJNYCH HISTORYCZNYCH OBUDÓW GÓRNICZYCH

W artykule przedstawiono analizę geometrii historycznych ustrojów konstrukcyjnych obudów górniczych począwszy od prostych obudów typu stojakowego i kasztowego, poprzez obudowy poligonalne, aż do wyrafinowanych konstrukcji typu kratownicowego i koszykowego. Analiza obejmuje struktury przestrzenne obudów oraz geometrię przekrojów elementów konstrukcyjnych i systemu ich wiązań tzw. zamków. Istotą opracowania jest zdefiniowanie relacji geometrycznych oraz przestrzennych pomiędzy kształtem ustrojów konstrukcyjnych obudów a antropogeniczną podziemną strukturą przestrzenną.