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REINFORCED CONCRETE FLOORS IN HISTORIC BUILDINGS FROM THE BEGINNING AND THE MIDDLE OF THE 20TH CENTURY – EXAMPLES OF STRUCTURAL STRENGTHENING IN THE PROCESS OF REVITALIZATION

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Abstract. *The paper presents a historical outline of structural solutions of reinforced concrete floors from the turn of the 19th and 20th centuries to the half of the 20th century in the Lower Silesia region of Poland. It is based on the analysis of archival documentation and expert research carried out during the design of the revitalization of historic public and industrial buildings. The structural typology of some simple RC floors slabs used in that time of introduction of concrete into construction life as well as constructional solutions of buildings erected in western Poland in those days are presented. Nowadays, while some of these buildings undergo refurbishment process to adapt them to new functional aims these RC floors have to be strengthened using different methods, depending on the assessment results. In some of the presented design study cases assessed technical state and load bearing capacity of floors ensure the possibility of their further use without the need for significant reinforcements, except for the need for surface material repairs. However, in some cases due to concrete deterioration processes and loss of its durability, despite necessity of material renovation, structural strengthening methods needed to be applied. For example, increasing the load bearing capacity of floors by making additional concrete layers cooperating with the existing reinforced concrete slab or by changing the static scheme by making new supports up to the complete replacement of floors (not only concrete ones) with modern, concrete rib-and-beam or composite ones were considered.*

1 INTRODUCTION

In many cities of the southwestern part of Poland (which geographically and historically is named Lower Silesia) there are still buildings, used for various purposes - from residential, public and industrial, which were built in the late nineteenth or early twentieth century. Due to their former function some of those buildings required large functional areas and therefore the need to construct floor slabs having significant spans as well as sufficient bearing capacity. The best choice was then using reinforced concrete structural elements, despite the fact that that were years when concrete had its beginnings in construction.

In the recent years, in connection with the various activities carried out to adapt these facilities to new utility functions, building engineers often meet and get to know interesting structural solutions from that time, many of them made using reinforced concrete. In the course of assessment works, aimed at diagnosing the technical state of these historic structures, including their safety and the development of appropriate rehabilitation projects, there are discovered different concrete elements as, for example, different types of monolithic floor slabs in industrial or public service buildings or even complete skeletal structures of workshops or department malls. Combining construction history analysis with current diagnostic methods can give not only an understanding of the past design solutions and development of structural design and construction ideas, but also is essential for the adequate design of repair interventions. However, what is obvious, with the time pace and aging process, these historic concrete structures at least lost partially their former material properties and bearing capacity.

The paper presents a historical outline of structural solutions of reinforced concrete floors from the beginning of the 20th century (also mentioning some later design solution), based on the analysis of archival documentation and research carried out during the rehabilitation processes of historic public and industrial buildings. The structural typology of selected historic German reinforced concrete floor slabs and some typical constructional solutions used in the first half of the 20th century in buildings erected in western Poland are discussed. Nowadays, while some of these buildings undergo refurbishment processes to accommodate them to new functional goals some of these slabs have to be strengthened using classic or modern methods. Procedures of technical state assessment of old RC structures as well as selection of some applied strengthening methods are described in the paper.

2 STRUCTURAL DESCRIPTION OF HISTORIC RC FLOOR SLABS

2.1 Typical historic RC floors

A description of typical solutions of reinforced concrete floor slabs that can be found in buildings constructed at the turn of 19th and 20th centuries, also in the region of the Lower Silesia, are presented, for example, in [1,2,3]. Below, based on the aforementioned literature as well as on the conducted own expert studies and structural assessments [4,5,6,7,8,9], several selected, most commonly used and met in Poland, reinforced concrete floors are briefly presented.

Four types of many Monier floor slabs solutions are presented in Fig. 1. They were mainly in use at the turn of the 19th and 20th century. Their typical spans were between 1.00 and 2.50 m (in 1909 even to 6.0 m), a slab thicknesses was only 3 to 10 cm, and the reinforcement was made of smooth round bars with a diameter of 6 mm, laid every 10 cm. In the first versions the reinforcement was placed in the compression and tension zone.

When executing a continuous slab across several fields, the reinforcement was bent at the moment zero points and carried out above the supports. Those slabs were mainly based on double-T beams (at upper or lower flange), but also on masonry walls.

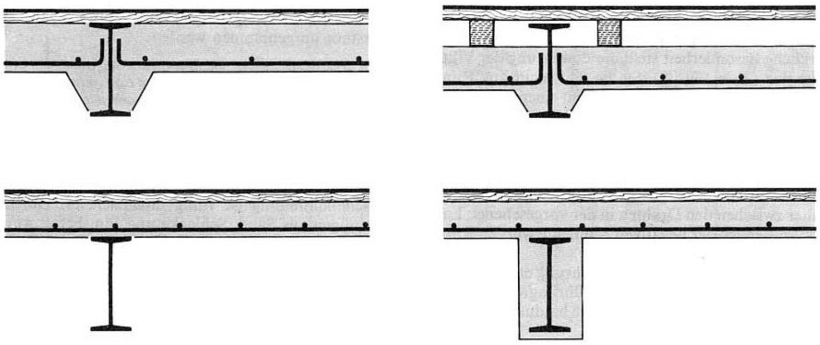


Figure 1: Examples of Monier floors (Monier decke) [1]

Another example of ingenious ideas was concrete floor with pre-tensioned reinforcement (Fig. 2). In order to achieve a higher bearing capacity of such floor and an effect of structural continuity, the iron inserts were preloaded. The round bars were pulled tight around the upper flanges of the beams or around anchor flat bars mounted in the masonry, and laterally shifted until a prestressing was reached. That floor slab was considered as a single-span one.

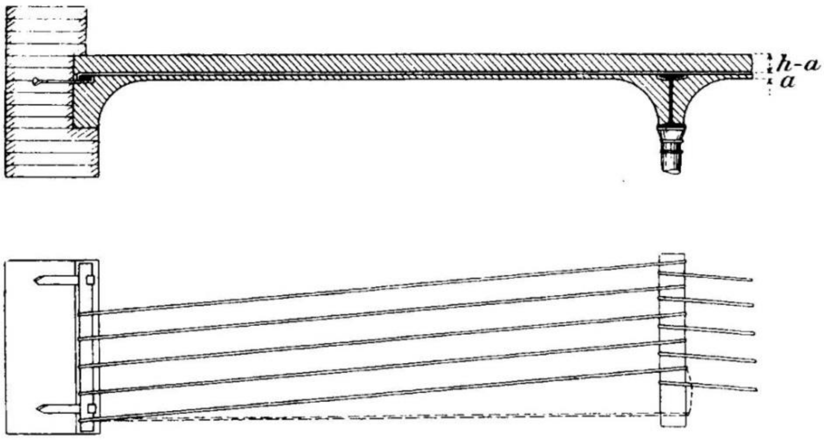


Figure 2: Tensioned concrete floor (Spanneisendecke) [1]

In 1897 the Koenen floor (Fig. 3) was built as the first version of a slab with cove-shaped supports running through several steel girders. Due to the formation of haunches at the support area, a bigger lever arm of the internal forces was achieved above the supports. The shear stresses, increasing towards the slab edge, are absorbed by the haunches. The reinforcement routes follow the moment curve and bars are bent up by the support at the moment zero points.

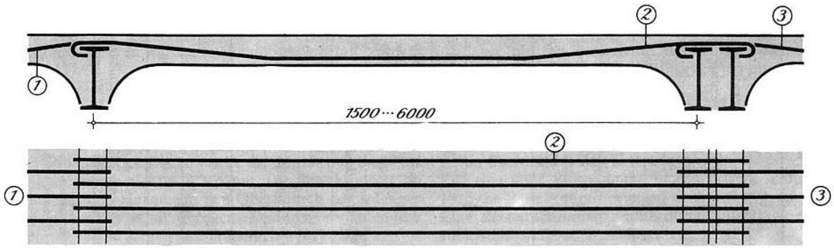


Figure 3: Koenen plate floor (Koenensche Voutenplatte) [1]

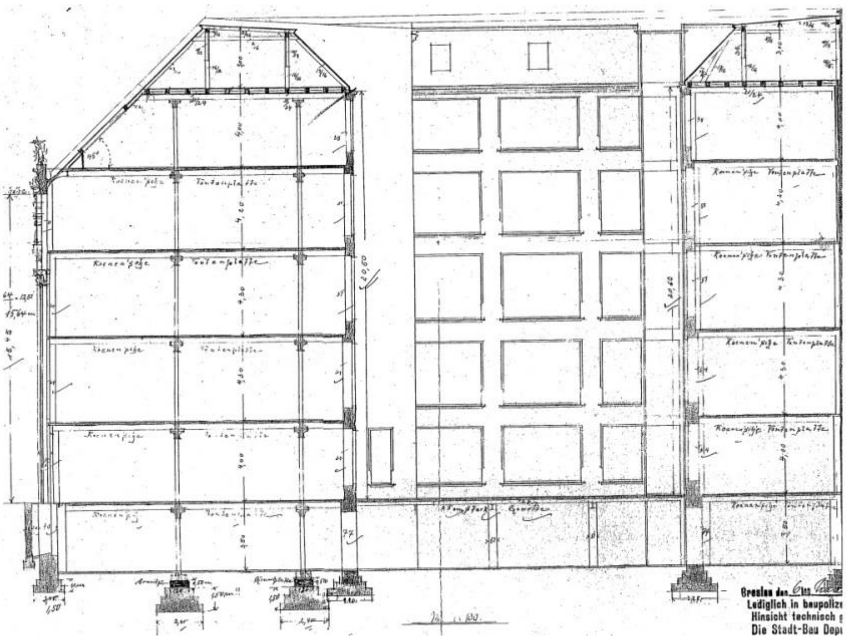


Figure 4: Cross-section of a public service building with Koenen plate floors (1899)

Figure 5: General view and rebar exposure of Koenen plate floor in a public service building

The reinforcement was anchored at the top of the slab in various ways: hooks at the upper flanges of the girders or a flat steel that was held by steel anchors mounted in masonry walls. By coupling the reinforcement with the wall clasp it was possible to achieve a high degree of clamping for the peripheral area using the wall dead load. Spans of up to 8.0 m were achieved for that floor. That type of floor can be often met in the 19th/20th century public service buildings in the Lower Silesia region (Figs 4 & 5).

The Wolles console floor (Fig. 6) is similar to the Koenen one, but there is no continuous layout of the reinforcement over supports. It is divided into bottom one in a span and upper one over supports. The characteristic element is that the upper bars were extended approximately 100 mm beyond the zero moment point.

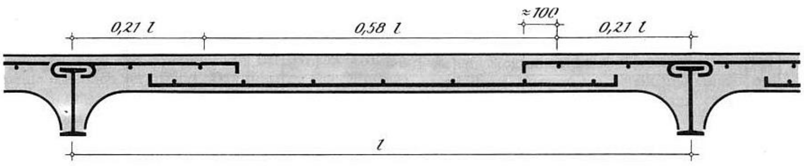


Figure 6: Wolles floor (Wollesche Konsoldecke) [1]

2.2 Examples of monolithic RC floors in historic industrial buildings

Below there are presented some examples of classic fully monolithic RC floors (being parts of 3D frame structures) that are still working without strengthening necessity in different public service and industrial buildings from the first half of the 20th century in the Lower Silesia region of Poland.

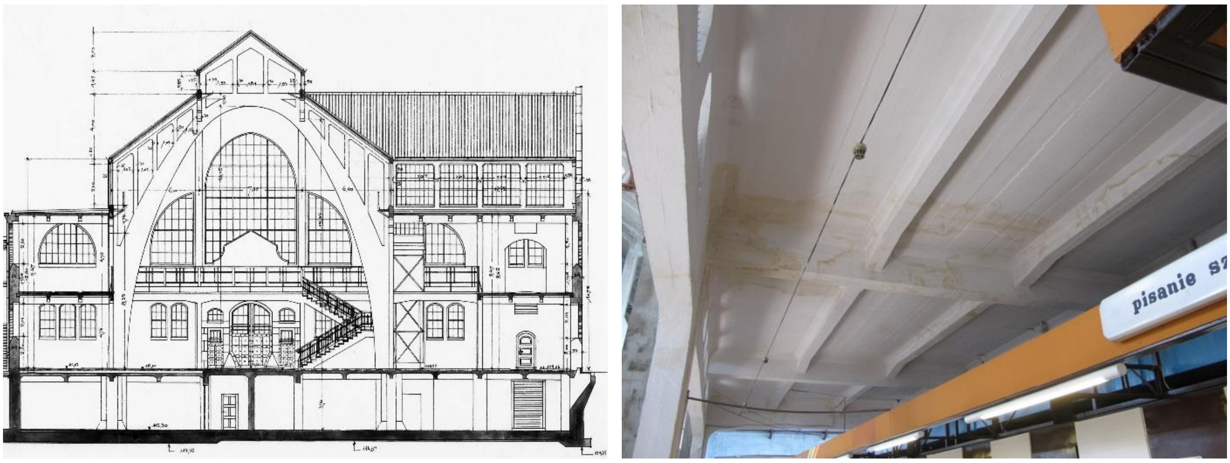


Figure 7: Archival drawing and general view of the RC rib floor in a market hall (1909)

First of them is one of the prominent monuments of RC historic structures – the market hall from 1908 (Fig. 7). The original design of the market hall building was made in the years 1901-1903 and consisted of the reinforced concrete foundation and the steel structure in the part above the ground level. However, the whole structure finally was made of concrete after performing an analysis of a variety design solutions of different market hall buildings existing at the time as well as due to the properties of concrete material such as: durability, fire resistance and no need of intensive maintenance [6,7]. From the constructional point of view we are dealing in this building with two construction materials: concrete/reinforced concrete of foundation slabs, basement walls, floors, and arched supporting structure, and the brick masonry exterior walls. Generally, the building remains in use in a perfect technical state.

The second object is a heritage industrial building of bakery flower warehouse built about 1913 (Fig. 8). The edifice has 8 floors above the ground, but has no basement. Although the external walls of the building are made of brick masonry, the main bearing structure is made of reinforced concrete: pillars, rib-slab floors, and roof frames on two attic floors. The assessment was made with an aim to determine the possibility of reconstruction and adaptation of the warehouse building to new utility purposes, and in turn, to extend its service life. Currently, the building is under refurbishment process.

Figure 8: Archival drawing and general view of the RC rib floor in a bakery plant (1913)

The next two buildings (Figs 9 & 10) are not so spectacular examples of the historic RC structures, but present the simplicity, clarity and usefulness of the use of this material in shaping the space of industrial buildings regardless the passage of time and the development of design methods and properties of the materials used.

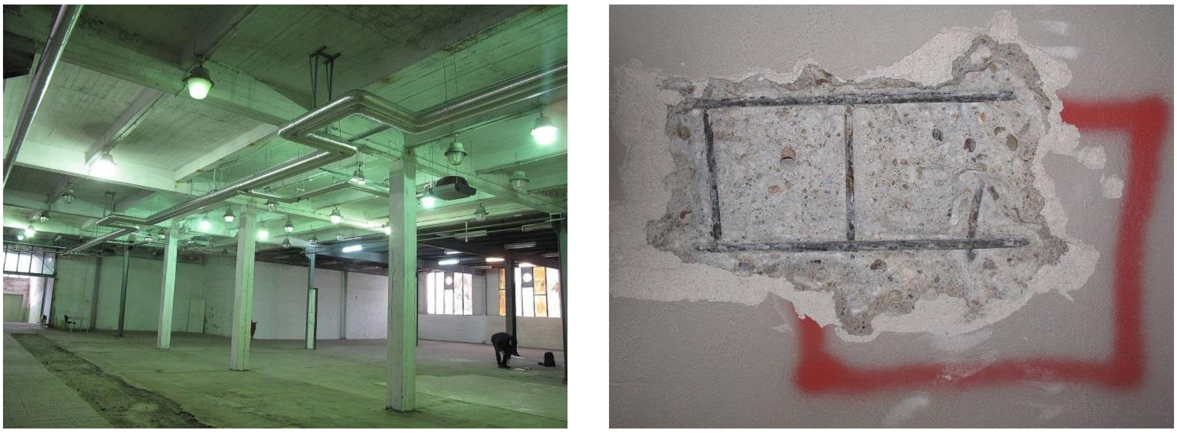


Figure 9: General view of the RC rib floor of a workshop and rebar exposure (1940)

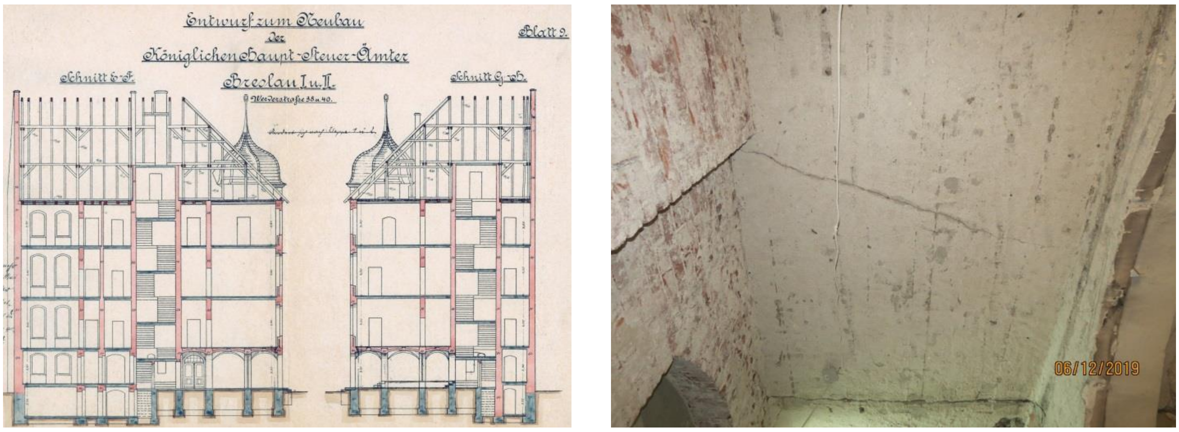
Figure 10: View of warehouse after partial demolition and the rib floor structure in a ground floor (1950)

In both cases the assessments of technical condition of buildings (including fire resistance demands) were conducted due to designed change of their future utility functions. Based on the non-destructive techniques (rebound hammer and pull-out methods) used and study of historical literature it was assumed that the concrete in the structure corresponded with concrete classes of C12/C15. According to the literature data and taking into account the age of the construction, it was determined that post-German so-called "commercial steel" with the design strength 150 MPa was used for reinforcement. Basing on the static and strength calculations it was determined that the carrying capacity of the floors in the considered buildings was sufficient to carry on new loads without necessity to strengthen their structure. The only necessary repair would be connected with improving the floors’ fire resistance by creating a new spray on their lower surface which would increase the thickness of the concrete cover of the bars, by the use of nano-concrete plaster, for example.

3 STRUCTRAL STRENGTHENING OF HISTORIC RC FLOOR – A CASE STUDY

3.1 Former public service building converted into an apartment house

The analyzed building was erected about 1909. Before the 2nd world war the building was the seat of the Central Customs Office, after the war it served as militia barracks. The building has 4 floors above ground (ground floor and three floors), an unused attic and is partly a basement (Fig. 11.a). The structural system of the building is two-bay one, with corridors located along the inner courtyard. The building's structure is traditional: the foundations are brick masonry ones; the load-bearing walls are made of brick; the floors are in the form of reinforced concrete slabs, locally are made with use of the prefabricated reinforced concrete panels. The roof truss is wooden, covered with ceramic tiles. Above the ground floor slabs were found in the form of cross-reinforced concrete slabs in rooms and unidirectional reinforced slabs in corridors. The structural thickness of the floors varied from 10÷12 cm in corridors to 16÷20 cm in rooms.



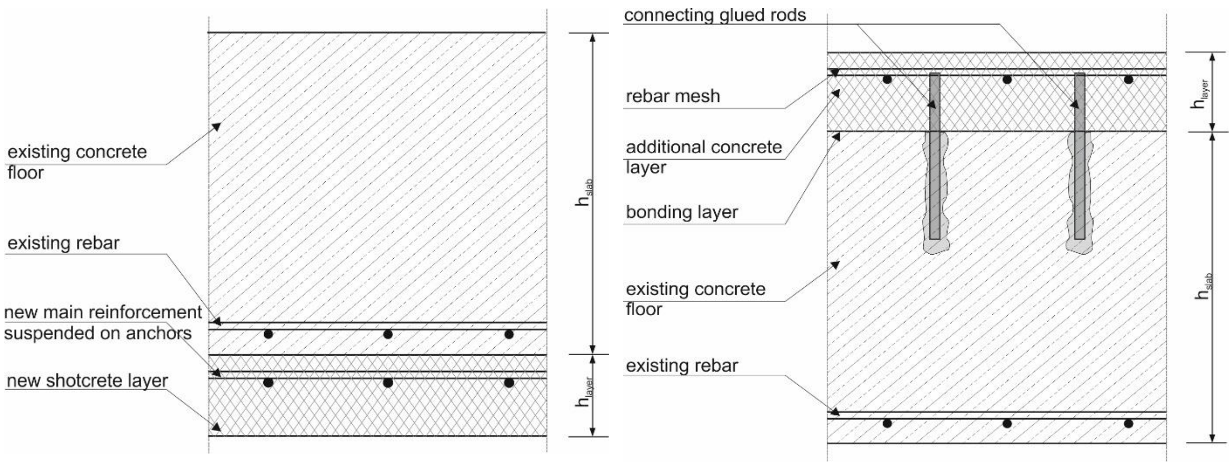
a) b)

Figure 11: a) Archival drawing of building cross-section; b) typical cracks in floor slabs

Numerous cracks were found in slabs over the corridors, especially at the ground and first floors. Those damages were caused by corrosion of reinforcement, poor concrete adhesion to band-iron and its torsion during concreting. In almost all the RC floors diagonal scratches of the panels were found in the slab corners (Fig. 11.b). These are typical cracks for thin reinforced concrete slabs, without upper reinforcement near supports. Such reinforcement was not found in the exposures and during rebar scanning tests.

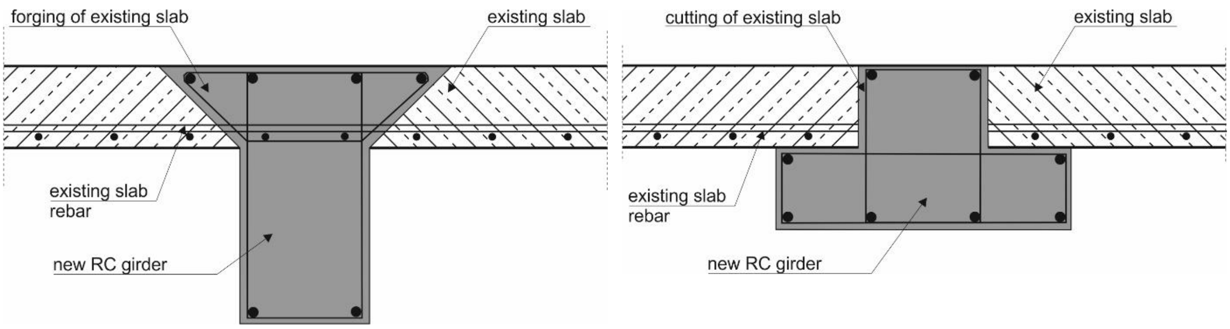
A number of rebar samples were taken out from floors projected to be demolished to determine in steel strength machine the quality of reinforcing steel used [1,10]. The test results let to assume the calculation yield stress for steel rebar as $f_{yd} = 250$ MPa.

Based on the concrete strength tests and literature analysis [1,11,12] it was assumed, due to the large variation in results, that the used concrete corresponded to the current class C12/C15 with a design strength of 8.0 MPa. Even assuming higher value of concrete strength, as 10.0 MPa, the slabs had not enough capacity for new loads. As the slabs were very thin it was impossible to state concrete strength using cores extracted from them.



a) b)

Figure 12: Slab strengthening ideas: a) shotcrete at bottom surface; b) additional concrete layer at upper surface



c) **d)**

Figure 12: Considered methods of floor slab strengthening: c) additional T-shape beam; d) additional inverted T-shape girder

The tensile pull-off examination of concrete surface of floors adhesion showed that it did not have enough strength to use FRP materials for strengthening and the surface repair would be too expansive.

The static and strength calculations carried out, preceded by the above mentioned material tests, showed that the reinforced concrete slabs above all the storeys did not have sufficient capacity associated with the residential, hotel or office function. This let to make a decision of strengthening all the floor slabs. Some techniques (Figs 12.a÷d) were considered, but finally construction of additional supporting inverted T-beams were applied (Figs 13.a,b).

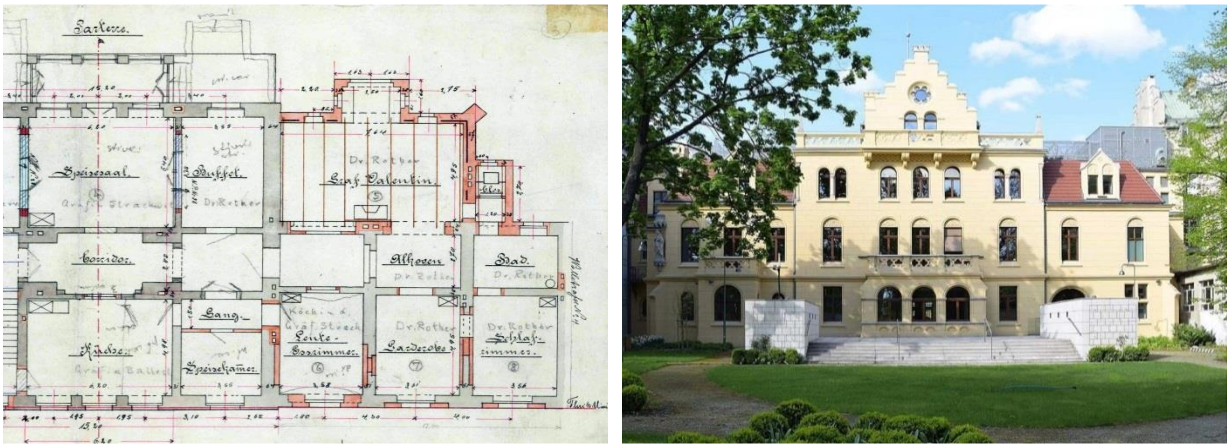
a) **b)**

Figure 13: a) Floor slab with cuttings; b) floor with additional inverted T-shape RC girder supports

4 MODERN CONCRETE FLOORS IN HISTORIC BUILDINGS – A CASE STUDY

4.1 Former city palace converted into a public service building

According to the preserved archival documentation the revitalizing object, in its current architectural and structural form, was designed and built in 1898 as a city palace of the family of the Ballestrem counts. Buildings that had existed in this place before were completely destroyed as a result of the explosion of the gunpowder tower in 1749, and new buildings were erected in their place. During its existence, the building was rebuilt and extended, as evidenced by the preserved historical documentation. The palace is a three-floor building with basement and attic (Fig. 15.a). The object has a central symmetry axis, a straight front elevation and a fragmented rear elevation (Fig. 15.b). The building's structure is traditional, i.e. foundations and load-bearing walls are made of solid brick, floors – vaults above basements, Klein type and wooden on the other floors, and the roof truss structure – wooden.



a) **b)**

Figure 15: a) Archival plan of old palace building; b) the palace after rehabilitation

According to the assumptions of the revitalization project, the building was to serve as a hotel, with a restaurant in a basement. In relation to these assumptions and the resulting design and functional requirements, a detailed assessment of the technical condition of the object, as well as conservatory opinion (including stratigraphic ones) was developed by specialists. The results of this assessment provided the basis for developing a construction design for the reconstruction and adaptation of the palace building to new utility functions. However, during the construction works, after full exposure or demolition of subsequent fragments of the structure, it was necessary to modify the adopted design solutions or introduce additional reinforcements. The designed new building function also enforces the introduction of correspondingly higher functional loads. All these factors had a major impact on the need to strengthen virtually all the foundations by using jet-grouting. All inter-floor floors, except for those located in rooms such as bathrooms or kitchens, were made as wooden ones. The layout of the floors was mixed, often even the neighboring rooms had a different course of bearing beams. Finally, all old wooden floors had to be replaced with new ones.

Originally, ceilings were considered to be made as traditional RC panel slabs on steel beams or modern rib-and-slab floor (RECTOR type) (Fig. 16). RECTOLIGHT floors are beam-honeycombed, prefabricated dense ribbed slabs. These floors consist of prestressed concrete beams and ceiling fillings made of pressed wood. The system is supplemented with: supporting reinforcements, welded steel mesh and monolithic concrete made on site. The biggest advantage of this system floor is its lightness and easy installation, which are of great importance when performing works in historic buildings located in the city center.

Figure 16: View of the RECTOLIGHT concrete floor

However, in the final solution, due to economic reasons, new inter-story floors were designed in the form of composite reinforced concrete slabs, made on lost formwork made of trapezoidal steel sheets, based on steel I-beams (Fig. 17).

Figure 17: View of the composite floor

5 FINAL REMARKS

Recently, many historic buildings in Poland undergo refurbishment process to adapt them to new functional aims and new loads. In case of public or industrial buildings from the end of the 19th and beginning of the 20th century there can be found ones in which concrete was used for the first time as structural material, especially for floor slabs. In most of the cases, due to concrete deterioration processes and loss of its durability, despite necessity of material renovation, strengthening methods are necessary to be applied. One of the main elements of proper definition of reinforcement method to be applied is historical analysis of design and construction of such structural elements, according to the archival and contemporary literature (what was presented in this paper), and the other indispensable action is careful assessment of their real construction and technical condition [13]. As the final resulted of such analyses some examples of different techniques of strengthening of old reinforced concrete floor slabs in historical buildings were presented in this paper. Also, examples of application of modern concrete slabs in place of deteriorated floors (not only the RC ones) were briefly described.

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