12th International Conference on Structural Analysis of Historical Constructions
SAHC 2020
P. Roca, L. Pelà and C. Molins (Eds.)

# FIRST REINFORCED CONCRETE BUILDING IN RIJEKA PORT – FERENC PFAFF'S WAREHOUSE NO. 17

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**Keywords:** industrial heritage, reinforced concrete, frame structure, construction history, reinforcement detailing

**Abstract.** *This paper will explore an early reinforced concrete warehouse, constructed from 1906 till 1909, which is the most impressive warehouse in Rijeka Port – with ground floor dimensions equal to 45x100 m, consisting of a basement, high ground floor and three storeys, designed to sustain 15 kN/m$^2$ floor loading. This warehouse is the first building in Rijeka Port constructed entirely as a reinforced concrete structure and demonstrates significant technical achievements, which have not been sufficiently valorised so far. Besides obtaining information about the structural design of early reinforced concrete structures special attention will be given to better understanding of early 20th century construction techniques and particularly to reinforcement detailing, since original plans and construction drawings with detailed information about the reinforcement have been preserved.*

## 1 INTRODUCTION

As the main port of the Kingdom of Hungary the city of Rijeka experienced significant growth at the end of the 19th and in the beginning of the 20th century, when becomes the largest construction site in the Monarchy. The largest construction works took place in the port where grand extension of the coast was made, with coastline shifts up to even 200 m. The port was built mostly from 1872 till 1894 [1], and can be described as a typical Mediterranean port with wide piers in the shape of a comb, protected by a 1707 m long breakwater (Fig. 1).

By 1940 there were around 40 warehouses built in the port and in the neighbouring railway zone. These warehouses were first built as temporary timber structures but were soon replaced using more permanent materials such as brick, steel and reinforced concrete. Due to damages caused by bombing in WWII and followed by modernization of the Port, there are only nine warehouses preserved from this period [2].

This paper will explore one of this preserved warehouses - the reinforced concrete Warehouse no. 17 (former XIV) located on 120 m long and 80 m wide Visin Pier (former Marie Valerie Pier), which is the largest warehouse in Rijeka Port. Although reinforced concrete has already been used in the port from 1893, as part of the Monier's floors in several warehouses – two of which still exist [3], this is the first building in Rijeka Port constructed entirely as a reinforced concrete structure. This warehouse is protected as a heritage monument inscribed in the Croatian registry of cultural objects. It is still part of the port, but nowadays, due to changes in the way the goods are transported it is no longer in use.

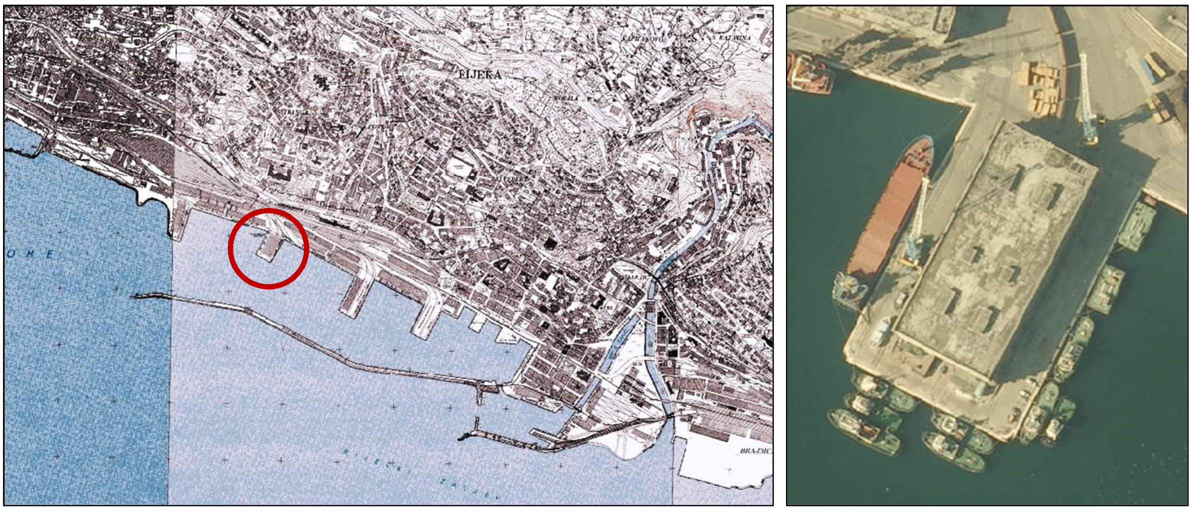

**Figure 1**: The Port of Rijeka with enlarged view of Warehouse no. 17 located on Visin Pier [4]

It should be emphasized that at the same time another monumental building (160 m long, 24 m wide and 17,5 m high) made completely of reinforced concrete was being constructed in Rijeka: the Emigrant Hotel, as the only purpose-built hotel to be used by emigrants travelling to America. It was designed by Szilárd Zielinski, professor of Polytechnics at the University of Budapest, as a frame structure according to Hennebique patent. These two buildings with the earliest use of reinforced concrete place Rijeka side by side with other European cities in terms of introducing new materials and construction techniques.

In this work emphasis will be given to: (I) obtaining information about the design of early reinforced concrete structures; (II) better understanding of early 20$^{th}$ century construction techniques and local peculiarities (reinforced concrete structures were constructed according to systems based on the original patents but were frequently adopted to the individual building as well as to the work of local builders); (III) since original plans and construction drawings are preserved with detailed information about the reinforcement provided (size and spacing of reinforcement as well as joint detailing) the next goal will be to analyse the detailing of reinforcement with an indication of the differences with respect to today’s practice.

We will present results based on the research of archival materials [5], what would be the first step in condition assessment of this historic building. Warehouse no. 17 is no longer in use and there are currently no plans for future usage; on the other hand it demonstrates significant technical achievements, which have not been sufficiently valorised so far, therefore our intention is to point out the importance of this 20$^{th}$ century heritage building.

## 2 ABOUT THE STRUCTURE

Warehouse no. 17 has been designed by Hungarian architect Ferenc Pfaff, at that time in charge of the Building Construction Division of the Hungarian Royal State Railways. It is a symmetric structure 100 m long and 45 m wide, consisting of a basement (with slightly larger dimensions – 100 x 49 m), high ground floor and three storeys (Fig. 2). The basement and the ground floor are divided in the longitudinal direction into two parts, separated by two tracks for railway wagons passing throughout the middle of the ground floor. All the floors above ground floor are divided by transversal walls into five smaller sections 20 m long, each provided with two elevator shafts (Fig. 3). Besides transportation of goods within the building, goods could also be transported from the outside by portal cranes since 1,6 m long cantilevered balconies are located on each floor along the building. A 1,7 m solid concrete slab is used as the foundation of the building (Fig. 4). Such a thick foundation base has been used due to very soft deposit under the pier. The lower edge of the foundation base is 0,3 m below the sea level. Additionally, under the columns 0,3 m deep square 1,3x1,3 m pad foundations are formed.

**Figure 2**: Front view of Warehouse no. 17 [6]

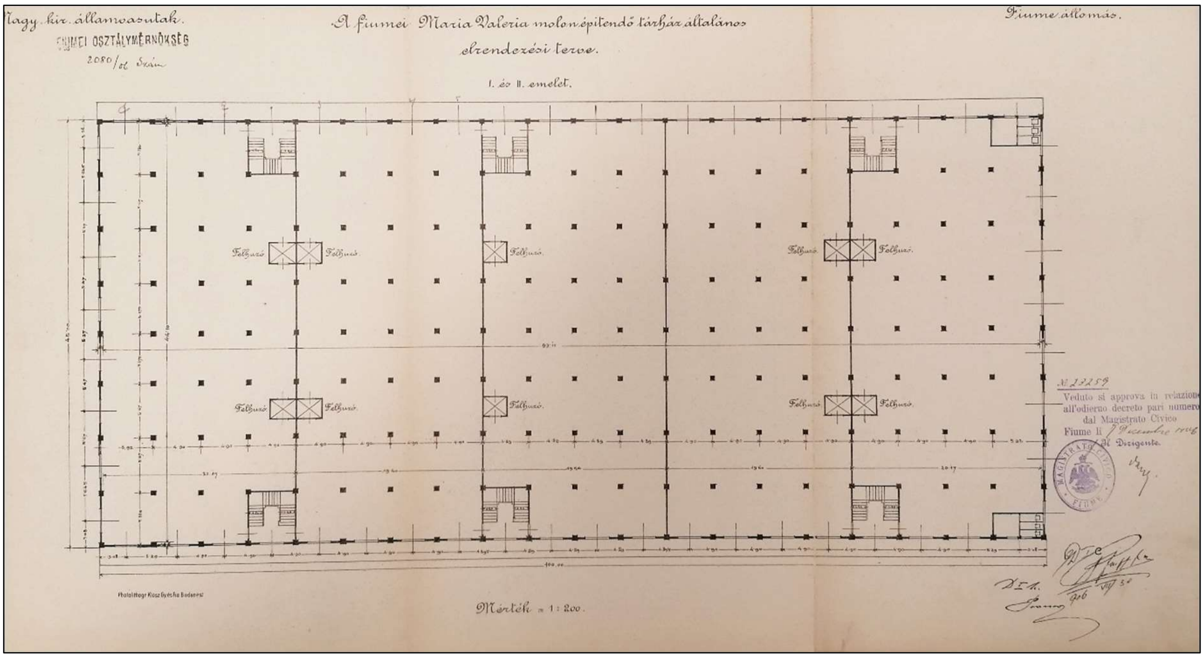


**Figure 3**: 1st and 2nd floor plan [5]

This warehouse is designed as a, for that time common, space frame structure. When selecting cross-sectional dimensions special attention was paid to being economical. Therefore, columns have a square cross-section variable over the building height: from 77 cm in the basement up to only 32 cm on the top floor. Peripheral columns have a rectangular cross-section. There is a total of 189 columns per floor: 9 columns in the transversal direction, spaced at 5,6 m, and 21 columns in the longitudinal direction spaced at 4,9 m (Fig. 3). Besides primary beams, intermediate beams have been added in both directions. In this way the slab span was effectively reduced from the basic grid of 5,6x4,9 m into just 2,8x2,45 m (Fig. 5).

The cross-sectional dimensions are summarized in Table 1. Near the supports (at a distance about 40 cm from the column/beam face) beams have slightly bigger dimensions: 8 cm increased width and 4 cm increased depth. All structural elements are in quite good condition: there is no spalling of concrete or visible rust from the reinforcement (Fig. 5).

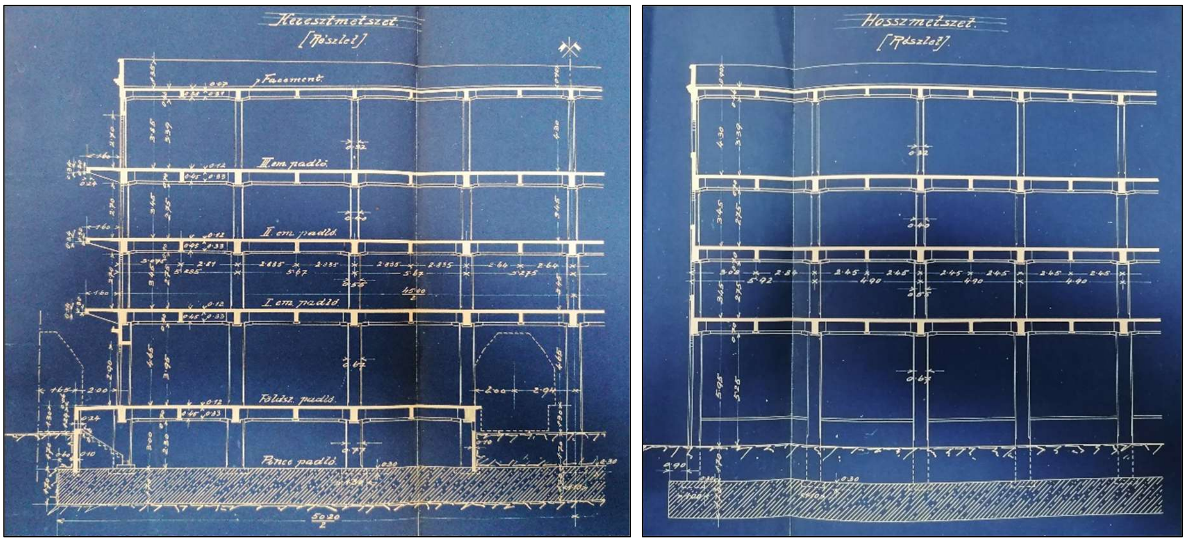

**Figure 4**: Transversal (left) and longitudinal cross sections (right) [5]

**Figure 5**: Layout of the basic column grid (5,6x4,9 m), primary and secondary beams on the 3rd floor [5]

**Table 1**: Cross-sectional dimensions in cm

| | storey height | columns | primary beams (bxh) | secondary beams (bxh) | slab thickness |
|---|---|---|---|---|---|
| basement | 2,30 m | 77x77 | | | |
| ground floor | 3,95 m | 67x67 | midspan: 32x70<br>support: 40x75 | midspan: 24x45<br>support: 32x49 | 12 |
| $1^{st}$ floor | 2,75 m | 55x55 | | | |
| $2^{nd}$ floor | 2,75 m | 40x40 | | | |
| $3^{rd}$ floor | 3,39 -3,84 m | 32x32 | | | |
| roof | | | midspan: 24x46<br>support: 32x50 | midspan: 16x38<br>support: 24x42 | 7 |

## 3 CONSTRUCTION

Warehouse no. 17 has been constructed from December 1906 till January 1909. The building contractor was *Grünwald Testvérek* (Brothers Grünwald) from Budapest. Fig. 6 presents two photographs taken during the construction, where one may notice that first the columns, beams and slabs have been built, while the 10 cm thick façade walls have been added afterwards.

Since the construction site was rather large, there were a lot of participants involved. To be specific occasionally even more than 300 workers were present, although their number varied on a daily basis, mostly due to wageworkers. For example on $29^{th}$ August 1907 (Fig. 7) there were 2 construction foremen, 3 stockmen, 5 mechanics, 57 carpenters, 18 blacksmiths, 42 concreters, 4 stonemasons, 10 women, 167 wageworkers and 6 carriers present at the construction site [5]. Also, on the same day three concrete test specimens (43-45) were cast (no record of obtained concrete strengths was so far detected).

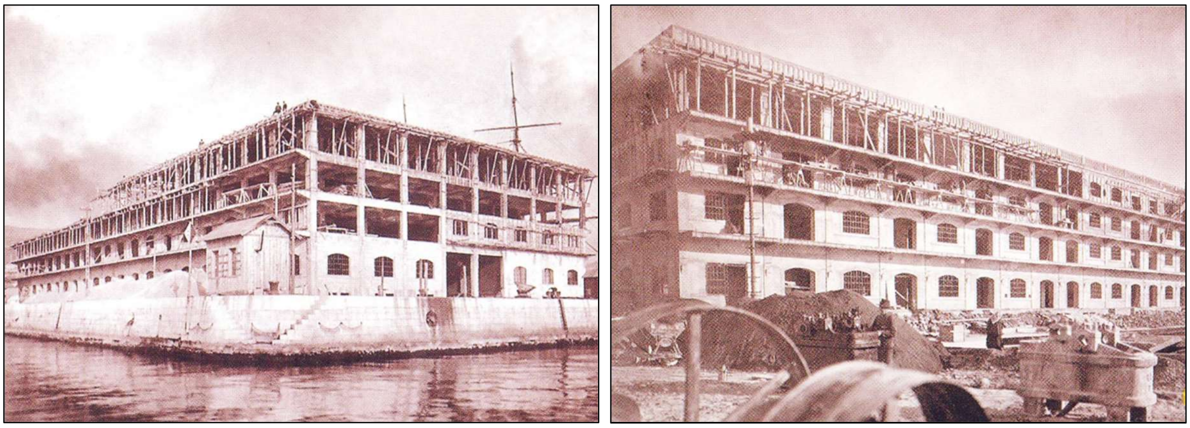

**Figure 6**: Warehouse no. 17 during construction [1]

## 4 STRUCTURAL DESIGN

Structural design and reinforcement plans were made by Kálmán Balogh, a chartered engineer from Budapest. All the floors are designed to withstand imposed storage load of 15 kN/m$^2$, except the (not accessible) roof which is designed for 3 kN/m$^2$. Exterior walls are calculated for wind load of 2 kN/m$^2$.

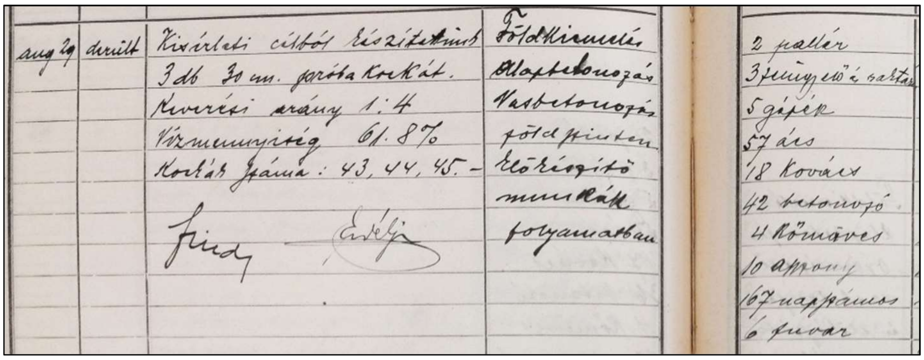

**Figure 7**: An extract from the Construction log book for 29th August 1907 [5]

At the end of the 19th century reinforced concrete has taken such a development that almost every day a new patented system appeared [7,8,9,10]. The theory of reinforced concrete was yet not completely understood (no generally recognized theory existed for the design [11]) and each system had different reinforcement details. At the beginning of the 20th century first standards and regulations appeared: about 1907 in England, France and Germany [10].

According to the linear theory, the stress distribution in the cross section is linear [7,9,12]. Concrete carries no tension, therefore bars are installed in the tensile region (Fig. 8). The rebars should not be subjected to loads exceeding 100 MPa. After hardening for 28 days under normal climatic conditions in 30 cm cubes concrete has to develop a compression strength of 20 MPa. The permissible stress in concrete in bending is limited to 3,5 MPa. The ratio of modulus of elasticity of steel and concrete is adopted as equal to 15 [5].

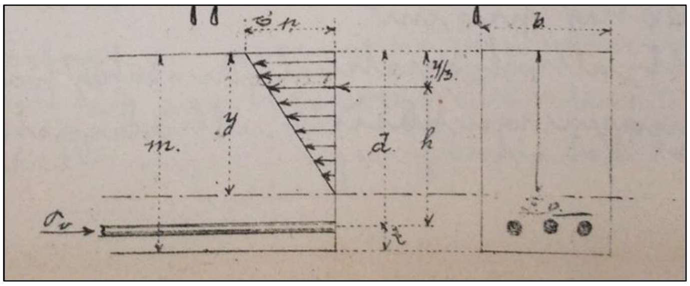

**Figure 8**: Distribution of stresses in reinforced concrete in case of simple bending [5]

Floor slabs are designed as two way spanning plates (Fig. 9). Continuous primary and secondary beams are designed as T-sections only for bending moments, not for shear (Fig. 10).

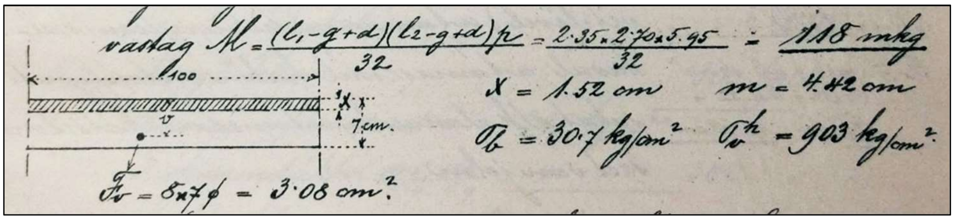

**Figure 9**: Structural design of the roof slab [5] (Note: old units are used in the figure 1000 kg/cm$^2$ = 100 MPa).

It was a common practice until 1908 when Mörsch published his book *Concrete-steel construction* [11] where he introduced the truss model for shear design based on experiments on T-shaped beams. The width of the slab acting with beam was taken as 1/3 of the span. Columns are designed only as compression members (Fig. 11).

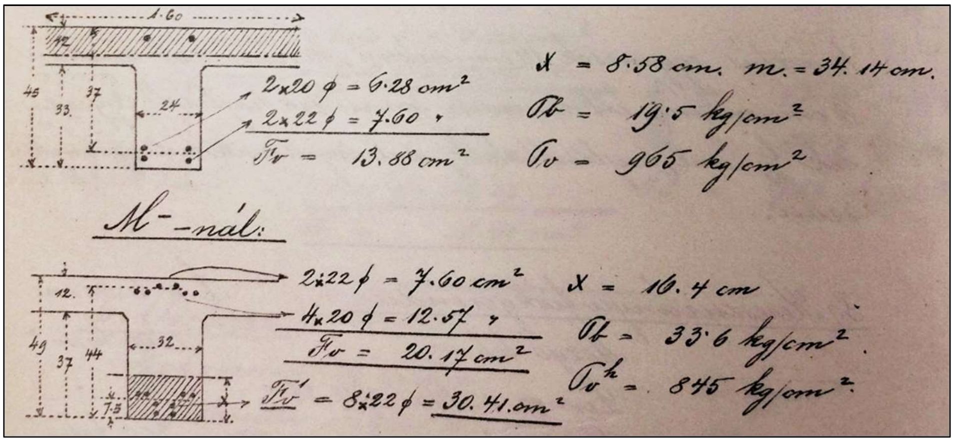


**Figure 10**: Structural design one of the secondary beam with 4,9 m span [5]

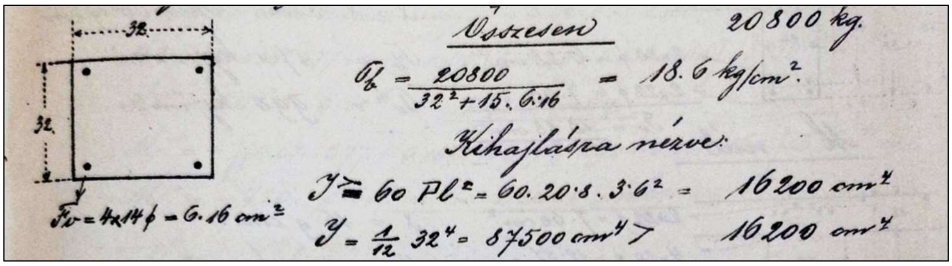


**Figure 11**: Structural design of the columns at the 3rd floor [5]

## 5 REINFORCEMENT DETAILING

Some basic features of the reinforcement detailing, with emphasis on the size, arrangement and shape of reinforcement, will be presented from the original construction drawings [5]. All the reinforcement plans were made by Kálmán Balogh, who used E. Coignet and N. de Tedesco principles for arrangement and detailing of reinforcement.

Concrete cover was not specified on the drawings. We may assume that it is thinner than what is prescribed by standards today, since at the time of construction adverse effects of chlorides infiltration and related deterioration of concrete structures was unknown. As indicative values, we may use values as reported in [11]: (I) recommendations from 1904 prescribe that the concrete cover should not be less than 1 cm, (II) in regulation from 1907 the cover should be at least 2 cm thick in beams and at least 1 cm in slabs.

### 5.1 Slabs

Fig. 12 reviews the reinforcement layout in the roof slab. Rebars ϕ7 are spaced at 16 cm, except in the middle third of the slab where spacing is 8 cm. In the middle third of the slab, half of the reinforcement is bent into the upper zone at the supports, at a distance of L/8 (60 cm) from the axis of the beam, and extended by L/16 (30 cm) over the beam axis (bent bars marked as dashed lines). Fig. 13 presents the reinforcement of the slab before concreting [1].

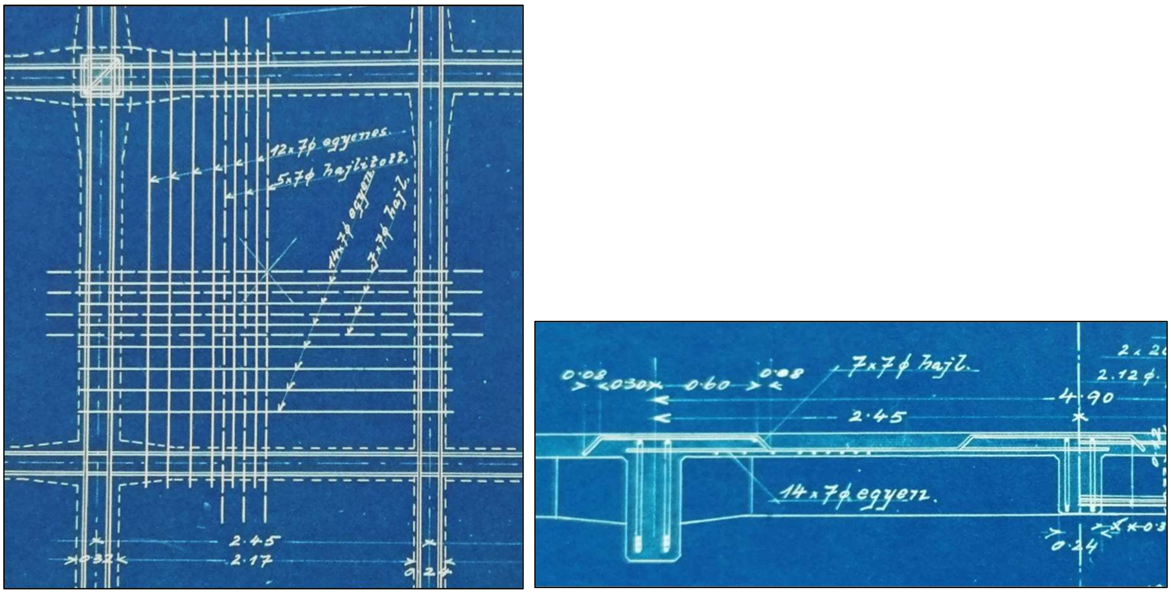


**Figure 12**: Reinforcement details of the roof slab (bars are labeled as: *egyeness* – straight, *hajlitott* – bent) [5]

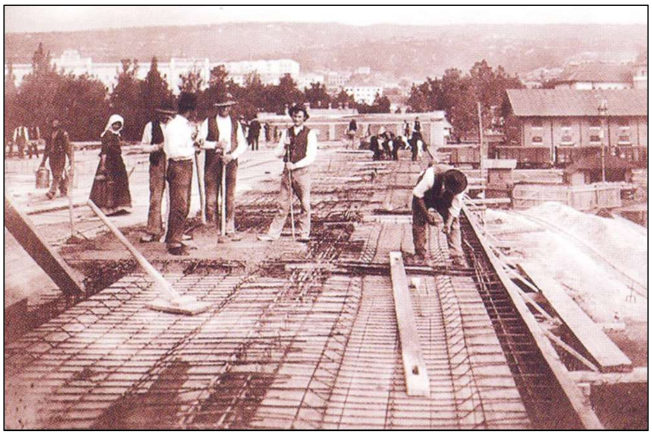

**Figure 13**: Warehouse no. 17 during construction - reinforcement arrangement of the slab [1]

### 5.2 Beams

Table 2 summarises the required reinforcement area in primary and secondary beams, while Fig. 14, 15 and 16 review the reinforcement detailing. Bottom bars (instead of being cut at the point where they are no longer required) are lifted into the upper zone at an angle of 45° and extended over the column, where they serve as main tensile reinforcement. At the same time this bent-up bars also serve as shear reinforcement. Mandrel diameter for bending was recommended as 20-40 cm [5]. The ends of reinforcing bars are not made with a hook (despite using plain round bars), meaning that bond relies only on adhesion and friction.

In addition to bent-up bars special enclosed type bars of trapezoidal shape are placed above the columns (as a "rider") and used as shear reinforcement. In the middle of the span two (or three) upper bars are of smaller diameter than the lower bars (ϕ12 in primary or ϕ10 in secondary beams). They are used for connection with lower bars via stirrups (see also Fig. 17). The branches of stirrups are twisted together over the upper bars so as to tie the bars together [8]: ϕ6 and ϕ5 are used for primary and secondary beams, respectively. Note that this shear reinforcement is spaced at 35 cm in primary beams and 30 cm in secondary beams. This spacing is decreased near supports: first and second spacing measured from the column face are reduced to 10 cm and 25 cm in primary beams, and 10 cm and 20 cm in secondary beams.

**Table 2**: Cross sectional area of required reinforcement in primary and secondary beams [5]

| floor | position | primary beams | | secondary beams | |
|---|---|---|---|---|---|
| | | span 5,6 m | span 4,9 m | span 5,6 m | span 4,9 m |
| ground floor, 1st, 2nd and 3rd floor | midspan bottom | 6ϕ24 | 6ϕ22 | 2ϕ20+ 2ϕ22 | |
| | | 27,14 $cm^2$ | 22,81 $cm^2$ | 13,88 $cm^2$ | |
| | support top | 10ϕ24 | 10ϕ22 | 4ϕ20+ 2ϕ22 | |
| | | 45,24 $cm^2$ | 38,01$cm^2$ | 20,17 $cm^2$ | |
| | support bottom | 8ϕ24 | 8ϕ22 | 8ϕ22 | |
| | | 36,19 $cm^2$ | 30,41$cm^2$ | 30,41 $cm^2$ | |
| roof | midspan bottom | 6ϕ16 | 6ϕ15 | 1ϕ16+ 2ϕ12 | 1ϕ15+ 2ϕ12 |
| | | 12,06 $cm^2$ | 10,6 $cm^2$ | 4,27 $cm^2$ | 4,02 $cm^2$ |
| | support top | 2ϕ18+ 8ϕ16 | 2ϕ20+ 8ϕ15 | 2ϕ16+ 2ϕ14 | 2ϕ15+ 2ϕ14 |
| | | 21,17 $cm^2$ | 20,42 $cm^2$ | 7,10 $cm^2$ | 6,61 $cm^2$ |
| | support bottom | 4ϕ16+ 4ϕ18 | 4ϕ15+ 4ϕ20 | 4ϕ14+ 4ϕ12 | 4ϕ14+ 4ϕ12 |
| | | 18,22 $cm^2$ | 19,64 $cm^2$ | 10,68 $cm^2$ | 10,68 $cm^2$ |

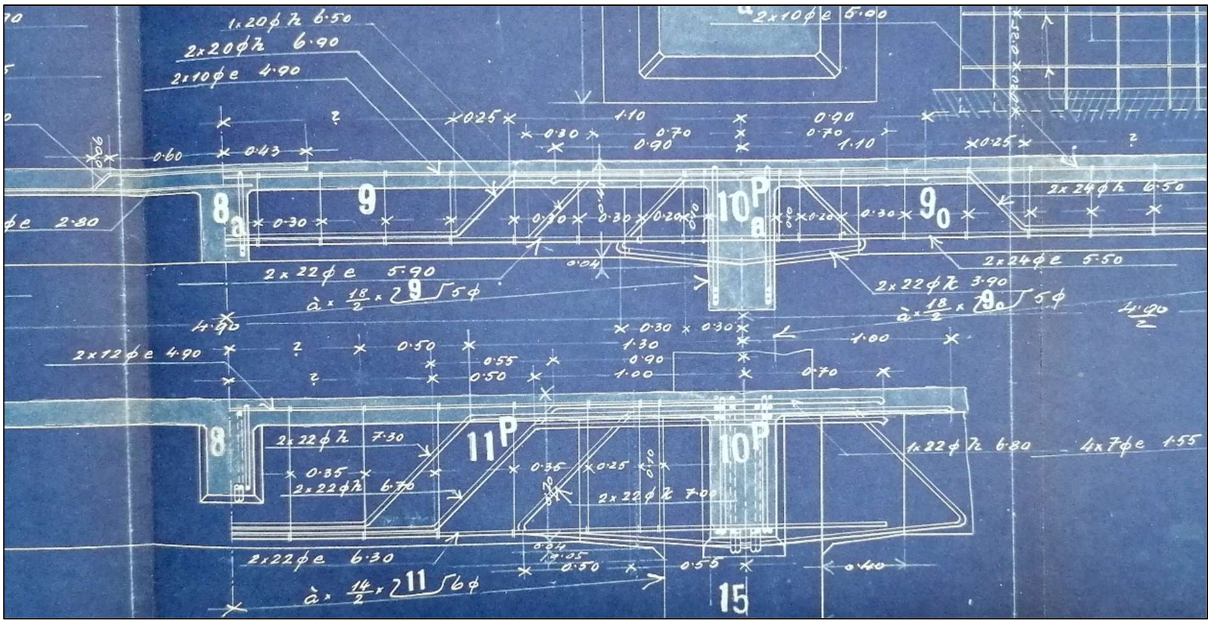

**Figure 14**: Reinforcement details of a secondary (above) and primary beam (below) – above the column in longitudinal direction (bars are labeled as: *e.* – straight, *h.* – bent) [5]

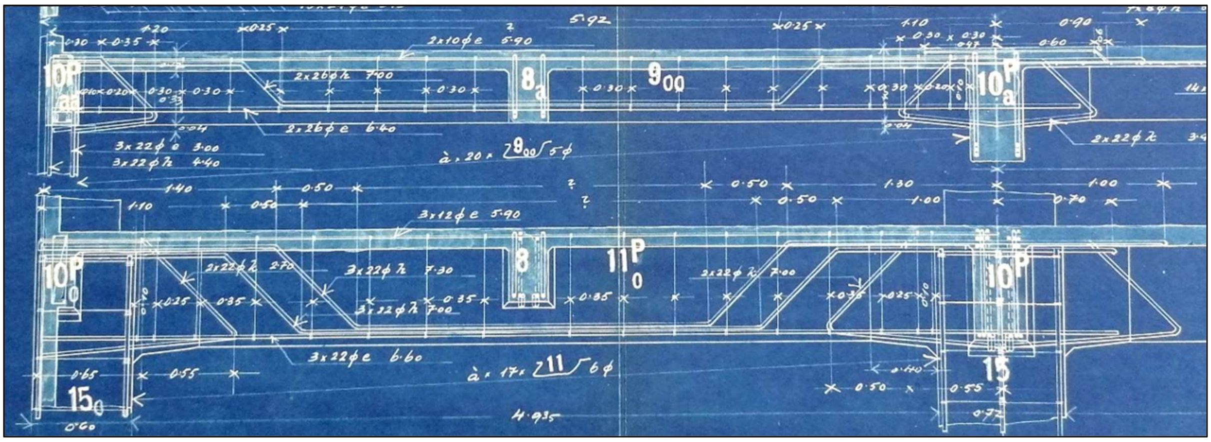

**Figure 15**: Reinforcement details of a secondary (above) and primary beam (below) – end span in longitudinal direction [5]

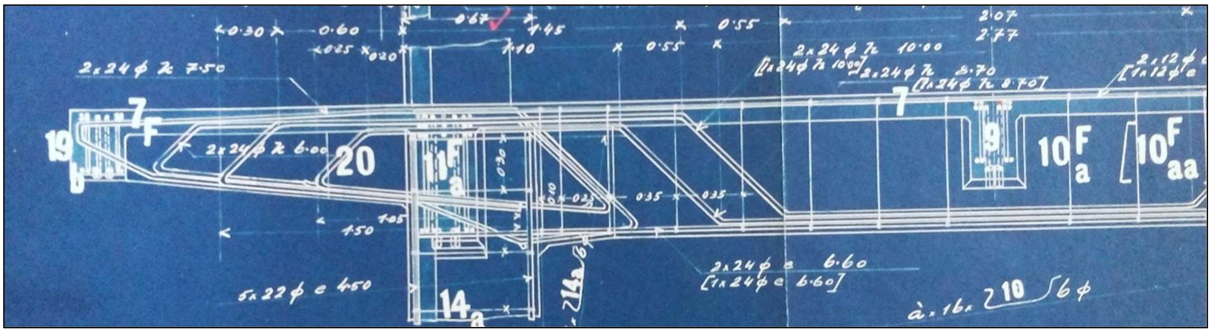

**Figure 16**: Reinforcement details of a primary beam – end span in transversal direction including cantilever [5]

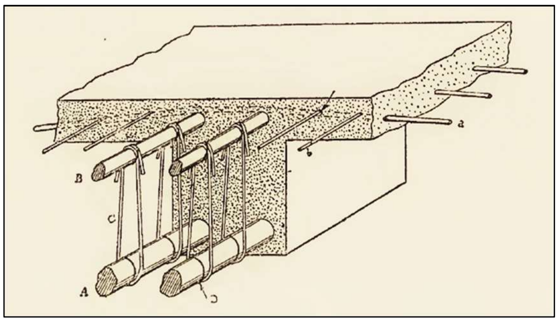

**Figure 17**: System *Coignet* - reinforcement details of a beam [13]

## 5.3 Columns

Columns are rigidly connected with the beams, whilst the haunches in beams give additional strength to the joint. They are reinforced with 8 longitudinal bars, except for columns on 3$^{rd}$ floor which have only 4 bars (Fig. 18). Stirrups enclosing the section of ϕ6 mm are spaced at 30 cm along the entire column length; additional inner links are also provided. Reinforcement for continuity between the floors is marked with red colour.

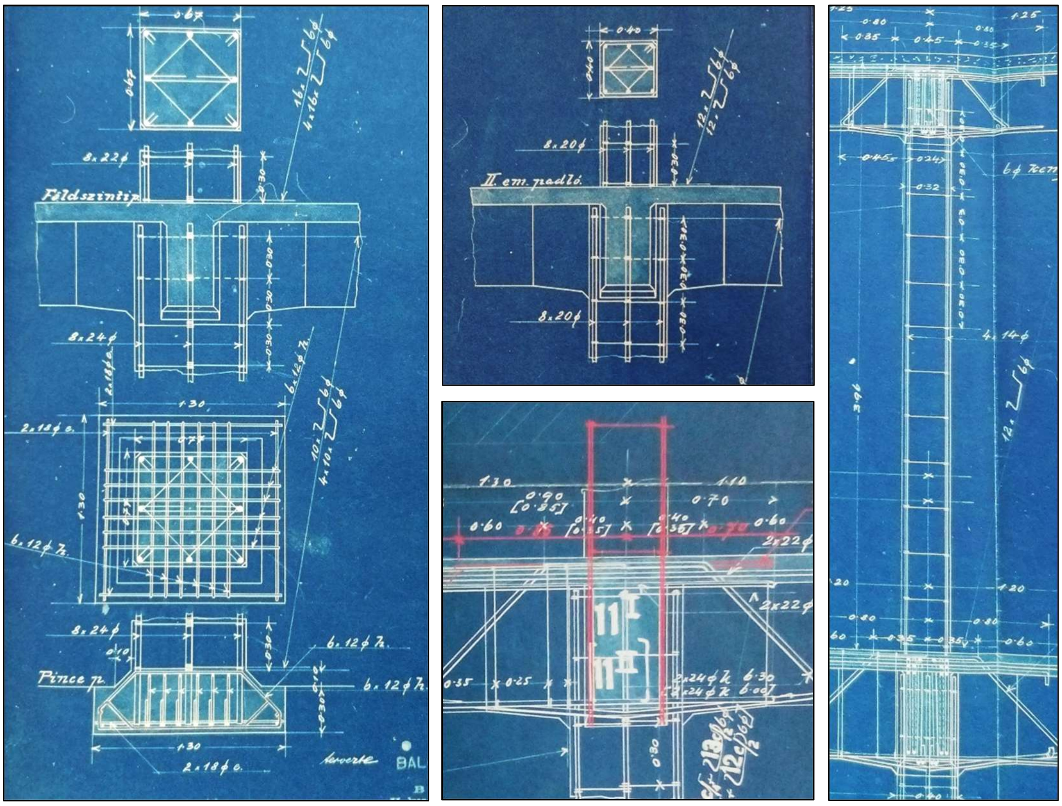

**Figure 18**: Reinforcement details of the columns [5]

## 5.4 Walls

Fig. 19 shows the reinforcement of an inner wall, only 8 cm thick. It consists of vertical and horizontal bars of $\phi 7$ spaced at 25 cm both in horizontal and vertical direction, on both sides of the wall. U shaped anchor bars $\phi 8$ of total length 80 cm are installed in bounding members (beam, column and plate) for connection with the wall.

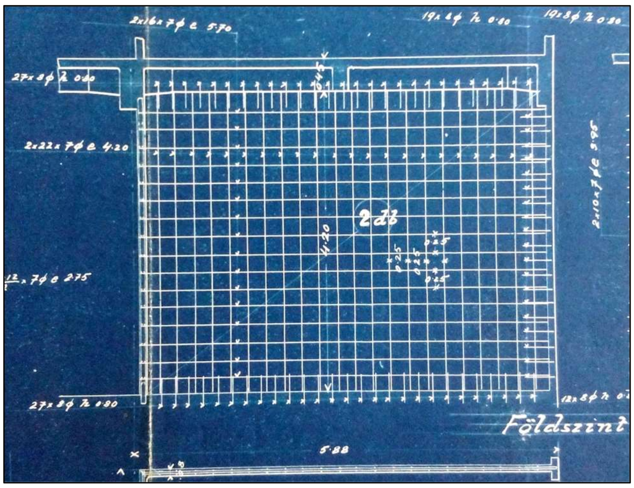


**Figure 19**: Reinforcement details of an inner wall [5]

## 6 CONCLUSIONS

- This paper presents an early reinforced concrete frame structure where special attention was given to better understanding of the early 20th century construction techniques.
- Basic features of the reinforcement detailing rules have been presented. At the time of construction, the theory of reinforced concrete was yet not completely understood and each patented system had different reinforcement details. Nevertheless, regardless of the reinforcement detailing this building is still operational, despite its long-term usage and environmental conditions (located next to the sea).
- This building demonstrates significant technical achievements, which are not sufficiently valorised. Regardless of the age of the building, it still has exceptional potential. Such a 20th century heritage industrial building should be given a new purpose and preserved for future generations.
- We presented results based on the research of archival materials. In the next step a more detailed field research should be performed in order to determine material characteristics (concrete and rebar strength, the amount of chloride ions, through visual inspection, evidences of historical repair) which would be used to assess the remaining lifespan in a more detailed analysis.

**Acknowledgements.** The Authors thank the University of Rijeka for supporting the publication of this paper through grant No. uniri-tehnic-18-127 and No. uniri-pr-tehnic-19-28. The Authors gratefully acknowledge Ferenc Cservenák for providing help with translation from Hungarian.

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