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Building Frames - Aspects of the development of reinforced concrete in Berlin

Estructuras de pilares y vigas - Aspectos del desarrollo del hormigón armado en Berlín

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ABSTRACT

In the beginning building with reinforced concrete meant building rather experimental structures. As experience grew over the years, a first design theory by Matthias Koenen published in 1886 was gradually improved. By 1910 the mixture of concrete was still adjusted according to the structural element or the intended load bearing capacity, but both the form and positioning of reinforcement as well as the structural calculation became more unified.

By presenting selected case studies of early reinforced concrete frame structures from Berlin the paper aims to highlight this crucial period of the evolution of reinforced concrete. Furthermore, it will show by analysis and evaluation of archival material and additional findings made during onsite investigations that the calculation and construction techniques in use around 1900 did not necessarily rely on the latest structural calculation methods. These statically redundant structures are still in good shape and in use today.

Keywords: Construction History; Historic Reinforced Concrete; Frame Structures; Calculation Development; Berlin.

RESUMEN

Construir con hormigón armado significaba en sus comienzos construir estructuras más bien experimentales. A lo largo de los años, la experiencia creció y la primera teoría de diseño de Matthias Koenen, publicada en 1886, fue paulatinamente mejorada. En 1910 la mezcla del hormigón se ajustaba todavía en función del elemento estructural o de la capacidad de carga prevista, pero tanto la forma y posición de la armadura como el cálculo estructural se unificaron.

Con la presentación de algunos casos de estudio de estructuras tempranas de hormigón armado en Berlín este artículo pretende resaltar este periodo crucial de la evolución del hormigón armado. En base al análisis y evaluación del material de archivo y otros descubrimientos derivados de las investigaciones in situ, se demostrará además que el cálculo y la técnica constructiva utilizada alrededor de 1900 no se basaba necesariamente en los últimos métodos de cálculo estructural. Estas estructuras estáticamente redundantes todavía están en buen estado y en uso hoy en día.

Palabras clave: *Historia de la construcción; Hormigón armado histórico; Estructuras de bastidores; Desarrollo de cálculos; Berlín.*

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1. INTRODUCTION

Reinforced concrete was introduced in England and France around the middle of the 19th century (1) and originates from two different forms of application. First from the search for a fireproof ceiling structure and second from building dynamic, free forms such as Joseph-Louis Lambot's (1814-1887) boat or Josef Monier's (1823-1906) plant pots. At this stage the idea of reinforced concrete as an individual building material was not yet understood. Gradually knowledge increased and eventually lead to a first design theory for beams and ceiling structures published in Berlin in 1886 (2). From then on more experimental free forms were only rarely built (3). Contractors and engineers rather built structures imitating forms known from timber or iron construction that were also easier to calculate (see figure 1).

Berlin still has a variety of pre-modern historic reinforced concrete buildings dating back to the 19th century. Research into reinforced concrete structures built between 1886 and 1918 in Berlin is the subject of a current PhD. The objective is to characterise the early applications and to help understand these structures should they become in need of retrofitting.

2. EARLY REINFORCED CONCRETE IN BERLIN

Reinforced concrete in Berlin was very much related to the ideas promoted by Monier or rather Gustav Adolf Wayss (1851-1917). He opened his business in 1886 and in cooperation with Mathias Koenen (1849-1924) their company, later known as Beton- und Monierbau AG dominated the local building market until after the first Prussian public regulations were issued in 1904 (4). Around 1890 Francois Hennebique (1842-1921) emerged as a competitor on the European level (5). He claimed to be the first to introduce a system of monolithically connected columns and beams (see figure 2) (6). However in Berlin his direct influence was minimal.

2.1. Impact of the 1st Prussian public regulations in 1904

The influence of Hennebique and his licensees in the German Empire was rather indirect (7), for example in Berlin only eight buildings were realized between 1899 and 1901 by Hennebique i.e. his licensees (8). Nevertheless his ideas (see figure 2) affected the development of reinforced concrete. The more than vivid discussions between scientists and engineers in the German Empire and other European countries, on the characteristics of reinforced concrete are documented in an extensive number of articles and books. These efforts eventually led to the 1st regulations for building with reinforced concrete in Prussia (9). These had various impacts on building in Berlin. Firstly it offered a more unified calculation routine that could be applied. Secondly it specified the positioning of reinforcement especially for columns and beams. Thirdly because of a more reliable assignment of building permits more companies became part of the reinforced concrete building market besides the famous Beton- und Monierbau A.G., originally founded by G.A. Wayss. For example names such as Baugesellschaft für Lolat-Eisenbeton GmbH, Keppich Eisenbeton or Eisenbetonbau Konrad Schwartz GmbH are now documented.

Leaving aside the different ceiling systems that were available (10), early reinforced concrete in Berlin generally features its own characteristics. Documented findings show ceiling structures with small diameter reinforcement mesh (6-10 mm) and beams and columns with larger reinfocement bars (16-23 mm) and stirrups with (6-8mm).

2.2. The origins of reinforced concrete frames in Berlin

It is specific in the history of reinforced concrete, that frames give a good example of how "[i]n the historical process, the structural engineer [only] gradually discovers the internal logic of the structures he has invented […]" (11, p.528). In the beginning reinforced concrete in buildings was not understood as a complex loadbearing structure, rather single elements such as beams and columns were calculated without composite effects. Nevertheless the way of construction in itself produced somewhat monolithic joints. In 1907 the first publications appeared discussing ways to calculate rigid frames (11, p.529), followed by a book (12) published in 1909 that included structurally indeterminate frames. Despite the increasing theoretical knowledge, examples in Berlin show that it took some time before the theory was put into practice.

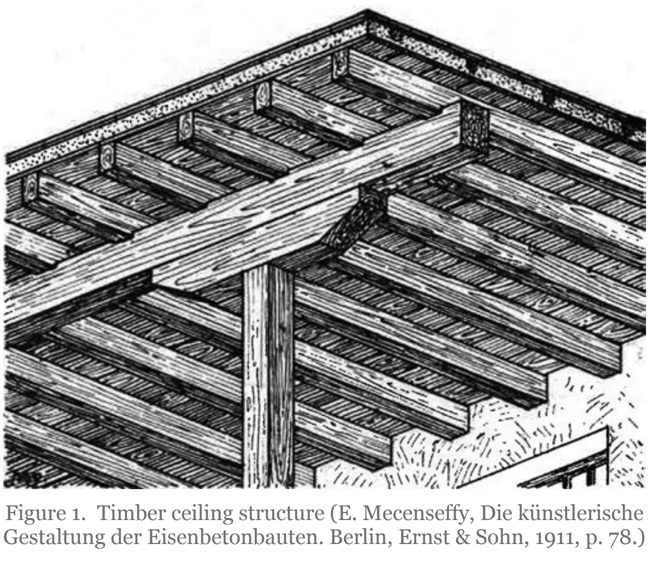

Figure 1. Timber ceiling structure (E. Mecenseffy, Die künstlerische Gestaltung der Eisenbetonbauten. Berlin, Ernst & Sohn, 1911, p. 78.)

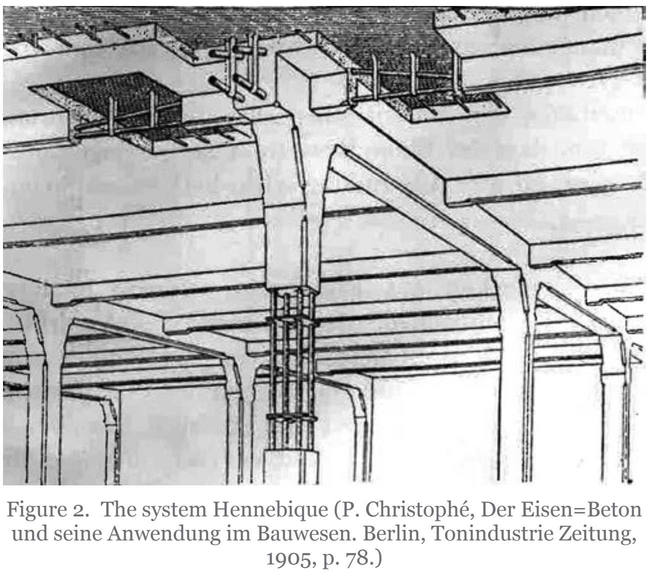

Figure 2. The system Hennebique (P. Christophé, Der Eisen=Beton und seine Anwendung im Bauwesen. Berlin, Tonindustrie Zeitung, 1905, p. 78.)

3. THE VICTORIA WAREHOUSE

The Victoria Warehouse is located along Köpenicker Straße in Berlin with direct access to the river Spree. Built in 1910/11 it was used to store parts of the annual grain supply for the city of Berlin. The building was designed by Franz Ahrens (1858-1937) and realized by the construction company M. Czarnikow & Co.. Their engineer R. Mesmer provided the calculation for the reinforced concrete elements (13).

3.1. Building details

The warehouse design combines a silo and a floor storage unit, featuring a reinforced concrete loadbearing structure that is partly visible from the outside. The building is 20 (m) wide and 60 (m) long, with an eaves height of about 20 (m) (see figures 3, 4 and 5). It is divided into six floors as well as a basement.

The internal layout of the floor storage features three rows of internal columns with a distance of 4.84 (m) in between. The distance from the outermost column to the outside walls is 5.03 (m). In longitudinal direction the distance between the internal columns is 4.44 (m) and to the gable 4.64 (m).

In between columns spans a system of vouted primary (60 (cm) height) and secondary (35 (cm) height) beams. The cross section of columns varies on each floor, from 65 by 75 (cm) in the basement to only 35 by 35 (cm) in the attic.

3.2. Calculation of RC frames 1911

The structural calculation from 1909/10 is documented in the building archive. In general it can be characterized with a very clear, almost standardized structure, following the flow of loads from top to bottom. The calculations in typewriting are supplemented by small pronouncing illustrations. In addi-

Figure 3. North-east facade (axsis I) of the Victoria Warehouse showing the frame structure of the floor storage on the right, 2016.

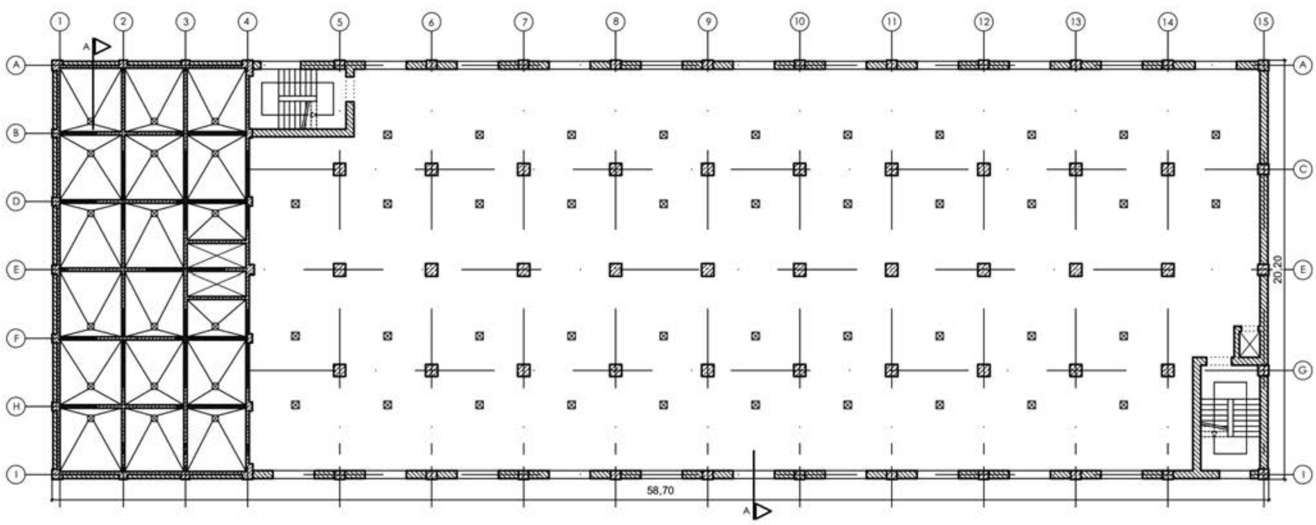

Figure 4. The groundfloor plan of Viktoria Warehouse of the 3rd floor, also indicating section A-A (CAD drawing by M. Kubiczek).

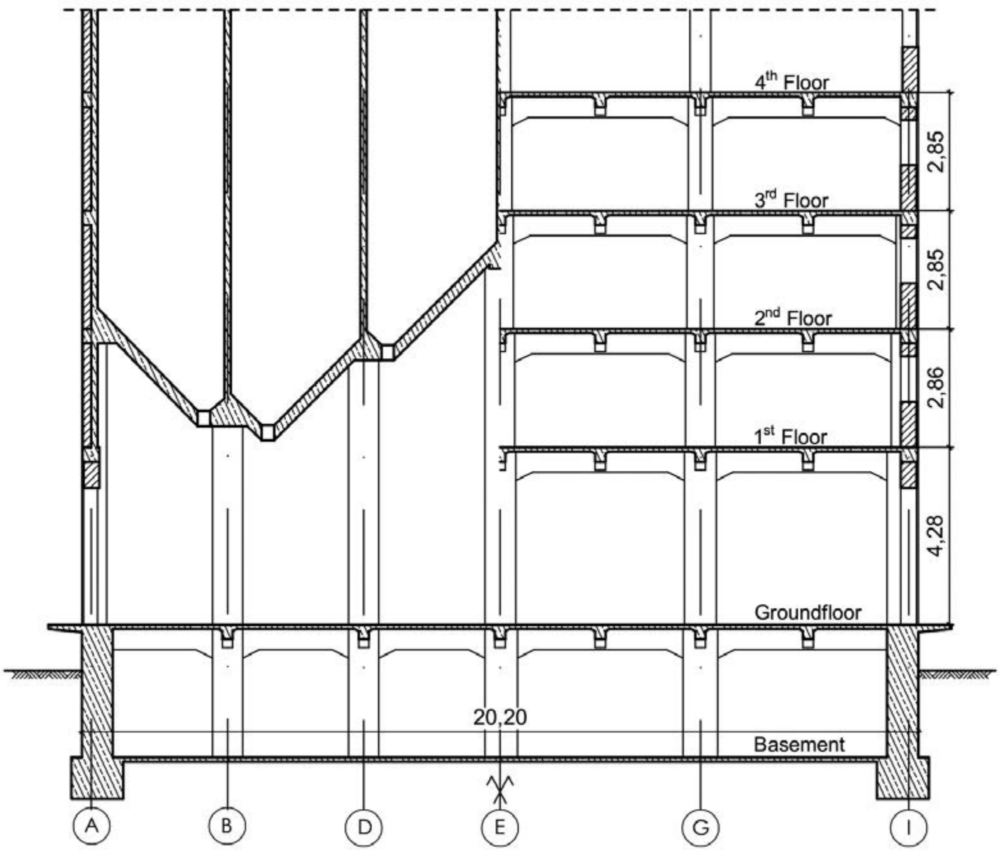

Figure 5. Partial section of Viktoria Warehouse, according to groundfloor, section A-A (CAD drawing by M. Kubiczek).

tion to manual sketches of special load positions, illustrations can also be found for reinforcement distribution and concrete cover for which apparently standardized stamps were used (see figure 6). These suggest that the company routinely carried out structural calculations for reinforced concrete.

The basis of the calculation was the 1907 regulation published by the Prussian building authorities (14). Accordingly, the beams were calculated as continuous. The length of the columns corresponds to the height of each floor.

Based on the documented archive material snow and wind loads were only applied within the calculation of the roof structure. Taking into account the silo storage part of the building the actual stiffness appears sufficient, but nevertheless there was no proof at all for overall wind loads. For live loads 1000 (kg/cm²) were applied.

For a more detailed analysis of the calculation and the design of the reinforcement a focus is put on the floor storage part of the building. Here the ceiling slabs and beams were calcu-

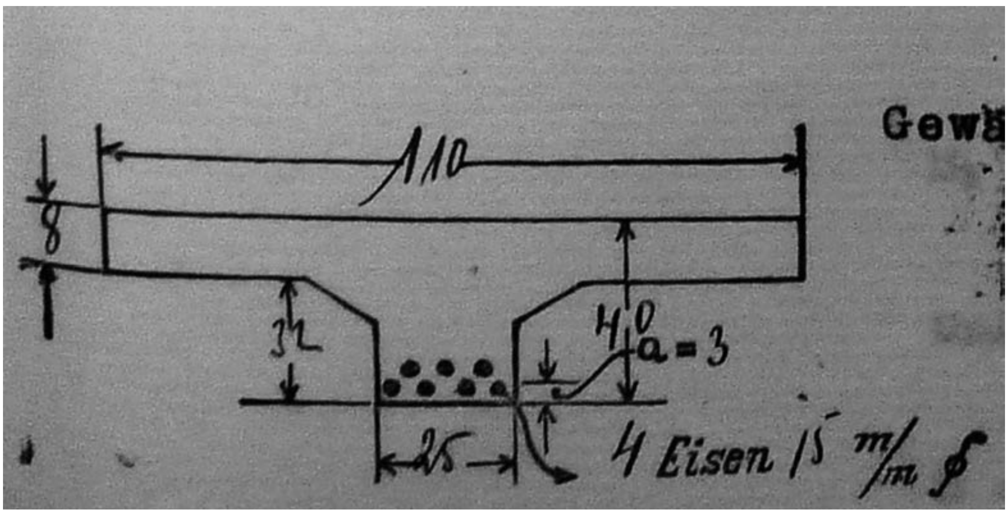

Figure 6. Detail in the structural calculation based on (Bauaktenarchiv Friedrichshain-Kreuzberg, Köpenicker Straße 24-26[a]).

lated as continuous, with negative moments above supports. For shear stress a maximum of 4.5 (kg/cm²) was taken into account. In areas with higher shear stress, reinforcement using stirrups was specified, though no details of the form of these stirrups were given.

A maximum of 40 (kg/cm²) for the compression strength of the concrete was decisive for dimensioning the columns cross section. Irrespective of their size all columns are reinforced with four longitudinal bars, one in each corner. Horizontal stirrups were not calculated.

3.2. Reinforcement routines in 1911

With the building still existing today, it was possible to investigate parts of the floor storage on the 3rd floor using non-destructive measuring devices such as a Profometer 5+. Due to the restricted access the results are somewhat limited. Nevertheless it was possible to compare them with archive material (see figure 7).

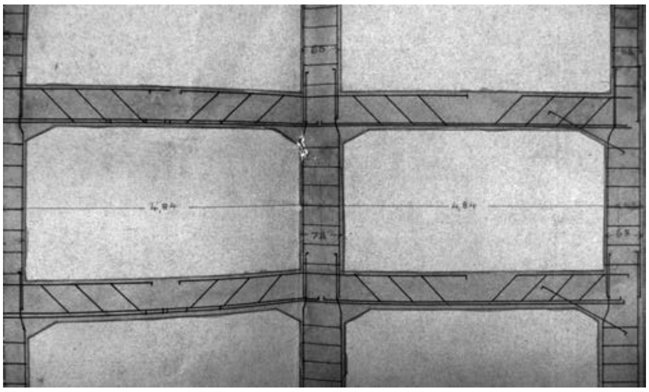

Figure 7. Detail of reinforcement as part of the structural calculation, based on (Bauaktenarchiv Friedrichshain-Kreuzberg, Köpenicker Straße 24-26a).

In conclusion it can be said, that the reinforcement generally meets the specifications in the structural calculation of that time. The ceiling slabs for example show a cross wise reinforcement using diameters of less than 20 (mm) with a spacing of 6 (cm) for the main and 15 (cm) for the transverse reinforcement. Beams are reinforced using also diameters smaller than 20 (mm) and positioned in two layers. The secondary and primary beams were reinforced with stirrups showing a general spacing of 20 (cm) in the field and 10 (cm) close to supports. For columns one reinforcement bar in each corner and also horizontal stirrups with a spacing of 40 to 65 (cm) were detected.

4. THE AQUARIUM BERLIN

The Aquarium is located at Budapester Straße 32 in Berlin. It was built in 1913 and still houses the Aquarium. The architectural design resulted from a close collaboration between Oskar Heinroth, later director of the Aquarium and the Berlin architect's office Zaar & Vahl. The structural calculation bears the signature of O. Leitholf, then a renowned structural engineer for iron structures. This is not surprising since the middle hall was originally covered with a large iron roof structure. Additionally some documents show the name of Eisenbetonbau Konrad Schwartz G.m.b.H..

4.1. Building details

The building (see figure 8) can be divided into three parts: the living quarters (not visible), the entrance (left) and the hall part (right). Only the hall part of the building features a storey frame. The two-hinged story frames surround the middle hall on three sides (see figure 9 and 10). The frames have a span of 7.10 (m) and a varying height of 2.7 (m) in the basement and 5.0 (m) on the ground floor. The beams have a cross section of 30 by 50 (cm) and vouted endings connecting to the columns. The cross section of the columns is continuously 80 by 80 (cm). In between the frames ceiling slabs span the distance of 2.7 (m).

Figure 8. The main façade (axsis F) of the Aquarium in Berlin, 2016.

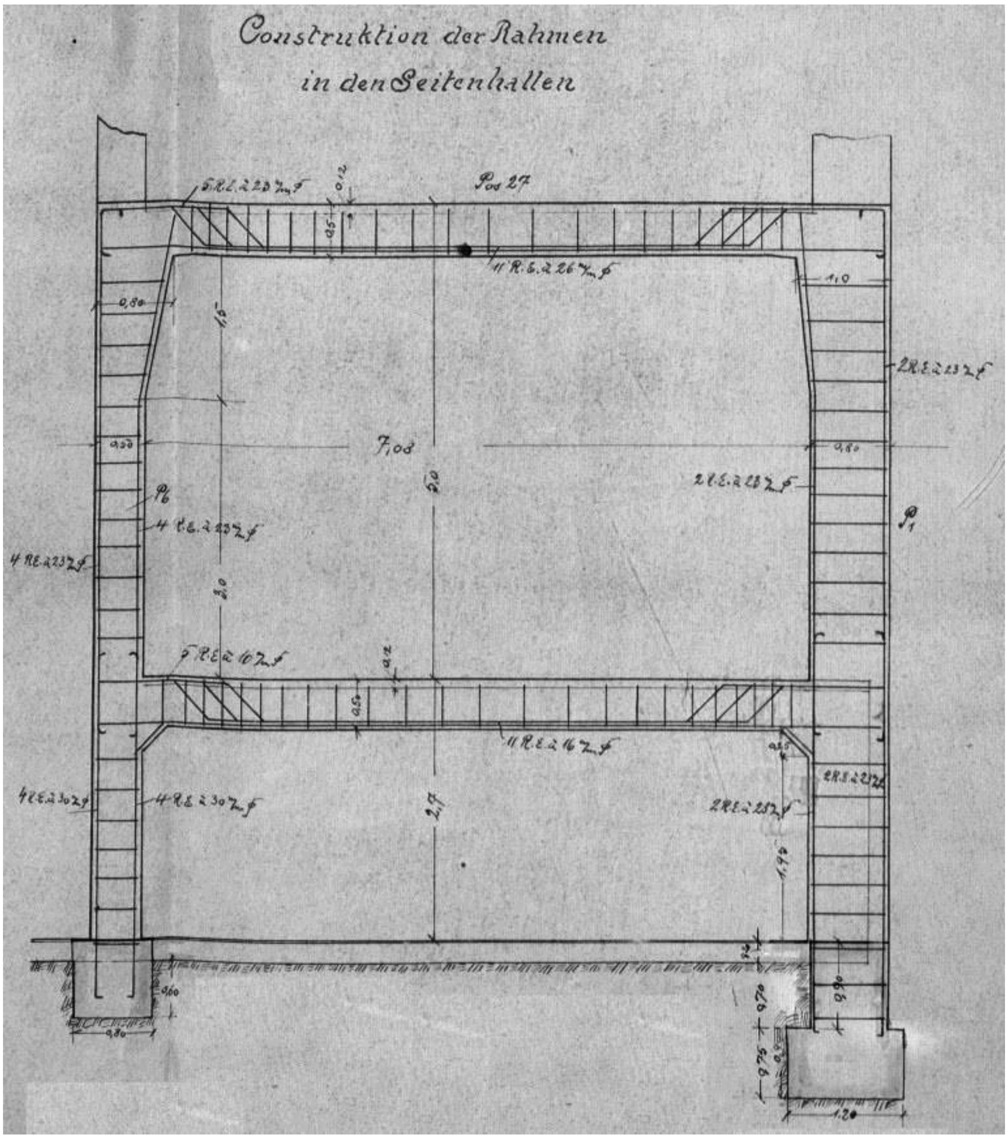

Figure 9. Cross section (section A-A) of the Aquarium in Berlin, based on building permit drawings and onsite investigation.

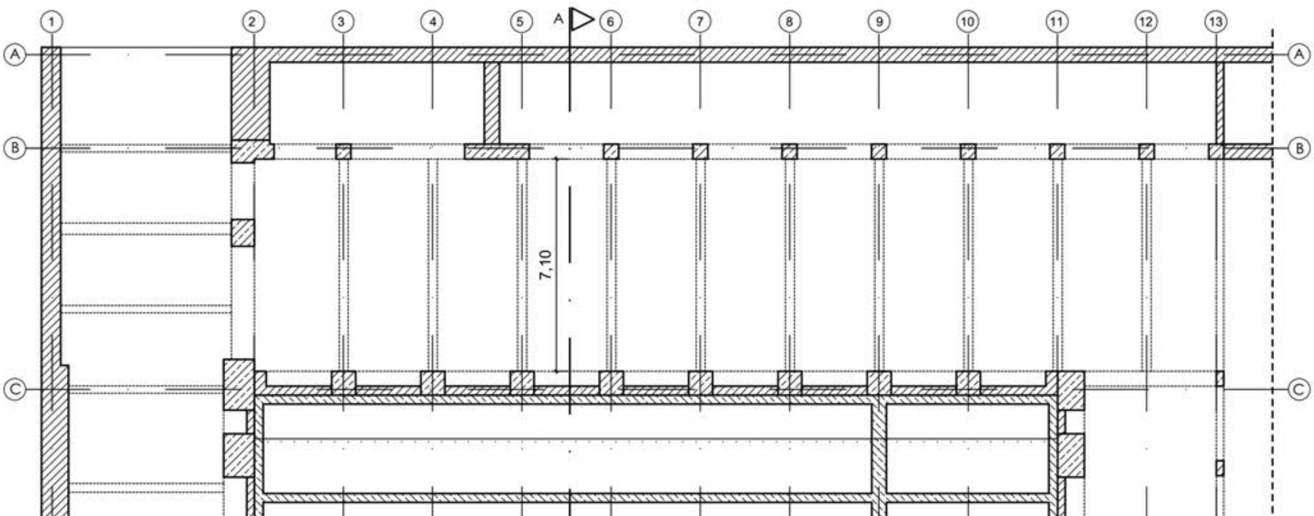

Figure 10. Partial groundfloor plan of the Aquarium, based on building permit drawings and onsite investigation, also indicating section A-A.

4.2. Calculation of RC frames 1913

Originally, the design featured a set up similar to the Victoria warehouse. The structure was composed of ceiling slabs and beams in combination with single storey columns. When analyzing the structural calculations it becomes apparent that due to the input from a specialized contractor the idea of monolithic reinforced concrete frames became part of the design.

Only then bending moments were taken into account where the beams connect to the columns. Thus, parts of the building became one of the first truly calculated monolithic reinforced concrete frames in Berlin (see figure 11). Although the contractor providing the calculation was a specialized company the realization of the structure shows some remarkable deficiencies that will be described in the following paragraph.

4.3. Reinforcement routines in 1913

An investigation after World War 2, in 1953 showed remarkable discrepancies between the planned and the realized reinforcement (15). As part of the PhD research an additional investigation was carried out in parts of the basement and ground floor. While the reinforcement of the ceiling slabs seems correct, the beams show less reinforcement than planned. About 40% of the longitudinal reinforcement was left out. The stirrups appear to have a diameter of about 7 (mm) and a spacing of 30 (cm), while originally flat iron bars were designed. The reinforcement of the columns shows a longitudinal bar in each corner and therefore meets the requirements. The horizontal stirrups within the columns appear to have a smaller diameter of 7 (mm) and spacing of 35 (cm) compared to a 10 (mm) diameter and a spacing of 60 (cm) as originally planned. Furthermore, the form of the stirrups seems to be somewhat irregular and does not follow the outer geometry of the column.

5. CONCLUSION

Although built at the time when a first textbook on reinforced concrete frames was just published, the Victoria Warehouse is still an example of the traditional way of calculation. Despite the outer appearance an analysis shows that it was not designed as a rigid frame structure. Proof that the idea of rigid frames was not yet a standard solution. While only two years later within the building project of the Aquarium a first attempt on building a rigid frame in Berlin is documented. When investigating these two examples one is reminded of Eduardo Torroja and his famous book “logic and form”, where he says that calculating a structure should come after designing it. “[…] Das Bauwerk entstammt niemals der Berechnung; sondern die Berechnung ist es, die der Skizze des Tragwerks entspringt […]“ (16, p.275). Especially with reinforced concrete, where the reinforcement is hidden from view, it becomes even more difficult to estimate the remaining load bearing capacities of these early reinforced concrete structures. In a time where the practical and also the theoretical knowledge were still being developed, each building requires detailed research in order to estimate the quality of the execution and the calculation of the construction.

6. ACKNOWLEDGMENTS

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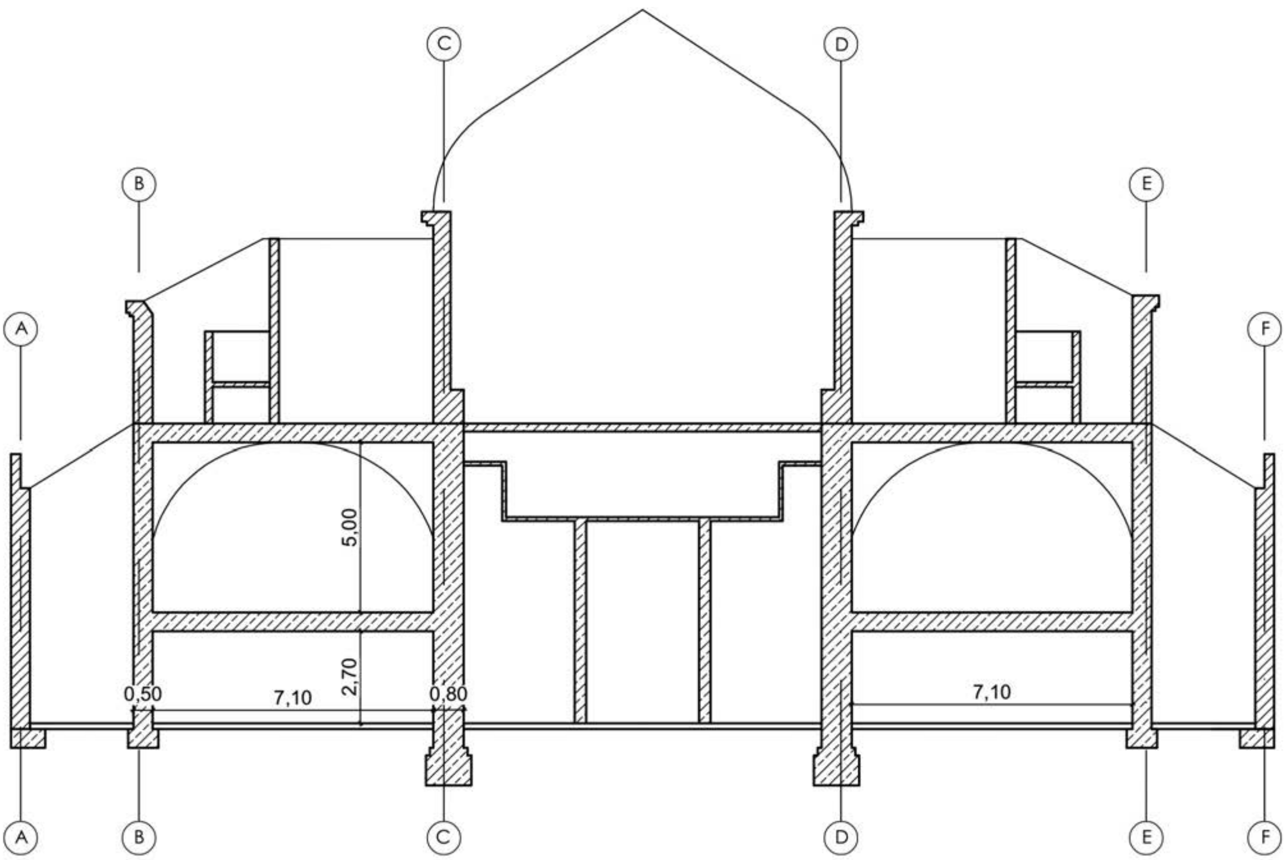

Figure 11. Reinforcement drawing as part of the structural calculation, illustration based on (Landesarchiv Berlin A Rep. 010-02 Nr. 31615).

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