Time to Re-Evaluate? – New Findings on the Application of the Hennebique System in Germany

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Introduction of Reinforced Concrete in the Southwest of Germany

The state of Baden-Württemberg is located in the southwest of Germany, founded in 1952 by merging the post-war states of Württemberg-Baden, (South) Baden and Württemberg-Hohenzollern (Fig. 01). Each of the three original states had been part of the German Empire since unification in 1871. When investigating the introduction of reinforced concrete in this part of Germany, additional boundary conditions that apply (building law, authorities, etc.) due to the different social and political developments need to be kept in mind. The initial situation for the industrial revolution was significantly different in Germany compared to Great Britain. One reason for the delayed development in Baden and Württemberg was territorial fragmentation. At the beginning of the 19th century, industrialisation initially proceeded more rapidly and successfully in the Grand Duchy of Baden than in Württemberg. Baden was located in a relatively convenient position, with the Rhine plain offering an excellent traffic route, including a railway line constructed between 1840 and 1863. Many entrepreneurs with financial resources from France and Switzerland came to Baden from 1836 onwards, to establish at least a branch of their companies in one of the German states in order to benefit from the advantages of the unified customs territory.

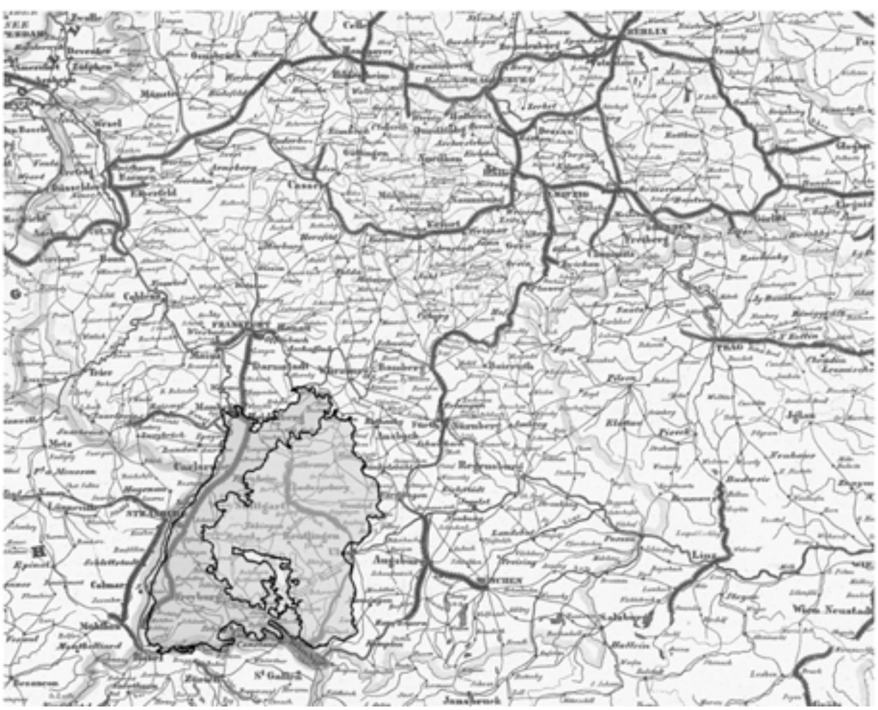

Figure 1: Historical map showing railway connections 1849, marked in grey are the states Baden, Württemberg and Hohenzollern. Scan: Based on Railway map 1849 with additional information

In 1838, Gustav Leube (1808–1881) founded Germany's first cement factory in Ulm (Württemberg) for the production of Roman cement. The founding of quite a number of other cement factories in the region soon followed [1]. The 1860s are considered the pioneering years of the cement industry in Württemberg [2]. Cement factories were also built in Baden during this gold-rush-like period, first in Mannheim and shortly afterwards also in Heidelberg [3]. The Portland cement factory in Heidelberg was founded in 1874 and is still in operation today under the name HeidelbergCement.

The spread of concrete construction, however, was hampered by the variable quality of Portland cement until the early 1870s. In 1868 the scientific work of the Berlin chemist Wilhelm Michaëlis finally established the foundations for the production of Portland cement [4]. Michaëlis was the first to provide precise information about the most favourable composition of the raw material mixture for artificially produced Portland cement. Based on his theses, the first cement standard was issued in 1878 and made mandatory for public building projects. As a result, demand for Portland cement rose sharply in the German Empire in the mid-1880s. With the standardisation of Portland cement, confidence in the newly developed binder ultimately grew.

From an early stage, concrete was used to construct buildings in Germany [5]. One of the oldest concrete houses in Germany is a railway caretaker's house near Blaubeuren (Württemberg), which the Leube brothers built in 1868 using Roman and Portland cement. They wanted to prove the usefulness of cement for building. Also residential buildings (Fig. 02) and even large-scale factory buildings were built using this material. The history of concrete buildings in the southwest is quite diverse.

Figure 2: Early example of a concrete town house called Villa Merkel (Württemberg). Photo: Iris Geiger-Messner LAD 2021.

With the knowhow to build larger concrete buildings and with the development of building with reinforced concrete under the influence of the Monier patent, it was only a question of time before reinforced concrete was properly introduced as a building material. The location of the Monier patentees, Freytag & Heidschuch in Neustadt an der Haardt in the southwest and Gustav A. Wayss in Berlin in the northeast of the German Empire, defined two poles in the development of reinforced concrete. Beginning in Berlin the first reinforced concrete structures were built in 1887, the same year in which a first design theory was published [6], but the realisation of larger buildings using a skeleton frame was only achieved after 1900.

After the expiry of the German Monier patent in 1894, there was no uniform theory about the bonding effect of concrete and iron. Construction companies used reinforced concrete according to their own construction designs and load tests. Above all, the companies Wayss & Freytag (founded in 1893) and Dyckerhoff & Widmann (founded in 1865) significantly advanced the use of reinforced concrete in southern Germany. However smaller regional companies, such as Brenzinger & Cie. from Freiburg, also played a part.

It is generally agreed that François Hennebique (1842–1921) was responsible for the decisive impulse in favour of reinforced concrete in the early 1890s. Hennebique was a French entrepreneur who created a system for reinforced concrete without formal academic training. He connected ceilings, beams and columns into a single unit and thus created the foundations for the widely used reinforced concrete construction method that bears his name. Hennebique had applied for patents in numerous countries from 1892, for example in Switzerland in 1893. These patents, as well as publications in his own journal Le Béton armé, accelerated the spread of his system. Ultimately, he became widely recognised through his presentations at the 1900 World's Fair in Paris.

The history of François Hennebique, his company and his significant contribution to the history of reinforced concrete have been the focus of various investigations over the past 30 years [7]. Based on patent rights and a specific business scheme, Hennebique’s company and a network of concessionaires with permanent licence contracts greatly influenced the introduction of reinforced concrete in Europe. Hennebique only granted execution rights to his licensees. He reserved for his own office the technical processing tasks associated with projects and the preparation of construction drawings in exchange for ten per cent of construction costs. There were also a few concessionaires in Germany. Eduard Züblin (1850–1916) took over the general agency of Hennebique's system for southern Germany in 1898, when he settled in Strasbourg and founded his concrete construction business Ed. Züblin. However, as the paper will highlight, even earlier applications of reinforced concrete in the southwest of Germany included a number of applications based on the 1892 Hennebique Patent. A fine example is situated in Dinglingen/Lahr (Baden), a small town between Strasbourg and Freiburg im Breisgau, close to the river Rhine and with an early railway connection.

The Eckenstein Malting Factory in Dinglingen/Lahr

The malting factory in Dinglingen was one of the most modern malting plants at the end of the 19th century. The original building had been built in 1889, when the area around Lahr had developed into one of the best barley and hop growing regions. For a long time, hop growing was curbed by the authorities in favour of viticulture and so did not become established in Baden until the middle of the 19th century. As a result of the rising population, beer consumption also increased steadily in the late 19th century. In the euphoria, the former brewer Louis Stauffert had built the malting plant in Dinglingen in 1889 [8]. However, the factory owner had overstretched himself financially and quickly had to sell the plant. The malting factory was located in the same neighbourhood as a number of important breweries. The director Eduard Eckenstein of the Schweizer Gesellschaft für Malzfabrikation Basel (Swiss Malt Manufacturing Company, Basel) therefore had a great interest in the Stauffert malting plant. Consequently, Eckenstein bought the plant 1893 as one of five branches in the best barley regions of Europe. The building was extended in 1895 and mechanised a little later. State-of-the-art turners and kilns were purchased and installed in the newly built reinforced concrete extension [9]. By 1927 the company had become the largest malt production company in Europe with five factories spread across Europe. The malting factory in Dinglingen still stands, little changed. It continues to produce malt under the name Malzfabrik Eckenstein & Co. GmbH, Lahr-Dinglingen. The air raids on Dinglingen in 1945 caused little more than glass damage to the malt house [10].

Contractor

The building company Brenzinger & Cie. of Freiburg im Breisgau was commissioned to carry out the reinforced concrete work for the extension of the malting factory in 1895 [11]. Founded in 1872 by Julius Brenzinger (1843–1924), the company had initially specialised in the manufacture of cement ceilings and slabs in the 1870s. At that time, Brenzinger's company bore the additional designations "Cementwarenfabrik, Betonbau-Unternehmung, Stuccatur- und Asphalt-Geschäft" (cement products factory, construction company, stucco and asphalt business) [12].

The installation of a sewer system in Freiburg im Breisgau in the 1880s led to the company receiving important orders for the production of cement pipes. At the same time, concrete building construction developed with the building boom in Freiburg. Thus, Julius Brenzinger, a trained stonemason and sculptor, also began to produce artificial stones as imitations of natural stones. In 1893 he gained national attention with his artificial stone production when he was commissioned by the Portland-Cementwerke Heidelberg-Mannheim to deliver an impressive collection of artificial stones for the World Exhibition in Chicago [13].

The construction company had already started using reinforced concrete in construction in the early 1890s. However, the factory in Dinglingen was its first larger building structure using reinforced concrete. Julius Brenzinger was particularly interested in concrete technology [14]. In 1898 he became co-founder of the Fachverein für Beton (Professional Association for Concrete), later known as Deutscher Beton-Verein (German Concrete Association). As chairman of the association, he regularly attended its meetings in Berlin. At this time Brenzinger used the Hennebique system, but later on he also used the Monier system [15]. It is not known how the company actually gained its knowledge of the Hennebique system. According to Hennebqiue`s company publication Le béton armé, Brenzinger was never listed as official concessionaire [16].

The first decades of Brenzinger & Cie. were characterised by growth as well as technical and artistic excellence. Julius Brenzinger already employed 140 people at the turn of the century when his son Heinrich (1879–1960) joined the company. By 1912 the construction company had almost 400 employees at various locations. The construction of bridges, elevated reservoirs, hydroelectric power plants, water towers, large factory buildings, hotels, sanatoriums and churches brought considerable inspiration and promoted reinforced concrete construction during the period when this construction method was flourishing. The Technical University of Karlsruhe awarded Julius, and later Heinrich, Brenzinger honorary doctorates for their achievements, and the Deutsche Beton-Verein named Julius Brenzinger an honorary member. The company's last significant buildings included large construction projects during the reconstruction period. In 2008 Brenzinger & Cie., now managed by the fourth generation of the Brenziger family, was transformed into a real estate company.

Architect

The design for the extension was carried out by the Freiburg architect Johannes Flink, who specialized as a brewery architect under the company name J. Flink & Cie [17]. Unfortunately, personal information about Flink is very scarce. His name and address were still listed in a Freiburg im Breisgau address book of 1922 [18].

The Building

The company premises of the still-functioning factory include a number of buildings from different times. However, the original building from 1889 still dominates the complex. It is a five-story high (about 22 metres) masonry building with an elaborate décor using different coloured bricks and pilaster strips. The decorative triangular gables were destroyed in the 1950s. The rectangular layout features an east–west orientation, with sidewalls 32 metres in length and gable walls about 19 metres long. The factory building and the extension were originally sloped with earth to protect them from heat. (Fig. 04)

From the beginning, the building enjoyed a connection to the nearby railway station. From there, after reloading into smaller carriage waggons the malt was delivered directly to the factory to be processed. (Fig. 03) This railway connection no longer exists, and delivery and collection are now solely by lorry.

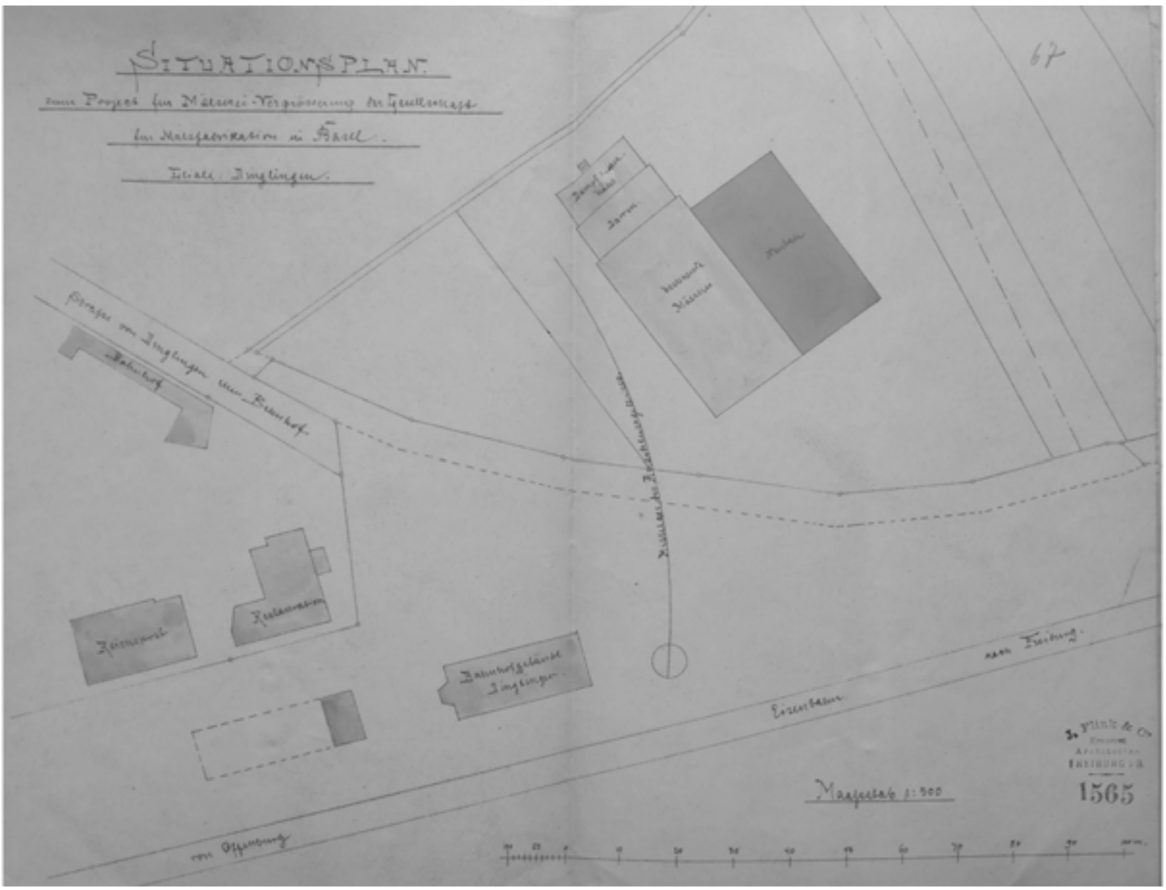

Figure 3: Map of the company property (the reinforced concrete extension is marked) as part of the building application of 1895. Photo: Kuban. Lahr Building Authority Archive.

The extension of 1895 to the south side of the factory building (Fig. 03) connects to the main building via a doorway on each floor. Contrary to the drawing of 1894 (Fig. 03) the extension was two-storeyed, of which only one storey was above ground.

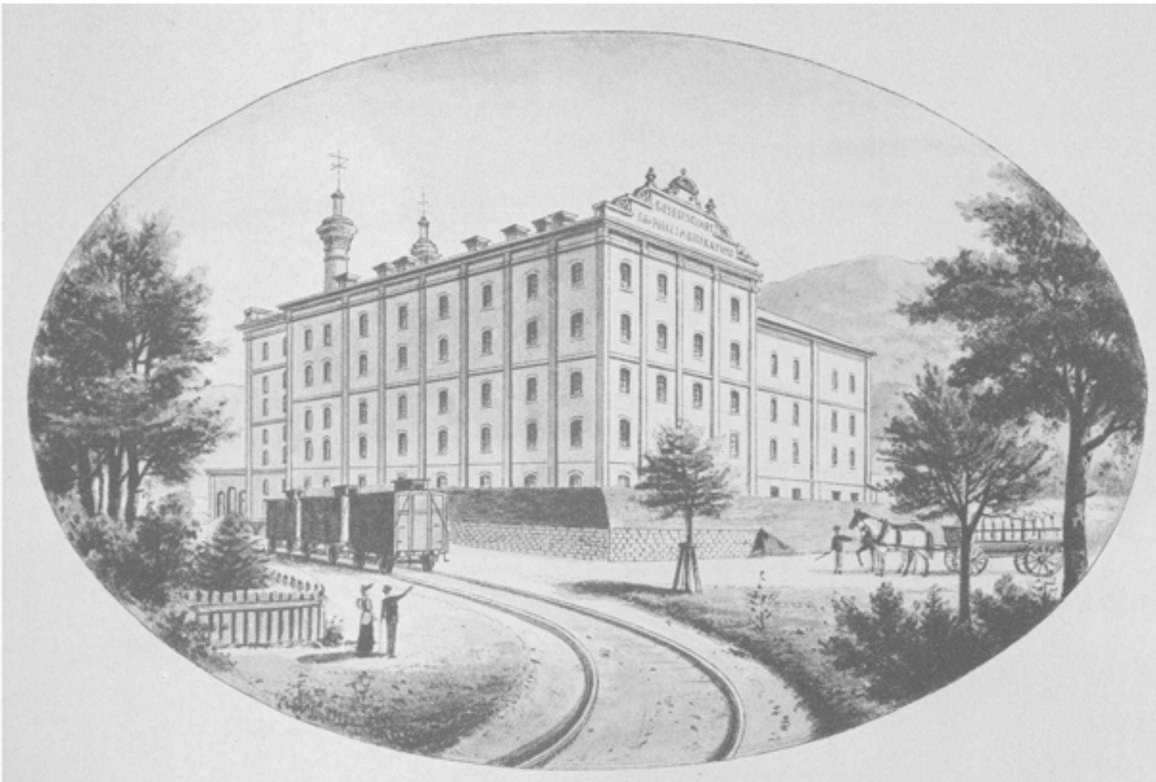

Figure 4: Drawing of the northwest façade of the malt factory in Dinglingen/Lahr. Photo: Wirtschaftsarchiv der Universität Basel, SWA H / Ba 501 Businessreport of the Gesellschaft für Malzfabrikation Basel, (presumably 1894).

In the building permit documents (dated April 1895), the structure is referred to as a cellar building. According to the accompanying drawings, both storeys were planned underground. The actual height of the earthen slope is not documented (compare Fig. 04 and Fig. 05). The building permit application includes a floor plan and a section. Unfortunately, more detailed drawings of the reinforcement, its form, dimensions and positioning are not documented [19].

The following descriptions are based on the construction drawings from the application for the building permit, as well as on findings from an onsite investigation focussing on the basement. The building itself covers an area of about 23 metres in width and 32 metres in length. The distance between floor and ceiling level is about 3 metres in both storeys. The top storey (i.e. the ground floor) has an incline of the ceiling level to the south.

The interior layout from north to south includes three rows of reinforced concrete columns 5 metres apart. Each row (from east to west) consists of five columns with a distance of 5.10 metres between each column. (Fig. 06) The columns on the upper floor have a dimension of 35 by 35 centimetres, while the columns in the bottom floor have a dimension of 41 by 41 centimetres.

The ceiling structures on both floors include three different beam types, with types two and three running perpendicular to type one. The following description concentrates on the basement structure. Here the primary load-bearing beams have a dimension of 18 by 33 centimetres and run east to west in the axis of the columns. Their supports at the columns as well as at the outer walls show haunches. The secondary and tertiary beams run north to south. The secondary beams also run in the axis of the columns and have a dimension of 18 by 24 centimetres. Their supports also show haunches. It should be noted that the built dimensions of the haunches, both with the primary and the secondary beams, show a length of 88 centimetres. Thus they are much larger than originally planned. The tertiary beams run north to south in between the column axes and have a dimension of 18 by 27 centimetres. These beams have a rectangular form without haunches. The ceiling between the basement and ground floor has a thickness of 10 centimetres.

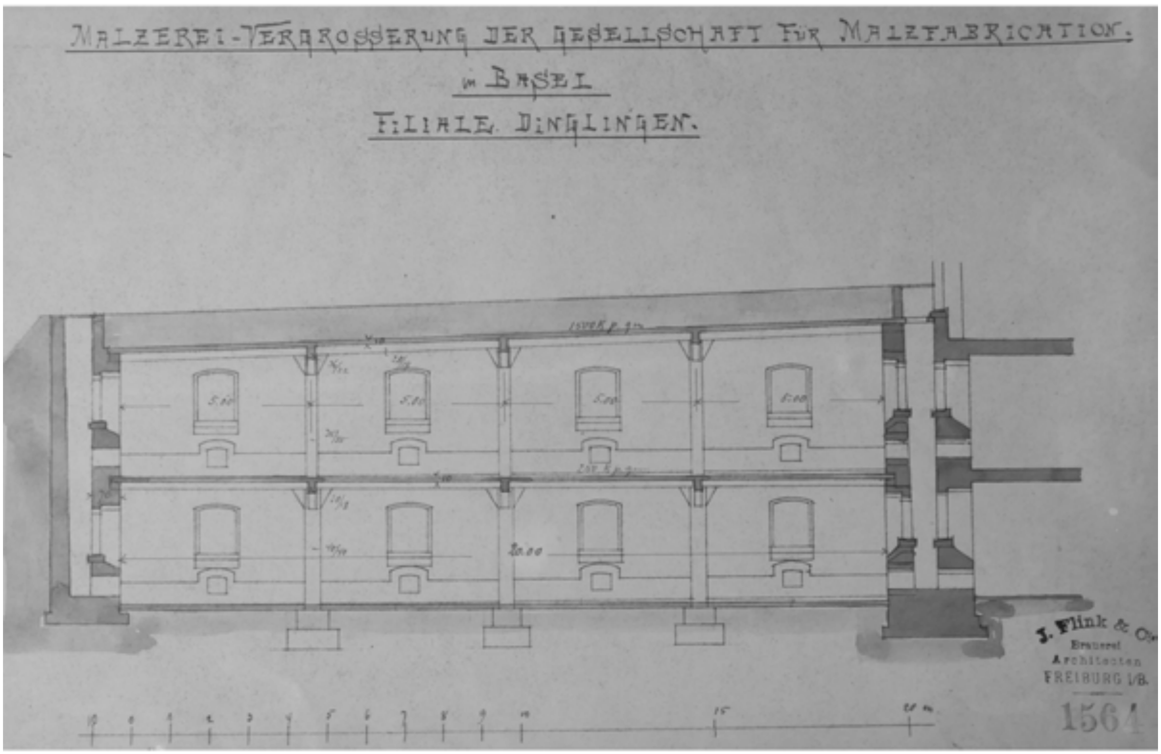

Figure 5: Section drawing (north–south orientation) as part of the application of building permission, 1895. Photo: Kuban. Lahr Building Authority Archive.

Brenzinger had obviously used information from the Hennebique system when building the extension to the malt house. In his company brochure, and later in a company chronicle to celebrate the company's 50th anniversary in 1922, he gladly listed the malthouse as a reference, describing it as using reinforced concrete ceilings in Hennébique construction, executed in 1895 (Fig. 07) [20]. And although the building records do not include a direct reference to Hennebique, the structure itself gives definite proof.

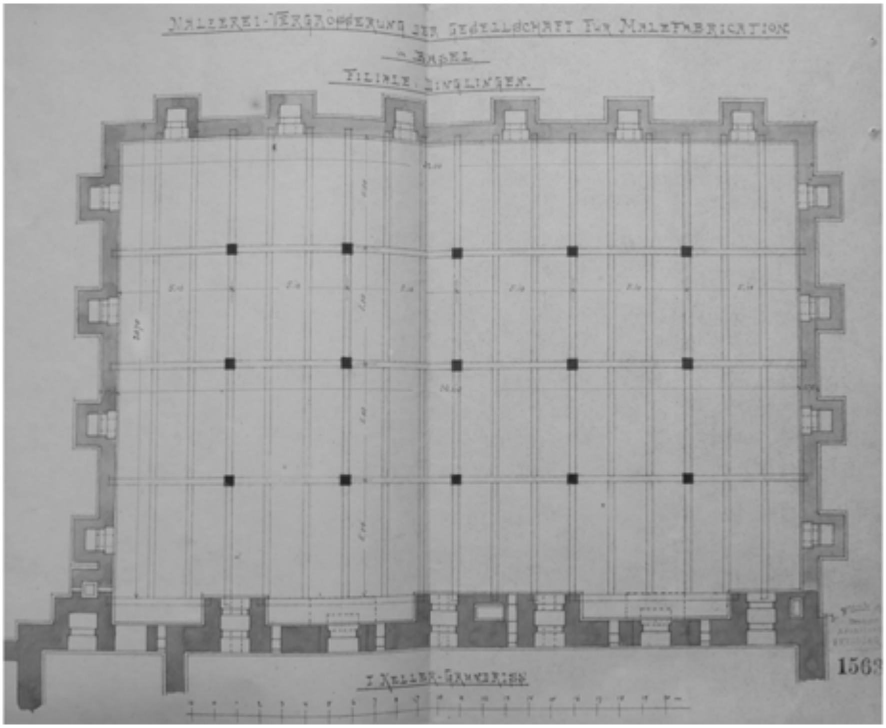

Figure 6: Ground floor plan, with the 15 columns highlighted as part of the application of building permission, 1895. Photo: Kuban. Lahr Building Authority Archive.

Figure 7: Interiour of the extension of the malt factory. Photo: Company chronicle for the 50th anniversary of the Brenzinger Company (1922), Badisches Landesmuseum Karlsruhe Außenstelle Südbaden: BA 2000-01514_Scan01_LABW_Staufen.

The Hennebique System

The Hennebique system is known for its flat iron stirrups, designed to absorb sheer forces and hold the longitudinal iron reinforcement in position. These, as well as round shaped reinforcement bars, were part of the design from the start. However, the composition of the reinforcement evolved over time [21].

By rigidly connecting the vertical columns with horizontal ribs and beams, a monolithic structure was created. The external shape consists of beams connected with haunches, a longstanding characteristic of monolithic reinforced concrete constructions that is generally associated with Hennebique. In order to compensate overlapping stresses and the supporting moment of crossing beams, haunches were included in the structure.

Wilhelm Ritter (1847–1906), Professor at the Eidgenössisches Polytechnikum in Zurich, sketched the course of forces in such a reinforced beam in 1899 through an analogy to the truss girder [22]. Even before, and around the same time as the malting factory was being built in Dinglingen/Lahr, the engineer and contractor Armand Favre (1859-1899) from Zurich had presented the advantages of the Hennebique system in an article in the Swiss construction journal Schweizerische Bauzeitung in February 1895 [23]. The reinforcement at the malting factory in Lahr/Dinglingen was designed accordingly.

Initially, Hennebique's reinforced concrete structure was supported with masonry perimeter walls. [24] Hennebiques T-beam system was the common for high loads and large spans [25]. For higher loads, round iron reinforcement bars were placed close together and even several times on top of each other. For large spans, secondary beams perpendicular to the main beams were common. Hennebique arranged longitudinal reinforcement bars in the columns in combination with flat iron strips as transverse connections to secure their position [26]. These horizontal, perforated flat iron strips, were a characteristic of Hennebique and gave the longitudinal reinforcement bars support during concreting. (Fig. 10 left)

The Malting Factory and its Reinforcement

Neither the original structural calculations nor the reinforcement design for the malting factory are documented, and it is not clear if and in what way François Hennebique and his company were directly part of this building project [27]. However, the findings in the malting factory seem identical to the flat iron stirrups used in the Hennebique system. (Fig. 08)

Figure 8: Stirrup for ceiling reinforcement found at the malting factory. Photo: Buchenau 2020.

As a result of aging and the corrosion of the reinforcement, the building structure nowadays lacks parts of its concrete cover and thus allows a direct investigation of the reinforcement of the ceiling, beams and columns. (Fig. 09) The ceiling slabs (10 centimetres) in both storeys have small round bars (ø 6 millimetres, 25 centimetres apart) spanning one-way between the tertiary beams, as well as small stirrups (Fig. 08). The stirrups in the ceiling slabs are made from iron strips with a thickness of 2.5 millimetres and a width of 20 to 23 millimetres. Bent to shape, each stirrup has a height of about 9 centimetres, leaving a concrete cover of about 0.5 centimetres at the top and bottom of the ceiling slab.

All the beams have longitudinal round bars with a diameter of more than 30 millimetres, positioned along the bottom flange and larger stirrups. The stirrups in the beams are also made from iron strips but with a thickness of 3 millimetres and a width of 40 to 47 millimetres. The height of these stirrups remains unclear as their ends are encompassed from the ceiling slab. Along the length of each beam, the stirrups are positioned with a distance of about 15 centimetres. (Fig. 09)

Figure 9: Details of the basement structure in its current state. Photo: Buchenau 2020.

The beams underneath the ground floor ceiling slab have up to four bars in the bottom layer and additional bars in a second layer around the middle height of the beams. The beams in the basement have only two bars each, in a single bottom layer. This obvious difference of the reinforcement ratio can be explained through the original design. The records show that the ground floor ceiling was designed for a live load of 15 kN/m² (resembling a significant cover of earth) while the ceiling between basement and ground floor was designed for a live load of only 2.5 kN/m². (Fig. 05)

The columns have round bars (ø 23 millimetres) as longitudinal reinforcement and horizontal stirrups with a spacing about 65 centimetres. The column stirrups are made from iron strips with a thickness of 5 millimetres. (Fig. 10)

Interestingly, the constructed structure almost perfectly matches a design made for a warehouse in Antwerp in 1894 by Henri Hertogs (1861–1930), a Belgian architectural engineer [28]. Both projects prematurely incorporate the system Hennebique patented only in 1896. Even more astonishing is the fact that the first design drawing for the project in Antwerp predates contact with the Hennebique company office. The Antwerp design was never executed, making the building in Lahr/Dinglingen an even more precious temporary witness.

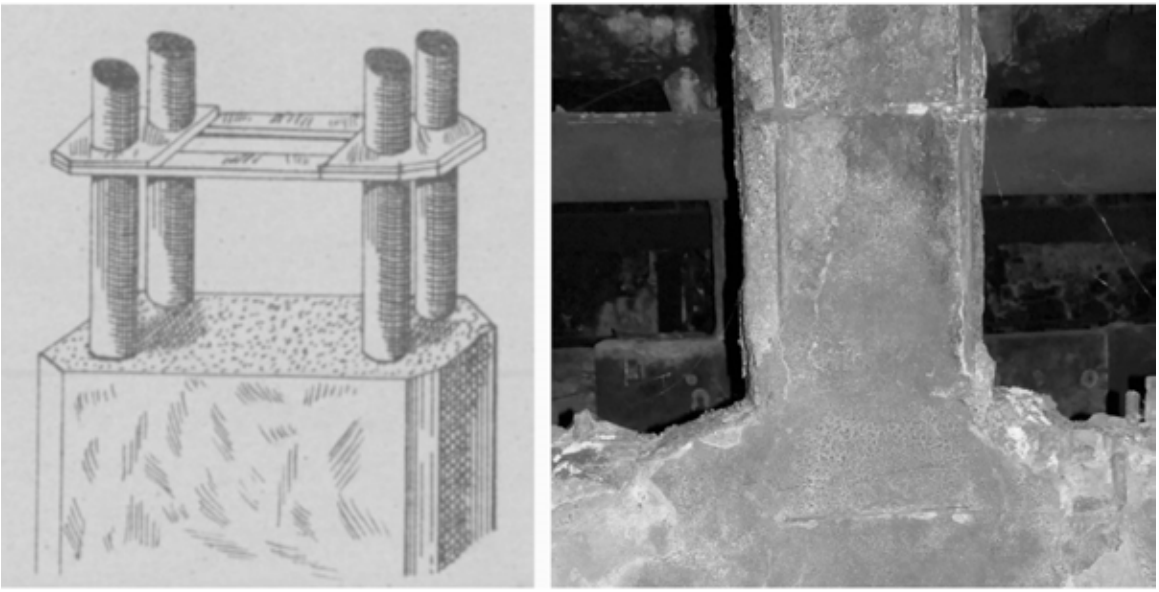

Figure 10: Reinforcement details of a column according to Ritter (left) and as built (right). Scan (left): from Hennebique com- pany magazine Le Béton Armé, Jul.1899, p. 13; Photo (right): Kuban 2020.

Conclusions

The malting factory structure in Lahr/Dinglingen seems to be the first 'Hennebique' structure in the German Empire [29] and maybe even one of the first in Europe still intact and in existence. Built in 1895 it predates so far the oldest known Hennebique construction in Germany by almost three years [30]. Comparatively smaller in size it nevertheless includes the Hennebique reinforcement system. It also seems to be one of the first multi-storey building structures made with reinforced concrete. The malt house extension was built by the medium-sized construction contractor Brenzinger & Cie. of Freiburg im Breisgau, apparently without a documented connection to the Hennebique's main office in Paris. However, there must have been some kind of influence from François Hennebique through his construction company, since the structure includes significant characteristics of the Hennebique system.

Julius Brenzinger was never an official concessionaire of the Hennebique patent. But with the company`s location close to Switzerland and France, and a Swiss owner for the building project, it seems very likely that the Hennebique patent was an influence. For example, the Swiss engineer and Hennebique representative Samuel de Mollins from Lausanne disseminated the construction method as early as 1893 in the journal Bulletin de la Société vaudoise des ingénieurs et des architectes, showing section drawings of a multi-storey structure [31]. The design shown in the article includes specific characteristics that can also be found in the built structure. Yet, further research is necessary in order to analyse Brenzinger`s company business organisation in more detail and also to evaluate possible influence on building with reinforced concrete in the neighbouring regions.

Given its importance, the Brenzinger & Cie. company should be mentioned alongside companies like Hennebique concessionaires such as Martenstein & Josseaux and Züblin [32], or the licensee Max Pommer [33]. All three started as local building contractors. However, they began building larger reinforced concrete buildings only in 1898 – significantly later. These projects included the former warehouse building in Strasbourg as well as buildings such as the Adlerwerke in Frankfurt am Main and the Röder printing company in Leipzig. The last building is still preserved. In conclusion, the case study presented in this paper shows that Hennebique was to some extent successful in Germany at an early stage.

Perhaps this success did not take the form of profitable patent fees, but in any case his influence on developments in the German building industry began earlier than has been thought in form of knowledge transfer.

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[33] Thomas Adam et al, *Max Pommer: Architekt und Betonpionier*, Beucha: Sax 1999; Krieg, *Max Pommer* (note 31).