

The Client's Influence on the Developments of Methods of Construction in Germany: The Example of Willy Stöhr (1905-1997)

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ABSTRACT: Willy Stöhr acquired his knowledge in the decisive development and innovation period of prestressed concrete before 1945 and became a member of the south German network; consisting of a few persons, of the incipient method of construction. In the early part of the orientation and competitive period of prestressed concrete (1945 to 1965), his knowledge, network and his position as a client combined to become a driving force in prestressed concrete bridge construction (Pelke 2006).

Willy Stöhr's journey through life reflects in an exemplary manner the behaviour of many German engineers in the period between Nazism and reconstruction, technical challenge and political repression, and shows the influence of German administrative engineers and the period when they had an effect on innovations in building.

FIRST PROFESSIONAL EXPERIENCE AND THE SHAPING OF THE ENGINEERS NETWORK

Willy Stöhr was born in Ulm on 23 March 1905 as the son of the master stonemason Gustav Stöhr. After passing his matriculation standard examination at the Senior Secondary School in Ulm 1923, he studied civil engineering at Stuttgart Technical University. In 1927, he completed his course of studies under Emil Mörsch (1872-1950), Hermann Maier-Leibniz (1885-1962) and Leopold Rothmund (1879-1967) as the best in his year with the overall grade of "good". His outstanding papers in the main degree examination were the "Statics of Structural Designs" and "Reinforced Concrete Construction", both of which he passed with distinction (StAHN a and UA Stuttgart).

Having become aware of the capable graduate from his institute, Mörsch found Stöhr a post in the technical office of the Berlin branch of the company Wayss and Freytag. "At this time, Emil Mörsch had the design work at Wayss & Freytag (W&F) firmly in his hand. His concern extended from the trainees to the oldest employee" (Bay 1969, p. 54). Emil Mörsch was to maintain ties with Stöhr and his family for all his life (PP).

It is possible that the placement served the exchange with Herrmann Bay (1901-1985) who at the same time became assistant to Mörsch for three semesters. Later, at the time of the important Frankfurt prestressed concrete trials around 1936, Bay was branch manager of the Neue Baugesellschaft Wayss & Freytag in Frankfurt and was to crown his career on the board of Wayss & Freytag AG as personally liable partner *). Between spring and autumn 1929, both worked in Berlin under Willy Haupt (Bay 1969, p. 45 and PK, Zeugnis W&F of 21 Oct. 1929).

With the beginning of the Great Depression after the Black Friday of 1929, Stöhr left W&F. He switched to the civil service, entering the Highways and Hydraulic Engineering Office Reutlingen on 04.11.1929 for training as a government architect (*Baumeister*). Apart from some small bridge designs, during his time at the Highways and Hydraulic Engineering Office Reutlingen, Stöhr was mainly involved in the regulation of the banks of the River Neckar as construction site manager. What a complete change for the young engineer who was accustomed to work on demanding static calculations in office and power station construction, and now had to prepare construction contract documents and supervise compliance with them. In December 1930, shortly before the end of his training, Stöhr transferred to the Highest Inspection of Works Authority, the Ministry of the Interior of Württemberg. On 20 February 1931, he was appointed a government architect. In the economically difficult period, he initially failed to gain admission to the higher technical civil service (StAHN a).

However, his knowledge acquired in the course of the regulation of the banks of the Neckar and the accounting of building works, enabled Stöhr to switch to the private sector. Between the beginning of April 1931 and mid-February 1934 he took on the local supervision of works, initially of the Rockenau barrage weir with lock and then of the Neckarzimmern barrage weir with lock. The contractors for Rockenau were the working groups C. Baresel AG and Sager & Woerner AG, and for Neckarzimmern C. Baresel AG and Grün & Bilfinger AG (PK, Zeugnis der Arge Rockenau of 19 April 1934 and Arge Neckarzimmern of 15 February 1934).

In February 1934, Stöhr transferred to the Bridges Department (Department 48) of the Supreme Management of Works of the *Reichsautobahnen* (OBR) in Stuttgart under Karl Schaechterle (1879-1971), who at this time was still allocated to the German State Railway (*Deutsche Reichsbahn*). Stöhr was allotted to the group under the State Railway official, Emil Klett. There he got to know Fritz Leonhardt (1909-1999). A life-long friendship came into being (PP).

Still completely in the tradition of his mentor Mörsch, Stöhr designed the reinforced concrete arched bridges at Unterbeihingen, Leipheim and Eltingen, initially under Karl Schaechterle, then, as from August 1935, under the latter's successor Klett (PK, Zeugnis der Reichsautobahnen Oberste Bauleitung of 31 March 1937).

The Neckar bridge at Unterbeihingen (1936) is a three-hinged arched plate bridge whose three openings span between 45 m and 50 m. The Neckar bridge is an early arched plate bridge which was based on the trials and studies on the theory of elasticity by Hermann Bay from the year 1934. The arched plate merges the arch with the structure and takes on the pressure from the dead load of the arch and the traffic eccentrically at the price of tensile stresses at the upper end of the plate. Stöhr's careful treatment of this supporting system was later to lead him to prestressed concrete (Mörsch 1958, p.322).

The Danube bridge near Leipheim (1937) has four three-hinged arches made of largely hollow, reinforced concrete ribs with an up to 80 m span. The Rohrbach bridge (1938) near Eltingen, not far from Stuttgart, consists of two-times seven rigid parabolic arches with spans from 27.0 m to 44.5 m, between which the clear transverse distance amounts to 7.0 m. The haunched reinforced concrete rib carriageway is borne by cross braced two-hinged reinforced concrete frames on the 4.0 m wide arches, the construction height of which varies between 80 cm at the crown and 160 cm at the impost. Stöhr won the internal competition for the best solution with his suggestion for a slender arch compared with the continuous beam made of steel or reinforced concrete which Fritz Leonhardt proposed (Klett and Rietl 1938, entry by hand pp. 2-3). Both large arched bridges were supervised by Paul Bonatz. "In 1935, on the first evening at the Bridges Office, Prof. Bonatz designed the *Albaufstieg* (the autobahn ascent of the Swabian Alb near Stuttgart) on the drawing board. On the same evening, in the presence of Bonatz, I was able to design the Rohrbach bridge for so long until he said 'now it's OK'. That was it then", Willy Stöhr recalled (Klett and Rietl 1938, entry by hand p. 3).

In 1937, freshly wed and led once again by Mörsch's quiet hand, Stöhr transferred to the "Bridges and Waterways" division of Heilbronn Civil Engineering Office (StAHN b, p. 2). The Rosenberg bridge, a 60 m span reinforced concrete three-hinged arch with a spandrel braced roadway, designed and erected under his supervision and surveyed by Mörsch, was opened to traffic in 1939. The bridge construction in Heilbronn already suffered from the Third Reich's preparations for war. At the beginning of the works on its foundations, the Nazis announced the construction of the *Westwall* ("Siegfried Line"), in preparation for the aggression against France.

"All building materials were confiscated, there was nothing left for private and local authority purposes. I then sought help from our university professor (meaning Mörsch) who was still in Stuttgart" (StAHN b, pp. 1). The bridge was built by W&F Stuttgart. In this connection, Stöhr mentions that he enlisted Mörsch's help again and again. On the one hand, Mörsch as a former director of W&F, helped him to procure building materials. On the other hand, the holder of the chair in reinforced concrete construction assisted Stöhr with the optimisation of the arch so that the bridge, with minimum material, was able to bear the increased military loads demanded even during construction (StAHN b, pp. 2).

He came to terms with the political conditions, as is to be read in (StAHN b, pp. 2). In his curriculum vitae, dated 23 Sept. 1947, Stöhr states that "through his work for a public authority in 1934, he was taken on indirectly by the SA, lastly as foreman, and, in 1938, unavoidably joined the Party (NSDAP), backdated to 1 May 1937, however, apart from payment of membership dues, did not assume any commitments whatever" (StAHN a and LA B.-W.). The NSDAP district records show an entry date of 24 May 1937. After the end of the war, already at the beginning of 1947, the denazification court in Öhringen responsible in his case classified Willy Stöhr, who initially had to suffer through having the same name as the Gauleiter Willi Stöhr, as a merely nominal member (LA B.-W.).

The *Reichsautobahnen* of the "car fanatic" Adolf Hitler were a large-scale project which served the Nazis for propaganda purposes for the presentation of their ideology. For his time with the Supreme Supervision of Building Works for the *Reichsautobahnen*, Stöhr made the compromise of being able to work in the technically trail-blazing environment without at the same time having to become a party member. Leonhardt explains in (1984, p. 63) that membership in the SA or the National Socialist Motor Corps (NSKK) was compulsory for engineers on the *Reichsautobahn*.

His transfer to Heilbronn Municipal Authority also entailed his appointment as municipal building officer (*Baurat*) and thus an established civil servant. The law on the permanent civil service of the Hitler state, promulgated in 1933 was, it is true, directed first and foremost against Jewish fellow citizens in Germany, but it was also increasingly employed as a sharp weapon against all established civil servants. Stöhr's career as an engineer, without membership of the party, would thus have been ended. His comment in his CV that he joined

the NSDAP in 1938 with back-dating allows us to assume that one of his NSDAP superiors help a protective hand over him.

The first part of Stöhr's life ended in autumn 1939. His technical network around Emil Mörsch had been built up. It links together Hermann Maier-Leibniz, Karl Schaechterle, Fritz Leonhardt, Paul Bonatz, Emil Klett and probably also to a limited extent the W & F engineers Hermann Bay and Karl Deininger.

He had proved his skill in bridge building.



Figure 1: The young Stöhr 1939 (left), Stöhr in the OT (middle) and at heyday of his professional activity 1957 (StAHN a, SAAI, PK)

ON THE WAY TO PRESTRESSED CONCRETE BRIDGE BUILDING

In November 1939, directly after Hitler's invasion of Poland, Stöhr applied for the post of a bridge specialist in the then newly created *Warthegau* district and was delegated by the town of Heilbronn in a temporary capacity as "Commissioner of the Inspector General of the German Highways Agency" (Fritz Todt) to the Reich Governor in Posen (*Poznań*) (PP mit StAHN a) to rebuild the destroyed bridges (StAHN a, CV of 23 Sept. 1947). It was the first deployment of the Organisation Todt (OT) outside of Germany (Seidler 1987). In order to keep its staff formally small, and thus be able to excel before Hitler in the NSDAP leaders' constant power struggle, the OT liked to use the trick of falling back on the staff of building authorities.

It can be shown that here he dealt with the new method of construction using prestressed concrete. He designed the first large prestressed concrete bridge, enriched by the special proposal by Franz Dischinger (1887-1953). The haunched, three-field continuous beam, with a mean span width of 80 m, was based on Franz Dischinger's non-deformable pre-stressing (Dischinger 1936). However, high-tensile, patent-enclosed bridge cables as external beam ties were the decisive step compared with the railway station bridge in Aue from 1936 (Schönberg and Fichtner 1939) in order to keep the losses resulting from creeping and shrinkage to a tolerable level (Stöhr 1941). The foundations, pillars and abutments of the third Warthe bridge, known as the South Bridge, were erected, the cables being procured from the west of Germany, when, in 1943, the advancing Red Army forced works to be stopped in occupied Poland. After the Second World War, at the request of the new military authorities, the South Bridge received a steel superstructure. Poland's state road construction authority had the "prestressing iron rods" incorporated into a prestressed concrete bridge over the River Narew in the town of *Łomża*, about 130 km to the north of Warsaw. On the occasion of its strengthening, a part of the prestressing iron rods were uncovered. They were still free of corrosion (Ryżyński 2002).

However, the development of prestressed concrete construction in German in the founding and innovation period (Pelke 2006) did not inevitably have its origin in scientific findings, but was due for the most part to the construction of the autobahns and Hitler Germany's preparation for war.

The routing of the autobahns without junctions and designed for high speeds with minimal gradients for goods traffic led to the need for a large number of bridges. The Nazi regime's preparation for war, through the so-called four-year plan of 18 October 1936 (*Verordnung zur Durchführung des Vierjahresplan 1936*; p. 887), of which Hitler had put Hermann Göring in charge, diverted first steel, then later, on account of the construction of the *Westwall* mentioned above, all building materials to the armaments industry or companies closely linked to armaments. Thus the construction of the autobahns shifted construction engineering from modern steel bridges towards reinforced concrete bridges with their cumbersome arches that did, however, conform with the ideology, or it led to the development of new, steel-saving methods of building (Schaechterle 1940).

The company *Neue Baugesellschaft Wayss & Freytag AG* recognised the potential of Freysinnet's prestressed concrete patent early on (Pelke 2007), as Schaper (1937, p. 467) also acknowledged. Only through the adaptation by Stöhr of the high-tensile wire cables used for suspension bridge construction by the company *Felten und Guillaume, Cologne-Mühlheim*, did the company *Dyckerhoff und Widmann* catch up with *Wayss & Freytag*.

Around the year 1942, the first consolidation of knowledge of prestressed concrete bridge construction is already to be observed, as the compilation by the Austrian Walter Passer (1942) documents. In 1943, the calculation and dimensioning of the prestressed concrete beam by Mörsch was available in book form (1943). Prestressed concrete completed its founding and first innovation period (Pelke 2006) and Stöhr was among the few engineers to master this new, pioneering method of construction.

With the third Warthe bridge, Mörsch's pupil Stöhr as a bridge builder had developed consistently, along the stages of the development of autobahn bridges, from the arched plate through the slender, steel-saving reinforced concrete arch to prestressed concrete.

IN THE ORGANISATION TODT (OT)

On 1 November 1942, Stöhr was finally taken over by the Reich Highways Administration in Berlin and promoted to senior executive officer (StAHN a, certificate of appointment of the Inspector General for German Highways). It may have been as a result of the defeat at Stalingrad that Stöhr was called up to a unit of engineers in the German Army in April 1943. But already in September 1943, Fritz Leonhardt, at that time senior construction supervisor of the OT task force Russia-North, succeeded in requisitioning him for the OT for the construction of an oil shale refinery in Estonia (Leonhardt 1984, p. 96 and LA B.-W.). There he got to know Wolfhart André. Freysinnet and prestressed concrete were the topic of discussions. Leonhardt himself found the time to travel to Freysinnet. He sent Stöhr to Gustave Magnel in Belgium. In Brussels, Stöhr recognised the influence of the relaxation of the tensioning wires on the bearing capacity of prestressed concrete structures (Leonhardt 1984 and PP).

In April 1944, the Fritz Leonhardt's "Baltoil team" was transferred to the OT Working Group Silesia for the construction of a new "Führerhauptquartier" (HQ for Hitler) (Leonhardt 1984, p. 100). With Seidler (1987, P.123) Stöhr can be allocated as a collaborator in the project *Riese* at Eulengebirge. There Stöhr was promoted to become a senior building supervisor, equivalent to the military rank of a major (LA B.-W.). A quite prominent position within the OT hierarchy, which was directly subordinate to a working group or chief building supervisor (colonel), and which we could today describe as a regional branch manager.

Between December 1944 and the day of the German capitulation in May 1945, Stöhr was assigned to the OT Working Group Norway (LA B.-W.). Captivity as a French prisoner-of-war followed, from which he fled at the beginning of 1946 to his pre-war place of residence in Öhringen, near to Heilbronn.

According to Stöhr's own details, during his time in the OT (StAHN a, CV of 23 Sept.1947), he dealt with "Reinforced concrete industrial buildings (OT Working Group Russia-North), railway and road bridges in wood and reinforced concrete (Norway) as well as galleries and navy structures (Silesia and Norway)". With Seidler (1987, pp. 54-61, pp. 102-107, pp. 116-127), Stöhr's details can be allocated to the aforementioned OT working groups.

His brief period of service in the German Army (*Wehrmacht*) can be attributed to the complete centralisation of the German Army's building activities under the umbrella of the OT, after Todt's death, by his successor Albert Speer, accompanied by the German defeat on the campaign in Russia (Seidler 1987, pp. 18-25).

"With the Führer's decree on the Organisation Todt" of 23 Sept. 1943, the complete ideologisation and militarisation of the building trade in Germany was concluded that had begun with Fritz Todt's construction of the *Reichsautobahnen*, Robert Ley's German Labour Front (*Deutsche Arbeitsfront*) and their support for Göring's four-year plan. Already with the founding of the OT on the occasion of the construction of the Westwall in 1938, the German building industry had been degraded to become a purely state-controlled business, the building authorities had become more or less militarised. Independent, consulting engineers were next to unknown.

CONSTRUCTION OF THE HERD BRIDGE ULM

On 27 June 1946, Stöhr was licensed as a self-employed civil engineer in Öhringen again and at the end of 1946 he took up the thread to prestressed concrete again for the construction of the Herd Bridge in Ulm. Despite several letters of application, he did not succeed in gaining a foothold in the city of Ulm for the preparation of the design.

Instead, between January and mid-March 1947 he prepared the special proposal for the joint undertaking Baresel und W&F, advised with regard to the architecture by W. Tiedje, Stuttgart, with prestressed arched plates in cantilevered construction. To compensate for the cantilever moment during the cantilevered construction and in order to reduce the horizontal pressure on the abutment in view of the difficult foundation work on the right, Bavarian bank, he arranged massive, back cantilevers. He wanted to have the individual concrete components prefabricated on land and then lifted into the bridge using heavy lifting gear.

The special proposal was discussed intensively during a hearing of the building committee of Ulm City Council on 20 March 1947 (TaUlm). Stöhr's solution of a prestressed, single field arched plate bridge was modified by the municipal architect and head of the Civil Engineering Office of the City of Ulm, König, through the omission of the cantilever and the inclusion of falsework. As a result, so König, both the prestressing and the two rear cantilevers would turn out more moderately. After the agreement of the joint undertaking Baresel and W&F, the contract was awarded for this modified special proposal by Stöhr (Kaiser and König 1950 and also Mörsch 1958, pp. 437-440).

It is remarkable that Stöhr, demonstrably before Finsterwalder, showed a realisable solution for cantilevering with prestressed concrete. To what extent he let himself be influenced in this by Freysinnet's Marne bridges and varied the latter's filigree portal frame bridge with the German arched plate solution, cannot be exactly reconstructed, however, in a letter dated 14 Sept. 1947, he refers to the Marne bridges. The contact with Freysinnet can be reconstructed through Leonhardt (1984, p. 99).

The Herd Bridge constructed in B 300 had a rising height of 7.73 m. 9 armour-plated roller bearings at the crown and 26 on the impost allow the necessary rotations of the three-hinged arch. The arched plates protruded 7.8 m massively to the rear over the imposts, ensuring adequate relief of the horizontal thrust. Between the imposts, the six arched plates were closed to form three box girders by the upper carriageway and the lower compression plate. Five cross plates per arch half and box girders ensured adequate shape accuracy (TaUlm). As also in the case of the New Canal Harbour Bridge erected afterwards, the bridge floor slabs lying in between were hinged supported on account of the "differing deflections of the arches", and the cantilevered footpath slabs were subdivided by joints.

The straight aligned prestressing steel was made up of 32 mm thick wire cables from the Felten & Guillaume Co., Cologne-Mühlheim. Each wire cable was made up of 35 wires with a diameter of 4,55 mm and showed steel qualities of 160 kg/mm² for the tensile strength, 120 kg/mm² for the yield strength, as well as a creep limit of 88 kg/mm². The original prestressing of 8,000 kg/cm² was provided with an overall allowance for the steel tensions for creep and shrinkage losses amounting to 1,500 kg/cm² in accordance with the findings of the Frankfurt trials of 1936 (Lenk 1937) by the W & F engineer Ambach (TaUlm).

The tensile stresses over the imposts were eliminated with a pressure reserve of 5 kg/cm² (Kaiser and König, 1950, p. 155). However, in the area of the crown, slight tensile forces were allowed at the same height and, at Mörsch's suggestion, the lightening key was covered by non-prestressed reinforcement. As the cross section only showed compressive stresses, Weyrauch's circle of stress served Ambach in order to determine the main tensile stresses and the shear reinforcement. As also later in the case of the New Canal Harbour Bridge in Heilbronn, Ambach remained in state I of uncracked concrete for his proofs, without considering the safety against rupture.

Ambach's production of evidence shows that the engineers of that time were still on the way from the arch under compressive stress to prestressed concrete.

The patented tensioning cables had cable end anchorages which were cast by the client with a zinc alloy. They were laid ungalvanised and unoiled in the openings provided, and prestressed with hydraulic presses by means of steel yokes against the hardened concrete, and then immediately encased with concrete. At the middle of the bridge, the cables were deflected in loops and led back to the anchorage points above the impost. Here the tensioning cables were arranged in threes to maintain the local compressive stresses in the concrete. The load application points were already identified as concrete reinforced brackets (TaUlm).

During the construction works, Stöhr acted in a consulting capacity for the working group carrying out the works (Mörsch 1958, p. 487). A letter of thanks from Mayor Scholl of the city of Ulm of 9 May 1947 proves Stöhr's substantial contribution towards the Herd bridge in Ulm (TaUlm). The Herd bridge was last repaired in 2001 and presents itself today in an excellent state.

CONSTRUCTION OF THREE MILESTONES OF PRESTRESSED CONCRETE

However, Stöhr had an urge to return to the service of the building authority. Already in autumn 1947, he applied to the town of Heilbronn again for a post.

With the "Law for Liberation from National Socialism and Militarism" of 05 March 1946, the American military authorities placed the implementation of denazification, which Willy Stöhr, as a former senior site engineer of the OT had also undergone, in German hands. Already in 1947, long before the unspeakable law on the termination of denazification of 1951, Stöhr was classified as a merely nominal member of the party, and thus found his way back to "his" civil engineering department in the town of Heilbronn at the beginning of November 1947. Through his prominent position in the OT, his status of a public official for life lapsed for a time, but was restored to him again already in December 1950. He also had to accept a downgrading to municipal architect. Stöhr only reached his old position of senior municipal architect again in 1960 (StAHN a). In 1963 he rose to become head of the Civil Engineering Office Heilbronn.

The town of Heilbronn, badly damaged in the Second World War by Allied air raids at the end of 1944, urgently needed the engineer Stöhr to rebuild its Neckar bridges which were closely linked with the operational capability of the industrial location Heilbronn and its Neckar Canal harbour.

The Rosenberg Bridge, with its foundations on rock, was erected under Stöhr's supervision with nearly the same parties involved for a second time on the existing substructures for increased, now civil loads as a two-linked arch (StAHN b, pp. 11). It is described by Mörsch (1958, pp.357-359). This handsome, but conventional bridge structure will not be dealt with any further here below.

Between 1948 and 1951, Stöhr designed and built three major milestones in prestressed bridge construction for the town of Heilbronn. "The responsibility and the freedom of the design lay wholly, ..., in Mr Stöhr's hands." Thus in retrospect (StAHN b, pp. 11) the former head of the building department of the town of Heilbronn, Daser.

The filigree, partially prestressed three-hinged frame of the Neckar Canal harbour bridge (1950) was the first prestressed concrete bridge in the world to span more than 100 m (span = 107,8 m). Immediately after followed the elastically restrained girder bridge Obere Badstrasse (1950), the massive rear cantilevers of which on

both sides allowed a nearly identical span (span = 96 m). Finally, Stöhr, with Leonhardt and Gass erected the girder bridge crossing the Neckar near Neckargartach (1951) that was prestressed longitudinally and transversely and spanned 225 m without joints (1951) (StAHN b, pp. 10-16).

The engineers of Herd Bridge in Ulm came together again for the construction of the New Canal Harbour Bridge (StAHN e). Stöhr designed, prepared the contractual documents, assessed the tenders and was in charge of the supervision of construction. On the contractors side we find Albert Kaiser in a leading position for the Stuttgart branch of W&F. Ambach took care of the static proof. Prof. Karl Deininger, Mörsch's successor on his chair and until 1939 manager of the W&F branch in Stuttgart, and thus Kaiser's predecessor, conducted the tests. Prof. Tiedje gave the structure its architectural finishing touches. The load-bearing system of Herd Bridge was logically consistently further developed by the engineers for the New Canal Harbour Bridge. The arched plates and foundation were freed from surplus concrete and found their adequate counterpart in the three-hinged frame. With nearly the same structural width, now two hollow beams instead of three were regarded as sufficient. The engineers compensated for the lack of calculation theories for torsion and warping torsion, as they had already done in Ulm, by seven transverse struts within each hollow beam and attached the cantilevered footpath slabs every 10 m. The carriageway slabs lying between the hollow beams compensated for their differing deflection by being supported statically determined.

In accordance with the greater stress and strain, the engineers selected 26 spiral cables made of patented steel wires from the Felten & Guillaume company for the prestressing reinforcement. The steel quality corresponded to that of the cables of Herd Bridge. Stöhr knew of the cables in storage in Cologne-Mühlheim for suspension bridges that had no longer been erected or had been destroyed, and purchased them for Heilbronn (StAHN b, pp. 12). The 38 mm thick spiral cables, woven out of 62 single wires with a diameter of 4.10 mm, now followed the moment curvature in partly closed prestressing ducts. The static calculation resembled the proof for the Herd Bridge (StAHN). The bridge was partially prestressed with posttensioning in part as not every single wire was coated, according to Stöhr (1950, p. 271).

In May 1950, the New Canal Harbour Bridge was opened to traffic. Some three years before Finsterwalder, Stöhr, together with the engineers from Wayss and Freytag, succeeded in proving the suitability of prestressed concrete for the construction of large bridges.

For the Obere Badstrasse bridge, opened to traffic just six months later (StAHN c), Stöhr developed the load-bearing system of the New Canal Harbour Bridge further into a two-hinged frame with counterweights and a single cell hollow box beam cross section. Fritz Leonhardt, a friend for many years from the days of building *Reichsautobahnen*, optimised the load-bearing member, by adding his prestressed concrete technique of concentrated tensioning tendons lying in rectangular sheet steel cases after Baur/Leonhardt (Leonhardt and Baur 1950). With Leonhardt, the contractor also changed to the building company Heinrich Butzer, whose chief engineer was Gass (Leonhardt, Stöhr and Gass 1951). In order to reduce the influences of creeping and shrinking, Leonhardt raised the rear side anchor spans by 50 % to 19.0 m. He dispensed with the additional pressure components of the frame thrust and transformed the static system into a haunched three-span girder with short end spans which served as counterweights for restraining the centre span. He knew how to skilfully conceal the rear anchor spans in the abutment.

The tendons were now made of seven-wire strands of 3 mm diameter which had a minimum failure strength of 175 kg/mm². They were laid continuously in endless loops. At mid-span they branched off into smaller sheet steel cases and, analogous to the New Canal Harbour bridge, they were deflected by 180 degrees. In the area of the side spans, three prestressing blocks made of reinforced concrete lying one behind the other replaced the familiar steel cross beams. The rearmost prestressing block had a tendon with 2x 320 wire strands, the two front tendons turned out smaller with 2x144 wire strands each. In order to keep the stress thrust compatible, the front tendons were staggered in 16 loops with 18 wire strands each, finer than those we know from the Herd Bridge and New Canal Harbour Bridge. Together, the three tendons gave a tensioning force of 5,900 to. They were tensioned by lost, hydraulic jacks which were installed between the prestressing block and load-bearing system of the side span. The Baur-Leonhardt prestressing method showed a certain inflexibility in the case of the use of longer tendons of differing lengths. In order to master the individual tendons' varyingly long tensioning distances, a play with the smaller tensioning loops on the prestressing blocks helped so that, when prestressing, the tensioning loops would only be carried along after discrete movements of the prestressing block. On conclusion of the prestressing procedure, all the tensioning loops showed the same expansion strains. After conclusion of the prestressing works, the sheet steel cases were immediately grouted with cement paste.

The calculation of the cross section sizes and dimensioning were carried out by Leonhardt's partner, Willi Baur. The statically indeterminate calculation, including the prestressing followed the flexibility matrix method. Creep and shrinkage deformations were determined exactly, in accordance with the theory of elasticity, with 7% for the concrete strength class B 300. Still all-inclusive, Baur introduced steel relaxation and a small additional safety factor, that was not explained in more detail, into the calculation. All the expansion shares joined together to give a total creep and shrinkage loss of 12%. Despite full prestressing, he improved the W&F engineers' all-in value by 6%. The safety against rupture and the restriction of the principal tensile stress against cracking were proved. The proof of the shear forces went beyond the restriction of the principal tensile stresses regarded as adequate at that time and was already like the last proof forms of global safety in areas undisturbed by warping torsion (Leonhardt, Stöhr and Gass 1951, p 267 with static calculation from StAHN c). Baur's particular attention was devoted to the shear-resisting connection of web and flange. Load bearing areas require a concrete of the highest quality B 450 locally.

One peculiarity of the first prestressed concrete bridges was the utilisation of the high concrete strength required for static reasons to drive directly on the carriage way slab. Without its finding its way into the dimensioning, Stöhr and Leonhardt ensured the imperviousness of the surface by constructional means by using a B 400.

With the Obere Badstrasse Bridge, Stöhr, now together with Leonhardt, developed the still experimental prestressed concrete technology of Herd Bridge and New Canal Harbour Bridge into the typical monolithic prestressed concrete of German character.

Just a little later, in 1951, the town of Heilbronn was to be permanently connected again to its suburb of Neckargartach (StAHN d). The surviving abutments and pillars of the vaulted bridge destroyed by German troops shortly before the end of the war gave a column grid pattern of 41.86 m for the end spans and 43.00 m for the three inside spans. The navigation span to be observed compelled a slender construction. Stöhr withdrew from the invitation to tender and left the choice between prestressed concrete and compound steel, the second new method of construction coming into being at the same time, for the superstructure to the companies bidding. However, Stöhr's guiding hand was retained. "We always had competing design prepared by the companies. ... The decision was only taken when everything was clear. Then came Bonatz, Mörsch, the town council. Then it was decided which plan would be implemented. Until then it was always the Civil Engineering Office's plans." Thus Stöhr in (StAHN b).

The Stuttgart building company Ludwig Bauer won the competition with a continuous, monolithic, parallel flange prestressed concrete superstructure over 225 m (Mörsch 1958, S. 190-193 with bid documents from StAHN d), whose partially prestressed carriageway slab joined two hollow box beams with a structural depth of 1.80 m into a monolithic overall cross-section. Cross girders at the third points of each span ensured an adequate distribution of the loads. The well-known tensioning procedure following Baur-Leonhardt fully prestressed the superstructure longitudinally. A new addition was a transverse prestressing of the carriageway block by means of closely laid, light LEOBA prestressing tendons (Leonhardt 1953). It was probably the first use of LEOBA stressing apparatus in bridge building. The calculating engineer, Oertel, reduced the prestressing loss along the superstructure as a result of friction by overtensioning and releasing. The Neckargartach Bridge was scaffolded and concrete over its whole length. In December 1951, Stöhr's third milestone was opened to traffic.

Owing to the shortage of steel in post-war Germany, an engineering jewel in the shape of the elevated pile bearings made of high strength concrete B 600 decorated the Neckargartach Bridge. The material testing institute of Stuttgart Technical University made a thorough examination of the concrete pile bearings.

Neckargartach Bridge, for several years the longest monolithic beam bridge in the world, was the pilot design for innumerable road bridges in Germany. The administrative engineer Willy Stöhr consciously held back during the formation of prestressing concrete technology within two years; now steering rather than collaborating in the progress of his prestressed concrete.

He began the third part of his professional career. Other local authority building tasks were on the agenda. He came full circle to the beginning of his professional career in the building authority. The successful design of the municipal Neckar embankment to be transformed into a recreational area meant more to the people of Heilbronn than his achievements in the development of bridge construction.

CONCLUSIONS

Let us conclude our walk along Stöhr's formative path and select the engineering image of the half sine wave for this. The path begins at the foot of the half wave with the Unterbeihingen arched plate bridge, ascends to 45 degrees to the third Warthe Bridge, rises 25 degrees to Herd Bridge Ulm and finds the New Canal Harbour Bridge in Heilbronn at the zenith. Still on the plateau, but already below 115 degrees is the Obere Badstrasse Bridge, descending we find Neckargartach Bridge. From 1952 on, a few prestressed concrete bridges, now already to be regarded as conventional, were still to be found in the Heilbronn region, but the half wave of the gain in knowledge had passed. Around 1955, with the wane of the main innovations, Stöhr took his leave of prestressed concrete bridge building (Pelke 2006). The engineers constructing the German autobahns of the post-war period were to find a fully developed construction technique for their bridges.

In 1968, Willy Stöhr retired as head of the civil engineering office. Nevertheless, bridge building remained his passion, as design sketches (TaHN) dating from 1993 still show.

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*) Note: In 1932, Wayss und Freytag AG was wound up and the company Neue Baugesellschaft Wayss & Freytag AG was founded, which reverted to the old name again in 1942.

ACKNOWLEDGEMENT

Special thanks goes to the Historian Dr. Reiner Ruppman for giving me the opportunity to understand people living in The Third Reich and supporting me to realize this paper.