The early history of prestressed concrete is almost entirely related to rearmament and the war effort, beginning in the early 1930s with the German preparations for the Second World War. For that reason, there are few records of the development of this technique: everything was top secret. We were fortunate to find a number of people who had lived at that time and who had a knowledge of the events in question. They provided us with a great deal of oral information, but in the meantime, all of them have died.

The story is somewhat bizarre. The underlying idea had been around for a long time, but it was Eugène Freyssinet who came up with the invention that allowed the idea to be put into practice. The French themselves showed no great interest in the invention. The Germans, on the other hand, wished to save steel for war (a war they were also to wage against France, of course), and the German company Wayss & Freytag obtained a licence from Freyssinet — only to use his system almost exclusively for the construction of bunkers.

Initially, the chief negotiator for Wayss & Freytag was Professor Karl W. Mautner, but since he was a Jew by birth, the Nazis soon removed him from all his offices. In the pogrom of 9 November 1938, he was arrested and detained in Buchenwald concentration camp for six weeks.

Sir Alan Harris — deputy head of P.C.C., the world’s first prestressed concrete firm, and later a partner of Harris and Sutherland engineers — informed us that the London firm of Mouchel Engineers invested quite a lot of money and obtained the help of the secret services of several governments to free Karl Mautner and get him and his wife out of Germany in the summer of 1939. Probably the most important contents of Mautner’s luggage were the records of prestressing trials carried out in France and Germany.

These events led to the triumphant advance of this technology in Britain. There, too, it was initially used almost exclusively for the construction of bunkers and for girders in temporary bridge construction intended to repair eventual war damage.

There is good reason to believe that all the parties involved in these developments fulfilled their contractual obligations. Freyssinet provided the know-how, and the recipient companies correctly paid their licence fees. For at least one German bunker, concrete anchorage cones for the sheaves of tensioning wires were delivered from France in 1943–44, together with the appropriate jacking devices presumably. As a result, a collaboration between European building contractors was possible after 1945 without disputes about money and fees.

These post-war developments parallel the emergence of the European Coal and Steel Community, which was formally established in 1952 and which may be seen as one of the predecessors of the European Union.

All’s well that ends well, one might say. But there is also a tragic side to this story: alone on one German
construction site where prestressed concrete was used, more than a thousand men lost their lives through accidents, starvation, freezing working conditions and Allied bombing, Figure 1.

As a young civil servant responsible for engineering construction in the provinces, Eugène Freyssinet was placed in charge of the construction of three bridges across the River Allier in the early years of the 20th century. He was utterly convinced that these structures were so economical that they would be unrivalled in price. Freyssinet mistrusted calculations. He therefore ordered the construction of a trial arch with a span of 50 m, the abutments of which were tied together by high-strength stressed wires. Interestingly enough, one finds the same simple wedge-shaped anchor pieces he employed in 1907 being used in 1944 in the construction of a German bunker, Figure 2.

Freyssinet kept a keen eye on his building sites and structures. Noticing the dangerous deformation that occurred in the first three-hinged arch bridge, he compensated for it by forcing apart the joint at the crown. According to the theories held at that time, deformation of this kind was impossible. Creep and shrinkage in concrete were unknown, indeed, inconceivable. Only in 1928 was Freyssinet in a position to quantify his observations in such a way that, together with Jean Séailles, he was able to submit the first application for a patent for the manufacturing process of prestressed concrete. Despite the long-term deformation to which concrete is subject, the system functioned because the elongation lines of the high-strength tensioning wires were adequate to maintain the prestressing effect even after the concrete had shortened in length.

In 1928, however, no one believed it was possible to exploit this process commercially. All Freyssinet was able to produce were prestressed concrete pylons for electric power lines; and in view of the critical economic conditions prevailing at that time, even they were not profitable.
In 1933, with a courage —or foolhardiness— born of desperation, Freyssinet accepted the assignment of saving the transatlantic quay in Le Havre. The project was beset with risks. The structure was in danger of collapsing even before being completed because it had been overlooked that there was silt beneath the gravel foundations, Figure 3. The main elements of Freyssinet’s solution were three large prestressed concrete girders, which he inserted beneath the structure, underpinning them with additional piles, Figure 4. Allegedly, these girders still form the main load-bearing members of the new terminal of 1954 which replaced the old structure after it was destroyed by Allied bombing in 1944.

The successful rehabilitation of the quay in Le Havre marked a breakthrough for Freyssinet. The leading engineers of his day pilgrimaged to the site — among them, Edme Campenon, who subsequently became Freyssinet’s lifelong partner in the construction firm Campenon Bernard.

In 1936–37, the Campenon Bernard company erected the world’s first prestressed concrete bridge in Oued Fodda, Algeria, Figure 6. It consists of 4 bays with a total of 12 precast girders that span a distance of 20 metres. The bridge still stands today. The idea of prefabricating the elements was also Freyssinet’s. For some time afterwards, though, there were no further contracts to follow this up.

Freyssinet’s application for a patent in Germany led initially to the usual objections and formal disputes. In many quarters, his technique was regarded merely as an extension of existing ideas. No record survives of the opposition that came from Dyckerhoff & Widmann, Franz Dischinger and Ulrich Finsterwalder, on the other hand, genuinely sought a means of realizing prestressed concrete that would not conflict with Freyssinet’s patent. Both engineers set their sights on reinforced concrete girders with trussed tendons on the underside.

Only one bridge was ever built to Dischinger’s 1934 patent —the Adolf Hitler Bridge over the Mulde.
in Aue, Saxony, in 1936–37. The steel tension chords (German steel quality St 52) were designed to allow for post-tensioning at a later date to compensate for creep and shrinkage. Post-tensioning was carried out repeatedly after 1950, but the effect always disappeared after a few years, and finally, in 1992, the bridge had to be demolished.

Ulrich Finsterwalder applied for a patent for a variation on the system of reinforced concrete girders trussed on the underside: he developed a «self-activating pretensioning» system that exploited the change of form of the girder resulting from its dead weight, Figure 7.

Four structures were executed in accordance with this patent. The first was a rural road bridge over the autobahn near Wiedenbrück. The bridge had to be demolished in 1997. The well-known civil engineer Fritz Leonhardt observed of this structure that at precisely the point where the greatest bending moment occurred, there was no prestressed concrete, only a tensioned steel (St 52) tendon and a hinged joint.

The bridge was followed by the trussed girders in the roof structure over Tempelhof Airport in Berlin (1936–38) with a span of 32.5 m and steel tension chords (St 52). This completely independent interpretation of «prestressed concrete», without a hinge in the middle of the span, has been refurbished and is still in good condition today.

The roof over the «Hall of the National Community» in Weimar, built for Hitler’s NS Party, consisted of identical trussed girders with a span of roughly 50 m. The building, which was completed long after the war by the East German government, is rather ugly, but still in good condition.

The same trussed girders were used for the fourth structure, the old airport in Munich, where they had a span of 80 m. The structure was demolished long ago, however.
Karl Mautner, acting on behalf of his company, Wayss & Freytag, seized the bull by the horns and entered into a licence agreement with Freyssinet in 1934. This agreement was evidently respected throughout the war and during the post-war years. In various publications, Wayss & Freytag claimed savings of 67 per cent of the normal reinforcing steel through the use of prestressed concrete according to Freyssinet's patent. That was not strictly accurate, however. What was really involved was the proportion of «permissible» stresses in the steel.

The company demonstrated the load-bearing capacity of prestressed concrete girders with two large-scale test elements. Karl Mautner was responsible for conducting these trials, but as a Jew, it was no longer possible for him to perform his role openly in Germany. He signed documents simply with his initial, «M». The results of these trials, however, were among the papers he took with him in 1939 when he fled to England.

In 1938, a first, small rural road bridge was erected with four girders, Figure 8, and a span of 32 m over the autobahn near Oelde (Beckum). The design was by Eugène Freyssinet himself, who had a mock-up girder constructed in Paris for the instruction of members of the Wayss & Freytag team. There were no drawings. Thanks to the care of the local authority responsible for this structure, the bridge near Oelde (Beckum) still stands today.

This was followed, before the war, by a quay structure and a series of precast prestressed concrete girders for factory halls that were important for the war effort. During the war years, prestressed concrete was used almost exclusively for bowstring roof girders over bunkers for the German navy. With spans of roughly 30 m, some 150,000 metres of these girders were produced in Germany, the Netherlands and Norway.

The largest structure, covering an area of roughly 5 ha (12 acres), was a submarine factory in Farge, Bremen, in which U-boats were to be built in a

Figure 8
The girders for the bridge at Oelde (1938) were cast in sections: The rear section is complete, the central section is hooded for steam heating, and on the right only the lower flange has been cast. Lower flange prestressed with straight wires of different length, pre-tensioned and anchored on a steel prestressing bed. The stirrups were prestressed against the fresh concrete.

Figure 9
Types of bowstring trusses for German bunkers with straight pre-tensioned wires anchored as shown in Figure 2 on a concrete prestressing bed.
conveyor-belt system of the kind advocated by Henry Ford. Three submarines a week were to be manufactured in this way. In view of the increasing effectiveness of Allied bombs, plans were made to increase the thickness of the bunker roof from 4.5 to 7 m. The load-bearing capacity of the prestressed concrete girders was inadequate for this, however. Concrete anchorage cones invented in September 1939 by Freyssinet were therefore obtained from Campenon Bernard in Paris for additional external sheaves of prestressing wires.

In all likelihood, neither Freyssinet nor Campenon Bernard collaborated with any great zeal with the Germans. The situation was probably similar to that described by Jean Paul Sartre: «Will I be understood if I say that the occupation was intolerable, yet at the same time that we coped quite comfortably with it?»

The only three prestressed concrete bridges realized in France during the war years were not built by Campenon Bernard, but by Sainrapt & Brice, a company that collaborated closely with the Germans and that was able to divert cement and steel destined

Figure 10
for the construction of the Atlantic Wall to other purposes.

Freyssinet also took the opportunity to test his new ideas. In 1941–42, he built a bridge with a modest 10.5-metre span in slab construction over a river in Elbeuf near Rouen. It is the first post-tensioned cast in-situ bridge. He used his new system of sheaves of prestressing wires with concrete anchorage cones being no longer straight but curved and coated with bitumen to avoid bonding. In addition there were straight transverse tendons of the same kind. In 1942–43, a similar slab bridge with a 20-metre span was built over a river in Longroy near Eu-le-Tréport. On this occasion, post-tensioning was applied step-by-step. Between 1942 and 1944, a precast footbridge with spans of 30 and 31 m was constructed over the railway line near Lens. None of these three bridges was a crucial transport structure or of any significance for the German occupying powers.

In that respect, the first railway bridge in prestressed concrete was presumably a different matter altogether. It was built in 1943–44 over the rue Miroir in Brussels by Gustave Magnel in collaboration with the construction company Blaton-Aubert and still exists today. The bridge was certainly of interest to the German military. In this structure, Magnel tested new, and again curved, multi-wire tendons in flexible rectangular ducts, since he was not entirely satisfied with Freyssinet’s solution. At that time Magnel had no contact with the latter, however.

Meanwhile, far removed from Europe, Robert Shama, an Egyptian who had studied in France, used Freyssinet’s new tendons in spectacular form in a military aircraft hangar built in Meerut north of Delhi. Erected in 1940–41, it was probably the first cast in-situ structure to be realized with curved tendons, even before the bridge at Elbeuf. The tendons passed through flexible sheathings and were anchored by means of those concrete anchorage cones invented only in 1939. Although C. G. Sexton announced this building as if it were his own, Sir Alan Harris believed Robert Shama to be the true author of the scheme. The construction firm was J. C. Gammon. According to information from the Aeronautical Information Service, Delhi, the hangar has since been demolished, but a similar structure dating from 1942–43 in Karachi still exists and appears to be in a good state, Figure 10.

In Germany, it was probably not possible to use curved prestressing, since Freyssinet’s German patent specified the use of straight prestressing reinforcement.

Between the construction of the many bunkers, a single structure for civilian use was erected: an autobahn bridge consisting of precast elements and spanning a distance of 42 m across the river Kłodzka Nysa. The bridge was built in 1940–41 east of Breslau (present day Wrocław in Poland) and is still in an excellent state of preservation (1998).

After the war, Freyssinet referred to the two German bridges as «assez mal», although at least one of them was directly designed by him and the other one complies with his concept for the first bridge. The way he dissociated himself from these objects is perhaps understandable, though, seen in the context of the times.

As described earlier, Karl Mautner had fled to London in the summer of 1939 with the results of the German and French trials in his luggage. In contrast to the reception given to prestressed concrete in Germany, it was the subject of an open debate at the Society of British Civil Engineers in England. As early as 28 May 1940, a trial girder was tested to failure. Parallel to this, in 1940–41, what was the largest bomb depot in the world at that time was constructed in an underground quarry, using some 3,000 prestressed concrete girders with a span of 5 m.

In England, as in Germany, Freyssinet’s 1929 patent was used solely with straight prestressing wires directly bonded to the concrete. Only in trial forms of construction were precast segments assembled with curved post-tensioned tendons.

This segmental form of construction — based on Freyssinet’s ideas — was first used in 1944 in a bridge in Djedeida near Tunis. The 75-metre-long bridge across the Medjerda Wadi has a 50-metre central span and was built with 3-metre precast segments by Campenon Bernard without the direct collaboration of Freyssinet. It was constructed because the Allied armies urgently needed a reliable line of access to Ferryville (now Menzel-Bourghiba), where the largest dry dock in the region was situated. The bridge still stands today, but it has been strengthened in the middle bay with two auxiliary transverse beams supported by piers.

In the public debates about prestressed concrete construction held at the Society of British Civil Engineers. Paul Abeles, an emigrant from Vienna,
disagreed with Freyssinet and Mautner, who insisted that the concrete should be free of cracks. Abeles claimed that this was not necessary and that a further 20 to 30 per cent saving in the quantity of steel could be made if cracks were tolerated in the concrete. According to the extensive investigations he had carried out, there was no danger of corrosion with cracks of limited width, he argued. Paul Abeles may therefore be regarded as the inventor of the questionable technique of partial prestressing.

Without doubt, the man who had the greatest commercial success with prestressed concrete prior to 1945 was Ewald Hoyer, who developed a system for small prestressed and pre-tensioned beams with very thin hard-drawn wires which he named «piano-string-concrete». The beams could be cut to any length required, since the wires expand elastically at the cut and re-anchor themselves instead of losing their tension. This principle had already been described in a French supplementary patent for which Freyssinet had applied. Hoyer was nevertheless granted a German patent as a result of special wartime legislation, and in Gennevilliers near Paris, he manufactured incredible quantities of beams for bunkers in the German Atlantic Wall. As many as 1,500 people worked in the Gennevilliers plant, and the occupying powers forced Campenon Bernard to place a number of its engineers at the disposal of this works. The thought that Hoyer’s German patent was not legally valid in France was something no one dared to express.

After a tremendous boom in the post-war years, the history of prestressed concrete —at least that with embedded tendons— is now coming to an end. Paul Abeles was, unfortunately, mistaken in the pronouncement he made in London in 1940. Prestressing steel does corrode through cracking of the concrete and even without cracks.

The close economic cooperation between France and Germany as one knows it today had its origins in the years between the two World Wars and continued —albeit in a different form— during the German occupation of France. In the post-war years, this cooperation led to the creation of the European Coal and Steel Community (ECSC) and ultimately, by way of the EEC, to the present European Union.

As this brief history of prestressed concrete shows, these developments were closely paralleled in the building sector, where early international links were forged between France, Germany and the UK. One sees, therefore, that some of the seeds of modern European cooperation were sown during the darkest years of the 20th century.

Perhaps one may end this story on a more conciliatory note. The painter Emil Nolde, who fell out of favour with the Nazis for his «degenerate art», was ultimately no longer able to purchase paint. Quite by chance, his friend Max Lütze was responsible at Wayss & Freytag for maintaining contacts with Freyssinet, and on those occasions when Lütze visited Paris, he brought back paint for Nolde. His paintings belong to the most beautiful things that ever came of prestressed concrete.

[English version by Peter Green]

REFERENCE LIST:


This volume also contains a full list of the relevant literature and communications.