Early Applications of Prestressing to Bridges and Footbridges in Brussels Area

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ABSTRACT: This paper traces the origin of three very early applications of prestressing by post-tensioning on bridges and footbridges built in the Brussels area 1942-1947. The proponent of prestressed concrete in Belgium was Professor Gustave Magnel from Ghent University who was well aware of the developments in prestressed concrete in France and in Germany. In 1941, he set up the project of building what would eventually be the 1st pretressed railway bridge in the world. It consisted of simple slabs with 20 m span. It was built in Brussels 1942-1944 on the North-South Railway Junction. For this application, Magnel developed with the contractor Blaton-Aubert a very successful system of prestressing cables and anchorages. This first realization of a prestressed concrete structure in Belgium was accompanied by an extensive testing program that included the on-site testing up to failure of a prestressed concrete beam with the same span and depth as the bridge deck. This experiment convinced rapidly the Corps of Civil Engineers of the Ministry of Public Works to accept considering bids to reconstruct bridges in prestressed concrete rather than in reinforced concrete. Early in 1944, several contracts for reconstructing bridges or footbridges in prestressed concrete had been awarded. The paper details two of these projects, which are footbridges, situated in the Brussels area. The first one, in Brussels, is a footbridge with 21 m span. It was opened to service before September 1944. The second one is a footbridge with 44 m span situated 15 km SW of Brussels. Its innovating feature was the application of external prestressing with high strength steel bars. It was opened to service in October 1947.

INTRODUCTION

At the end of their fascinating account of the diffusion of the ideas of Freyssinet (1879-1962) on prestressing in Europe before and during World War II, Grote and Marrey (2000) devote a single page to the first application of prestressed concrete in Belgium: the railway bridge deck over the *rue du Miroir* in Brussels, prestressed in 1944. This bridge is not only the 1st prestressed concrete structure designed in Belgium – although not the 1st one in service – but the 1st prestressed concrete railway bridge in the world. Besides, the Brussels area saw also the construction of two other very early prestressed concrete structures: the footbridges over the Charleroi to Brussels Canal in Brussels, *rue de Gosselies*, in 1944 and at Malheide some 15 km SW of Brussels in 1947. This paper attempts to situate the importance of this bridge and the two footbridges in the History of prestressing and to understand why and how these early and original structures were designed and constructed.

THE INTERNATIONAL CONTEXT OF PRESTRESSING AT THE OUTBREAK OF THE SECOND WORLD WAR

As is well known, E. Freyssinet and J. Séailles were the first to set up the correct principles of prestressed concrete in their patent submitted in 1928 (Fernandez Ordoñez, 1979). The first application of prestressed concrete by Freyssinet was the production of electric poles prestressed by pre-tensioning, but it was a commercial failure. It was the salvation from a disastrous failure of the Le Havre Maritime Railway Station by Freyssinet (1934-1935) that demonstrated the potential of prestressing which was subsequently and before 1939 applied on a grand scale in Algeria by Campenon-Bernard. The principles of prestressing by pre-tensioning with wires and by post-tensioning with flat jacks were fully described by Freyssinet in publications between 1933 and 1936. Fernandez Ordoñez (1979) reports that Freyssinet received a standing ovation at the 2nd IABSE congress in Berlin in 1936 after his lecture on the applications of prestressed concrete. And the journals *Beton und Eisen* and *Die Bautechnik* largely contributed between 1936 and 1940 to the diffusion of the results of the experiments conducted in Germany on prestressed concrete based on Freyssinet's ideas and patents.
However, it is only at the end of the summer of 1939, just on the eve of the 2nd World War, that Freyssinet submitted his patent for post-tensioning by cables, with the cone anchorage and the "Freyssi" jack allowing ten-

sioning simultaneously 12 ∅ 5 mm high strength steel wires. Freyssinet did not publish any paper between 1936 and 1941. His new prestressing system by post-tensioning was first publicly described at an important conference that he gave in Paris on November 30, 1941 which was published in the influential French journals *Travaux* in November 1941 and *Le Génie Civil* in December 1941. During that conference Freyssinet showed the project of the first application of his new prestressing technique: the Luzancy bridge, whose construction had begun in 1941, but that would not be completed before 1945. Finally, the STUP Company created by Campenon-Bernard to allow Freyssinet to exploit his brevets independently was set up on February 22, 1943.

GUSTAVE MAGNEL AND THE INTRODUCTION OF PRESTRESSED CONCRETE IN BELGIUM

This was the context of the diffusion of ideas about prestressed concrete at the outbreak of World War II. Belgium was invaded by German armies on May 10, 1940 and fully occupied by the German troops until September 1944 (part of the Belgian territory being still occupied at the beginning of 1945).

Undisputedly, the introduction and popularization of prestressed concrete in Belgium has to be attributed to Gustave Magnel (1889-1955) who was a Professor of Structural Engineering at Ghent University where he had directed since 1926 a laboratory dedicated to research on concrete and concrete structures (Taerwe, 2005; Radelet-de Grave, 2005). Magnel is the author of the 1st publication in Belgium dealing (partly) with prestressed concrete (Magnel, 1940). In this paper published in October 1940, he rapidly mentions the name of Freyssinet, but mostly refers to the German prestressing methods used by Hoyer (pretensioning with small wires) and Dischinger (external prestressing with steel bars). This paper does not even mention the problems associated with the time-dependent prestress losses and their influence on the choice on the steel grade for the prestressing reinforcement.

In the 1st edition of the 4th volume of his textbook *Pratique du Béton Armé* (Magnel, 1942a) written before June 30, 1941 (date of the preface), Magnel devotes 19 pages to prestressed concrete. It is presented as the text of a lecture given by Magnel to the Corps of Civil Engineers of the Ministry of Public Works in 1941. In this text, Magnel mentions for the first time the Freyssinet system of post-tensioning with ∅ 5 mm steel wires tensioned at 850 MPa and the cone anchorage. He also presents for the first time in one of his publications his project for "experimental" railway bridge decks in prestressed concrete to be constructed in Brussels as part of a bridge belonging to the North-South railway Junction, over the *rue du Miroir*. He also announces that he is currently testing in his laboratory several adaptations of the Freyssinet anchorage before using the anchorage in a full scale prestressed concrete structure. We must infer from this that Magnel knew about the Freyssinet cone anchorage well before the conference by Freyssinet in November 1941 and the two associated publications.

THE RAILWAY BRIDGE OVER THE RUE DU MIROIR IN BRUSSELS

Magnel has described the railway bridge over the *rue Du Miroir* in many publications, ultimately in the well-known English version of his textbook (Magnel, 1954). The bridge (Fig. 1) consists of six concrete slabs with 20 m span and 3.65 m breadth.

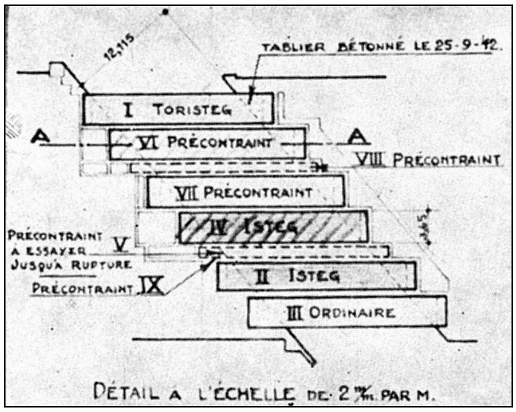

Figure 1: Railway bridge *rue du Miroir* in 2005 (left) and plan from 1942 (right); (Baes 1956, p.18)

The slabs differed by their reinforcement and thereby by their depth h. One slab (Fig.2: III) was reinforced with ordinary round steel bars working at 100 MPa (h = 1. 85m), two (Fig.2: II & IV) with high bond Isteg steel bars working at 160 MPa (h = 1.85m), one (Fig. 2: I) with high bond Toristeg steel bars working at 160 MPa (h = 1.24m) and two (Fig.2: VI & VII) were prestressed by post-tensioning with 29 cables consisting of 56 ∅ 5 mm high strength steel wires tensioned at 850 MPa (h = 1.15m) (Magnel, 1947). An experimental beam with the same depth, prestressing and span as the decks, but with a reduced breath b = 0.65 m was also constructed. It was intended to be submitted to extensive testing. To launch this bold project and during the war, Magnel managed to obtain the support of the Belgian Railway State Company (SNCB), of the Office of the North-South Railway Junction (ONJ), of the Belgian National Foundation for Scientific Research (FNRS) and of his colleagues from the Council of the Bureau SECO, an office founded in 1934 by the insurance companies in order

to enforce the technical control of the constructions. Magnel asked his colleagues from the University of Brussels Professors Louis Baes (1883-1961) and Frans Van den Dungen (1898-1965) to take care of the measurements during the dynamic and up to failure testing of the experimental beam (Magnel, 1947). This took place in 1942 and André Paduart (1914-1985), then engineer of the Bureau SECO (Espion et al., 2003), collaborated with Louis Baes for the testing (Paduart, 1954). It should however be underlined that, if the prestressing of the experimental beam took place in 1942 (Baes, 1949, 1956), the prestressing of the two slabs only occurred between March and September 1944 (Magnel, 1944).
The prestressing by post-tensioning of the beam and slabs was done with a system developped in collaboration by Magnel in his laboratory and the contractor Blaton-Aubert who had been commissioned for the construction of the bridge (Magnel, 1949). This system consisting of cables and anchorages is known under the name of "sandwich cable" (Fig.2). It consists as in the Freyssinet system of ∅ 5 mm steel wires tensioned at 850 MPa. In this system, however, the wires are gripped in pairs by wedges. It only requires a small 10-t jack.

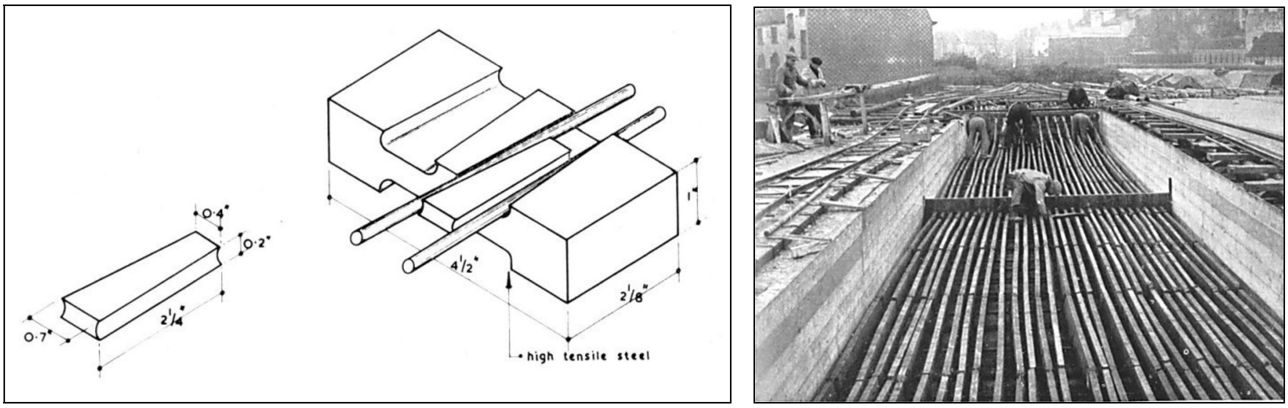

Figure 2: The Blaton-Magnel "sandwich system" (left) and laying the ducts of the prestressing cables in the decks of the *rue du Miroir* railway bridge (right); (Magnel 1948, p. 353)

Blaton-Aubert was one of the licensees of Freyssinet in Belgium, and Magnel says in March 1944 that this system was developed with the consent of Freyssinet (Magnel, 1944) and, later (Magnel, 1949), that for all the applications of the sandwich system in Belgium a patent fee was paid to the STUP. Magnel justifies the development of a "Belgian" system of prestressing by the difficulties to have access during the war to the anchorages, cables and jacks of the Freyssinet system (Magnel, 1949). He also put forward a motivation to improve the anchorage developed by Freyssinet (e.g. Magnel, 1944). In a conference given in front of a hundred people at the Association Belge pour l'Etude, l'Essai et l'Emploi des Matériaux (ABEM) on February 27, 1942, Magnel presents the results of the testing of some prestressed beams in his laboratory (Magnel, 1942b). The photographs illustrating his paper show early, but certainly not final, versions of the development of his anchorage. During this conference, he mentionned the Luzancy project and presented the project of the *rue du Miroir* railway bridge.
In the 4th volume of his textbook *Pratique du Béton Armé* (Magnel, 1942a), Magnel limits himself to general principle formulae to compute prestressed concrete (pp.170-179). These formulae are developed and applied to the design of a bridge deck bearing a striking resemblance with the *rue du Miroir* deck (without naming it) in a paper by Soete, an engineer with the Railway State Company (Soete, 1942). In several publications (e.g. Magnel 1947; 1948, 1949), Magnel states that the expects that the results of the tests performed in 1942 on the experimental beam *rue du Miroir* by his colleagues Baes (for the testing up to failure) and Van den Dungen (for the dynamic testing) will be published by them, but this has unfortunately never been done publicly. It should be noted that the construction of this bridge had begun in 1942, but that there were still no rails on it in 1947 (Magnel, 1948), which prevented to finalize the dynamic testing of the bridge, which was opened to service with the whole North-South Brussels Railway Junction in 1952.
In order to avoid any misunderstanding about the nature of the development of prestressing in Belgium during the war, it must be recalled that Magnel, Baes and Van den Dungen were well known patriotic figures resistant to the German occupation, and that all three have been deprived of their university chair by the Nazis.

THE FOOTBRIDGE AT THE RUE DE GOSSELIES OVER THE CANAL CHARLEROI-BRUSSELS IN BRUSSELS

The publicity given by Magnel around the project of the *rue du Miroir* bridge and its economical advantages, and the success of the experiments conducted in his laboratory and with the testing of the beam on the site and at the scale of the bridge, rapidly convinced the civil engineers of the Ministry of Public Works to accept considering alternative bids by contractors to reconstruct destroyed bridges in prestressed concrete rather than in reinforced concrete. Early in 1944, several contracts for reconstructing bridges or footbridges in prestressed concrete had been awarded (Magnel, 1944).
The footbridge in Brussels *rue de Gosselies* over the Charleroi to Brussels Canal (Fig. 3) is one of these early projects. The starting of its construction was imminent in March 1944 (Magnel, 1944) and it was prestressed and opened to service before September 1944 (Santilman, 1948) e.g. before the liberation of Brussels by the allied armies. This footbridge is described by Magnel (1944; 1948; 1954) and at length by Santilman (1948).

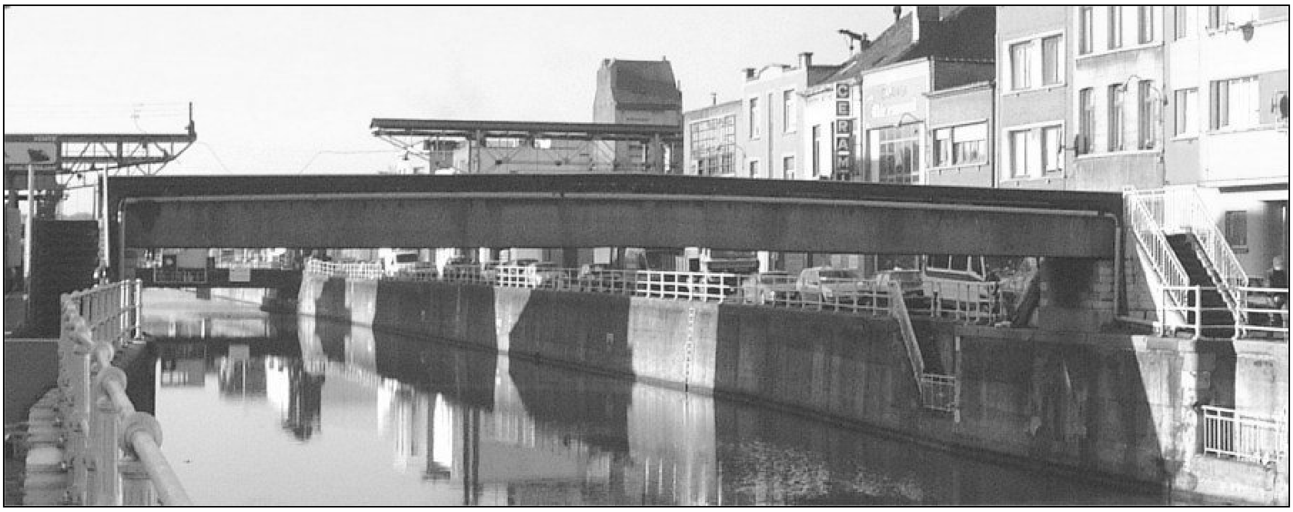

Figure 3: The footbridge *rue de Gosselies* over the Charleroi to Brussels Canal in Brussels

This footbridge with L = 21m span consists of two prestressed beams with depth h = 1.4 m each prestressed by one straight cable 36 ∅ 5 mm and one parabolic cable 40 ∅ 5 mm. The contractor was again Blaton-Aubert and the prestressing cables and anchorages are therefore of the sandwich type. A reinforced concrete cast in situ slab connects the two beams (Fig.4).

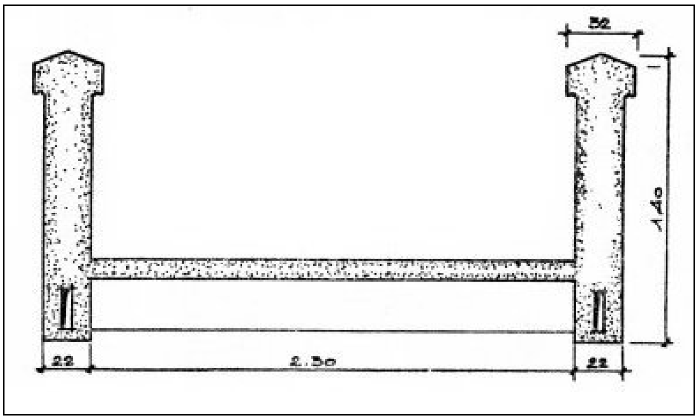

Figure 4: Cross section of the *rue de Gosselies* footbridge (Magnel, 1948)

This footbridge bears some resemblance, including in its unappealing aspect, with one of the very early construction prestressed with the Freyssinet system in France during the occupation: the footbridge built by the contractor Saint-Rapt et Brice at Bully-Grenay over railway lines (Fernandez Ordoñez, 1979; Grote and Marrey, 2000). The cross-section of the footbridge at Bully-Grenay is very similar: two beams with uniform depth h: 1.8 m for a span of 31 m. The project of the Bully-Grenay footbridge dates back to 1942, but the construction was not completed before 1944, and the first publication about this structure appeared in March 1944 (Fernandez Ordoñez, 1979). It is therefore unlikely that the design of the footbridge in Brussels may have been influenced by the Bully-Grenay project. The footbridge in Brussels still exists in its original state.

THE FOOTBRIDGE AT MALHEIDE OVER THE CANAL CHARLEROI-BRUSSELS

The contract for another prestressed concrete footbridge had been awarded before March 1944 (Magnel, 1944). This one is for a footbridge with 44.5m span spanning the same Charleroi to Brussels Canal, but in Malheide (Lembeek) some 15 km upstream SW of Brussels; it was the replacement of a reinforced concrete bowstring footbridge destroyed in 1940. According to Magnel (1944) and Santilman (1948) several bids for prestressed concrete structures were received because the invitation for tenders imposed that less than 5 tons of steel be used to reconstruct the footbridge; a reconstruction in reinforced concrete would have used 23 tons of steel. Magnel himself in his 1944 paper or in the various editions of his textbook (Magnel, 1948, 1954) presents a project for this footbridge with sandwich cables, which, however, was not realized.
The prestressed concrete project that the Ministry of Public Works selected (Fig. 5) was radically different. The Ministry kept, because it was financially more interesting, the project proposed by the contractor SETRA (*Société d'Etudes et de Travaux*) consisting of a slightly arched footbridge externally post-tensioned by high strength (1150 MPa) threaded Ø 40 mm steel bars with manganese addition tensioned at 700 MPa (Paduart, 1948). The SETRA Company was directed by the engineer Carlos Wets who had submitted a Belgian patent for

this kind of prestressing on May 28, 1943 (awarded February 15, 1944) (Möll, 1954). In 1944, the Technical Director of the SETRA Company was the 30 years old engineer André Paduart who had just left the Bureau SECO (Espion et al., 2003).

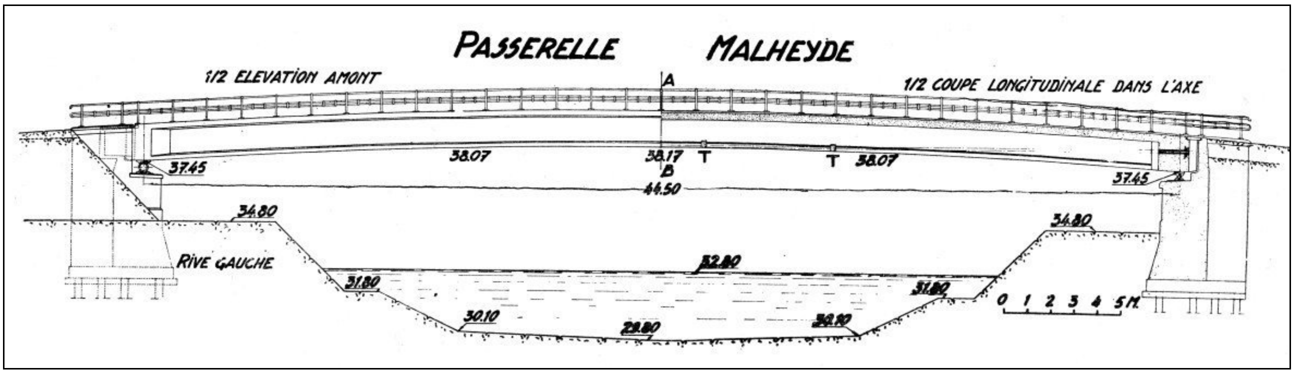

Figure 5: Elevation of the Malheide footbridge (Santilman 1948, p. 334)

The concept of external prestressing with large diameter steel bars is generally attributed to Franz Dischinger (1897-1953) in his German patent DRP 727 429 submitted December 7, 1934 (Möll, 1954). The first practical application of this patent by Dischinger, then a Professor in Berlin, was for the construction by Dyckerhoff and Widmann, former employer of Dischinger, of the railway station bridge in Aue (Saxony) 1936-1937 (Schönberg and Fichtner, 1939). However, this bridge with a central span of 69 m was externally prestressed with Ø 70 mm in St 52 tensioned at 220 MPa. Such a low level of initial steel stress is not compatible with a permanent prestressing after time-dependent losses due to creep and shrinkage of concrete. Dischinger was well aware of this fact. This is the reason why he had invented external prestressing in order to be able to re-stress the bars from time to time after occurrence of prestress losses. This was effectively realized at least three times on this bridge (Wittfoht, 1984) that did not perform very well and which no longer exists.

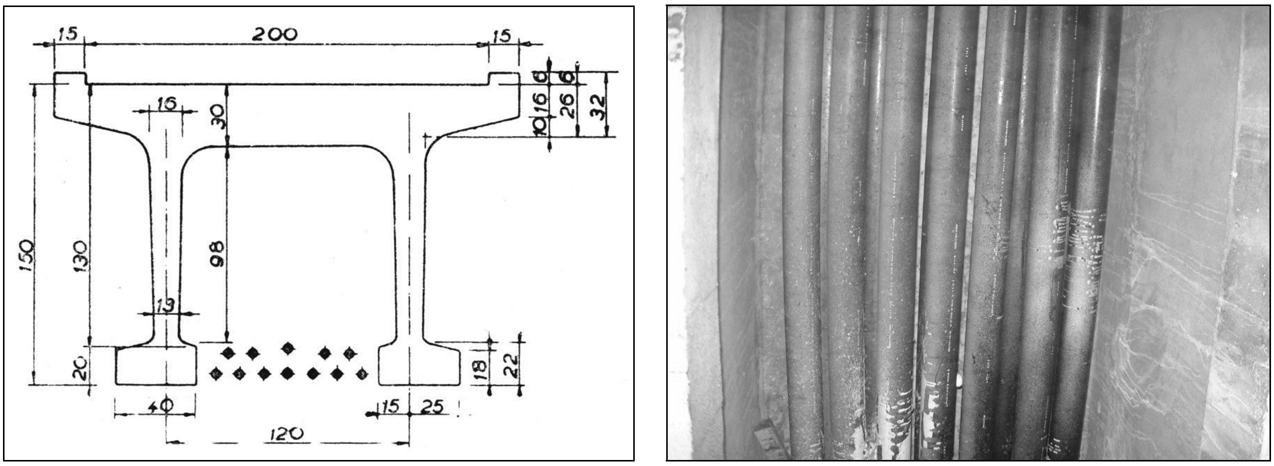

Figure 6: Cross-section of the footbridge at Malheide (left) (Paduart 1948, p. 329)
and the prestressing ∅ 40 mm bars today (right)

One can therefore appreciate that the project proposed by Wets, which is effectively external prestressing with large diameter steel bars (Fig.6), is totally different from Dischinger's ideas since it uses steel tensioned at a much higher stress level, only slightly inferior to the initial stress levels in the steel wires Ø 5 mm used either by Freyssinet or Magnel, but sufficiently high to keep a long-term permanent prestressing after time-dependent losses. Therefore, the SETRA project for the Malheide footbridge was particularly innovating and bold. So much that the Administration required that the SETRA Company first realized a full scale prototype. The cost of the prototype was shared equally by the Administration and the Company (Wets, 1946).

This prototype was a beam with 30m span, slightly arched as the footbridge itself (to give a varying eccentricity to the prestressing), with a Π-shaped cross-section. This prototype was intended to be submitted to extensive testing. The construction of the beam and the tests took place in Haren (Brussels) under the direction of André Paduart (Wets, 1946). Once again, as for the test beam of the *rue du Miroir*, Professors Louis Baes and Frans Van den Dungen were involved in the static and dynamic testing. The prototype was cast November 27, 1945. The tests were carried out February-March 1946 in front of a large technical audience. In particular, the beam was loaded uniformly up to the appearance of first cracking at 2.41 the service load. The results are reported by Paduart (1946, 1948), Wets (1946) and in detail by Santilman (1948).

Figure 7: The footbridge at Malheide

Once again, the tests proved to be very satisfactory and the Administration agreed to proceed with the construction of the footbridge itself in Malheide. The construction began in the summer of 1947. The structure was decentred on September 5, 1947 and opened to service on October 15, 1947 by the Minister of Public Works himself. At that time, it was the prestressed concrete beam with the largest span in Belgium, and the first concrete construction externally prestressed after the bridges in Germany. Curiously, in his publications and even as late as 1954, Magnel prefers to show the unrealized project (his own?) for a footbridge at Malheide prestressed by sandwich cables rather than this elegant structure prestressed with a concurrent system. This footbridge still exists today (Fig.7).

CONCLUSIONS

Brussels and its surroundings is a fascinating place for the History of prestressed concrete. We may find there today three structures which may be considered as landmarks in the evolution of prestressed concrete by post-tensioning.

The bridge decks over the *rue du Miroir* in Brussels were designed in 1941 by the pioneer Gustave Magnel. Their construction began in 1942 and they were prestressed in 1944. This bridge is the first prestressed concrete railway bridge in the world. This bridge would have been the first application of the "sandwich" prestressing system of cables and anchorages developed by Magnel in collaboration with the contractor Blaton-Aubert.

This system was inspired by the Freyssinet system of cone anchorage patented in 1939. It will be abundantly used in Belgium during at least 20 years. From the point of view of the application of post-tensioning by cables to prestressed concrete bridges, this bridge in Brussels is more important than the mere and small projects realized in France during that period by the licensee of Freyssinet Saint-Rapt et Brice at Elboeuf-sur-Andelle in 1942 or at Longroy in 1943.

The footbridge over the Canal at the *rue de Gosselies* in Brussels is probably the first prestressed concrete construction opened to service in Belgium. This occurred before September 1944. The prestressing system was the sandwich system.

The footbridge over the Canal at Malheide, although opened in 1947, had been tendered before March 1944. It was the first application in Belgium, and probably elsewhere, of external prestressing with high strength steel bars, well before the development in 1950 by Dyckerhoff and Widmann of their famous "Dywidag" bars in steel St 90. In the "Dywidag" bars, the tension in service did not exceed 450 MPa at the beginning of the 1950's (Möll, 1954), whereas the bars at Malheide where already tensioned at 700 MPa. The 30m long prototype built at Haren in 1946 and the 44.5 m footbridge built at Malheide in 1947 do not seem to have resulted in other applications with this system of prestressing.

REFERENCES

Baes, L., 1949: Quelques aperçus relatifs à l'évolution de la résistance des matériaux…. *Annales des Travaux Publics de Belgique – Numéro jubilaire 1843-1948*, p.114.

Baes, L., 1956: *La précontrainte dans l'Art de Bâtir aujourd'hui*. Bruxelles: Annuaire S.A.D.Br.

Espion, B. et al., 2003: Contributions of André Paduart to the art of thin concrete shell vaulting. In: Huerta, S.

(ed.): *Proc.1st International Congress on Construction History*, Madrid, pp. 829-838.
Fernandez Ordoñez, J. A.,1979: *Eugène Freyssinet*. Barcelona: 2c editions.
Grote, J.; Marrey, B., 2000: *Freyssinet, Prestressing and Europe*. Paris: Editions du Linteau.
Magnel, G., 1940: Le problème de la fissuration du béton et l'emploi des aciers à haute limite élastique. *Annales des Travaux Publics de Belgique*, pp. 589-659.
Magnel, G., 1942a: *Pratique du Calcul du Béton Armé, 4ème partie*. Gand: Rombaut-Fecheyr.
Magnel, G. 1942b: *Essais de quelques poutres en béton précontraint*. Bruxelles: ABEM.
Magnel, G.,1944: Les applications du béton précontraint en Belgique. *Science & Technique* 2 (5), pp.1-12.
Magnel, G., 1947: Les travaux de la Jonction Nord-Midi : les ponts expérimentaux de la rue du Miroir. *Science & Technique* 5 (7-8), pp.7-10.
Magnel, G., 1948: *Le Béton précontraint*. Gand: Fecheyr.
Magnel, G., 1949: L'avenir du béton précontraint. *Annales des Travaux Publics de Belgique – Numéro jubilaire 1843-1948*, pp.177-181.
Magnel, G., 1954: *Prestressed Concrete 3rd edition*. New-York: McGraw-Hill.
Möll, H., 1954: *Spannbeton*. Stuttgart: Berliner Union.
Paduart, A., 1946: Les poutres précontraintes en arc à tirant rectiligne. *Architecture-Urbanisme-Habitation* 1-2-3.
Paduart, A., 1948: Ponts de grande portée en béton précontraint réalisés en Belgique. In *Publ. Prélim. 3ème Congrès de l'A.I.P.C.*, Liège, pp.325-332.
Paduart, A., 1954: Construire, c'est à la fois une science et un art. *Revue Générale des Sciences Appliquées* II, pp. 94-102.
Radelet-de Grave, P. 2005 : Gustave Magnel (1889-1955), a scientific biography. In: Huerta, S.(ed.): *Essays in Honour of Jacques Heyman*. Madrid: Instituto Juan de Herrera, pp. 389-427.
Santilman, H.N.F., 1948: Note sur l'emploi du béton précontraint dans la construction des passerelles de la rue de Gosselies et de Malheide sur le Canal de Charleroi à Bruxelles. *Annales des Travaux Publics de Belgique*, pp. 127-141, 309-340.
Schönberg, M.; Fichtner, F., 1939: Die Adolf-Hitler-Brücke in Aue (Sa.). *Die Bautechnik* 17 (8), pp.97-104.
Soete, A., 1942: Berekening van beton met voorspanning. *Annales des Travaux Publics de Belgique*, pp. 553-572.
Taerwe, L.R., 2005: Contribution of Gustave Magnel to the Development of Prestressed Concrete. In: Russel, B.W. and Gross, S.P. (eds): *Proc. Ned H. Burns Symp. on Historic Innovations in Prestressed Concrete*, ACI-SP-231-1.
Wets, C.,1946: Résultats des experiences faites sur une poutre en béton précontraint de 30m de portée, *Science & Technique* 4 (9-10), pp.13-20.
Wittfoht, H., 1984: *Building Bridges*. Düsseldorf: Beton-Verlag.

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